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Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes

An evidence and policy overview on the state of knowledge and gaps

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Foreword

Malnutrition, in all its forms, is a global concern that has lasting health, developmental and economic impacts for individuals, communities and nations. One-tenth of the global population faces hunger. Three billion people are unable to afford healthy diets. At the same time, one in three people is overweight or obese, almost a quarter of children under five years of age are stunted and anaemia affects more than half a billion of women. While all forms of malnutrition have multiple causes, healthy diets are central to prevention of them all. Sustainable agrifood systems must be part of the solution to achieve affordable healthy diets for all, specifically those in situations of vulnerability.

Nutrient needs of humans varies substantially over their life course. While there are a variety of dietary patterns that can meet those needs, foods that are rich in nutrients are a critical part of a healthy diet. Terrestrial animal source foods provide energy and many essential nutrients, such as protein, fatty acids and several vitamins and minerals that are less common in other food types.

Livestock species and breeds are adapted to a wide range of environments. They contribute to healthy diets particularly in areas less suited or unsuitable for crop production. However, to optimize this contribution to human and planetary health, the livestock sector must contribute to addressing a range of challenges. These include issues related to the environment (e.g. deforestation, land-use changes, greenhouse-gas emissions, unsustainable water and land use, pollution, food–feed competition), herd management (e.g. low productivity, overgrazing, poor animal welfare), animal health related issues (e.g. diseases, antimicrobial resistance), human-livestock related issues (e.g. zoonotic and food-borne diseases) and social issues (e.g. equity).

At its 27th Session, in October 2020, FAO's Committee on Agriculture (COAG) requested the Organization "to produce a comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable food systems, nutrition and healthy diets."

The assessment follows an agrifood systems approach and applies a One Health perspective to the economic, social and environmental dimensions when reviewing how the livestock sector contributes to the 2030 Agenda for Sustainable Development. It will consist of four component documents. This first component document – a milestone in the work of COAG's Sub-Committee on Livestock – focuses on the downstream impacts of terrestrial animal source food consumption as part of healthy diets and provides a robust systematic review of the evidence for its contribution to health and nutrition outcomes. This review includes an analysis of policy consumption recommendations.

The assessment supports COAG's Sub-Committee on Livestock in its quest to optimize the role of livestock, including their contributions to poverty alleviation, food security and nutrition, sustainable livelihoods and the realization of the 2030 Agenda.

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[3] https://www.fao.org/3/cb8424en/cb8424en.pdf

Abbreviations and acronyms

AIDS	acquired immunodeficiency syndrome
AMR	antimicrobial resistance
BMI	body mass index
CAC	Codex Alimentarius Commission
CI	confidence interval
CMA	cow's milk allergy
COVID-19	coronavirus disease 2019
DFD	dark firm dry
DNA	deoxyribonucleic acid
DIAAS	Digestible Indispensable Amino Acid Score
DALY	disability-adjusted life year
DHA	docosahexaenoic acid
DPA	docosapentaenoic acid
EPA	eicosapentaenoic acid
ECDC	European Centre for Disease Prevention and Control
EFSA	European Food Safety Authority
FAPDA	FAO Food and Agriculture Policy Decision Analysis
FAO	Food and Agriculture Organization of the United Nations
FBDG	food-based dietary guideline
FBD	food-borne disease
GM	genetically modified
GMO	genetically modified organism
HR	hazard ratio
HIV	human immunodeficiency virus
IFAD	International Fund for Agricultural Development
LMIC	low- and middle-income countries
MUFA	monounsaturated fatty acids
INRAE	National Research Institute for Agriculture, Food and Environment, France
NCD	non-communicable disease
OR	odds ratio
PBF	plant-based food
PCB	polychlorinated biphenyl
PDCAAS	Protein Digestibility-Corrected Amino Acid Score
PSE	pale soft exudative
PUFA	polyunsaturated fatty acids
RCT	randomized control trial
RNI	recommended nutrient intake
RR	relative risk
RE	retinol equivalent
RNA	ribonucleic acid
SPS	sanitary and phytosanitary

SARS	severe acute respiratory syndrome
spp.	multiple species
SDG	Sustainable Development Goal
TASF	terrestrial animal source food
FERG	The Foodborne Disease Burden Epidemiology Reference Group of the World Health Organization
TMAO	trimethylamine-N-oxide
UI	uncertainty interval
UN	United Nations
UNICEF	United Nations Children's Fund
UNDP	United Nations Development Progamme
USDA	United States Department of Agriculture
USD	United States dollar
GINA	WHO Global Database on the Implementation of Nutrition Action
WFP	World Food Programme
WHO	World Health Organization
WOAH	World Organisation for Animal Health
YLD	years lived with disability
YLL	years of life lost

Key findings

Terrestrial animal source food (TASF), within healthy dietary patterns, can make vital contributions to efforts to meet the global nutrition targets for 2025 endorsed by the World Health Assembly[1] and the Sustainable Development Goals (SDGs) that aim to reduce stunting among children under five years, low birthweight, anaemia in women of reproductive age (15–49 years), overweight among children under five years, and obesity and diet-related non-communicable diseases (NCDs) in adults.[2]

Nutrient and bioactive composition and value of terrestrial animal source food

- TASFs provide higher-quality proteins than other foods, with some nuanced differences in digestibility. Specific amino acids and bioactive factors with roles in human health (carnitine, creatine, taurine, hydroxyproline and anserine) are primarily found in TASF. The long-chain fatty acids and the ratios of essential fatty acids found in TASF are important for cognition across all phases of the human life course.

- Iron and zinc in red meat are bound in compounds that are more bioavailable and may be more easily digested than those in which they are bound in plant-based foods. Milk is well recognized for its high concentration and bioavailability of calcium, among other nutrients. Eggs have high concentrations of choline and some long-chain fatty acids. Generally, TASFs are a rich source of selenium, vitamin B12 and choline. Consumption of TASF has been shown to counteract the effects of antinutrients found in plant-based foods.

- The nutritional quality of TASFs (especially the fat composition) can be influenced by (in order of priority) choice of animal species and feeding system, followed by breed and production environment.

Effects of terrestrial animal source food on nutrition and health over the life course

- Dietary intakes of TASF can have effects on nutrition (improved nutrient status, increased anthropometry), health (reduced infectious disease, increased NCDs, immune system function broadly, improved bone health), and cognition (improved development, neuroprotection, neurological disease prevention).

- For people in all life-course phases – including pregnant and breastfeeding women, infants and young children, school-age children and adolescents, adults and older adults – the majority of evidence related to the influence of TASFs on nutrition and health comes from trials assessing milk and dairy products. Beef and eggs follow in terms of availability of evidence, with fewer studies available on pig and poultry meat, meat from wild animals, insects and meat from other minor species. Overall, the evidence suggests that, among apparently healthy individuals, TASF intakes at appropriate levels benefit several health outcomes. A robust evidence base shows that milk and dairy consumption during pregnancy increases infant weight at birth and may also increase birth length and foetal head circumference. Among infants and young children, egg, milk and meat consumption has been studied, with mixed findings depending on overall diet and environmental exposure. Evidence shows that consumption of milk and dairy products by school-age children and adolescents increases height and reduces overweight and obesity. Beef consumption in this life-course phase has been shown to improve cognitive outcomes.

- In adults, findings largely indicate that consumption of milk and dairy products (such as yoghurt) has positive effects in terms of reducing risk of all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. Relatively robust evidence shows that egg consumption among adults does not increase the risk of stroke or coronary heart disease. Compelling evidence suggests that, in adults, meat intake of between 85 and 300 g/day can protect against iron deficiency. Poultry meat has not been studied as much as beef, but findings suggest non-significant effects on stroke risk, with subgroup analysis suggesting a protective effect in women.

- The evidence base for red meat consumption in adults has been thoroughly assessed by the Global Burden of Disease Study and shows some increased risk of chronic disease associated with consumption of 23 g (18–27 g)

1. Global nutrition targets 2025 (https://apps.who.int/nutrition/global-target-2025/en/).
2. WHO. 2014. *Global nutrition targets 2025: Policy brief series (WHO/NMH/NHD/14.2)*. Geneva, Switzerland, WHO. https://apps.who.int/iris/bitstream/handle/10665/149018/WHO_NMH_NHD_14.2_eng.pdf

per day of red meat, and 2 g (0–4 g) per day of processed meat. However, other studies have shown non-significant effects of beef on chronic disease biomarkers.

- Significant gaps remain in the evidence base for older adults. Preliminary evidence, however, suggests that milk and dairy products, and possibly other TASFs, may play a role in mitigating sarcopenia, fractures, frailty, dementia and Alzheimer's disease

- Cow's milk and poultry eggs are among the eight food groups that pose allergenic risks to consumers, and it is therefore mandatory in many countries to state their presence in foods as part of precautionary allergen labelling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread but does not automatically lead to lactose intolerance, which also greatly varies in severity.

Policy recommendations on terrestrial animal source food consumption

- Findings are based on a desk review of policy documents including food-based dietary guidelines (FBDGs), non-communicable disease-related documents and documents related to food and agriculture legislation and nutrition policies and programmes.

- Most policy recommendations address TASF consumption in general, followed by meat, milk and dairy products and eggs. There is significantly less coverage of offal, poultry, pig meat, meat from wild animals, and insects.

- Most recommendations on TASF consumption are linked to human micronutrient needs and NCDs and target the entire population. Micronutrient-related recommendations tend to be more detailed than NCD-related recommendations, providing quantitative indications in terms of daily or weekly TASF intake. There are no specific recommendations on TASF consumption to address the risks associated with multiple forms of malnutrition (e.g. coexistence of micronutrient deficiency with overweight, obesity and NCDs).

- In total, the review of policy documents identified 378 recommendations on TASF consumption that follow a life-course approach, 325 in FBDGs. Although the review identified a similar number of quantitative and qualitative recommendations, those in the FBDGs of high-income countries were the most detailed.

- Environmental sustainability considerations were only included in documents from eight upper middle- and high-income countries, and these mostly provided qualitative recommendations. Animal welfare was only mentioned in the FBDGs of Denmark and Sweden, which mentioned the use of animal welfare labels to inform consumers.

Food safety and food-borne disease issues related to terrestrial animal source food

- One-third of the global food-borne disease burden is associated with the consumption of contaminated TASFs, mainly linked to bacterial causes and diarrhoea. While evidence on food-borne disease hazards and health outcomes, and on risk analysis methods, is well documented, knowledge of the national burden (incidence and severity) of food-borne diseases is lacking. The main transmission routes along the value chain are crucial to the targeting of national policies but are not well understood.

- Changing agricultural practices (especially those related to the intensification of livestock production and input use), the lengthening and broadening of value chains, and increasing consumption of processed food contribute to increasing exposure to food-borne disease hazards. Antimicrobial resistance presents additional challenges, beyond those related to nutrition and food safety.

- Food-safety burdens must be alleviated by enhancing sanitation and mitigating health risks at the interfaces between animals, humans and the environment, through a One Health approach. Strengthening national food-control systems is key to ensuring food safety for better health and nutritional outcomes.

Emerging topics

- While cost and access remain a barrier, milk powder has been used extensively as an ingredient in fortified and blended foods, with evidence for its effectiveness when used as a therapeutic supplement in the management of severe acute malnutrition in infants and young children. Egg powder and fish powder have been used to a significantly lesser extent as ingredients in fortified and blended foods, probably because of palatability and shelf-life issues and the processing techniques involved.

- Science related to TASF alternatives, including plant-based food and cell-cultured “meat”, is relatively new. Evidence suggests that these products cannot replace TASF in terms of nutritional composition. Microalgae are highly regarded as a TASF alternative because of their rich nutritional composition and the advantages they may offer as a natural carbon sink. Nevertheless, plant-based meat alternatives that are widely available on the market have been found to be deficient in some essential nutrients and high in saturated fat, sodium and sugar. Further research is also needed to complete food-safety risk assessment for cell-cultured “meat” produced at industrial scale.

- While insects can provide many essential nutrients and there is some evidence on nutrition outcomes, cultural barriers and individual preferences currently interfere with consumer acceptability. The environmental sustainability appeal of using insects as human food seems compelling and may increase demand in the coming years. Nevertheless, food-safety concerns should be considered in the scaling up of insects as food or animal feed.

- Current “omics” applications provide promising options for characterizing nutritional quality and safety, and developing precision or personalized nutrition (especially for defined targeted groups such as young children).

- Microbiome science has recently revealed that some of the effects of the diet on health may be mediated by the gut microbiome – the trillions of microorganisms that live in the human gut. Diverse TASFs, including meat and fermented dairy products, influence the composition and functions of the gut microbiome and consequently affect human health via the production of microbial metabolites. High intake of red and processed meat and of animal saturated fats may induce deleterious effects, while fermented dairy products seem to be associated with reduced inflammation. Positive or negative impacts on health may be modulated by the overall quality of the diet (in terms of fats, sugars and fibre).

- Assessment of the roles of TASF in sustainable healthy diets needs to consider regional variations in natural resources, background health and nutrition as well as people’s nutritional needs over the life course, the availability and accessibility of food, and the ecosystem roles of livestock. Emerging evidence on the sustainability of diets shows that greater species diversity in the diet (plant-based foods, TASFs and aquatic foods) contributes to higher nutrient adequacy.

Preliminary gaps

- In conclusion, the findings of this document reveal some gaps in evidence and policy related to the contributions of TASF to healthy diets. To summarize:

- A deeper understanding of the interactions of TASF nutrients and bioactive compounds with other foods in the overall diet and of the effects of TASF on nutrition, health and cognitive outcomes across the course of human lives is required.

- Gaps remain in the literature on the nutritional composition and health effects of several types of TASF, including those from poultry, goats, sheep, pigs, rabbits, wild animals and insects.

- Robuster evidence is needed on the health effects of TASF consumption (underconsumption and overconsumption). Specifically, there is a need for studies with consistent design and methods, implemented in a range of different contexts (low- and middle-income countries and high-income countries).

- While beyond the scope of the present assessment, examining the significance of TASF in the diets of unhealthy populations (for example, those that are diabetic, overweight or obese) may be merited given the high prevalence of these conditions.

- National FBDGs should be updated with recommendations that provide ranges for daily intake of TASFs in different life-course phases. These recommendations should consider the implications of underconsumption and overconsumption of TASF given the increasing coexistence of micronutrient deficiencies and NCDs.

- National FBDGs should be used to better inform livestock policies, programmes and legislative frameworks on nutrition outcomes.

Setting the scene

At its twenty-seventh session, in October 2020, the Committee on Agriculture (COAG), one of FAO's governing bodies, requested FAO to produce a "comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets." At the same session, the COAG established a Sub-Committee on Livestock to provide targeted guidance to stakeholders on this specific sector of agriculture.

The assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets will be based on four component documents prepared for consideration by governing body sessions. The process will be accompanied and guided by a multidisciplinary scientific advisory committee.

This document is the first component document of the assessment and focuses on the contribution of terrestrial animal source food (TASF) (see Box 1) to healthy diets for improved nutrition and health. Although – in line with the mandate from COAG – the focus of the document is on TASF, it recognizes that human nutrition requires dietary diversity and a full spectrum of healthy foods and food groups, including aquatic foods, to promote and maintain health. The document builds on *Livestock-derived foods and sustainable healthy diets* (UN Nutrition, 2021), a document prepared by UN Nutrition that provides a general overview of topics covered by the four component documents of the present assessment and considers the major health benefits, opportunities and potential trade-offs associated with sustainable production and consumption.

Box 1. What is terrestrial animal source food?

In this assessment, terrestrial animal source food (TASF) is taken to comprise all food products obtained from terrestrial animals. The assessment covers TASFs derived from animal production systems of any scale, including integrated plant–animal production systems, specialized livestock production systems, and grazing systems and pastoralism. TASF includes food derived from the hunting of wild animals and from wildlife farming.

Food products covered include those derived from mammals, birds and insects. They are classified into the following food groups:

- eggs and egg products;
- milk and dairy products;
- meat and meat products;
- food from hunting and wildlife farming; and
- insects and insect products.

Each group includes subgroups (e.g. red meat and poultry) and multiple food items coming from different species (e.g. beef and chicken meat). The assessment focuses mainly on unprocessed TASFs, as there are many different processed TASFs. However, the health consequences of processed TASFs are discussed in Section C, where evidence is available, and processed blended food products containing TASF ingredients are introduced in Section E. Aquatic food is beyond the scope of the assessment.

Source: Food groups adapted from FAO & WHO. 2022. Global Individual Food consumption data Tool (GIFT). [Cited 10 February 2022]. www.fao.org/gift-individual-food-consumption/en/

[4] The 166th FAO Council, in its report (http://www.fao.org/3/nf693en/nf693en.pdf), defined agrifood systems as follows: The agrifood system covers the journey of food from farm to table – including when it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. It also encompasses non-food products that also constitute livelihoods and all of the people as well as the activities, investments and choices that play a part in getting us these food and agricultural products. In the FAO Constitution, the term "agriculture" and its derivatives include fisheries, marine products, forestry and primary forestry products.

The present document deepens the analysis via a systematic review focused specifically on nutrition and health outcomes related to TASF intake. It is intended to build consensus on the role of TASF in healthy diets by considering the vulnerability of different target groups from economic, health and contextual perspectives.

Healthy diets are fundamental to people's health and well-being. TASFs are among a range of food groups (see Box 2) that can contribute to diverse and balanced dietary patterns. This document focuses on the endpoints of the conceptual framework for agrifood systems (see Figure 1), specifically on how TASFs in diets lead to nutrition and health outcomes. The other three component documents will move upstream in the framework to examine the factors determining demand for, and supply and consumption of, TASF (Document 2), livestock-sector benefits, trade-offs and synergies with respect to food security and sustainable agrifood systems (Document 3), and opportunities for transforming the livestock sector sustainably to optimize food and nutrition security (Document 4). It should be noted that the scope of this first component document is to assess the contribution of TASFs, at appropriate levels, in apparently healthy individuals and not to assess risks among individuals suffering from medical conditions.

Box 2. Food groups and subgroups related to terrestrial animal source food

A **food group** is a set of foods that share similar nutritional properties or biological characteristics.

The following food groups and subgroups related to terrestrial animal source food are adapted from those used under the FAO/WHO Global Individual Food consumption data Tool (GIFT) (FAO and WHO, 2022):

Eggs and egg products: mainly from poultry (chicken, duck, goose, quail and turkey), including fresh and processed foods such as dried eggs.

Milk and dairy products: from mammalian livestock species, most commonly cattle, water buffalo, goat, sheep, dromedary and Bactrian camel. This group comprises the following subgroups:
- fresh and processed milk: milk and products derived from milk by reducing water or/and increasing sugar content and isolating milk protein, such as evaporated, condensed and powdered milk and milk protein;
- cheese, such as cured and uncured cheese, brined cheese, ripened cheese (soft and hard), cheese rind and processed cheese, such as spreads;
- cream, whey and any other milk products: products derived from milk by isolating its different fractions, including dried products such as powdered whey, cream and sour cream, and isolated whey protein, and manufactured products such as flavoured whey, cream and sour cream;
- fermented milk products, such as yoghurt, kefir, kumis and sour and fermented milk, including flavoured and non-flavoured products;

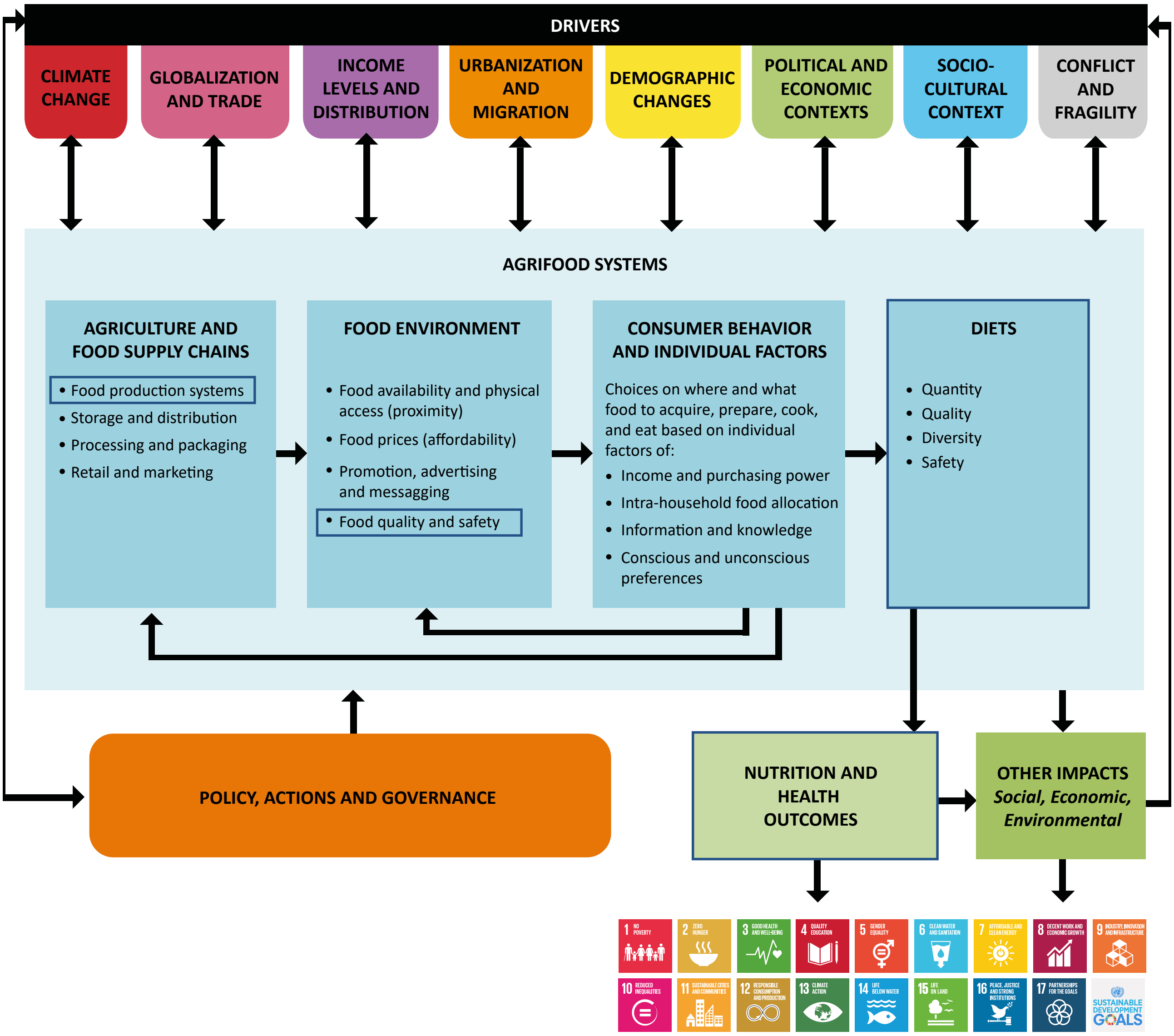
Meat and meat products: red and white meat from livestock (both ruminants and monogastrics), offals and processed meat:
- red meat: meat from cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse, donkey and yak;
- white meat: meat from rabbit and from chicken and other avian species (including duck, Muscovy duck, goose, guinea fowl, turkey, quail, pigeon, pheasant, ostrich) – characterized by its paleness;
- processed meat: a range of meat products that have undergone treatment such as salting, curing, smoking, marinating, drying or cooking;
- offals: organ meat and blood from mammalian and avian species, including liver, kidney, heart, lungs and intestines.

Food from hunting and wildlife farming: food obtained from hunting of wild animals and from non-domesticated animals raised on farms.

Food from invertebrates, including insects and insect products: insects such as beetles, flies, bugs, ants and grubs, and other invertebrates such as spiders, mites, ticks and earthworms, including processed products such as dried invertebrates and manufactured products such as powdered.

Source: Food groups adapted from FAO & WHO. 2022. Global Individual Food consumption data Tool (GIFT). [Cited 10 February 2022]. https://www.fao.org/gift-individual-food-consumption/en/

Figure 1. Agrifood systems for healthy diets



Note: Blue frames indicate elements assessed in this component document. Contextual information on different food production systems is provided to explain differences in the quality and consumption of TASF. However, food production systems were not the subject of this component document and will be covered in Component Document 3.

Sources: FAO. 2021. *Vision and Strategy for FAO's Work in Nutrition*. [Cited 15 February 2022]. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1415836/. FAO. 2021. *Report of the Council of FAO*. CL 166/REP. Rome.

Summary

About this document

At its twenty-seventh session, in October 2020, FAO's Committee on Agriculture (COAG) requested FAO to produce a "comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets." This assessment will involve four component documents prepared for consideration by FAO's governing bodies. A synthesis document will be prepared based on the four component documents. The present document (Component Document 1) is the first part of the assessment and focuses on the downstream impacts of terrestrial animal source food (TASF) on healthy diets for improved nutrition and health. An overview of the approach, scope and timeline of the assessment and of stakeholder involvement in its preparation was agreed by the First Session of COAG's Sub-Committee on Livestock in March 2022 (FAO, 2022a). The Sub-Committee on Livestock invited Members to provide comments on a draft version of the document, and these have been incorporated into the present version.

Component Document 1 is a synthesis of evidence on TASF's contributions to human nutrition and health, in line with the mandate from COAG. The document considers TASF within the context of healthy diets and the full array of foods and food groups important to human health, including aquatic animal foods.

The document was prepared through a consultative process involving a team from FAO, a scientific advisory committee and a wider group of technical experts (potential contributors). Three major themes were identified and these constitute the focus of the three sections of the document: 1. nutrient composition and value of TASF; 2. effects of TASF on health and nutrition over the life course; and 3. food safety and food-borne diseases. A fourth section focuses on emerging topics related to TASF and describes novel themes in the literature that have prospects for growth and salience in public discourse.

Terrestrial animal source food and the world nutrition situation

TASF, within the context of healthy diets delivered by efficient, inclusive, sustainable and resilient agrifood systems, can make important contributions to efforts to meet the 2025 World Health Assembly and 2030 Sustainable Development Goal (SDG) nutrition targets. Trends in nutrition indicators show that the world is currently not on track to attain several of these targets. This document provides evidence that TASF, within appropriate dietary patterns, can help achieve milestones related to reducing stunting and wasting among children under five years of age, low birthweight, anaemia in women of reproductive age (15–49 years), overweight among children under five years of age, and obesity in adults.

Evidence from the evolutionary past of *Homo sapiens* shows that higher dietary intakes of TASF were associated with increased stature, brain size and longevity, probably establishing metabolic requirements in the human body that still need to be met today. At present, TASF dietary patterns vary across agrifood systems, with populations in some

regions having high intakes and consuming too much and those in others consuming to little. The ways in which TASF affects chronic disease and livestock production affects the environment are attracting increasing attention in the public domain. This has given rise to the need to provide decision-makers with an assessment of the evidence in this field.

Nutrient and bioactive composition and value of terrestrial animal source food

Several macronutrients, micronutrients and bioactive compounds found in TASF play unique and important roles in human health. TASF can provide large proportions of recommended nutrient intake (RNI) across the life course. The food matrix and overall diet of individuals modulate the digestibility, including the absorption and metabolism, of TASF nutrients in humans. TASF provides high-quality proteins, as indicated by the Digestible Indispensable Amino Acid Score (DIAAS), relative to other foods. Some amino acids and other compounds (carnitine, creatine, taurine, 4-hydroxyproline and anserine) are primarily available in human nutrition through consumption of TASF. These nutrients contribute vital functions in immune defence, anti-inflammatory pathways, memory and cognition. TASFs are also dense in dietary fats that can either promote or compromise health. Consuming diverse diets and appropriate levels of TASF can provide the necessary ratios of essential fatty acids (linoleic to α-linolenic acids) and blood cholesterols (high-density lipoprotein to low-density lipoprotein) and enable the absorption of fat-soluble vitamins needed for human health. Dietary intakes of long-chain fatty acids from TASF are important for brain development and cognition across the life course, particularly in the absence of aquatic food.

TASF can also provide critical micronutrients (minerals and vitamins) in bioavailable forms. Iron and zinc deficiencies are highly prevalent in populations around the world, contributing significantly to the global burden of disease. Animal meats offer these minerals in compounds that are more efficiently metabolized than those obtained from plant-based foods (PBFs). However, evidence suggests that iron availability from eggs and insects is lower than from meat. TASF is also a rich source of selenium, which plays crucial roles in anti-inflammatory and genome-level processes. Vitamin B12, which is necessary for growth, neurodevelopment function and maintenance, is largely sourced from TASFs in human nutrition, with only a few exceptions among PBFs (e.g. some seaweeds). Choline, which is also concentrated in some TASFs, has garnered recent attention for its vital roles in human growth, neurotransmission, and cell-membrane integrity and function, among other roles. Vitamin C, which is necessary for growth, development and repair of all body tissues, is found to some degree in milk and some types of meat but is absent in eggs, meaning that it needs to be obtained mainly from PBFs.

Phytates, tannins and oxalates, found in some foods such as legumes and cereals, can interfere with the absorption of minerals and other nutrients in humans. Consumption of TASF has been shown to counteract the effects of these antinutrients.

Lipids and fat-soluble vitamins in TASF have been shown to be affected by animal diets, and this has implications for decisions on animal feeding. In populations that do not consume significant quantities of fish, meat can contribute to dietary omega-3 requirements, especially when the diets of the animals from which the meat is sourced include plants that are dense in polyunsaturated fatty acids.

Effects of terrestrial animal source food on nutrition and health across the life course

This section summarizes evidence on the roles of TASFs in human biology across the life course and the impacts of dietary intakes on nutrition (nutrient status and anthropometry), health (infectious disease, chronic disease and bone health) and cognition (development, neuroprotection and neurological disease prevention). Differential effects are revealed by life-course phase: women during pregnancy and breastfeeding (including mother, foetus and breastfeeding child); infants and young children; school-age children and adolescents; adults; and older adults. Overall, most evidence comes from trials assessing milk and dairy products, followed by beef and eggs. There is generally good regional representation in sampled populations, except in the case of older adults, for whom evidence comes predominantly from high-income countries.

A robust evidence base shows that milk and dairy consumption during pregnancy increases birth weight in offspring and may also enhance birth length and foetal head circumference outcomes. Among infants and young children, egg, milk and meat consumption has been studied, with findings varying depending on overall diet and environmental exposure. Evidence for school-age children and adolescents also focuses on milk and dairy products and indicates that consuming them has positive effects in terms of increasing height and reducing overweight and obesity. Beef consumption during this phase has been shown to improve cognitive outcomes.

In adults, findings largely indicate that eating milk and dairy products, specifically yoghurt, has positive effects in terms of reducing risk of all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. However, evidence for an association between milk consumption and coronary heart disease is equivocal. Evidence shows that egg consumption in adults does not increase risk of stroke or coronary heart disease. Synthesized findings from risk analyses show that consumption of modest amounts of unprocessed red meat (ranging from 9 to 71 g/day) has minimal health risk. For processed red meat, however, very low levels of consumption can elevate risk of mortality and chronic disease outcomes, including cardiovascular disease and colorectal cancer. Robust evidence shows that meat intake (85 to 300 g/day) is positively associated with iron status in adults. Poultry meat has been less studied than beef, but findings suggest that it has non-significant effects on stroke risk, with subgroup analyses suggesting a protective effect in women.

Among older adults, epidemiological evidence for the health effects of TASF comes primarily from high-income countries. A fairly strong evidence-base shows that lean red meat consumption has positive effects on muscle health. Other evidence suggests that milk and dairy products and other TASFs have a potential role in mitigating sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer's disease.

Cow's milk and poultry eggs are among the eight foods that pose allergenic risks to consumers, and it is therefore mandatory in many countries to state their presence in foods as part of precautionary allergen labelling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread but does not automatically lead to lactose intolerance, which also varies greatly in severity.

Policy recommendations on terrestrial animal source food consumption

Food-based dietary guidelines (FBDGs) are the most comprehensive reference for TASF consumption. FBDGs from 95 countries provide recommendations on TASF consumption, primarily linked to micronutrient intake for health benefits (e.g. iron intake), followed by the mitigation of potential health risks (i.e. diet-related non-communicable diseases [NCDs]).

Most FBDGs target the general public, although many make recommendations for specific groups in the life-course cycle. Most policy recommendations address TASF consumption generally. Next most frequent are recommendations on meat (in general), milk and dairy products, eggs and red meat. In the red meat category, most recommendations refer to beef; other types of meat, such as pork, goat meat and sheep meat, are less well covered. There is also less coverage of poultry, white meat (in general), offal, meat from wild animals, and insects. Micronutrient-related recommendations tend to be more detailed than NCD-related recommendations, providing quantitative indications in terms of daily or weekly intakes of TASFs. There are no specific recommendations on TASF consumption to address the risks associated with multiple forms of malnutrition (e.g. coexistence of micronutrient deficiency with overweight, obesity and NCDs). Environmental sustainability considerations were found only to be included in the FBDGs of eight upper middle- and high-income countries, with only the Netherlands providing quantitative recommendations. Animal welfare was found only to be mentioned in the FBDGs of Denmark and Sweden, where it was mentioned in the context of food labelling.

Food safety and food-borne disease issues related to TASF

One-third of the global food-borne disease burden is associated with the consumption of contaminated TASF, mainly linked to bacterial causes and diarrhoea. While evidence on food-borne disease hazards and health outcomes, and on risk analysis methods, is well documented, knowledge of the national burdens (incidence and severity) of these diseases is lacking. For example, effective targeting of national policies requires knowledge of the main transmission routes along the value chain, but these are not well understood.

Changing agricultural practices (especially those related to the intensification of livestock production and input use) lengthening and broadening of value chains, and greater consumption of processed food contribute to increasing exposure to food-borne disease hazards. Antimicrobial resistance presents additional challenges beyond those associated with food safety and nutrition. Food-safety burdens need to be alleviated by enhancing sanitation and mitigating health risks at the interfaces between animals, humans and the environment, through a One Health approach. Strengthening national food-control systems is key to ensuring food safety for better health and nutritional outcomes.

Emerging topics

This section addresses some recently emerged topics pertaining to TASF, nutrition and health. Fortified, blended foods containing TASF, most commonly milk powder, have been studied globally, and there are indications that they can have positive effects on child growth and development outcomes. However, the independent effects of the TASF ingredients cannot be directly linked to outcomes. Early findings for TASF alternatives, including cell-derived and plant-based alternative "meats", suggest that some products can mimic the taste and texture of TASF, but evidence for their effects on human nutrition and health outcomes is lacking. Insects and insect powders show promise as nutritious, sustainable food sources. Issues of preference and culture remain to be resolved in product development and marketing.

Major developments in microbiology offer insights into the relationship between TASF and human health. These developments include, first, methodological advances in "omics", spanning genomics, transcriptomics, proteomics, metabolomics and nutrigenomics. These fields provide evidence related to the pathways and metabolites involved in TASF's roles in nutrition and health. A second development is the rapidly expanding science of the microbiome, which essentially shows that the microbiome plays a mediating role in the relationship between TASF and human health. Species diversity, the abundance of short-chain fatty acids and the presence of pathogens are among the factors driving this association. Animal models and trials in humans demonstrate that red and processed meats and animal fats can damage human health via microbial metabolites, such as trimethylamine-N-oxide and hydrogen sulfide, while fermented dairy products have positive impacts.

Connections to other component documents

Component Document 1 summarizes the evidence for the downstream effects of TASF on human nutrition and health outcomes. Building on this analysis, Component Document 2 will examine factors influencing demand for TASFs and their supply and consumption, historically and into the future. It will illuminate factors affecting access to, and affordability of, TASFs and the quantity, quality, safety and diversity of TASFs within dietary patterns. Moving further upstream, Component Document 3 will assess the contribution of the livestock sector to food security and sustainable agrifood systems. Component Document 4 will present options for sustainably changing the livestock sector in ways that contribute to the development of more sustainable agrifood systems, healthier diets and better nutrition. Ultimately, all four documents will be combined into a high-level synthesis document on the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets.

Section **A**

Introduction

Key findings

- Trends in nutrition indicators show that the world is currently not on track to attain several of the 2025 World Health Assembly[1] and 2030 Sustainable Development Goal (SDG) nutrition targets.
- Terrestrial animal source food (TASF) within appropriate dietary patterns can make important contributions to reducing stunting and wasting in children under five years of age, low birthweight, anaemia in women of reproductive age (15–49 years), overweight in children under five years of age, and obesity and diet-related non-communicable diseases (NCDs) in adults.
- Evidence from the evolutionary past of *Homo sapiens* shows that higher levels of TASF intake were associated with increased stature, brain size and longevity, probably establishing metabolic needs in the human body that have remained into the present.
- Globally, 21 percent of total caloric supply is comprised of TASF. The figure is higher in Europe (37 percent) and the Americas (30 percent), but in Africa it is only 11 percent. The highest level of TASF relative to total caloric supply is in Northern America (43 percent), followed by Australia and New Zealand, and Northern Europe (both 41 percent). The lowest levels are in Eastern Africa and Middle Africa (6 percent) and Western Africa (4 percent).
- Globally, 47 percent of children between 6 and 23 months of age consume dairy and 22 percent consume eggs. However, this masks a significant disparity between the poorest and wealthiest quintiles.
- Certain agrifood systems may be particularly salient with respect to the substantial role of TASF in human nutrition. Conversely, in populations practising vegetarianism for religious, cultural or other reasons, TASF may play a very minor role.

Summary

This section summarizes recent data on the world nutrition situation, focusing on progress towards the global nutrition targets set by the World Health Assembly and the Sustainable Development Goals (SDGs). It also provides an overview of trends in nutrition indicators by region, showing the geographical variation in different forms of malnutrition.

It provides an overview of TASF dietary patterns using data from the FAO Food Balance Sheets. It also presents trends in the global and regional supply of TASFs, which show great disparities across regions and subregions. It provides an overview of the contribution of TASFs to caloric supply and of energy and protein supply from plant- and animal-source foods (including those from both terrestrial and aquatic sources), differentiated by region. It also provides a snapshot of the percentage of children between 6 and 23 months consuming TASFs, such as dairy, eggs and flesh foods (including those from both terrestrial and aquatic sources), which shows high discrepancy by wealth quintile. The section further includes a brief evidence-based overview of the role that TASF played in hominin evolution over the last 2 million years and introduces the importance livestock and TASF to food security and nutrition. It emphasizes the extent to which certain agrifood systems may be particularly salient in the consideration of the substantial role of TASF in human nutrition. For example, pastoralist populations whose livelihoods have traditionally depended on livestock have historically consumed more TASF and some of the food systems of some Indigenous Peoples incorporate TASF through hunting, gathering or livestock production. The section further presents the results of a study that examined the inclusion of wild foods in the diets of eight groups of Indigenous People across the world. At the other end of the consumption spectrum, there are populations that practise vegetarianism for cultural or religious reasons.

[1] Global nutrition targets 2025 (https://apps.who.int/nutrition/global-target-2025/en/).

1. The world nutrition situation

Healthy diets are those that include an appropriate balance of the foods necessary to achieve the optimal growth and development of all individuals and to meet their physiological needs and support their physical, mental and social wellbeing at all life stages (CFS, 2021). Healthy diets are safe, diverse, balanced and based on nutritious foods. They help to protect against malnutrition in all its forms, including undernutrition, micronutrient deficiencies, overweight and obesity, and lower the risk of diet-related non-communicable diseases (see Box A1).

More practically, FAO, IFAD, UNICEF, WFP and WHO (2022) defines healthy diets as follows:

They

1. *start early in life with early initiation of breastfeeding, exclusive breastfeeding until six months of age, and continued breastfeeding until two years of age and beyond combined with appropriate complementary feeding;*
2. *are based on a great variety of unprocessed or minimally processed foods, balanced across food groups, while restricting highly processed food and drink products;*
3. *include wholegrains, legumes, nuts and an abundance and variety of fruits and vegetables;*
4. *can include moderate amounts of eggs, dairy, poultry and fish, and small amounts of red meat;*
5. *include safe and clean drinking water as the fluid of choice;*
6. *are adequate (i.e. reaching but not exceeding needs) in energy and nutrients for growth and development and meet the needs for an active and healthy life across the life cycle;*
7. *are consistent with WHO guidelines for reducing the risk of diet-related NCDs and ensuring health and well-being for the general population; and*
8. *contain minimal levels of, or if possible no, pathogens, toxins or other agents that can cause food-borne disease. According to WHO the characteristics of a healthy diet include the following: less than 30 percent of total energy intake comes from fats, with a shift in fat consumption away from saturated fats towards unsaturated fats and the elimination of industrial transfats; less than 10 percent of total energy intake comes from free sugars (preferably less than 5 percent); at least 400 g of fruits and vegetables are consumed per day; and not more than 5 g of salt (which should be iodized) is consumed per day.*

The Committee on Food Security Voluntary Guidelines on Food Systems and Nutrition (CFS, 2021) recognizes that healthy diets may vary according to individuals' characteristics (e.g. age, sex, health status, economic security, lifestyle and level of physical activity) and with geography, culture and customs, food preferences and the availability of foods. There can be tremendous diversity and variation in dietary preferences within the range of what may be a healthy diet.

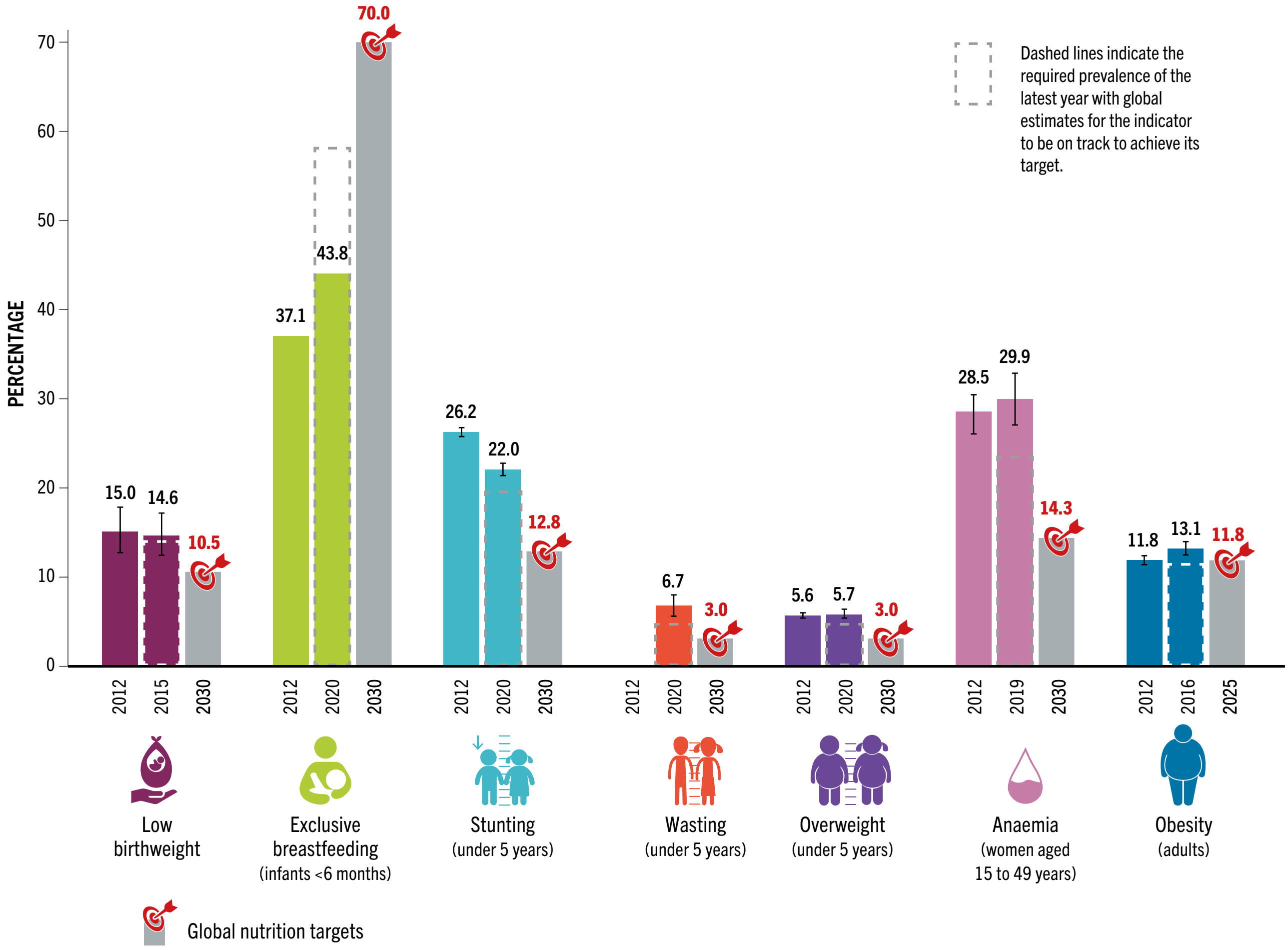
The review provided here also recognizes that there is variability in TASF consumption patterns globally and that this is a consequence of both choice and circumstance. It considers TASF within the context of diverse and varied diets and recognizes that TASF intake levels affect health by acting synergistically in the diet matrix and in response to external factors.

The world is not on track to meet the World Health Assembly or the SDG nutrition targets by 2030 (see Figure A1). Large gaps remain for several milestones, including those for exclusive breastfeeding from zero to six months and anaemia in women of reproductive age (15–49 years). Anaemia affects nearly one in three women worldwide. Efforts to meet the 3 percent target for the prevalence of child wasting by 2030 and to ensure that there is no increase in overweight among children under five years of age are also not on track. Overweight affects 14.6 percent of children and adolescents globally, and obesity affects 4.3 percent (WHO, 2021a). Prevalence of low birthweight was 14.6 percent globally in 2015, only a small reduction from 2012, and the 10.5 percent target is unlikely to be met. These statistics mask vast differences across countries in prevalence of these public-health problems.

Stunting is the only indicator showing substantial improvements in the last two decades (see Figure A2), although the 2021 *State of Food Security and Nutrition in the World* predicts that the COVID 19 pandemic may reverse this trend for the first time. Anaemia among women of reproductive age persists at very high levels across multiple regions. Again, limited progress has been made towards the target of a 50 percent reduction. Adult obesity has also risen sharply across many regions. Globally, 39 percent of adults 18 years or older (1.9 billion) were overweight in 2016 and 13 percent (650 million) were obese (WHO, 2021e). Annually, 41 million people die from non-communicable diseases (NCDs) – approximately 71 percent of all deaths globally. The majority of these deaths occur in low- and middle income countries (WHO, 2021c). Four conditions are responsible for over 80 percent of premature NCD deaths annually: cardiovascular diseases (17.9 million); cancers (9.3 million); respiratory diseases (4.1 million); and diabetes (1.5 million). Unhealthy diets are among the leading risk factors for NCD morbidity and mortality (Afshin *et al.*, 2019).

The *State of the World Food Security and Nutrition* (2022) reports that the prevalence of undernourishment increased from 8.4 percent to 9.9 percent globally between 2019 and 2020. This translates into an estimated 118 million more people experiencing hunger and a total of around 811 million people worldwide (FAO, IFAD, UNICEF, WFP and WHO, 2022).

Figure A1. Progress towards World Health Assembly global nutrition targets



[1.] Wasting is an acute condition that can change frequently and rapidly over the course of a calendar year. This makes it difficult to generate reliable trends over time with the input data available – as such, this report provides only the most recent global and regional estimates.

[2.] The potential impact of the COVID-19 pandemic is not reflected in the estimates.

[3.] Although 2010 is the WHO baseline for adult obesity, to ensure consistency throughout this report, the year 2012 is used as the baseline. The global target for adult obesity is for 2025.

Data sources: Data for stunting, wasting and overweight are based on UNICEF, WHO & International Bank for Reconstruction and Development/World Bank. 2021. UNICEF, WHO, World Bank Group Joint Child Malnutrition Estimates, April 2021 Edition. Cited 2 May 2022. https://data.unicef.org/topic/nutrition, www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb, https://data.worldbank.org; data for exclusive breastfeeding are based on UNICEF. 2021. Infant and Young Child Feeding: Exclusive breastfeeding. In: UNICEF Data: Monitoring the Situation of Children and Women. Cited 2 May 2022. https://data.unicef.org/topic/nutrition/infant-and-young-child-feeding; data for anaemia are based on WHO. 2021. Global Health Observatory (GHO). In: WHO. Geneva, Switzerland. Cited 2 May 2022. http://apps.who.int/gho/data/node.imr.PREVANEMIA?lang=en; data for adult obesity are based on WHO. 2017. Global Health Observatory (GHO). In: WHO. Geneva, Switzerland. Cited 2 May 2022. http://apps.who.int/gho/data/node.main.A900A?lang=en; and data for low birthweight are based on UNICEF & WHO. 2019. UNICEF-WHO Low Birthweight Estimates: levels and trends 2000–2015. Geneva, Switzerland. Cited 2 May 2022. Data.unicef.org/resources/low-birthweight-report-2019
Source: FAO, IFAD, UNICEF, WFP and WHO. 2022. *The State of Food Security and Nutrition in the World 2022: Repurposing food and agricultural policies to make healthy diets more affordable. The State of Food Security and Nutrition in the World (SOFI) 2022.* Rome, Italy, FAO, IFAD, UNICEF, WFP, WHO. https://doi.org/10.4060/cc0639en

Box A1. Different forms of malnutrition

Malnutrition is an abnormal physiological condition caused by inadequate, unbalanced or excessive intake of macronutrients and/or micronutrients. Malnutrition is also characterized by physiological inefficiencies in the utilization of nutrients. It may manifest in a variety of ways depending on nutritional status, and different forms of malnutrition can co-occur.

Stunting or chronic malnutrition

Low height-for-age, reflecting a past episode or episodes of sustained undernutrition. In children under five years of age, stunting is defined as height-for-age more than 2 standard deviations below the WHO Child Growth Standards median (FAO, IFAD, UNICEF, WFP and WHO, 2022).

This form of malnutrition may be associated with both physical and cognitive delays in growth and development as well as an elevated risk of death. It occurs particularly in the first 1 000 days, i.e. between conception and the age of two years, as a result of inadequate maternal and/or child nutrition. It can be caused by lack of access to adequate and high-quality foods and/or by disease.

Wasting or acute malnutrition

Low weight-for-height, generally the result of weight loss associated with a recent period of inadequate dietary energy intake and/or disease. In children under five years of age, wasting is defined as weight-for-height more than 2 standard deviations below the WHO Child Growth Standards median (FAO, IFAD, UNICEF, WFP and WHO, 2022). This form of undernutrition indicates recent and severe weight loss, which is often associated with infectious disease and acute starvation. Children under five years of age are most vulnerable to wasting, in particular when transitioning from exclusive breastfeeding to complementary feeding. The occurrence of wasting often varies seasonally or increases as result of emergencies such as droughts or floods. Stunting and wasting often coexist.

Underweight

Underweight is defined as weight-for-age z score more than 2 standard deviations below the WHO Child Growth Standards median. A child who is underweight may be stunted, wasted or both. Mortality risk increases in children that are even moderately underweight.

Micronutrient deficiencies or hidden hunger

Micronutrient deficiencies are shortages of essential vitamins and minerals that the human body requires in small amounts. Most micronutrients come from dietary sources, as the body does not produce them or only does so in inadequate quantities. Some micronutrients cannot be stored in the body for long periods, for example water-soluble vitamins. Regular consumption of food rich in those micronutrients is therefore necessary to avoid deficiency. Micronutrient deficiency can cause severe and even life-threatening conditions such as anaemia, xerophthalmia, osteoporosis and impaired immune function.

Anaemia

Anaemia is a condition in which the number of red blood cells or the haemoglobin concentration within them is lower than normal, decreasing the capacity of the blood to carry oxygen to the body's tissues. This results in symptoms such as fatigue, weakness, dizziness and shortness of breath. The optimal haemoglobin concentration needed to meet physiological needs varies with age, sex, elevation of residence, smoking habits and pregnancy status. The most common causes of anaemia include the following: nutritional deficiencies, particularly iron deficiency, though deficiencies in folate and vitamins B12 and A are also important causes; haemoglobinopathies; and infectious diseases, such as malaria, tuberculosis, HIV and parasitic infections. Anaemia is a serious global public health problem that particularly affects young children and pregnant women. WHO estimates that 42 percent of children under five years of age and 40 percent of pregnant women worldwide are anaemic (WHO, 2021d).

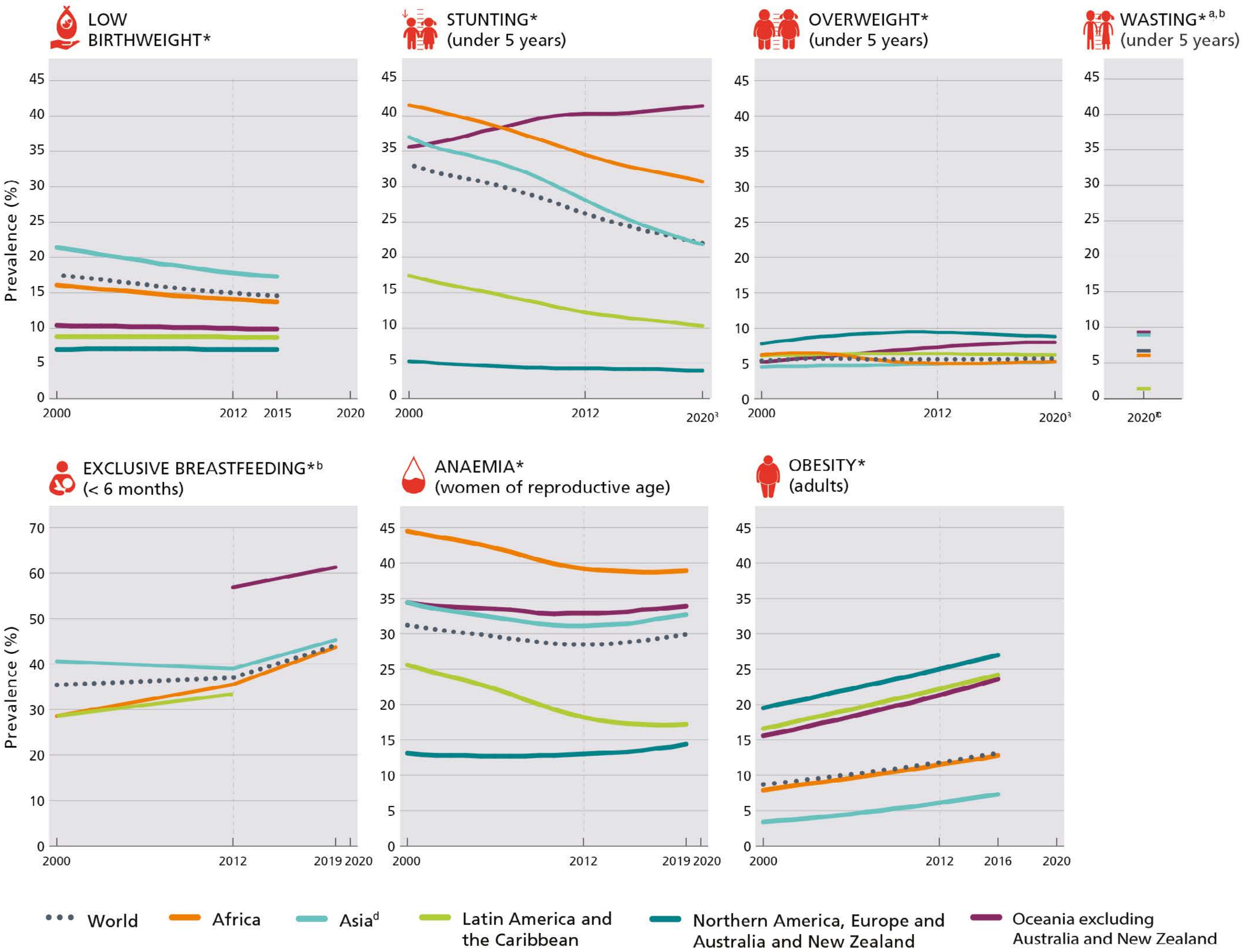
Overweight and obesity

Body weight that is above normal for height as a result of an excessive accumulation of fat. It is usually a manifestation of expending less energy than is consumed. In adults, overweight is defined as a body mass index (BMI) of 25 kg/m^2 or more, and obesity as a BMI of 30 kg/m^2 or more. In children under five years of age, overweight is defined as weight-for-height more than 2 standard deviations above the WHO Child Growth Standards median, and obesity as weight-for-height more than 3 standard deviations above the WHO Child Growth Standards median (FAO, IFAD, UNICEF, WFP and WHO, 2022).

Diet-related non-communicable diseases

Non-communicable diseases (NCDs), also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental and behavioural factors. Unhealthy diets and a lack of physical activity may show up in people as raised blood pressure, increased blood glucose, elevated blood lipids and obesity. These are called metabolic risk factors and can lead to cardiovascular disease, the leading NCD in terms of premature deaths (WHO, 2021c). The NCDs that are most commonly studied in association with consumption of red and processed meat include colorectal cancer, type 2 diabetes and ischaemic heart disease.

Figure A2. **Trends in nutrition indicators by region**



[a.] Wasting is an acute condition that can change frequently and rapidly over the course of a calendar year. This makes it difficult to generate reliable trends over time with the input data available and, as such, this report provides only the most recent global and regional estimates.

[b.] For wasting and exclusive breastfeeding, estimates are not shown for regions/years where population coverage was below 50 percent.

[c.] The collection of household survey data on child height and weight were limited in 2020 due to the physical distancing measures required to prevent the spread of COVID-19. Only four national surveys included in the database were carried out (at least partially) in 2020. The estimates on child stunting, wasting and overweight are therefore based almost entirely on data collected before 2020 and do not take into account the impact of the COVID-19 pandemic.

[d.] For wasting and low birthweight, the Asia estimate excludes Japan.

Data sources: Data for low birthweight are based on UNICEF & WHO. 2019. UNICEF-WHO Low Birthweight Estimates: levels and trends 2000–2015, May 2019. In: UNICEF data. New York, USA, UNICEF [Cited 19 April 2021]. data.unicef.org/resources/unicef-who-low-birthweight-estimates-levels-and-trends-2000-2015; data for stunting, wasting and overweight are based on UNICEF, WHO & World Bank. 2021. UNICEF-WHO-World Bank: Joint child malnutrition estimates - Levels and trends (2021 edition). https://data.unicef.org/resources/jme-report-2021, www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb, https://datatopics.worldbank.org/child-malnutrition; data for exclusive breastfeeding are based on UNICEF. 2020. UNICEF Global Database on Infant and Young Child Feeding. In: UNICEF. New York, USA. [Cited 19 April 2021]. data.unicef.org/topic/nutrition/infant-and-young-child-feeding; data for anaemia are based on WHO. 2021. Global Health Observatory (GHO). In: WHO. Geneva, Switzerland. [Cited 26 April 2021]. www.who.int/data/gho/data/themes/topics/anaemia_in_women_and_children; data for adult obesity are based on WHO. 2017. Global Health Observatory (GHO). In: WHO. Geneva, Switzerland. [Cited 19 April 2021]. www.who.int/data/gho/data/indicators/indicator-details/GHO/prevalence-of-obesity-among-adults-bmi-=-30-(age-standardized-estimate)-(-).
Source: FAO, IFAD, UNICEF, WFP and WHO. 2021a. *The State of Food Security and Nutrition in the World 2021: Transforming food systems for food security, improved nutrition and affordable healthy diets for all.* Rome, FAO. 240 pp. https://doi.org/10.4060/cb4474en

2. Terrestrial animal source food, dietary patterns and agrifood systems: historic legacy and current challenges

This assessment considers TASF within the context of dietary patterns and broader agrifood systems. As discussed below in Sections B and C, nutrition and related health outcomes depend on the interaction of TASFs with other foods, environmental exposures and metabolic processes. This subsection discusses how dietary patterns have evolved over the course of human evolution, and then presents an overview of the diversity of current dietary patterns incorporating TASF, and of agrifood systems, locally and regionally. Other component documents of the assessment will address these issues in greater detail.

2.1

Hominin evolution and terrestrial animal source food

Evidence suggests that TASF played an important role in hominin evolution over the last 2 million years. Information from isotope studies, archaeological assemblages, dental wear analyses and ethnographies of contemporary gatherer–hunter–fisher groups suggests that TASF was present in hominin diets in relatively high proportions and that they were among the factors driving important physiological changes (Kuipers, Joordens and Muskiet, 2012; Larsen, 2003; Stanford and Bunn, 2001). Dietary patterns today diverged from those of our ancestors only in recent history, precipitated by changes in climatic conditions, agriculture and technological advances. The discordance theory posited by Konner and Eaton suggests that this sudden change in diets resulted in chronic disease (Eaton and Konner, 1985), while others, building on the discordance theory, suggest a broader array of poor health outcomes (Eaton and Iannotti, 2017). Dietary diversity and a higher proportion of energy from TASF were among the key characteristics distinguishing the ancient gatherer–hunter–fisher diet from the diet of modern *Homo sapiens* (Kuipers, Joordens and Muskiet, 2012).

Some studies have used contemporary gatherer–hunter–fisher groups to examine diets in human evolution. One recent analysis concluded that approximately one-third of dietary energy intakes in these groups comes from meat consumption (Pontzer and Wood, 2021). An older analysis reviewed ethnographies from 229 gatherer–hunter–fisher groups and showed that TASF comprised between 45 percent and 65 percent of total energy intakes (Cordain *et al.*, 2000). These estimates may have limitations, however, including a potential gender bias (data from more men than women are used), the fact that modern hunter–gather populations do not rely exclusively on foraging, and the large diversity of dietary patterns across groups (Milton, 2003). Estimates for macronutrient intakes as a proportion of total calories range widely across ecological zones: 10 percent to 35 percent for protein; 20 to 50 percent for carbohydrates; and 20 to70 percent for fat (Kuipers *et al.*, 2010). Many scholars agree that TASFs were part of diets that were very diverse overall and that provided migrating groups with flexibility and the capacity to adapt to different environments (Turner and Thompson, 2013; Marlowe, 2005).

Several different types of TASF have been documented in hominin diets, depending on the environment and the period in hominin evolution. Archaeological assemblages from early hominin species suggest that they ate TASFs from lacustrine ecosystems and drew on a diverse range of terrestrial animals and aquatic animals, including crocodiles, turtles and fish (Braun *et al.*, 2010). Although some evidence points to scavenging for meat among early Pleistocene species, predation and hunting were probably more common means of sourcing meat (Domínguez-Rodrigo *et al.*, 2021). The use of tools appears to be connected to very early carnivorous behaviours, including the consumption of animal tissue and intake of nutrients from bone marrow (Pante *et al.*, 2018; Thompson *et al.*, 2019). One study applied paleobiological and paleoecology approaches to analyse trophic-level consumption patterns over time (Ben-Dor, Sirtoli and Barkai, 2021). It showed that during the Pleistocene era the trophic level of the human lineage evolved from a low base in *Homo habilis* to a high (carnivorous) state in *Homo erectus* and that there was a reversal of this trend over the period from the Upper Palaeolithic to the Neolithic and the emergence of agriculture.

There is consensus about the junctures in hominin evolution when significant anatomical and physiological changes occurred, and there is some evidence regarding the role of TASF in driving these shifts (Aiello and Wheeler, 1995; Milton, 2003). The first juncture occurred around 2 million years ago with the emergence of *Homo erectus*. Evidence suggests marked increases in stature, body mass and brain size, and some have linked these changes to increased levels of TASF in the diet (Kuipers *et al.*, 2010). Others have attributed larger brain sizes compared to other primates in part to early habitats near aquatic ecosystems and improved diets that included TASF (Broadhurst *et al.*, 2002; Burini and Leonard, 2018; Cunnane and Crawford, 2014; Mann, 2018). Other physiological changes that arose during human evolution and marked a divergence from other primates suggest dietary requirements for TASF (Mann, 2018). These include the following: inability to absorb vitamin B12 produced by gut bacteria (Domínguez-Rodrigo *et al.*, 2012); preferential absorption of haem iron over ionic forms (Henneberg, Sarafis and Mathers, 1998; Lönnerdal and Hernell, 2013); greater dependency on dietary choline (Domínguez-Rodrigo *et al.*, 2012; Wiedeman *et al.*, 2018); reduction in taurine production from amino-acid precursors (Chesney *et al.*, 1998; Ripps and Shen, 2012); and reduced conversion of alpha-linolenic acid into eicosapentaenoic acid (EPA)/docosahexaenoic (DHA) (Emken *et al.*, 1993).

Multiple lines of evidence show that the greatest dietary shifts away from TASF and towards plant based (PBF) food followed the widespread adoption of agriculture (crop and livestock production) during the Neolithic era, and during industrialization. Skeletal evidence suggests that for many populations, agriculture was associated with poorer diets, shorter stature, shorter lifespan, greater infectious-disease burden (as a consequence of higher population density) and more dental caries, among other health deficits (Armelagos *et al.*, 2014).

In summary, evidence shows that TASF has been integral to shifting dietary patterns and anatomical features during hominin evolution. High proportions of the energy obtained from the ancestral gatherer–hunter–fisher diet were probably derived from TASF of a wide variety of types, and embedded within diverse diets determined by ecosystem habitat. Critical aspects of anatomical and physiological evolution, such as stature, brain size, and longevity, were associated with patterns of TASF consumption. The evolutionary history linking TASF and health suggests the importance of TASF in diets today.

2.2

Terrestrial animal source food and dietary patterns around the world today

FAO and WHO define sustainable, healthy diets as follows:

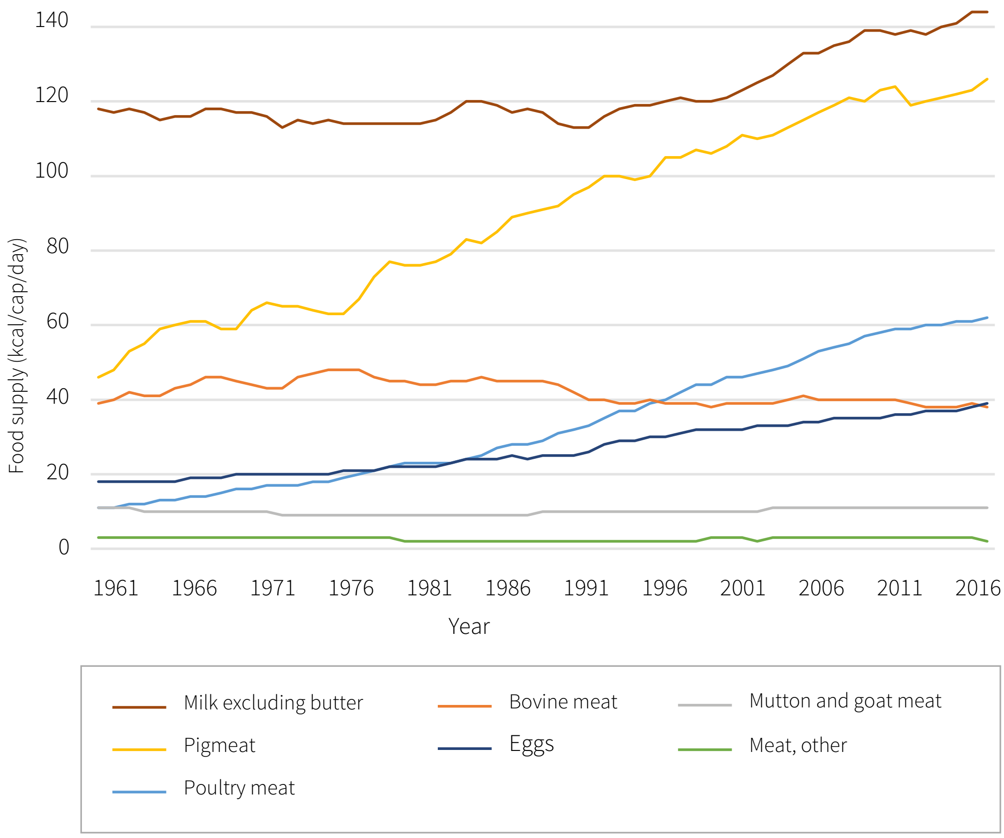
> *dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable. The aims of Sustainable Healthy Diets are to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations; contribute to preventing all forms of malnutrition (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs; and support the preservation of biodiversity and planetary health. Sustainable healthy diets must combine all the dimensions of sustainability to avoid unintended consequences. (FAO and WHO, 2019)*

The twentieth century was an era of rapid industrialization that saw significant advances in sanitation and hygiene, vaccination, use of antibiotics and other public health interventions in some parts of the world. It has been suggested that these factors, along with increased consumption of TASF in some populations, were associated with increased stature and other improvements in health during this period (Roser and Appel, 2013). At the start of the twenty-first century, a "nutrition transition" occurred in tandem with rapid urbanization and greater access to processed food (Popkin, 2006). Dietary patterns associated with this nutrition transition generally include increased fat intakes, increased consumption of refined sugar and processed food, and reduced fibre intakes.

Figure A3 shows that during the six decades between 1961 and 2016 the per capita supply of most types of TASF increased, probably because of growing stability and wealth. Bovine meat is an exception, with per capita supply levels increasing steadily until around 1990 and then beginning to decrease. Pig meat supply showed the greatest increase over this period, rising at a relatively steady rate, while egg and milk supply increased more notably after 1990. However, these trends were not uniform across all the regions and subregions of the world. There are clear disparities in TASF supply (see Figure A4). Europe, North America and Oceania had the highest supply levels, marked particularly by high milk consumption relative to other TASFs and regions. The combined Americas region showed the largest increases in the supply of poultry meat after1990, while intakes of other TASFs remained relatively stable. In Asia, there were large differences by subregion, with Eastern Asia showing steep increases in pig meat, Central Asia consuming higher levels of milk than the other subregions, and Southeastern and Southern Asia having fairly low levels of consumption for all TASFs except pig meat and milk, respectively. In Africa, levels of all TASFs remained low and stable, except in Southern Africa, where supplies of poultry meat increased and there were slightly higher supplies of milk and bovine meat. Within regions, there are also stark differences in country-level TASF supply patterns.

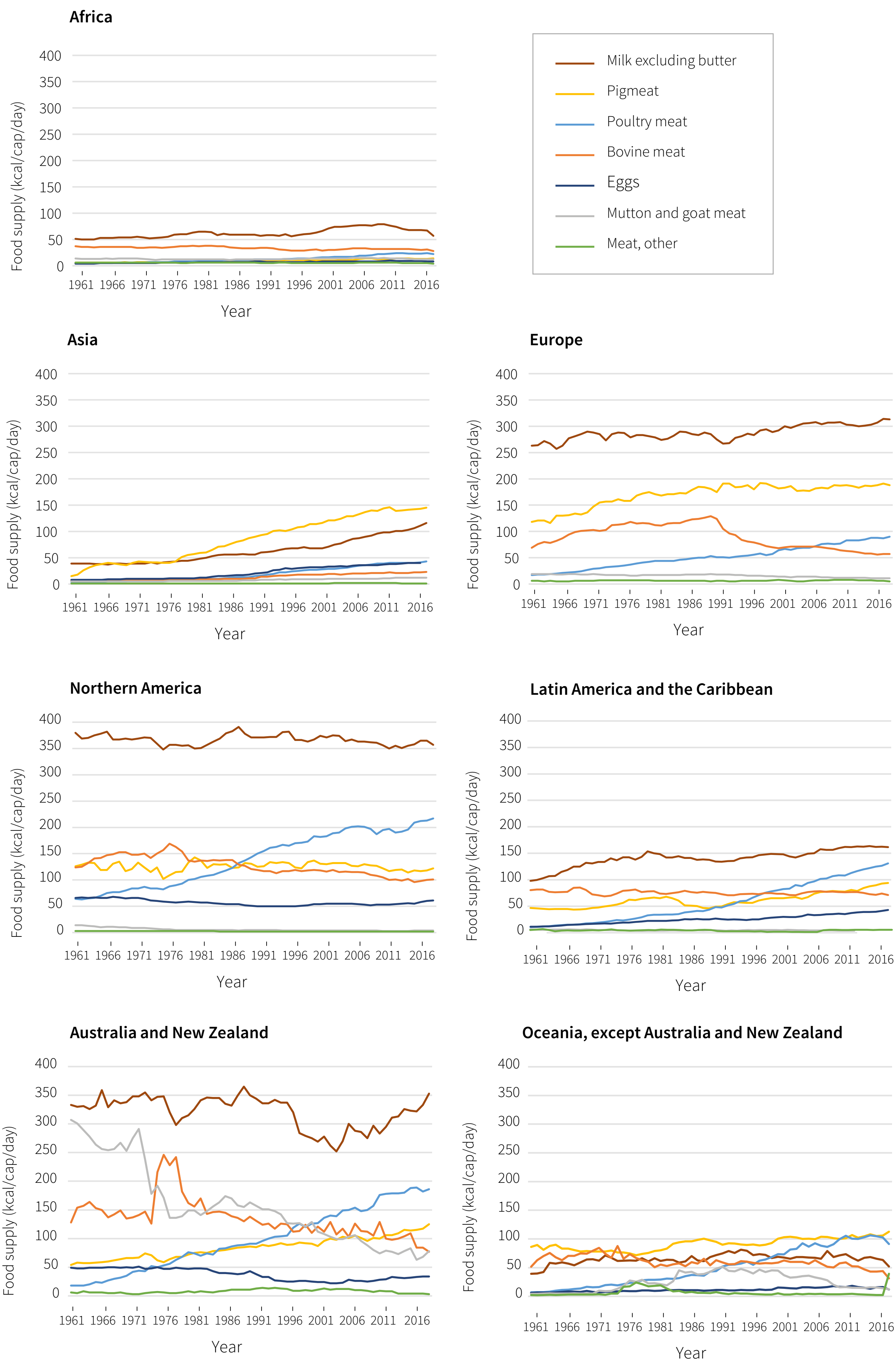
While the energy density from global cereal supply remained constant between 1961 and 2013, the nutritional content decreased because production of highly nutritious cereals (e.g. millet and sorghum) declined relative to that of less nutritious, high-yielding cereals, such as rice and maize (DeFries *et al.*, 2015). For example, the iron content in the global cereal supply decreased by 19 percent.

Figure A3. Trends in global food supply of terrestrial animal source food



Source: FAO. 2022. FAOSTAT. [Cited 10 February 2022]. https://www.fao.org/faostat/en/#home.

Figure A4. **Trends in food supply of TASF by region and subregion**

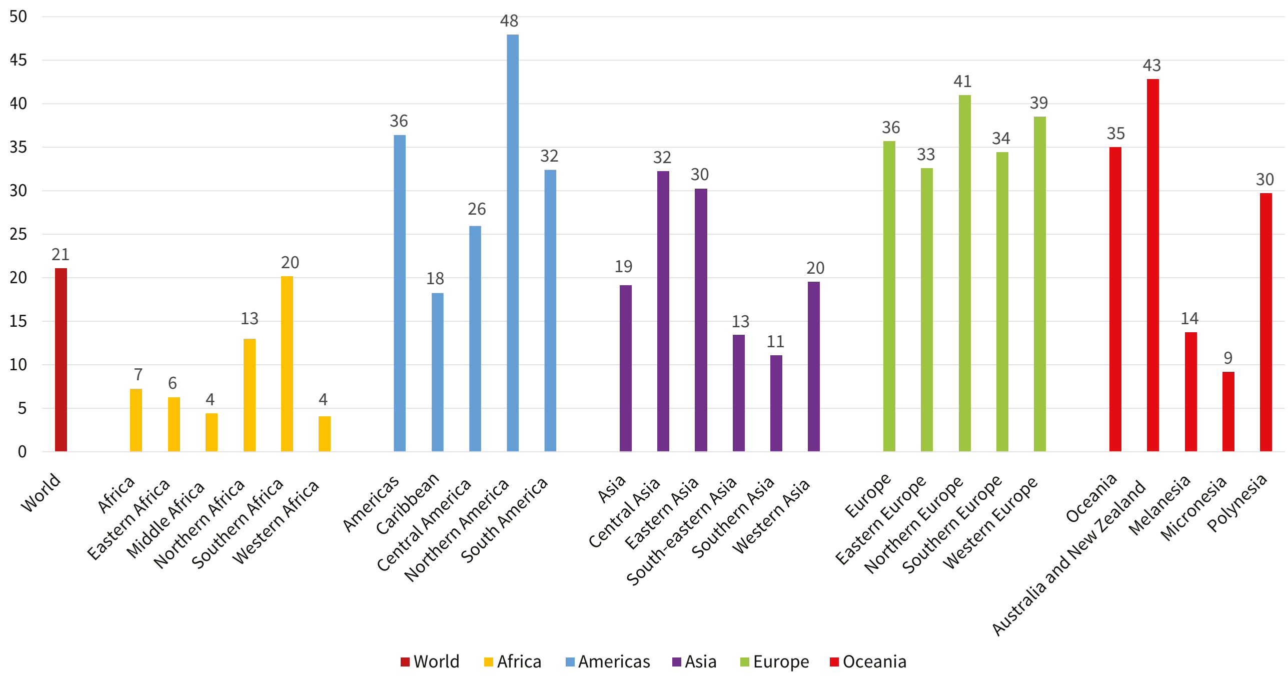


Source: FAO. 2022. *FAOSTAT*. [Cited 10 February 2022]. https://www.fao.org/faostat/en/#home.

There are also regional differences in the proportion of total caloric supply contributed by TASF (see Figure A5 Table). Globally, 21 percent of total caloric supply is provided by TASF. Regions showing higher proportions include Europe (36 percent) and the Americas (30 percent), while the figure for Africa is only 11 percent. The highest proportion of caloric supply contributed by TASF is in Northern America (48 percent), followed by Australia and New Zealand (43 percent), and Northern Europe (41 percent). The level in Eastern Africa and Middle Africa is 6 percent and that in Western Africa is 4 percent (Tables A1 and A2). Populations in which the proportion of calories supplied by TASF is high often have unhealthy dietary patterns, sedentary life-styles, high levels of overweight and obesity and high NCD burdens, although in some countries, such as Australia, red meat consumption is associated with healthy patterns such as vegetable consumption (Sui, Raubenheimer and Rangan, 2017). There are also country-level disparities in the supply of TASF and particular categories of TASF (Figure A6). Australia, Finland and the United States of America consume greater quantities of TASF per capita than other countries.

Note that estimates used for Figures A3 to A6 were derived only from food balance sheets and do not account for food loss and waste and thus may overestimate supply patterns to a certain degree. Because of data limitations, the estimates presented do not include individual dietary consumption.

Figure A5. Contribution of terrestrial animal source food to caloric supply by region and subregion



Note: The food categories included are bovine meat, mutton and goat meat, pig meat, poultry meat, meat other, eggs, and milk-excluding butter. 2000 kcal/day considered as average of the total calories consumed per day.
Source: FAO. 2022. *FAOSTAT*. [Cited 16 November 2021]. https://www.fao.org/faostat/en/#home.

Table A1. Protein supply from plants and animals by region

Region/Subregion	Eggs	Fish, seafood	Meat	Milk, excluding butter	Vegetal products	TOTAL
			(g/capita/day)			
World	3	5	15	9	50	82
Africa	1	3	6	3	51	64
Eastern Africa	0	2	4	3	49	58
Middle Africa	0	3	6	1	34	44
Northern Africa	1	4	10	7	67	90
Western Africa	1	3	4	1	52	62
Americas	4	4	32	15	40	95
Northern America	5	5	42	22	40	114
Central America	5	4	20	9	46	84
Caribbean	2	3	16	7	40	67
South America	3	3	29	11	38	85
Asia	3	6	11	7	53	81
Central Asia	2	1	17	21	53	93
Eastern Asia	6	10	20	3	61	100
Southern Asia	1	2	3	11	49	65
South-eastern Asia	3	12	10	2	44	71
Western Asia	3	2	14	12	57	87
Europe	4	6	26	20	45	102
Eastern Europe	4	5	24	16	47	97
Northern Europe	4	7	29	21	46	107
Southern Europe	4	9	28	18	45	104
Western Europe	4	6	25	26	42	104
Oceania	2	6	34	15	35	92
Australia and New Zealand	3	6	36	20	36	101
Melanesia	0	6	27	1	31	65
Micronesia	1	23	10	1	35	70
Polynesia	2	13	34	7	35	91
Southern Africa	2	2	23	4	45	76

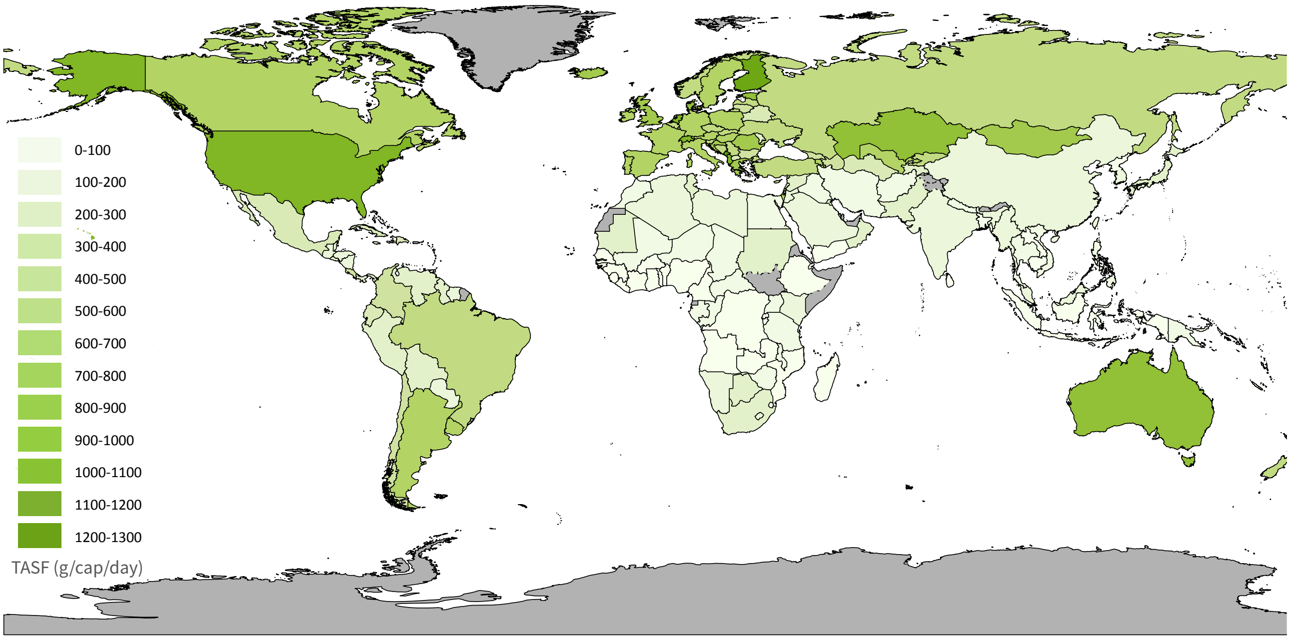
Source: FAO. 2022. *FAOSTAT*. [Cited 10 February 2022]. https://www.fao.org/faostat/en/#home

Table A2. Energy supply from plants and animals by region

Area	Eggs	Fish, seafood	Meat	Milk, excluding butter	Vegetal products	TOTAL
			(kcal/capita/day)			
World	39	35	240	144	2431	2889
Africa	8	18	81	57	2403	2567
Eastern Africa	3	10	63	59	2110	2245
Middle Africa	1	20	73	14	2070	2178
Northern Africa	16	27	111	132	2901	3187
Southern Africa	25	11	305	74	2395	2810
Western Africa	7	21	47	26	2547	2648
Americas	53	25	422	252	2479	3231
Northern America	62	35	528	369	2720	3714
Central America	62	23	303	154	2417	2959
Caribbean	24	18	214	126	2403	2785
South America	43	17	400	205	2304	2969
Asia	43	40	225	116	2428	2852
Central Asia	22	4	256	368	2361	3011
Eastern Asia	81	61	467	58	2545	3212
Southern Asia	13	15	32	176	2280	2516
South-eastern Asia	43	74	193	31	2484	2825
Western Asia	33	12	153	205	2650	3053
Europe	50	47	351	313	2444	3205
Eastern Europe	56	36	322	275	2440	3129
Northern Europe	46	54	418	356	2360	3234
Southern Europe	44	62	357	287	2519	3269
Western Europe	49	46	353	368	2439	3255
Oceania	26	42	411	261	2222	2962
Australia and New Zealand	34	41	470	353	2308	3206
Melanesia	5	41	253	17	1980	2296
Micronesia	10	154	160	14	2715	3053
Polynesia	21	99	449	125	2174	2868

Source: FAO. 2022. *FAOSTAT*. [Cited 10 February 2022]. https://www.fao.org/faostat/en/#home

Figure A6. **Terrestrial animal source food in national food supply**



Note: World average per capita supply of terrestrial animal source food per day is 383 g. Terrestrial animal source food include bovine meat, mutton and goat meat, pig meat, poultry meat, meat other, eggs and milk-excluding butter.
Source: FAO. 2022. *The nutrition and health potential of geographical indication foods.* Rome, FAO. 92 pp. https://doi.org/10.4060/cb3913en

FAO defines food security as the condition in which "all people, at all times, have the physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The original four dimensions of food security include – availability, access, utilization, and stability. Two additional dimensions are now recognized as fundamental aspects of food security: agency, which includes empowerment, the capacity to act independently; and sustainability, which includes respect for and protection of ecosystems over the long term in their interaction with economic and social systems (HLPE, 2020). This document focuses primarily on utilization and the vital importance of TASF in providing bioavailable nutrients as part of healthy diets in certain life-course phases.

Moderate and severe forms of household food insecurity correlate with poor-quality diets in many contexts. One study across four countries (Kenya, Mexico, Samoa and Sudan) examined dietary patterns in relation to food insecurity as measured by the global Food Insecurity Experience Scale (Alvarez-Sanchez, 2021). Analyses of household food consumption and expenditure surveys revealed that in these four countries households experiencing moderate or severe food insecurity consume less meat and dairy products. Consuming less fruits and vegetables was also associated with food insecurity in Kenya and Sudan. The authors concluded that the more food insecure households are, the larger the share of staples in the diet and the smaller the presence of nutritious food groups, such as fruits and vegetables, pulses and TASFs. A significant disparity in consumption of TASF between the poorest and wealthiest quintiles among children between 6 to 23 months is shown in Figure A7.

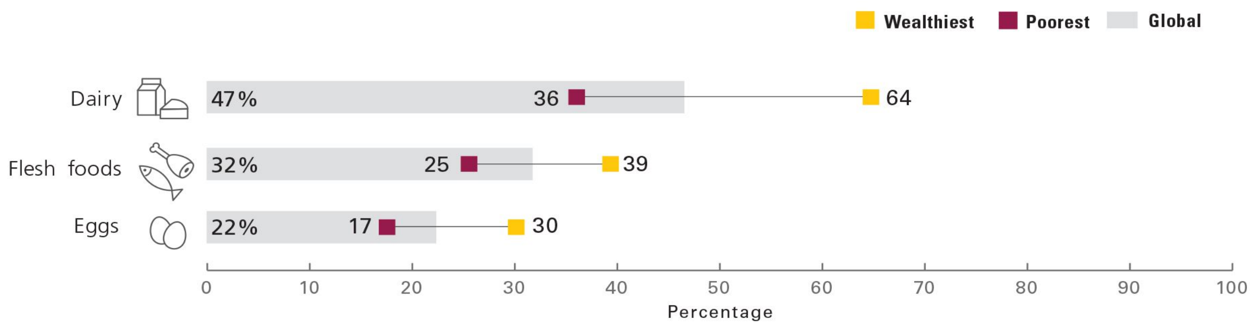
TASF and dietary patterns should be viewed within the larger context of agrifood systems. The web of factors influencing livestock production and agrifood systems more broadly will be discussed in later component documents.

2.3

Agrifood systems, locally and regionally

Dimensions of food security can be represented within an agrifood system framework that encompass food supply chains (availability) and food environments (access), with individual factors and consumer behaviour ultimately leading to diets that translate into nutrition and health outcomes (FAO, 2018; Food Systems Dashboard, 2021). Food supply chains encompass TASF production, storage, distribution, processing, packing, retail and marketing. Food safety and food-borne diseases are covered in Section D, which addresses the various aspects of the food supply chain. Food environments that encompass

Figure A7. Percentage of children between 6 and 23 months consuming TASF, by poorest and wealthiest quintile relative to the global average



Notes: "Flesh foods" in the figure refers to meat, fish, poultry and organ meats. Data from UNICEF global databases, 2021, based on multiple indicator cluster survey (MICS), demographic and health surveys (DHS) and other nationally representative sources.
Source: Adapted from UNICEF. 2021. Fed to fail: 2021 Child Nutrition Report. In: UNICEF DATA. [Cited 14 December 2021]. https://data.unicef.org/resources/fed-to-fail-2021-child-nutrition-report/.

affordability, communication and accessibility, among other elements, will be addressed in other Document 2 together with consideration of consumer behaviours and other individual factors contributing to agrifood systems.

External drivers can play a powerful role in the dynamics of an agrifood system. Some of these factors, may contribute to the role of TASF and livestock production in agrifood systems. Examples include the following: environment and climate change; globalization and trade; income growth and distribution; urbanization; population growth and migration; politics and leadership; sociocultural context; and infrastructure, including electricity and access to refrigeration. Environmental conditions related to water, sanitation and hygiene (WASH) are especially important drivers of nutritional status via their influence on enteric disease. Similarly, environmental and climatic conditions may influence how TASFs are produced, stored, distributed, processed, marketed and consumed. While these factors will be covered in the later component documents of the assessment, the influence of the multidimensionality of agrifood systems on how TASFs are integrated into diets and associated with nutrition and health outcomes needs to be noted here.

Policymakers globally are increasingly recognizing the need to transform agrifood systems to promote livelihoods and human and planetary health. In September 2021, key stakeholders from around the world convened for the UN Food Systems Summit with the aim or arriving at a consensus on the changes needed in agrifood systems if the Sustainable Development Goals are to be met by 2030 (see Box A2).

Certain types of agrifood system may be particularly salient with respect to the roles of TASF in human nutrition. For example, Indigenous Peoples' food systems have been recognized for their knowledge base and practices related to resilience and sustainability (FAO, Alliance of Bioversity International and CIAT, 2021). A study of eight different Indigenous Peoples' groups globally showed that animal source foods were present and were used – in balance with PBFs – for nutrition and livelihoods across all food systems (FAO, Alliance of Bioversity International and CIAT, 2021). Among the Indigenous Peoples featured were the Inari Sámi people of Nellim, Finland, who practise reindeer herding, the nomadic herders and pastoralists of Aratène, Mali, and the Bhotia and Anwal peoples of Uttarakhand, India, who practise agropastoralism in combination with gathering. Fishing contributed the food systems of two other groups, the Melanesians of Solomon Islands and the Tikuna, Cocam and Yagua peoples of Puerto Nariño, Colombia. The study found that the diets of Indigenous Peoples include a wide variety of hunted wild species, and wild products more broadly, that potentially provide nutritional advantages (see Table A3).

Indigenous Peoples' food systems point to the notion of territorial diets. The French word "terroir" refers to the origins of food or other products arising from a geographic area but also encompassing sociocultural elements. Geographical indications may be assigned to food arising from interactions between local populations and local environments (FAO, 2021). Some have described the Mediterranean, traditional and new Nordic and Japanese diets as territorial diets emerging from local agrifood systems (FAO and WHO, 2019). The TASFs within these diets

Box A2. Livestock-related policy at the 2021 United Nations Food System Summit

In 2021, the United Nations Food System Summit was convened as part of the Decade of Action to achieve the Sustainable Development Goals by 2030. The summit process included multistakeholder dialogues based on structured discussions between governments and other stakeholders, and supported the development and shaping by countries of national pathways towards sustainable food systems.

An analysis of national pathways that emerged from the summit was conducted to identify national priorities and plans for action relevant to the livestock sector (FAO, 2022b). Livestock policy issues were covered in 90 out of the 106 national pathways reviewed (those available via the Food Systems Summit Dialogues Gateway as of 18 October 2021). A widespread concern was the need to increase livestock productivity to address environmental issues and/or enhance food and nutrition security and healthy diets. Enhancing the consumption of terrestrial animal source food and its role in nutrition, food security and diverse and healthy diets featured in 42 percent of African and 37 percent of Asian national pathways. There were some thematic differences by region. In Europe, 44 percent of the national pathways addressed the further development of the One Health approach, 28 percent addressed animal welfare and 22 percent addressed reducing consumption of meat, milk and dairy products, and eggs. Animal welfare and reducing consumption were not mentioned in national pathways from other regions.

Analysis of livestock-related themes in national pathways, by region

Region	Self-sufficiency	Productivity	Animal welfare	Environmental sustainability	Food safety	One Health	Increasing consumption	Decreasing consumption	Total
Africa	0	20	0	13	0	0	14	0	47
Asia	2	10	0	7	3	2	7	0	31
Europe	0	5	5	7	1	8	2	4	31
LAC	0	2	0	5	1	1	3	0	12
Near East	1	4	0	2	0	1	1	0	9
North America	0	0	0	1	0	0	0	0	1
Southwest Pacific	0	2	0	6	0	0	1	0	9
World	3	43	5	41	5	12	28	4	141

Note: Number of national pathways covering livestock-related theme published by 18 October 2021. LAC = Latin America and the Caribbean.
Source: Food Systems Summit Dialogues Gateway (Cited 18 October 2021) https://summitdialogues.org/overview/member-state-food-systems-summit-dialogues/convenors.
Source: FAO. 2022. Livestock-related outcomes of the 2021 UN Food Systems Summit. Information Document, COAG Sub-Committee on Livestock, First Session, Rome 16–18 March 2022 (COAG:LI/2022/INF/11). Rome. http://www.fao.org/3/ni117en/ni117en.pdf

are produced within the respective regions and are integral to the cultural element of the diets as a whole.

TASFs play a particularly prominent role in certain populations. For example, pastoralists, whose livelihoods have traditionally depended on livestock, have historically consumed high levels of TASF. However, with increased marginalization, diminishing land tenure and climate change there have been declines in TASF intake among pastoralists and consequent health repercussions (Iannotti *et al.*, 2014). Populations also vary in terms of the diversity of the TASFs they consume. At the other end of the consumption spectrum, there are populations that practise vegetarianism for cultural or religious reasons. In India, Hinduism encourages lacto-vegetarianism to uphold the principle of non-violence towards animals but also to protect the mind and the spirit.

Climate change has negatively affected many communities around the world. For example, rising temperatures and drought have impacted many pastoralist communities, resulting in severe food insecurity for populations already at risk of low consumption of healthy diets (Herrero *et al.*, 2016; Inman, Hobbs and Tsvuura, 2020). Other extreme

Table A3. **Indigenous Peoples' wild food**

Indigenous Peoples	Geographic area	Wild food in diet (percentage)	Wild species hunted for consumption (number)	Examples of edible hunted species and biological classification
Baka	Cameroon	37	60	Nightjar (*Caprimulgus* sp.) (bird) Water chevrotain (*Hyemoschus aquaticus*) (mammal)
Inari Sámi	Finland	5	7	Capercaillie (*Tetrao urogallus*) (bird) Moose (*Alces alces*) (mammal)
Khasi	India	10	13	Red wild fowl (*Gallus gallus*) (bird) Leopard cat (*Prionailurus bengalensis*) (mammal)
Melanesians	Solomon Islands	15	11	Pacific reef heron (*Egretta sacra*) (bird) Flying fox (*Pteropus vampyrus*) (mammal)
Tikuna, Cocama and Yagua	Colombia	25	26	Ruddy ground dove (*Columbina talpacoti*) (bird) Palm weevil (*Rhynchophorus* sp.) (insect)
Maya Ch'orti'	Guatemala	10	9	Rock dove (*Columba livia*) (bird)

Note: Wild foods include animal source food and plant based food.
Source: Adapted from FAO, Alliance of Bioversity International & CIAT. 2021. *Indigenous Peoples' food systems: Insights on sustainability and resilience from the front line of climate change.* Rome. 420 pp. https://doi.org/10.4060/cb5131en.

weather events, such as floods and tropical storms, are causing irreparable damage to production systems, and there is evidence that vector-borne diseases in animals are becoming more common as a result of climate change (Kimaro, Toribio and Mor, 2017).

The production of TASFs in some agrifood systems has attracted the public's attention in the context of dialogues on climate change and environmental sustainability. While this topic will be covered in Component Document 3, important sustainability issues related to the consumption of TASFs within healthy diets are introduced here. Overconsumption of TASFs and rising demand for TASFs in some populations are likely to be contributing to the environmental impacts and climate change effects associated with livestock production. Agriculture, forestry and other land use broadly contribute approximately 21 percent of greenhouse-gas emissions, and livestock production contributes an estimated 14.5 percent (Clark *et al.*, 2019; Gerber and FAO, 2013). Greenhouse-gas emissions in livestock systems arise primarily from feed production, enteric fermentation in ruminants and manure storage. Unsustainable freshwater use and biodiversity losses have also been documented in livestock production systems. Comprehensive life-cycle assessments that fully encompass all stages of production are needed in order to adequately compare the contributions of different food groups to climate change and environmental degradation.

In summary, the global nutrition situation points to the important role played by TASF across different dietary patterns and its importance for meeting global milestones. Evidence from the evolutionary history of our species indicates that there a wide variety of TASFs were consumed in our ancient past, and that their introduction into hominin diets approximately 2 million years ago was associated with significant anatomical and physiological changes. TASF should be viewed within a larger multidimensional agrifood systems framework that comprises the following elements: TASF's contribution to healthy diets for nutrition and health outcomes (covered in this document 1); factors determining demand for, and supply and consumption of, TASF (covered in Component Document 2); the role of livestock and its impacts on the environment and climate change (covered in Component Document 3); and benefits, opportunities and trade-offs associated with livestock and TASF (covered in Component Document 4).

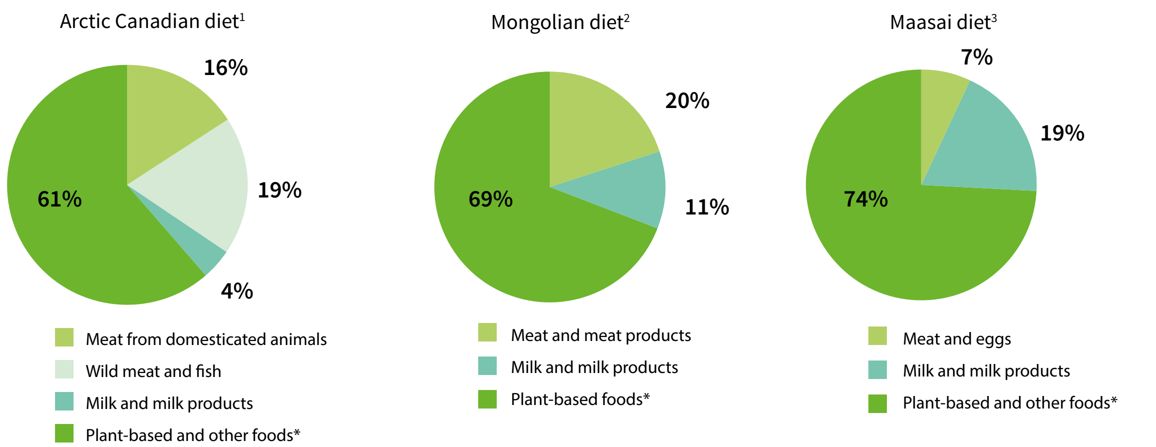
Box A3. Animal source food in dietary patterns – some examples of traditional diets

Arctic Canadian: The Arctic Canadian tundra is characterized by low temperatures and a short growing season that does not allow crop production. Thus, hunting and fishing activities play a central role in the culture of Arctic communities. Their traditional diet includes a variety of hunted meat and fish and is particularly high in protein and micronutrients (e.g. vitamins, iron and zinc). Animal source foods – comprising meat from livestock, meat from wild animals, fish and dairy – represent around 40 percent of the total calories consumed (Kuhnlein and Receveur, 2007).

Maasai: The Maasai live in southern Kenya and northern parts of the United Republic of Tanzania, along the Great Rift Valley on semi-arid and arid lands where there is limited potential for crop production. Their agropastoral communities depend mostly on cattle, sheep, goats and dromedaries. TASF (meat, poultry, eggs, milk and milk products) provides 26 percent of the total dietary energy intake of a Maasai community in Kenya (Transmara district), with 19 percent of total calories coming from milk and milk products (Hansen *et al.*, 2011).

Mongolian: Nearly 36 percent of total calories consumed in the Mongolian diet come from TASFs, with 20 percent provided by meat and meat products and 11 percent by milk and milk products. However, cereals are still the main source of energy, providing on average 55 percent of the daily intake (FAO/UNICEF/UNDP, 2007). The country's extreme weather conditions and the high proportion of grassland (80 percent of total land area) relative to available arable land (< 1 percent) explain the major role played by livestock products in the Mongolian diet.

Total energy obtained from different food groups in some traditional diets



[1] Adapted from Kuhnlein and Receveur, 2007. *Grain, fruits and vegetables provide around 30 percent of total energy.
[2] Adapted from FAO/UNICEF/UNDP, 2007. *Vegetables provide around 3 percent of total energy.
[3] Adapted from Hansen *et al.*, 2011. *Cereals and grain products represent 45 percent of total energy.

Sources: FAO, UNICEF & UNDP. 2007. Report Joint Food Security Assessment Mission to Mongolia Ulaanbaatar, Mongolia April 2007. [Cited 3 February 2022]. https://www.fao.org/3/j9883e/j9883e00.htm; Hansen, A.W., Christensen, D.L., Larsson, M.W., Eis, J., Christensen, T., Friis, H., Mwaniki, D.L. *et al.* 2011. Dietary patterns, food and macronutrient intakes among adults in three ethnic groups in rural Kenya. Public Health Nutrition, 14(9): 1671–1679. https://doi.org/10.1017/S1368980010003782; Kuhnlein, H.V. & Receveur, O. 2007. Local cultural animal food contributes high levels of nutrients for Arctic Canadian indigenous adults and children. The Journal of Nutrition, 137(4): 1110–1114. https://doi.org/10.1093/jn/137.4.1110.

Structure of this document

Nutrient composition and value of five types of TASF are covered in Section B as a precursor to a review of the evidence for TASF's effects on nutrition and health outcomes in different phases of the life course, which is covered in Section C. Section D addresses food safety and food-borne disease issues related to TASF. Section E provides an overview of emerging topics that extend beyond the gaps identified in the other sections. Each section commences with key findings and a summary.

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Section **B**

Nutrient composition and value of terrestrial animal source food

Key findings

- Terrestrial animal source food (TASF) provide higher quality proteins than other foods, with some nuanced differences in digestibility. Some specific amino acids and bioactive compounds with roles in human health (carnitine, creatine, taurine, hydroxyproline and anserine) are found primarily in TASF. The long-chain fatty acids and the ratios of essential fatty acids found in TASF are important for cognition across the human life course.
- Iron and zinc in red meat are bound in compounds that are more bioavailable and may be more easily digested than those in which these nutrients are bound in plant-based foods. Milk is recognized for its high concentration and bioavailability of calcium, among other nutrients. Eggs have high concentrations of choline and some long-chain fatty acids. TASFs are also generally a rich source of selenium, vitamin B12 and choline. Consumption of TASF has been shown to counteract the effects of antinutritional compounds found in plant based foods.
- The nutritional quality of TASFs (especially the fat composition) can be influenced by (in order of priority) animal species and feeding system, breed and production environment.
- Husbandry practices barely affect the protein composition and amino acid profile of TASFs.
- Feed and feeding systems mostly affect the nutritional quality of TASFs, especially fat and fatty acid content and especially in monogastric livestock (such as poultry and pigs). High dietary intake of polyunsaturated fatty acid-dense plants, in both ruminants and monogastrics, results in higher quantities of beneficial fatty acids (omega-3) in eggs, meat and milk. Feed and feeding systems affect, in particular, the technological and organoleptic quality and the commercial value of TASFs.
- Genetic selection programmes predominantly focus on increasing production and productivity, improving economic performance and meeting the demands of the food-processing industry. A few initiatives aim to improve nutritional quality.
- Causing stress to animals before slaughter affects the quality of TASF.
- Drivers of livestock production include consumer demand and market opportunities..

Summary

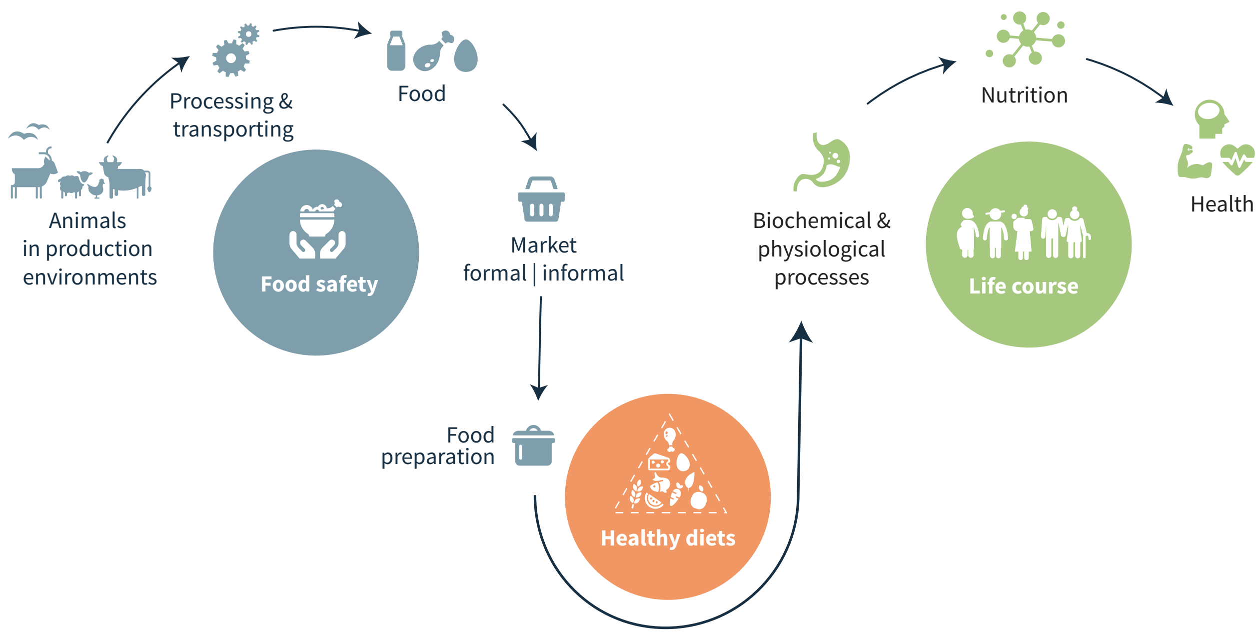
This section summarizes the available evidence on the nutrient and bioactive-compound composition of TASF. Several of the nutrients and bioactive compounds highlighted play important roles in human nutrition and health. TASF digestibility is modulated both by the food matrix and by the overall diet of the individual. TASF can provide large proportions of the recommended nutrient intake (RNI) of both macronutrients and micronutrients throughout the life course. Evidence indicates that all TASFs provide high-quality proteins (as indicated by Digestible Indispensable Amino Acid Scores). Some amino acids and bioactive compounds are predominantly found in TASF, for example, carnitine, creatine, taurine, hydroxyproline and anserine. The lipid and fat-soluble vitamin content of TASF is highly responsive to animal diets, and this has implications for decision-making in animal feeding. The ratio of high-density lipoprotein to low-density lipoprotein cholesterol affects human health. Excess low-density lipoprotein cholesterol, which is caused primarily by high levels of transfat in the diet, can build up "plaque" in blood vessels and increase the risk of heart disease and stroke. Some carbohydrates identified in TASF have been found to be potentially beneficial to human health, for example β-lactoglobulin in milk, oligosaccharides in milk and honey, and fibre in insects.

Evidence shows that TASFs are micronutrient dense and provide several limiting micronutrients in bioavailable matrices that are more easily absorbed and metabolized than those in other foods. TASFs are an especially important source of vitamin B12, which is not found in bioavailable forms in plant based food. The evidence also indicates that TASFs are rich sources of the entire vitamin B complex. Choline, which has relatively recently been recognized for its role in health and development, is found in high concentrations in liver, eggs and other TASFs. Very high proportions of the RNI can be met by consuming these products. Animal meats and insects are important dietary sources of iron and zinc. Deficiencies in these two nutrients remain highly prevalent across multiple populations globally. Selenium is also found in high concentrations in TASF. Milk and dairy products and other TASFs provide high proportions of the RNI of calcium, which is vital for bone health and various other biological processes. TASF contain a range of bioactive compounds that have been associated with anti-inflammatory and antioxidative processes.

1. Introduction

This section reviews the literature on the nutrient composition and value of TASF. It also describes the evidence base concerning distinct nutrients found in various TASFs and their products, and the pathways through which they affect human health (see Figure B1). The first subsection describes the concepts, definitions and methods used. This is followed by a discussion of particular nutrients that may be more bioavailable and/or more highly concentrated in TASFs than in plant based foods (PBFs) and of their roles in selected aspects of human biology and public health. Evidence on the food chemistry and composition of TASFs and their products is also summarized, and factors at the production level that cause variation in the nutritional quality of TASFs are described. The section ends with a recap and a discussion of gaps and needs.

Figure B1. Pathway from animal production to human health



2. Concepts, definitions and methods

Essential nutrients are compounds or single elements that need to be included in the diet either because the human body does not produce them endogenously or does not do so in sufficient quantities to sustain optimal health. Deficiencies in essential nutrients may lead to serious health problems and even death. Approximately 150 nutrients or components are included in global food composition databases and studied in human health and nutrition. Generally, nutrients are classed as macronutrients (proteins, fats and carbohydrates), which provide energy, among other roles, or micronutrients (vitamins and minerals and trace elements), which are necessary for healthy development, disease prevention and well-being.

Human nutrient requirements established by FAO and WHO are used to guide the preparation of recommendations on nutrient intakes for consumers and are periodically updated based on the latest evidence. This guidance indicates the amount of nutrients needed to maintain health in an otherwise healthy individual or group of people (WHO and FAO, 2004). Nutrient requirements are used by countries and international bodies, including the Codex Alimentarius Commission, to develop applications and tools for improving nutrition, for example food labelling. Nutrient requirements are also established at regional and national levels, for example the dietary reference values[3] established by the European Food Safety Authority (EFSA) and the United States of America's comprehensive set of dietary reference intakes, which includes recommended dietary allowances, adequate intakes and upper limits (USDA, 2021).

Evidence shows that, in addition to macronutrients and micronutrients, there are more than 26 000 biochemical compounds present in foods and that these probably influence human health (Barabási, Menichetti and Loscalzo, 2020a, 2020b). These compounds can enhance or interfere with metabolic processes. There is also evidence for food synergies that give rise to the need to consider dietary patterns and the interactions between food compounds in the diet (Jacobs, Gross and Tapsell, 2009). This section considers the nutrient composition of TASFs but also the bioavailability of nutrients in foods and the diet.

Nutrients and other bioactive compounds in foods may be absorbed, metabolized, transported, stored and excreted differently depending on nutrient density and bioavailability. Food and diet matrices in which nutrients and bioactive compounds interact are important determinants of the mechanical and biochemical processes of human nutrition (Capuano and Janssen, 2021). Nutrient density refers to the quantity of nutrients provided per calorie (e.g. per 100 kcal) or contained in a given food volume (e.g. per 100 g) or serving size (Drewnowski and Fulgoni, 2014). Nutrient bioavailability refers to the proportion of nutrient intake that is absorbed and metabolized. Bioavailability depends on the composition of the food and interactions with the overall diet as well as on the health status of the individual consuming the foods. For example, the absorption of iron is enhanced when consumed with meat or vitamin C-rich foods (Gropper, Smith and Carr, 2021). There may also be compounds that interfere with absorption, for example phytates in the case of iron. These antinutritional compounds are highlighted in this section.

Nutrient and food quality affect absorption, metabolism, storage and excretion processes. The Digestible Indispensable Amino Acid Score (DIAAS), defined as the percentage of digestible indispensable amino acids compared with a reference protein, is an example of a metric used to rate protein quality (FAO, 2013) (see Box B1). The Global Diet Quality Score (GDQS) was recently developed to measure nutrient adequacy and diet-related NCD risk and was found to perform comparably with other metrics, including the Minimum Dietary Diversity-Women and Alternative Healthy Eating Index 2010 scores (Bromage *et al.*, 2021). Some TASFs improve the score (e.g. eggs, chicken meat, game meat and low-fat dairy products), while some contribute positively only in moderate amounts (e.g. red meat) and others have a negative effect on the score (processed meat, and high-fat dairy products).

Food quality refers to the attributes of a food that influence its nutritional value and make it acceptable or undesirable to the consumer (FAO and WHO, 2003). The factors affecting food quality are presented in Subsection 5.

This document primarily covers raw TASFs, but processed products are covered to some extent. Processing methods are grouped into six categories (see Table B1), each of which serves to preserve food and protect it from contamination (FAO, 2021b). Other forms of food preparation include mixing, grinding and cutting. Processing may serve not only to preserve food but also to change its palatability and nutritional quality. The concept of ultraprocessed food has been recognized and a classification scheme known as NOVA that ranks foods according to the extent and purpose of industrial processing has been developed (Monteiro *et al.*, 2019).

[3] https://www.efsa.europa.eu/en/topics/topic/dietary-reference-values

Box B1. Amino acid digestibility: Digestible Indispensable Amino Acid Score (DIAAS)

Protein quality is closely associated with the capability of different food sources to supply the amino acids and nitrogen required to support multiple functions in the human body. High-quality proteins have high digestibility and contain all the indispensable (dietary essential) amino acids at an adequate level and in an adequate pattern. Understanding the food security situation requires accuracy in the measurement of protein quality (Minocha *et al.*, 2017).

In 1990, FAO and WHO adopted the Protein Digestibility-corrected Amino Acid Score (PDCAAS), which relates protein quality to indispensable amino acid profile and digestibility. In 2011, FAO proposed a revised system for expressing protein quality, the Digestible Indispensable Amino Acid Score (DIAAS) (FAO, 2013). While in PDCAAS amino acid digestibility is related to rat crude protein nitrogen faecal digestibility, DIAAS considers the ileal digestibility of each individual amino acid. PDCAAS overvalues low-quality protein sources that are limited in indispensable amino acids and undervalues high-quality protein sources (Rutherfurd *et al.*, 2015). In addition, PDCAAS does not adequately account for the bioavailability of specific amino acids, for example lysine, which can be modified in the Maillard reaction during food processing.

DIAAS and PDCAAS are calculated as the percentage of digestibility for the protein in question in relation to a reference protein with an "ideal" amino acid composition. FAO advice for individual foods or food ingredients is not to truncate the values above 100. Truncation penalizes proteins with high concentrations of indispensable amino acids, which are of particular interest from a nutrition security perspective. A score above 100 indicates potential to complement protein of lower quality. Not truncating the score allows the protein quality of individual foods or food ingredients to be calculated. However, the calculation for a mixed diet should be done using truncation.

DIAAS may be conceptually superior, but published amino acid digestibility datasets are unavailable for a wide range of human foods (FAO, 2014). It should therefore be noted that PDCAAS remains the validated method for determining protein quality. In recent years, new data have become available on the ileal digestibility of individual amino acids for foods and diets from various regions through the Proteos Phase III project undertaken by the Riddet Institute (Massey University), the University of Illinois, AgroParisTech, and Wageningen University.

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PDCAAS truncated (PDCAASt) or without truncation (PDCAAS) and DIAAS for individual protein sources

Protein source	Protein quality score (percent)			PDCAASt-DIAAS (percent)
	PDCAASt	PDCAAS	DIAAS	
Whole milk powder	100.0	116.1	115.6	-15.9
Egg	100.0	105	113	-13
Beef	100.0	114.0	111.6	-11.6
Chicken breast	100.0	101	108	-8
Soybean	100.0	102.0	99.6	0.4
Peas	78.2	78.2	64.7	13.6
Barley	59.1	59.1	47.2	11.8
Wheat	46.3	46.3	40.2	6.1

Source: Adapted from Ertl et al., 2016.

The following synthesis of the literature is presented as a narrative review. The literature search on which it is based covered studies that examine the nutrient composition of TASFs in their original forms and TASF products. Studies on aquatic foods, foods in which TASFs are only ingredients and fortified TASFs were excluded. Literature addressing the health implications of common nutrients and bioactive compounds generally found in TASFs is also summarized. The databases and search terms used are listed in Box B2.

Table B1. Types of food processing

Category of process	Examples processes
Heating to destroy enzymes and microorganisms	Boiling, blanching, roasting, grilling, pasteurization, baking, smoking
Removing water from the food	Drying, concentrating by boiling, filtering, pressing
Removing heat from the food	Cooling, chilling, freezing
Increasing the acidity of the food	Fermentation, adding citric acid or vinegar
Using chemicals to prevent enzyme and microbial activity	Salting, syruping, smoking, adding chemical preservatives such as sodium metabisulphite or sodium benzoate
Excluding air, light, moisture, microorganisms and pests	Packaging

Source: Adapted from Trager, J. 1996. The food chronology, Aurum Press, London, UK: Fellows, P. 2004. Processed foods for improved livelihoods. FAO Diversification Booklet 5. Rome. FAO.

Box B2. Search terms by database used for Section B

Protein quality is closely associated with the capability of different food sources to supply the amino acids and nitrogen required to support multiple functions in the human body. High-quality proteins have high digestibility and contain all the indispensable (dietary essential) amino acids at an adequate level and in an adequate pattern. Understanding the food security situation requires accuracy in the measurement of protein quality (Minocha *et al.*, 2017).

Search terms using Academic Search Complete via EBSCO

("animal source food" OR "livestock derived food" OR "animal derived food" OR "meat" OR "red meat" OR "dairy product") AND ("nutrient") OR ("nutritional composition") OR ("nutrient composition") OR ("nutritional content") OR ("macronutrient") OR ("micronutrient") OR ("nutritional value")

Search terms using PubMed

("animal source food" OR animal source food* OR "animal sourced food" OR "animal based food" OR "livestock derived food" OR "TASF") AND ("macronutrient" OR "protein" OR "amino acid" OR "lipid" OR "DHA" OR "EPA" OR "carbohydrate" OR "protein quality" OR "micronutrient" OR "vitamin A" OR "calcium" OR "iron" OR "bioactive compound" OR "taurine" OR "carnosine" OR "creatine") OR (("eggs") AND ("poultry" OR "duck" OR "emu" OR "muscovy duck" OR "ostrich" OR "partridge" OR "peafowl" OR "pheasant" OR "pig" "pigeon") OR ("milk" OR "dairy product")) OR ("lactose" OR "buffalo" OR "camel" OR "cow" OR "cattle" * OR "donkey" OR "goat" OR "mare" OR "mithan" OR "sheep") OR ("red meat" OR "meat" AND "alpaca" OR "beef" OR "goat" OR "guinea pig" OR "llama" OR "pheasant" OR "pig" OR "poultry" OR "sheep") OR ("Insects") OR ("honey" OR "bee products" OR "apis" OR "bees") OR ("game meat" OR "bushmeat" OR "wildlife food") AND ("nutrient composition" OR "nutrient value" OR "nutritional value" OR "nutrient density" OR "nutrient content") NOT ("aquatic animal food" OR "fortified" AND "animal source food" OR "ingredient" AND "animal source food")

Search terms using ScienceDirect

("animal source food" OR animal source food* OR "animal sourced food" OR "animal based food"* OR "livestock derived food" OR "TASF") AND ("macronutrient" OR "protein" OR "amino acid" OR "lipid" OR "DHA" OR "EPA" OR "carbohydrate" OR "protein quality" OR "micronutrient" OR "vitamin A" OR "calcium" OR "iron" OR "bioactive compound" OR "taurine" OR "carnosine" OR "creatine") OR (("eggs") AND ("poultry" OR "duck" OR "emu" OR "muscovy duck" OR "ostrich" OR "partridge" OR "peafowl" OR "pheasant" OR "pig" "pigeon") OR ("milk" OR "dairy product")) OR ("lactose" OR "buffalo" OR "camel" OR "cow" OR "cattle" * OR "donkey" OR "goat" OR "mare" OR "mithan" OR "sheep") OR ("red meat" OR "meat" AND "alpaca" OR "beef" OR "goat" OR "guinea pig" OR "llama" OR "pheasant" OR "pig" OR "poultry" OR "sheep") OR ("insects") OR ("honey" OR "bee products" OR "apis" OR "bees") OR ("game meat" OR "bushmeat" OR "wildlife food") AND ("nutrient composition" OR "nutrient value" OR "nutritional value" OR "nutrient density" OR "nutrient content") NOT ("aquatic animal food" OR "fortified" AND "animal source food" OR "ingredient" AND "animal source food"

3. Nutrients in terrestrial animal source foods and their importance for human nutrition

This subsection examines the nutrients and bioactive compounds found in TASF that have been associated with health and nutrition (see Box B3). It highlights key macronutrients, micronutrients and bioactive compounds that are highly concentrated in TASF and/or more bioavailable in TASF than in other food.

When analysing the nutritional aspects of food there is also a need to consider components that can affect the bioavailability of specific nutrients. This is the case for antinutritional compounds. These are substances that naturally occur in PBFs and TASFs and interfere with the absorption of nutrients.

Box B3. Food components: nutrients, bioactive compounds and antinutritional compounds

A nutrient is a substance that is required by the body for optimal growth, development and maintenance of good health. Nutrients are classified according to quantitative requirement:

Macronutrients: calorie-containing components of food needed in substantial quantities, typically above 10 g per day. These include carbohydrates, proteins and fats.

Micronutrients: nutrients required by the body in small amounts, usually below 2 g per day. These include vitamins and minerals.

Nutrients can be also classified according to their essentiality. Their deficiency causes specific symptoms that can lead to health problems.

Essential nutrients: nutrients that cannot be produced by the human body in sufficient quantities to meet physiological requirements and must therefore be supplied from foods or other sources (e.g. supplements).

Conditionally essential nutrients: nutrients that are produced by the human body in sufficient amounts to meet the body's physiological requirements but for which intake via food or other sources (e.g. supplements) may be essential under certain conditions when biosynthesis is inadequate.

Non-essential nutrients: nutrients required by the human body that can be synthesized by the human body under normal conditions and are thus not required in the food.

Bioactive compounds are substances that are able to modulate metabolic functions leading to beneficial outcomes. TASFs contain various bioactive compounds that are being studied, including carnitine, anserine, creatine and anersine.

Classification of nutrients by essentiality

Classification	Nutrients
Essential nutrients	Amino acids: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine
	Fatty acids: alpha-linolenic acid, linoleic acid
	Water-soluble vitamins: vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), vitamin B7 (biotin), vitamin B9 (folate), vitamin B12 (cobalamin), vitamin C
	Fat-soluble vitamins: vitamin A; vitamin E; vitamin K
	Minerals: calcium, chlorine, chromium, cobalt, copper, iron, iodine, manganese, magnesium, molybdenum, phosphorus, potassium, selenium, sodium, zinc
	Choline
Conditionally essential nutrients	Vitamins: vitamin D
Non-essential nutrients	Amino acids: alanine, arginine, asparagine, creatine, cystine, glutamine, glycine, proline, serine, taurine, tyrosine
	All digestible carbohydrates
	All fatty acids except for linolenic acid and linoleic acid

Antinutritional compounds occur predominately in PBFs. Examples of antinutritional compounds that interfere with mineral uptakes from TASF include phytates (phytic acid) and oxalates (oxalic acid).

3.1

Macronutrients

TASFs are most often associated with protein content and quality. Proteins are found throughout the human body, with over 40 percent found in skeletal muscle, 25 percent in body organs and the remainder in skin and bones (Gropper, Smith and Carr, 2021). Living cells in the body depend on proteins for their architecture and for various functions. Proteins can be grouped into the following categories, among others: catalysts (e.g. enzymes); messengers (e.g. hormones); structural elements; immunoprotectors; transporters; and buffers. In general, intake of high quality proteins optimizes human health outcomes, for example increasing muscle mass, throughout the life course (Tagawa *et al.*, 2021). However, there are particular phases of the life course when higher intakes of protein are important, for example in pregnant and lactating women and in older adults to prevent sarcopenia (Paddon-Jones and Rasmussen, 2009; Wolfe, Miller and Miller, 2008). Though not covered in this assessment, populations that are chronically or acutely ill may also require additional protein intakes (Phillips, Paddon-Jones and Layman, 2020).

TASFs are an important source of high-quality proteins containing digestible and indispensable (essential) amino acids. In recent years, there has been renewed focus on the role of high-quality proteins in the prevention of stunted growth. One study, with observational design, conducted in 116 LMICs found that utilizable protein (total protein corrected for biological value and digestibility) was negatively associated with stunting after adjusting for energy and gross domestic product (Ghosh, Suri and Uauy, 2012). In another study, which focused on children aged 12 to 59 months in Malawi, lower serum concentrations of specific essential amino acids (tryptophan, isoleucine, valine, methionine, threonine, histidine, phenylalanine and lysine) and conditionally essential amino acids (arginine, glycine and glutamine) were found to be associated with child stunting (Semba *et al.*, 2016). A recent narrative review discussed the importance of TASFs as sources of the essential amino acids needed by young children for growth and neurocognitive development and highlighted the amino acid sensing rapamycin complex 1 (mTORC1) as a key regulator of these processes (Parikh *et al.*, 2022).

Some amino acids and their metabolites are notably present in TASF and absent, or found at low levels, in PBF. These compounds have been classified as bioactive and many have been studied for their association with human health outcomes. Taurine, creatine, carnosine, 4-hydroxyproline and anserine were all discovered in cattle and are concentrated in beef but lacking in PBF (Wu, 2020). They play key roles in anti-inflammatory and immunological defence pathways, memory and cognition (Avgerinos *et al.*, 2018; Benton and Donohoe, 2011), eye health and cardiovascular maintenance (Ripps and Shen, 2012). Some TASFs may contain higher concentrations of the essential amino acid tryptophan, a precursor of serotonin, recently found to be connected to brain function via the microbiome (Gao *et al.*, 2020) and to depression in older adults (Klimova, Novotny and Valis, 2020) and postnatal women (Trujillo *et al.*, 2018). Diets consisting primarily of the staple food maize are deficient in tryptophan and may also interfere with the absorption of minerals found in TASF.

The composition of essential fatty acids in TASFs affects human health outcomes (see Box B4 for further information on the classification and importance of fat compounds). For example, the ratio of linoleic acid to alpha-linolenic acid influences how efficiently these fatty acids are endogenously converted into the longer chain fatty acids arachidonic acid, aminopenicillanic acid and docosahexaenoic acid (DHA) (Bernard *et al.*, 2013). The elongation and desaturation of alpha linolenic acid to long-chain omega-3 PUFAs may be limited if there is excess dietary linoleic acid. The long-chain fatty acids have known benefits to human health and play vital roles throughout the life course, inter alia in neurodevelopment, anti-inflammatory processes and cell-membrane integrity (Hadley *et al.*, 2016; Swanson, Block and Mousa, 2012). There is some evidence that DHA supplementation improves cognitive outcomes in young children (Drover *et al.*, 2011), but systematic and narrative reviews have shown that supplementation trials have only minimal effects on health outcomes throughout the life course (Abdelhamid *et al.*, 2018; Jiao *et al.*, 2014). Dietary TASF intervention trials, which are discussed in Section C, have demonstrated impacts on DHA status.

Some fats, such as saturated fatty acids and transfats, have been implicated in negative human health outcomes. Dietary guidelines generally recommend limiting saturated fats to approximately 10 percent of total energy intake (FAO, 2010), although the evidence base is mixed. A systematic review and meta-analysis using the GRADE approach to assess the quality of evidence found no association between saturated fat intakes and all-cause mortality, cardiovascular mortality, total coronary heart disease, ischaemic stroke or type 2 diabetes (de Souza *et al.*, 2015). However, the analysis was not able to rule out any risk or association between saturated fat and coronary

Box B4. Important fat compounds provided by terrestrial animal source foods

TASFs are rich in a variety of fats. Dietary fats not only provide essential fatty acids but also help in the absorption of fat-soluble vitamins. In the human body, they are usually present as triacylglycerols. Fatty acids are components of triacylglycerols. The conformation and abundance of fatty acids vary depending on the source of the food and can influence many health outcomes.

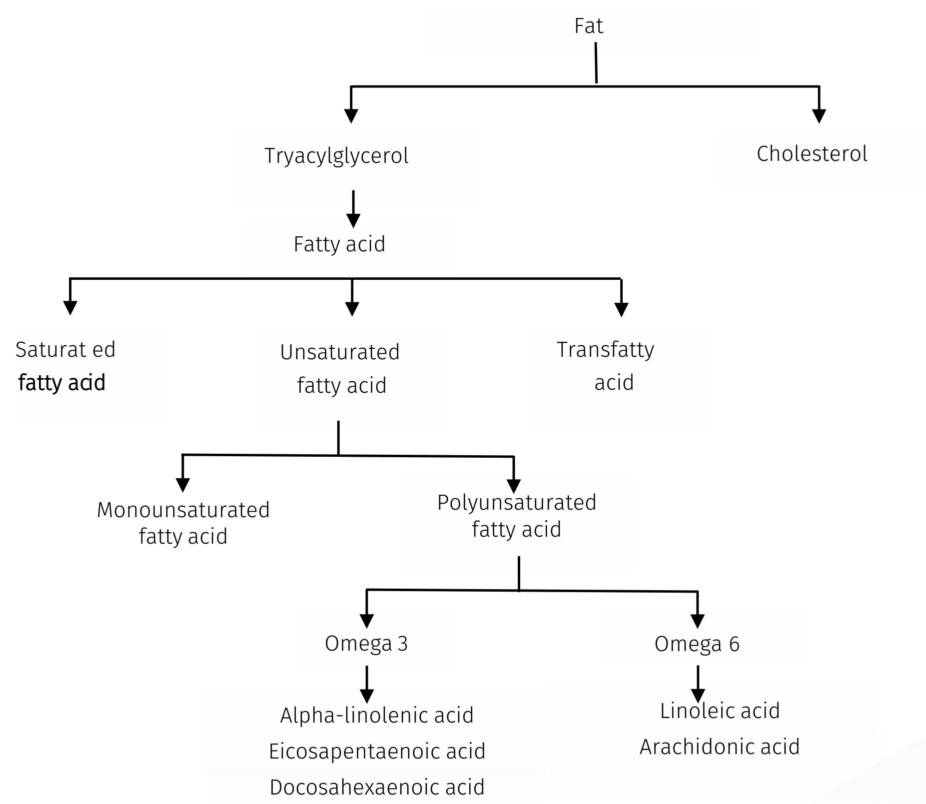
Fatty acids can be divided into three large groups: saturated fatty acids, unsaturated fatty acids and transfatty acids. Unsaturated fatty acids include monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs). PUFAs are especially important, as they include two essential fatty acids: alpha-linolenic acid and linoleic acid. These two fatty acids are required nutrients that cannot be synthesized by the human body and therefore have to be obtained from dietary sources.

Another important fat compound is cholesterol, which is made in the liver and can also be found in food. Cholesterol is transported in human blood on two types of lipoproteins: low-density lipoprotein and high-density lipoprotein. The ratio of high-density lipoprotein to low-density lipoprotein affects human health. Excess low-density lipoprotein cholesterol can build up "plaque" in blood vessels and increase the risk of heart disease and stroke, while high-density lipoprotein, the "good" cholesterol, removes low-density lipoprotein from the blood by transporting it to the liver from where it is flushed out of the body (CDC, 2020).

Examples of fatty acids and their roles in health outcomes

Fatty acid	Health outcome
Arachidonic acid Docosahexaenoic acid Eicosatetraenoic acid	Vital roles in neurodevelopment, anti-inflammatory processes and cell-membrane integrity
Docosapentaenoic acid Omega-6	Potential reduction of non-communicable disease risk
Ratio of omega-6 to omega-3 fatty acids	Low ratio enables endogenous production of the long-chain fatty acids DHA and EPA, which are important for neurodevelopment
Transfatty acids	High levels in the diet can increase the risk of death and coronary heart disease

Classification of the main dietary fats



heart disease mortality (RR 1.15, 0.97 to 1.36; P = 0.10). The certainty of the associations for saturated fats, however, was ranked as "very low." Some reviews suggest that observational studies examining the links between saturated fats in meat and risk of disease need to consider overall diet or the types of cooking methods used, which may modulate effects on disease (Geiker *et al.*, 2021; Martínez Góngora *et al.*, 2019; Tárraga López, Albero and Rodríguez-Montes, 2014; Ward *et al.*, 2016). Another systematic review and meta-analysis of RCTs and prospective cohort studies in children and adolescents aged between two and 19 years showed that diets with reduced saturated fat content compared to control diets significantly reduced total cholesterol, low-density lipoprotein cholesterol and diastolic blood pressure (Te Morenga and Montez, 2017). There was no evidence for adverse effects on growth or anthropometry.

There is more evidence suggesting that transfat intakes are associated with negative health outcomes, probably because they increase levels of low-density lipoprotein and reduce levels of high-density lipoprotein (de Souza *et al.*, 2015; Te Morenga and Montez, 2017). Transfats may derive naturally from ruminants or be produced through processing in which hydrogen is added to vegetable oil to convert it from a liquid into a solid (WHO, 2018). In the systematic review and meta-analysis described above, transfat was found to be associated with all-cause and coronary heart disease mortality and total coronary heart disease, but not with type 2 diabetes or ischaemic stroke (de Souza *et al.*, 2015; Te Morenga and Montez, 2017). When the investigators stratified the data to distinguish the effects of industrially produced transfat from those of ruminant transfat, the findings showed that only industrially produced transfat was associated with coronary heart disease and coronary heart disease mortality, and that ruminant trans-palmitoleic acid was negatively associated with type 2 diabetes. In view of the evidence linking transfat intake with coronary heart disease, a global initiative, REPLACE Trans Fat, has been established to eliminate all industrially produced transfat from the food supply by 2023 (WHO, 2021).

3.2

Micronutrients

Vitamins play various roles in human nutrition and can occur in various forms. These forms may differ between TASF and PBF, and recommended intakes of vitamins vary by life-cycle phase (see Annex Table B1). Vitamin B12, also known as cobalamin, is an important nutrient in terms of the relation between TASF and human health given that it is largely absent in PBF. It can be found in some PBFs such as seaweed, mushrooms (technically fungi rather than plants) and tempeh, although in forms that may not be as bioavailable as the vitamin B12 in TASF (Watanabe *et al.*, 2013; Zugravu *et al.*, 2021). Vitamin B12 plays an important role in cellular metabolic processes such as DNA synthesis and methylation. Deficiencies may result in pernicious anaemia and compromised neurodevelopment and brain function (Green *et al.*, 2017). Other B vitamins serve as cofactors in enzyme systems throughout the human body. Riboflavin, or vitamin B2, is needed for the production of two coenzymes, flavin mononucleotide and flavin adenine dinucleotide, that have roles in cellular respiration, growth, development and maintenance of epithelial tissue. Vitamin B6 in its phosphorylated form pyridoxine is found largely in plants and has to be dephosphorylated to be absorbed, while vitamin B6 in meat takes the form of esters that are more bioavailable (Brown, Ameer and Beier, 2021). Pyridoxine serves as a coenzyme for the synthesis of amino acids, sphingolipids, neurotransmitters and haemoglobin, among other bioactive substances, as well as for the metabolism of glycogen. Other B vitamins, such as B1 and B3, are also contained in TASF and important in human health (Gropper, Smith and Carr, 2021).

Choline has gained increasing attention in recent years for its importance in growth, brain function and gene interactions (Leermakers *et al.*, 2015; Smallwood, Allayee and Bennett, 2016). In human physiology, choline serves as a precursor for phospholipids (phosphatidylcholine and sphingomyelin) that are integral to cell-membrane integrity and signalling, for acetylcholine, which influences neurotransmission, neurogenesis, myelination and synapse formation, and for betaine, which donates a methyl group in the homocysteine production pathway (Caudill, 2010; Zeisel and da Costa, 2009). Recent systematic and narrative reviews point to the importance of choline for growth and neurodevelopment in the first 1 000 days of life (Bragg, Prado and Stewart, 2021; Derbyshire and Obeid, 2020). Eggs (and beef to a lesser extent) contain high concentrations of this nutrient. Another essential nutrient found in TASF is vitamin K, which is important for blood coagulation and calcium-binding pathways (the K2 form is only found in TASF) (Halder *et al.*, 2019).

The minerals zinc and iron are highly bioavailable in the muscle tissue of meats. Iron plays multiple roles in the human body, most notably in oxygen transport in the haemoglobin blood protein but also in other pathways involved in growth, neurodevelopment and immunity (Gropper, Smith and Carr, 2021; McCann, Perapoch Amadó and Moore, 2020). Iron is especially important during pregnancy, when there is significant plasma volume expansion

(Georgieff, 2020) (see Annex Table B2 for more information on recommended intakes of minerals by life-cycle phase). Zinc is necessary for the activity of over 300 enzymes in the human body and also serves vital functions in growth, development and immunity (Gropper, Smith and Carr, 2021). Deficiencies in iron and zinc contribute substantially to the global burden of disease (Black *et al.*, 2013). Although selenium is not recognized as being widely deficient in human populations, it does play important roles in health (Gashu *et al.*, 2016; Speckmann and Grune, 2015). It is important for immune function and for its antioxidant and epigenetic effects. Selenium is among the nutrients known to be influenced by environmental factors, such as soil concentration (Gibson *et al.*, 2011). Calcium and phosphorous are considered macrominerals found in TASF and are important for bone health, among other roles (Gropper, Smith and Carr, 2021).

The ratio of sodium to potassium dietary intakes has been linked to human health outcomes, particularly for its effects on hypertension and cardiovascular disease (Gonçalves and Abreu, 2020; Ndanuko *et al.*, 2021; Perez and Chang, 2014). Consumption of milk and dairy products in a population in the United States of America has been found to be associated with lower ratios of sodium to potassium (< 1), which is consistent with WHO guidelines for reduced risk of mortality (Bailey *et al.*, 2015). A study among Australian school-age children showed that dairy products were an important food source of potassium (Grimes *et al.*, 2017).

4. Evidence for the nutrient composition of different terrestrial animal source foods

The evidence on nutrient composition with potential implications for human health was reviewed for the following five categories of TASF:

- eggs and egg products;
- milk and dairy products;
- meat and meat products;
- TASFs from hunting and wildlife farming; and
- insects, including grubs, and their products.

TASFs from hunting and wildlife farming were included as a separate group because of consistent findings that for some nutrients their composition diverges from that of meats obtained from livestock. Insects and insect products are not generally included in food-based dietary guidelines. However, they are explored in this subsection because there is a growing literature on their value in human health and nutrition.

4.1

Eggs and egg products

Chicken eggs are the most widely consumed type of egg, although the diets of many populations also include eggs from other poultry species, such as turkey, duck, quail and goose (FAO, 2015b). Egg in shell is the predominant product on the market, although there are others, including liquid eggs and egg powder. Eggs provide a range of different nutrients but have especially high concentrations of high-quality proteins, essential fatty acids, DHA, choline, selenium, riboflavin and vitamin B12 (Iannotti *et al.*, 2014) (see Tables B2, B3, Annex Tables B3 and B4). The literature on the nutrient composition of eggs often differentiates the nutrient content of the yolk from that of the white. These two constituents originate during different phases of egg

Table B2. Amino-acid composition of poultry eggs

Nutrient	Chicken	Duck	Chicken egg yolk		Chicken egg white		Goose	Quail	Turkey
	Average	Average	Average	Range	Average	Range	Average	Average	Average
Protein (g)	12.6	12.8	15.8	15.6–15.9	11.1	10.9–11.2	13.9	13.0	13.7
Alanine (g)	0.74	0.63	0.82	0.81–0.84	0.70	0.69–0.70	0.68	0.76	0.80
Arginine (g)	0.82	0.77	1.11	1.1–1.13	0.66	0.65–0.66	0.83	0.84	0.88
Aspartic acid (g)	1.33	0.78	1.5	1.45–1.55	1.22	1.21–1.22	0.84	1.29	1.36
Cystine (g)	0.27	0.29	0.29	0.26–0.29	0.32	0.29–0.34	0.31	0.31	0.33
Glutamic acid (g)	1.67	1.79	1.92	1.87–1.97	1.64	1.53-1.76	1.94	1.66	1.74
Glycine (g)	0.43	0.42	0.48	0.47–0.48	0.41	0.41	0.46	0.43	0.46
Histidine (g)	0.31	0.32	0.45	0.42–0.48	0.28	0.27–0.28	0.35	0.32	0.33
Isoleucine (g)	0.67	0.6	0.89	0.87–0.91	0.70	0.66–0.74	0.65	0.82	0.86
Leucine (g)	1.09	1.10	0.89	0.37–1.4	1.03	1.02-1.04	1.19	1.15	1.20
Lysine (g)	0.91	0.95	1.19	1.16–1.22	0.81	0.81	1.03	0.88	0.92
Methionine (g)	0.38	0.58	0.40	0.38–0.43	0.42	0.40–0.43	0.62	0.42	0.44
Phenylalanine (g)	0.68	0.84	0.68	0.68–0.69	0.7	0.69–0.71	0.91	0.74	0.77
Proline (g)	0.51	0.48	0.57	0.49–0.64	0.39	0.34–0.44	0.52	0.52	0.54
Serine (g)	0.97	0.96	1.34	1.33–1.34	0.83	0.80–0.86	1.04	0.99	1.04
Threonine (g)	0.56	0.74	0.81	0.87–0.94	0.58	0.45–0.71	0.80	0.64	0.67
Tryptophan (g)	0.16	0.26	0.21	0.18–0.23	0.16	0.13–0.18	0.28	0.21	0.22
Tyrosine (g)	0.5	0.61	0.47	0.27–0.68	0.45	0.45–0.46	0.66	0.54	0.57
Valine (g)	0.86	0.89	0.97	0.95–0.95	0.84	0.81–0.87	0.96	0.94	0.99

Note: All nutrient values are expressed per 100 g edible portion on fresh weight basis.
Source: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov.

production and serve separate functions in the development of the chick: the yolk is derived from hepatic tissue and is primarily nutritive, and the white is secreted in the oviduct and serves largely for defence (Nys and Guyot, 2011).

The combination of amino acids and proteins in eggs is considered a gold standard against which other proteins are compared (see Table B2). The concentration of proteins does not vary greatly across bird species, with slightly higher levels in turkey eggs (13.7 g/100 g) and goose eggs (13.9 g/100 g) than in chicken eggs (12.6 g/100g) (see Table B2). One study found a higher quantity of essential and total amino acids in the albumen of turkey eggs than in that of chicken, duck, goose, quail and pigeon eggs, although a higher ratio of essential to total amino acids was found in duck and goose eggs than in chicken, turkey, quail and pigeon eggs (Sun *et al.*, 2019).

Egg proteins are noted for their high digestibility – further enhanced through heating and the denaturation of some structural proteins (Réhault-Godbert, Guyot and Nys, 2019). Egg yolks contain a mix of low- and high-density lipoproteins, livetins and phosvitins. Phosvitins have been shown to interfere with iron absorption (Yilmaz and Ağagündüz, 2020). The vitelline membrane proteins and lipids separate the egg yolk from the egg white. Ovoalbumin and ovomucoid, proteinase inhibitors that can resist thermal heating, are the primary proteins contained in the egg white. Antibacterial proteins, such as lysozyme, peptides, ovotransferrin, ovoglobulin, cystatin, avidin and ovoflavin, are also present in the egg white, probably contributing to human nutrition (Guha, Majumder and Mine, 2018). One older review summarized evidence indicating that the proteins and peptides contained in eggs have been associated with multiple health-promoting biological processes and characteristics, including antimicrobial, immunomodulatory, antiadhesive, antioxidative, anticancer and antihypertensive activities or properties (Kovacs-Nolan, Phillips and Mine, 2005).

Eggs of all poultry species contain a wide range of fatty acids (see Table B3). Lipids are highly concentrated in the egg yolk relative to the white (see Annex Table B3). Duck eggs (13.8 g) and goose eggs (13.3 g), on average contain more lipids per 100 g than chicken eggs (8.5 g). One study showed that there is a higher ratio of unsaturated to saturated fats in eggs than in other TASFs (Réhault-Godbert, Guyot and Nys, 2019). Cholesterol concentrations are also relatively high in eggs compared to other TASFs and to food broadly, although there is some uncertainty in the evidence-base for correlation of intake levels with plasma cholesterol (Kim and Campbell, 2018). Cholesterol has been associated with the development of cardiovascular disease (Kuang *et al.*, 2018). One systematic review and meta-analysis of randomized controlled trials that looked at various interventions involving higher egg consumption showed that these interventions led to higher low density lipoprotein cholesterol to high density lipoprotein cholesterol ratios than that found in the control group (mean difference = 0.14, $p = 0.001$, $I2 = 25$ percent) (Li *et al.*, 2020).

Eggs contain several bioavailable vitamins and some minerals at high concentrations (see Table B4 and Annex Table B4). Eggs are among the richest dietary sources of choline, containing both lipid-soluble and water-soluble forms. Like other TASFs, eggs contain vitamin B12 (eggs from various poultry species can provide more than 50 percent of age- and sex-specific RNI in a single egg), as well as significant concentrations of other B vitamins. Eggs have been noted for containing the carotenoids of lutein and zeaxanthin, which are important in anti-inflammatory pathways (Eisenhauer *et al.*, 2017; Wallace, 2018). Eggs contain no vitamin C, probably because birds can produce it endogenously. Niacin is also found at very low levels. Some minerals and trace elements that are limited in the diets of vulnerable populations are provided by eggs in bioavailable forms. Egg yolks have higher concentrations of minerals than egg whites, and there is some variability across species. Egg shells are also rich in highly bioavailable calcium – 1 g of chicken egg shell contains about 380 mg of calcium (Bartter *et al.*, 2018; Omer *et al.*, 2018). Turkey eggs are more highly concentrated than the eggs of other birds in some important minerals, including calcium (99.0 mg per 100 g), iron (4.1 mg per 100 g) and zinc (1.6 mg per 100 g) (see Table B4). Evidence regarding the impact of dietary egg intake on human mineral nutrition is equivocal.

Table B3. Composition of fats and fatty acids of poultry eggs

Nutrient	Chicken		Chicken egg yolk		Chicken egg white		Duck	Goose	Quail	Turkey
	Average	Range	Average	Range	Average	Range	Average	Average	Average	Average
Fat (g)	8.5	8.5–9.5	27.4	26.5–28.2	0.09	0–0.2	13.8	13.3	11.1	11.9
SFA (g)	2.76	2.3–3.1	9.1	8.6–9.6	0	0	3.7	3.6	3.6	3.6
SFA 4:0 (g)	0	0	0	nd	0	0	0	0	0	0
SFA 6:0 (g)	0	0	0	nd	0	0	0	0	0	0
SFA 8:0 (g)	0	0	0	0– 0.14	0	0	0	0	0	0
SFA 10:0 (g)	0	0	0	0–0.01	0	0	0	0	0	0
SFA 12:0 (g)	0.01	0–0.02	0	0–0.01	0	0	0	0	0	0
SFA 14:0 (g)	0.04	0.03–0.05	0.11	0.10–0.12	0	0	0.05	0.05	0.053	0.04
SFA 16:0 (g)	1.95	1.66–2.23	6.50	6.13–6.86	0	0	3.00	2.85	2.67	2.72
SFA 18:0 (g)	0.68	0.54–0.81	2.24	2.06–2.42	0	0	0.63	0.70	0.84	0.88
MUFA (g)	3.61	3.55–3.66	12	11.70-12.03	0	0	6.52	5.75	4.32	4.57
MUFA 16:1 (g)	0.21	0.20–0.22	0.74	0.57–0.92	0	0	0.44	0.39	0.47	0.67
MUFA 18:1 (g)	3.35	3.28–3.41	11.00	10.70–11.39	0	0	6.08	5.35	3.85	3.90
MUFA 20:1 (g)	0.019	0.01–0.03	0.08	0.07	0	0	0	0	0	nd
MUFA 22:1 (g)	0	0	0	0–0.01	0	0	0	0	0	nd
PUFA (g)	1.55	1.19–1.91	3.56	2.92–4.20	0	0	1.22	1.67	1.32	1.66
PUFA 18:2 (g)	1.26	0.96–1.56	2.9	2.25–3.54	0	0	0.56	0.68	0.94	1.17
PUFA 18:3 (g)	0.05	0.05–0.05	0.09	0.07–0.10	0	0	0.102	0.55	0.04	0.08
PUFA 18:4 (g)	0	0	0	0	nd	0	0	0	0	nd
PUFA 20:4 (g)	0.14	0.08–0.18	0.22	0–0.44	0	0	0.32	0.28	0.12	0.13
PUFA 2:5 n-3 (EPA) (g)	0	0	0.01	0	0	0	0	0	0	nd
PUFA 22:5 n-3 (DPA) (g)	0.08	0.08	0	0	0	0	0	0	0	nd
PUFA 22:6 n-3 (DHA) (g)	0.06	0.06	0.11	0	0	0	0	0	0	nd
Fatty acids, total trans (g)	0.02	0.01–0.04	0.03	0	0	0	nd	nd	nd	nd
Cholesterol (mg)	430	372–488	1065	1050–1080	0	0	884	852	844	933
Choline (mg)	294	294	820	820	1.1	1.1	nd	263	nd	nd

Notes: All nutrient values are expressed per 100 g edible portion on fresh weight basis. SFA = saturated fatty acid. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. RAE = retinol activity equivalents. Slaughter weight and degree of maturity at slaughter weight influence nutrient composition. nd = not available (no values found).
Sources: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov.

Table B4. Mineral composition of poultry eggs

Nutrient	Chicken		Chicken egg yolk		Chicken egg white		Duck	Goose	Quail	Turkey
	Average	Range	Average	Range	Average	Range	Average	Average	Average	Average
Calcium (mg)	52	47–56	115	100–129	6	5–7	64	60	64	99
Magnesium (mg)	12	12	6.5	5–8	11	11	17	16	13	13
Phosphorus (mg)	189	180–198	394	390–398	12.5	10–15	220	208	226	170
Potassium (mg)	139	138–140	106.5	104–109	141	119–163	222	210	132	142
Sodium (mg)	146	142–150	53	48–58	175	166–175	146	138	141	151
Iron (mg)	1.8	1.6–1.9	3.4	2.7–4	0.1	0.1-0.2	3.9	3.6	3.7	4.1
Zinc (mg)	1.2	1.1–1.3	2.4	2.3–2.5	0	0	1.4	1.3	1.5	1.6
Copper (mg)	0.06	0.06–0.07	0.10	0.07–0.13	0.012	0–0.02	0.06	0.06	0.06	0.06
Manganese (mg)	0.027	0.03	0.07	0.05–0.08	0.01	0–0.01	0.04	0.04	0.04	0.04
Selenium (µg)	28.2	25.7–30.7	56.0	56.0	15.5	11-20	36.4	36.9	32.0	34.3
Iodine (µg)	57.6	57.6	80	80	0	0	n/a	nd	nd	nd

Note: nd = not available (no values found); avg. = average.
Sources: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov.

4.2

Milk and dairy products

Globally, humans consume milk and dairy products from multiple animal species, including cattle, buffalo, mithan, yak, goat, sheep, horse, alpaca, llama, reindeer, dromedary and Bactrian camel. The milk from these species varies in composition. Animal milk is produced around parturition with the biological purpose of nourishing offspring and is nutrient-dense and complete across many nutrients and bioactive compounds (Mozaffarian, 2019). Animal milk contains complementary nutrients that act in synergy to optimize metabolism, for example lactose and casein acting to enhance calcium absorption (Chalupa-Krebzdak, Long and Bohrer, 2018). One recent untargeted metabolomics study using chromatography–nuclear magnetic resonance spectroscopy and various types of mass spectrometry identified 296 cow's milk metabolites and metabolite species with the potential to have implications for health (Foroutan *et al.*, 2019). Sphingomyelin in animal milk may be protective against gut dysbiosis and inflammation (Norris *et al.*, 2019).

Like eggs, milk and dairy products have been recognized for their importance as sources of high-quality proteins. The two primary protein categories in milk are casein (insoluble) and whey (soluble), which make up approximately 80 percent and 20 percent of the protein content, respectively. Whey proteins can act in concert with other nutrients, specifically minerals, to enhance absorption and metabolism. For example, the glycoprotein lactoferrin binds iron and may increase its bioavailability and play key roles in immunity and inflammatory processes (Hao *et al.*, 2019), although animal milk is generally not considered a good source of iron (Hurrell *et al.*, 1989; Ziegler, 2011). β-lactoglobulin has high affinity for retinol and other carotenoids and may enhance vitamin A absorption and metabolism (Mensi *et al.*, 2013). Caseins serve as protein carriers for calcium and phosphorous. The protein insulin like growth factor 1 (IGF 1) in milk has been linked to child growth, although evidence is mixed for this effect (Grenov *et al.*, 2020; Hoppe, Mølgaard and Michaelsen, 2006). One recent analysis showed that the protein content of plant-based alternatives to milk – containing, respectively, soybean, oats, hemp, coconut, rice and nuts – was on average an estimated 48 percent of that in bovine milk (Chalupa-Krebzdak, Long and Bohrer, 2018).

Milk lipids are primarily comprised of triacylglycerols (98 percent) and very small fractions of diacylglycerol (2 percent), cholesterol (< 0.5 percent), phospholipids (1 percent) and free fatty acids (0.1 percent) (Pereira, 2014). Milk fatty acids are a function of feed, stage of lactation and animal species (see also Subsection 5). Bovine milk contains approximately 70 percent saturated and 30 percent unsaturated fatty acids. Oleic acid, conjugated linoleic acid and omega 3 fatty acids in bovine milk may promote positive human health outcomes (Haug, Høstmark and Harstad, 2007). Concerns about saturated fats and their association with cardiometabolic health have been raised but largely derive from observational studies (Poppitt, 2020). One systematic review of RCTs examined the effects of cheese consumption on blood lipids and lipoproteins and found that it increased total cholesterol or low-density liprotein cholesterol levels when compared to tofu or fat-modified cheese, and reduced low-density lipoprotein cholesterol when compared to butter (de Goede *et al.*, 2015). The findings of a narrative review that examined the effects of consuming dairy products on cholesterol levels varied by product type, with some decreasing total cholesterol and increasing high-density lipoprotein cholesterol and others increasing triglycerides and low-density lipoproteins (Duarte *et al.*, 2021). Further discussion of broader health effects for milk, yoghurt, cheese and other dairy products is provided in Section C.

Macronutrient concentrations in milk differ by species (see Table B5). Protein levels per 100 g are highest in reindeer milk (10.4 g), followed by mithan (6.5 g), sheep (6.0 g) and alpaca (5.8 g) milk. Fat concentrations per 100 g are highest in reindeer milk (16.1 g), followed by mithan (8.9 g), buffalo (7.5 g) and sheep (7.0 g) milk. Amino acid and fatty acid compositions also vary across species (see Annex Tables B5 and B6).

With regard to micronutrients, milk and dairy products are especially well recognized for their high concentrations and high bioavailability of calcium, which is bound to casein in micellar form but also to whey proteins and inorganic salts. Other macrominerals concentrated in milk are phosphorous, magnesium and potassium, and the microminerals zinc and selenium are also provided by milk. Iodine is found in bovine milk (see Annex Table B7). Among dairy products, dry milk powder unsurprisingly, has the highest concentrations of several vitamins and minerals, although fresh buttermilk, cream and sour cream also have relatively high micronutrient levels (see Annex Tables B8 and B9). Fat-soluble vitamin contents again vary with animal diets and across milk products (whole, low-fat and skimmed). Whole milk contains bioavailable vitamin A. Raw cow's milk contains low levels of vitamin D (0.06 μg/100 g) relative to some TASFs but may be fortified in commercially available products. Where water-soluble vitamins are concerned, milk provides high levels of vitamin B complex and some vitamin C.

Table B5. Nutrient composition of milk from mammalian livestock species and humans

Species	Value	Energy (kcal/kJ)	Carbohydrates (g)	Fibre (g)	Lactose (g)	Protein (g)	Fat (g)
Human	Avg.	71/295	7.1	0	nd	1.2	4.3
	Range	70–71/291–298	6.9–7.2	0	nd	1.03–1.4	4.1–4.4
Buffalo	Avg.	99/412	nd	0	4.4	4	7.5
	Range	71–118/296–495	nd	0	3.2–4.9	2.7–4.6	5.3–9.0
Cattle	Avg.	64/270	5.0	0	5.2	3.35	3.5
	Range	61–69/256–290	4.8–6.1	0	4.6–6.1	3.2–3.5	5.3–9.0
Mithan	Avg.	122/510	nd	nd	4.4	6.5	8.9
	Range	nd	nd	nd	4.1–4.6	6.1–6.8	7.7–10.3
Yak	Avg.	100/417	nd	nd	4.8	5.2	6.8
	Range	nd	nd	nd	3.3–6.2	4.2–5.9	5.6–9.5
Goat	Avg.	70.6/295	4.4	0	nd	3.7	4.3
	Range	69–74/288–308	4.4	0	nd	3.6–3.9	4.1–4.5
Sheep	Avg.	108/451	5.4	0	nd	6.0	7
	Range	nd	nd	nd	4.4–5.2	4.4–6.6	5.6–6.2
Alpaca	Avg.	71/299	5.1	nd	5.1	5.8	3.2
	Range	nd	4.4–5.6	nd	4.4–5.6	3.9–6.9	2.6–3.8
Bactrian camel	Avg.	76/319	4.2	nd	4.2	3.9	5
	Range	nd	nd	nd	nd	3.6–4.3	4.3–5.7
Dromedary	Avg.	56/234	nd	nd	4.3	3.1	3.2
	Range	44–79/185–332	nd	nd	3.5–4.9	2.4–4.2	2.0–6.0
Llama	Avg.	78/326	nd	nd	6.3	4.1	4.2
	Range	nd	nd	nd	5.9–6.5	3.4–4.3	2.7–4.7
Reindeer	Avg.	196/819	nd	nd	2.9	10.4	16.1
	Range	nd	nd	nd	1.2–3.7	7.5–13.0	10.2–21.5
Donkey	Avg.	37/156	nd	nd	6.4	1.6	0.7
	Range	nd	nd	nd	5.9–6.9	1.4–1.8	0.3–1.8
Horse	Avg.	48/199	nd	nd	6.6	2	1.6
		nd	nd	nd	5.6–7.2	1.4–3.2	0.5–4.2

Note: avg. = average; nd = not available (no values found); all values per 100 g of milk.
Sources: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; Balthazar, C.F., Pimentel, T. C., Ferrão, L. L., Almada, C. N., Santillo, A., Albenzio, M., Mollakhalili, N. *et al.* 2017. *Sheep milk: physicochemical characteristics and relevance for functional food development. Comprehensive Reviews in Food Science and Food Safety,* 16(2): 247–262. https://doi.org/10.1111/1541-4337.12250; *FoodData Central USDA. 2021. FoodData Central*. [Cited 15 December 2021]. https://fdc.nal.usda.gov; Frida, 2021; Medhammar *et al.*, 2012; T*abla de Composición de Alimentos Colombianos, 2021.*

The nutrient composition of milk from animals other than cows has been analysed and described in the literature. One review suggests that non-cow milks may be more easily digested than cow's milk, probably because of the softer curds formed in the stomachs of humans during gastric digestion (Roy *et al.*, 2020). This effect may be explained by the varying composition of other species' milks in terms of casein compounds, fat globules and protein-to-fat ratio. Another study (Gantner *et al.*, 2015) compared the nutrient composition of multiple animal milks, including human milk, and found that fat content varied the most compared to other nutrients, and that there were more commonalities in content between human milk and other non-ruminant milks than between human and ruminant milks. For example, the structure of fat globules and triacylglycerol in ruminant milk was found to be significantly different from that in non-ruminant (including human) milk. Non-ruminant milk was also found to contain higher percentages of unsaturated, lower saturated and MUFAs than ruminant milk.

Some evidence on the nutritional composition of milk from other animals is summarized below. A review that examined buffalo, horse and dromedary milk at the level of breed, and yak, mithan, musk ox, donkey, Bactrian camel, llama, alpaca, reindeer and moose milk at species level, found that inter-species nutrient values (g per 100 g) ranged from 0.70 to 16.1 for total fat, 1.6 to 10.5 for protein, 2.6 to 6.6 for lactose, and 67.9 to 90.8 for water (Medhammar *et al.*, 2012). Reindeer and moose milks were found to have the highest concentrations of fat and protein, and moose milk to be the richest in minerals (calcium, sodium and phosphorus). By contrast, mare and donkey milks were found to have the lowest concentrations of protein and fat, although their fatty-acid profiles were more closely aligned to human nutrient requirements. Donkey milk has been found to have low allergenicity, attributed to the whey proteins serving as bioactive peptides and low casein levels (Vincenzetti *et al.*, 2017). TASF sensitivity and allergy issues are addressed in Section C.

Buffalo milk makes up 12 percent of global milk production and more than half of the milk consumed in India and Pakistan (Arora, Sindhu and Khetra, 2020). While composition varies with genetics, nutrition, season and stage of lactation (see Subsection 5), it contains 6 to 12 percent fat, 4 to 5 percent protein, 4 to 5.5 percent lactose, 0.8 percent ash and 82 to 83 percent water (see Table B5 for a comparison of cattle and buffalo milk). Another study compared buffalo milk to cow's milk and showed that the former had higher levels of fat, protein, calcium and vitamins A and C but lower levels of vitamin E, riboflavin and cholesterol (Abd El-Salam and El-Shibiny, 2011). An *in vitro* experiment found that fermented buffalo milk showed higher bacterial viability than cow's milk (Simões da Silva *et al.*, 2020).

Camel milk provides high-quality food to populations living in arid and semi-arid regions particularly (Rahmeh *et al.*, 2019). One review of the nutrient composition of camel milks, including dromedary, Bactrian camel and other camelid milks, showed that on average they had high concentrations of vitamin C (up to ten times higher than cow's milk), high concentrations of total salts, calcium and oligoelements, including iron, copper and zinc, and low cholesterol (Benmeziane-Derradji, 2021).

The micronutrient composition data compiled for the present assessment (see Annex Table B10) indicate that among the species compared the highest levels of vitamin A in retinol equivalents per 100 g are present in the milks of Bactrian camels (97 μg), buffaloes (69 μg), sheep (44 μg) and cows (43 μg), the highest vitamin B12 concentrations per 100 g in the milks of sheep (0.71 μg), cows (0.46 μg) and buffaloes (0.45 μg), the highest iron concentrations per 100 g in the milks of yaks (0.57 mg) and dromedaries (0.21 mg), and the highest zinc concentrations per 100 g in the milks of yaks (0.90 mg), Bactrian camels (0.70 mg) and dromedaries (0.60 mg).

4.3

Meat and meat products

Meat and meat products from the following animal species are reviewed in this subsection and in the subsection on food from hunting and wildlife farming: cattle, buffalo, sheep, goat, pig, horse, rabbit, deer, chicken, turkey, quail, pheasant, duck, goose, pigeon and guinea fowl. These animal tissues covered in this subsection include muscle and offal (organs and any other edible non-muscle tissues). Some evidence in public health nutrition distinguishes between red meat (from species such as cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse and donkey) and white meat (from rabbits and avian species).

Meat, like eggs and milk, is considered a high-quality protein food. The protein and amino-acid composition of meat from muscle tissue aligns well with human nutrition requirements, in part because it is similar to human skeletal muscle (Geiker *et al.*, 2021). Meat from muscle tissue contains an array of amino acids, including all the essential ones (see Annex Tables B11 and B15 for a comparison between meat and offal). Those present in the highest concentrations are in glutamic acid and glutamine, followed by arginine, alanine and aspartic acid (Williams, 2007). Cooking practices have been shown to influence ileal amino acid digestibility (and hence the DIAAS). Regardless of processing type, the DIAAS for meat generally exceeds 100; overcooking can, however, lower digestibility and reduce the DIAAS (Bailey *et al.*, 2020). Poultry meats have been highlighted for their low content of the structural protein collagen, a characteristic that facilitates digestion (Marangoni *et al.*, 2015).

The bioactive compounds carnitine, creatine, taurine, hydroxyproline and anserine – all present in meat – have been shown to confer positive effects on human health, as described above (Wu, 2020). Meat is the most abundant dietary source of taurine, which serves as an antioxidant, among other roles in human health (Williams, 2007). There is evidence that carnitine levels and metabolism increase during pregnancy and lactation and potentially play a critical role in infants during the first 1000 day period (Manta-Vogli *et al.*, 2020).

Depending on multiple factors (e.g. animal diet, tissue type, ruminant versus non-ruminant origin), meat contains approximately 50 percent MUFAs, 40 percent saturated fatty acids, 5 percent transfatty acids and 4 percent PUFAs (see Annex Tables B12 and B16 for comparison between meat and offal). Fatty acids found in meat include oleic (C18:1), palmitic (C16:0) and stearic (C18:0) acids (Valsta, Tapanainen and Männistö, 2005). Meat is also the primary dietary source of docosapentaenoic acid (DPA) (C22:5 omega 3), which is available from mammal and poultry meat but not from fish (De Smet and Vossen, 2016). The evidence suggests that DPA potentially reduces chronic disease risk (McAfee *et al.*, 2010). One review noted that once the skin is removed, poultry meat can be a good source of unsaturated fats (Marangoni *et al.*, 2015). Meat, more broadly, can provide the long-chain fatty acids DHA and EPA, which are important for human health (Mann and Truswell, 2017).

Animal diet has a stronger association with the fatty-acid composition of meat in monogastrics than in ruminants (see Subsection 5.1). This is because of the metabolic degradation of fatty acids in the rumen (one of the stomachs of ruminants), which is absent in monogastric animals. Meat from ruminants is influenced by fermentation, lipolysis and biohydrogenation processes in the rumen and contains conjugated linoleic acid and unique branched-chain fatty acids that have positive implications for health (Geiker *et al.*, 2021; Vahmani *et al.*, 2020). Cooking can also change fatty acid composition. A study examining beef and lamb meat found that levels of omega 3 and omega 6 PUFAs increased with cooking (Purchas *et al.*, 2014).

Tables B6 and B7 show some differences in the macronutrient composition of meats, particularly between meats from livestock species and meats from wild animals. The meats from wild animals tend to contain more protein, while meats from livestock species have higher total fat content. These differences are reflected in findings described below in the subsection on foods from hunting and wildlife farming. Protein levels per 100 g are highest in pheasant (23.6 g), turkey (22.6 g) and rabbit (21.6 g) meats, while fat levels per 100 g are highest in pig (65.7 g) sheep (61 g) and cattle (33.99 g) meats.

Meat is among the most important food sources of iron and zinc, the critical limiting minerals in diets globally. Iron in meat is generally complexed as haem iron, which is absorbed at higher rates (on average 25 percent; range 15-35 percent) than the non-haem iron predominantly found in PBF (2-3 percent) (Gropper, Smith and Carr, 2021). Older analyses produced similar findings, with rates ranging from 15 percent to 25 percent for haem iron and from 5 percent to 12 percent for non-haem iron (Carpenter and Mahoney, 1992; Hallberg, 1983; Hurrell and Egli, 2010). Zinc supplied by meat is also more bioavailable than that from PBF (Gropper, Smith and Carr, 2021). Other important minerals found in meat include selenium, copper and phosphorous. Fresh or unprocessed meat is low in sodium. Like other TASFs, meat provides vitamin B12 and a range of other B vitamins – vitamin B3 (niacin), vitamin B2 (riboflavin) and vitamin B5 (pantothenic acid). Poultry meat has been highlighted for its vitamin B1 (thiamine), vitamin B6 and vitamin B5 contents. All organ meats except tripe are rich in vitamin B12 (Williams, 2007). Choline and DHA are found in the highest concentrations in the liver (Enser *et al.*, 1998). Liver also has high concentrations of vitamin A in its bioavailable form, retinol, as well as iron and folate. The vitamin D metabolite 25 hydroxycholecalciferol is provided by meat, and there is evidence for high biological activity (Williamson *et al.*, 2005).

Comparing the micronutrient concentrations of various meats (including some meats from wild animals) shows that there are high concentrations of iron per 100 g in cattle (3.48 mg), pigeon (3.45 mg), deer (3.40 mg) and turkey (3.45 mg) meats (see Annex Tables B13 and B17). For zinc, the highest concentrations per 100 g among the species compared are found in horse (2.9 mg), goat (2.6 mg), cattle (2.4 mg) and goose (2.34 mg) meats. Where vitamins are concerned (see Annex Tables B14 and B18), vitamin A in retinol equivalents per 100 g is particularly high in pheasant (50 µg) and pigeon (51 µg) meats, followed by sheep (42 µg) and goat (33 µg) meats. The highest vitamin C concentrations per 100 g among the species compared are found in in goose (7.2 mg) and pigeon meats (6.1 mg). The highest concentrations of vitamin B12 per 100 g among the species compared are found in deer (6.31 µg) and horse (6.23 µg) meats.

Table B6. Nutrient composition of meat from mammalian and avian livestock species

Species	Value	Energy (kcal/kJ)	Carbohydrates (g)	Protein (g)	Fat (g)
Cattle	Avg.	443/1819	nd	13.6	34.0
	Range	276–592/1160–2478	nd	12.1–15.0	23.5–61.4
Water buffalo	Avg.	99/414	0	20.4	1.4
Sheep	Avg.	577.5/2418	0	9.5	61.0
	Range	553–577/2315–2522	nd	8.2–10.8	57.6–64.6
Goat	Avg.	276/1155.5	0	32.8	23.5
	Range	109–443/456–1855	nd	12.2–20.6	2.31–44.6
Pig	Avg.	632/2640	0	9.3	65.7
Horse	Avg.	133/556	0	21.4	4.6
Rabbit	Avg.	124.5/520.5	0	21.6	3.6
	Range	113–136/472–520.5	nd	20–23.2	2.1–5.6
Deer	Avg.	120/502	0	23.0	2.4
Chicken	Avg.	243/1020	0	14.7	20.0
Turkey	Avg.	115/479	0	22.6	1.9
Quail	Avg.	153/641.5	0	20.2	7.8
	Range	134–172/561–722	nd	18.5–21.8	4.5–11.0
Pheasant	Avg.	133/556	0	23.6	3.6
Duck	Avg.	128/536	0.5	18.1	5.8
	Range	121–135/506–566	0–0.1	17.8–18.3	5.5–6
Goose	Avg.	161/674	0	22.8	7.1
Pigeon	Avg.	216.5/906.5	0	16.9	16.7
	Range	142–291/594–1219	nd	16.2–17.5	
Guinea fowl	Avg.	110/460	0	20.6	2.5

Note: nd = not available (no values found); avg. = average.
Source: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov.

Other studies have compared the micronutrient contents of different meats. One review covering various meats consumed in Australia and New Zealand found mutton to be denser than beef, veal and lamb in nutrients with biological value (Williams, 2007). Some recent reviews describe the characteristics of some less-consumed meats, such as processed sheep and goat meat (Teixeira *et al.*, 2020), pheasant, quail and guinea fowl meat (López-Pedrouso *et al.*, 2019) and meat from South American camelids (Popova *et al.*, 2021).

4.4 Food from hunting and wildlife farming

Consumption of meat from hunted animals (game) and meat from farmed wild animals has been increasing throughout the last two decades (Costa *et al.*, 2016). FAO defines wild meat as "terrestrial animal wildlife used for food" (FAO, 2019). The European Union defines wild game under EU Regulation No. 853/2004 as follows:

> *wild ungulates and lagomorphs, as well as other land mammals that are hunted for human consumption and are considered to be wild game under the applicable law in the Member State concerned, including mammals living in enclosed territory under conditions of freedom similar to those of wild game, and wild birds that are hunted for human consumption.*

Particularly in high-income countries, demand for wild meats has increased, as they are perceived to be healthier and leaner and free of antibiotics and hormones. In some LMICs, populations depend on hunting and wildlife farming for food security. Serious concerns have been raised about the environmental impacts of hunting practices (legal and illegal) and their role in the depletion of wildlife, largely driven by urban demand for wild meat and human encroachment into wildlife areas. Ripple *et al.* (2016) report that, as of 2015, hunting was a primary threat to the survival of 301 mammalian species classified as threatened according to the IUCN Red List of Threatened Species and that all these species were found in LMICs and only eight also found in high-income countries. Almost 72 percent of emerging infectious diseases transmitted from animals to humans (zoonotic diseases) originate from wildlife (Jones *et al.*, 2008).

Hunting increases exposure to wildlife and hence to the risk of zoonotic diseases (Van Vliet *et al.*, 2017a). The consumption of meat from wild animals is associated with food-safety risks if appropriate handling and cooking practices are not followed, and there is also a risk that meat from wild animals may be contaminated with chemical residues (toxic metals and polycyclic aromatic hydrocarbons) (Van Vliet *et al.*, 2017a) (see also Section D). However, many populations depend on hunting and wildlife farming for food security, with these practices supplementing cultivation and livestock production or substituting for them when they are not possible (Hoffman and Cawthorn, 2012). One recent study identified 15 countries that would be at risk of food insecurity if prohibitions of meat from hunting were introduced, and highlighted the trade-offs in terms of species losses that could occur as a consequence of land-use changes associated with replacing protein from wild meat with protein from livestock (Booth *et al.*, 2021). In South America, 5 million to 8 million people were estimated to regularly rely on meat from wild animals as a source of protein in the early years of this century (Rushton *et al.*, 2005). Hunted animals range across multiple taxonomic groups, including ungulates, rodents, rabbits and hares, kangaroos, reptiles, birds and bats. A study in the Congo Basin estimated that 40 million tonnes of bush meat are harvested each year (Van Vliet *et al.*, 2017b).

One review of meat from wild animals examined nutrient compositional differences across representative species (Costa *et al.*, 2016). Total protein concentrations do not vary significantly, but they are on average higher in some meats, for example meat from the common duiker (*Sylvicapra grimmia*) (25.0 g/100 g), hare (*Lepus europaeus*) (24.7 g/100 g), wild rabbit (*Oryctolagus cuniculus*) (23.7 g/100 g), elk (*Alces alces*) (22.7 g/100 g), roe deer (*Capreolus capreolus*) (22.8-25.7 g/100 g and fallow deer (*Dama dama*), 22.0 g/100 g (see Table B7) (Costa *et al.*, 2016). Some species have markedly higher total fat concentrations, notably the pigeon (*Columba livia*) (4.32-7.85 g/100 g), springbok (*Antidorcas marsupialis*), (2.5-5.3 g/100 g) and fallow deer (*Dama dama*) (2.5 g/100 g).

Other studies have examined differences in nutrient concentrations across different meats from wild animals or compared them to meat from livestock species. Meats from wild European animals, including those from red and fallow deer, wild boar, hare and wild rabbit, were reviewed for nutritional characteristics by Soriano and Sánchez-García (2021) and found to have high protein content and low fat content. Compared to meat from livestock species, the wild sources were found to have higher proportions of omega 3 PUFAs and PUFAs generally, and the wild ruminants had lower omega 6/omega 3 ratios (around 4). High nutrient densities were found for phosphorous, potassium, zinc, iron, vitamin E and the vitamin B complex. Another study (Bureš *et al.*, 2015) compared meat from red and fallow deer with that from Aberdeen Angus and Holstein cattle, and found lower total levels of crude fat and collagen and higher polyunsaturated to saturated fatty acid ratios in the venison than in the beef. The atherogenic index measuring the composite of triglycerides and high-density lipoprotein cholesterol was also lower in the venison than in the beef. A study of the fatty-acid profiles of some wild North American and African ruminants found them to be similar to those of pasture-fed cattle but different from those of grain-fed cattle (Cordain *et al.*, 2002).

Several studies have examined the nutritional composition of meat from wild animals specific to certain regions: wild fallow deer (*Dama dama*) in South Africa (Cawthorn *et al.*, 2020); wild axis deer (*Axis axis*) in Croatia (Kelava

Ugarković *et al.*, 2020); wild boar in Italy (Russo *et al.*, 2017); birds and game hunted by the Eastern James Bay Cree people of Quebec, Canada (Proust *et al.*, 2016); European game (Valencak *et al.*, 2015); wild boar in Latvia (Strazdiņa *et al.*, 2014); wild ungulates in Italy (Ramanzin *et al.*, 2010); and wild animals in Nigeria (Abulude, 2007). Findings from these studies are comparable to the reviews described above, generally showing high levels of protein, healthy fats and a range of multiple minerals and vitamins in the meats of these wild animal species.

Table B7. Examples of protein and fat composition of meat from wild animals

Species		Protein (g)	Fat (g)
	Ungulates		
Kudu	*Tragelaphus strepsiceros*	23.6-24.3	1.56–1.58
Impala	*Aepyceros melampus*	18.9–20.0	1.2–4.3
Springbok	*Antidorcas marsupialis*	17.4–18.4	2.5–5.3
Blesbok	*Damaliscus dorcas phillipsi*	19.3–22.4	0.21–6.8
Common duiker	*Sylvicapra grimmia*	25.7	2.12
Red deer	*Cervus elaphus*	21.7	0.6
Fallow deer	*Dama*	22.0	2.5
Roe deer	*Capreolus*	22.8–25.7	1.0–2.1
Elk	*Alces*	22.7	1.33
Mouflon	*Ovis ammon*	22.9–22.3	0.6 –1.0
Wild boar	*Sus scrofa*	21.4–23.6	1.1–4.4
	Leporidae		
Wild rabbit	*Oryctolagus cuniculus*	23.7	0.2
Hare	*Lepus europaeus*	24.7	1.5
	Game birds		
Quail	*Coturnix japonica*	22.9–22.9	2.3–2.3
Pheasant	*Phasianus colchicus*	22.2–25.3	0.1–0.4
Pigeon	*Columba livia*	20.6–23.6	4.3–7.9

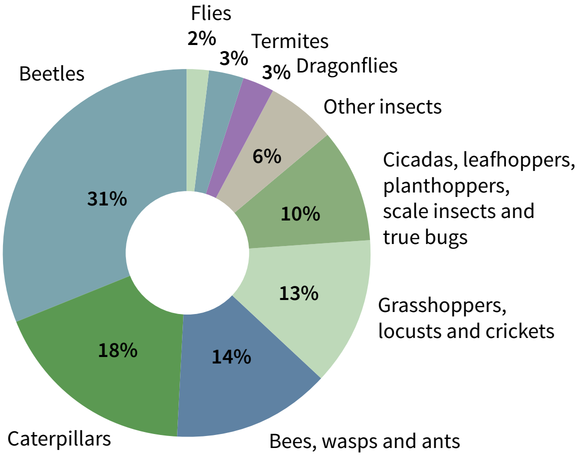
Source: Adapted from Costa, H., Mafra, I., Oliveira, M.B.P.P. & Amaral, J. S. 2016. *Game: types and composition. Encyclopedia of Food and Health*, pp. 177–183. Elsevier. https://doi.org/10.1016/B978-0-12-384947-2.00345-7

4.5

Insects and insect products

Insects are increasingly recognized for their value and potential in human health and nutrition but also for their significance with regard to environmental sustainability and livelihoods (Nowakowski *et al.*, 2021). FAO estimates that the diets of more than 2 billion people include insects and that more than 1 900 insect species are consumed by humans globally (Huis *et al.*, 2013). The most commonly consumed insects are beetles (Coleoptera) (31 percent), caterpillars (Lepidoptera) (18 percent), bees, wasps and ants (Hymenoptera) (14 percent), grasshoppers, locusts and crickets (Orthoptera) (13 percent) and cicadas, leaf-hoppers, planthoppers, scale insects and true bugs (Hemiptera) (10 percent) (see Figure B2). Entomophagy, or consumption of insects, has been integral to hominin evolution and is practised in many cultures to this day (de Carvalho, Madureira and Pintado, 2020). However, barriers to consumption and consumer acceptance of insects and insect products have been described, and include neophobia and disgust (Jantzen da Silva Lucas *et al.*, 2020; Onwezen *et al.*, 2021). Some studies have focused on practices in certain countries, such as Ghana (Parker *et al.*, 2020), Indonesia (Adámková *et al.*, 2017) and Kenya (Kinyuru *et al.*, 2015). Issues related to the culture of insect consumption and consumer demand for and acceptance of insects as food will be covered in Component Document 2 of this assessment.

Figure B2. Insects consumed by humans by biological classification



Source: Based on Jongema. 2017. List of edible insects of the world (April 1, 2017). In: WUR. [Cited 14 December 2021]. https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm.

Environmental sustainability features (e.g. feed conversion rates) will be covered in Component Document 3.

Depending on the insect species, the nutritional composition may vary with stage of metamorphosis, sex, habit and feed. For example, larval and pupal stages tend to have higher energy and fat levels than adult insects; female insects have significantly higher concentrations of fat and energy than males. Studies have shown that insects contain high concentrations of protein and healthy fats (Churchward-Venne *et al.*, 2017). One recent review compared insect nutritient composition with other TASFs (Orkusz, 2021). The review showed that some insect species have higher protein, PUFA and cholesterol concentrations than other TASFs and lower levels of saturated and MUFAs, thiamine, niacin, cobalamin and iron. The vitamin C and dietary fibre contents of insects were also highlighted as a possible source of health advantages.

A review of 236 species showed that edible insects could supply protein, MUFAs and/or PUFAs in sufficient quantities to meet daily requirements for these macronutrients (Rumpold and Schlüter, 2013). Another, more recent, review explored the potential of insect farming as a source of both human food and animal feed (Hawkey *et al.*, 2021). It compared the macronutrient content of ten commonly used insects and found protein content in the orders Orthoptera and Diptera (flies) to be between 51 percent and 76 percent. Fat content was proportionally lower than protein content across all orders, with some species exceptions, including the greater wax moth (*Galleria mellonella*) (51.4–58.6 percent). Insects also contain several bioactive compounds (Jantzen da Silva Lucas *et al.*, 2020). In a study examining 212 insect species from Africa, investigators found that Lepidoptera had the highest protein content (20–80 percent) and fat content (10–50 percent), while Coleoptera had the highest carbohydrate content (7–54 percent) (Hlongwane, Slotow and Munyai, 2020).

Table B8. Examples of protein and fat composition of meat from wild animals

Bee product	Description	Functional properties
Honey	Natural sweet substance produced by bees from the nectar of plants or from the secretions of living parts of plants or excretions of plant-sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honeycomb to ripen and mature	Antimicrobial activity and antioxidant capacity
Pollen	Bees' main source of protein for feeding their larvae: protein content varies between 7 percent and 35 percent	Used to desensitize allergic patients and to treat various prostate problems
Propolis	A natural antibiotic substance made by bees from tree resin mixed with wax, honey and enzymes	Antioxidant, antimicrobial and antifungal activities
Royal jelly	A secretion with high nutrient content used to feed queen bees and bee larvae	Used as a dietary supplement because of its assumed stimulant and therapeutic value

Sources: Alvarez-Suarez, J., Tulipani, S., Romandini, S., Bertoli, E. & Battino, M. 2010. *Contribution of honey in nutrition and human health: a review. Mediterranean Journal of Nutrition and Metabolism*, 3: 15–23. https://doi.org/10.1007/s12349-009-0051-6; FAO & WHO. 2019b. Codex Alimentarius. Standard for Honey CXS 12-19811. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/es/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B12-1981%252FCXS_012e.pdf; Krell, R. 1996. Value-added products from beekeeping. FAO Agricultural Services Bulletin. Rome, Italy, FAO. 429 pp. https://www.fao.org/publications/card/en/c/a76265ff-7440-57a6-82da-21976b9fde8d/.

Insects and insect products have also been reviewed for their micronutrient content. A systematic review of edible insects globally highlighted the wide range of nutrients contents found in insects (Weru, Chege and Kinyuru, 2021). Drawing data from 91 species, this study found that among minerals, potassium levels were especially high across multiple species and copper levels were relatively low. For vitamins, insects were found to have high concentrations of vitamin E and low concentrations of vitamin C. Some studies have highlighted the potential of insects to mitigate iron and zinc deficiencies globally. One analysis showed that levels of these minerals across commonly reared and wild-harvested insects were similar or higher than those in other TASFs (Mwangi *et al.*, 2018). The authors noted, however, that the iron and zinc in insects are derived from non-haem compounds and thus that their bioavailability is unknown.

Insect products have also been studied for their effects on human health and nutrition outcomes. Honey has been a valuable source of energy and nutrients for *Homo* species for millennia (Marlowe *et al.*, 2014). In recent years, honey produced by the honey bee and stingless bees has been recognized for its anti-inflammatory and antioxidative factors as well as for its nutritional advantages (Alvarez-Suarez, Giampieri and Battino, 2013; Ranneh *et al.*, 2021) (see Table B8). Specifically, the flavonoids and phenolic acids in honey probably play roles in antioxidant and anti-inflammatory processes (Cianciosi *et al.*, 2018; Khalil, Sulaiman and Boukraa, 2010; Machado De-Melo *et al.*, 2017). Other studies have found that honey may confer antidiabetic effects and protect cardiovascular health (Cianciosi *et al.*, 2018). Insect powders and processed products obtained through drying and fermentation, among other processing methods, are being considered for use in meeting nutritional needs and mitigating malnutrition globally (Kewuyemi *et al.*, 2020; Melgar-Lalanne, Hernández-Álvarez and Salinas-Castro, 2019).

5. Differences in nutrient content and quality associated with animal characteristics and husbandry

This subsection explores how animal characteristics such as genetic traits, sex and age as well as livestock husbandry practices and other aspects of the production system determine the nutrient composition and quality of TASFs. Livestock husbandry practices encompass methods and measures applied by the producer. They include, inter alia, feeding, reproductive management, housing, and health and welfare care from birth until slaughter. Nutritional attributes relate to nutrient composition and bioavailability, and affect human health. Organoleptic attributes relate to the sensorial experience of the consumer (e.g. taste, texture). Producers often get paid on the basis of commercial attributes, including criteria such as quantity and composition (e.g. protein and fat content, marbling of meat) and the characteristics of the production system. Food safety is linked to factors such as the absence (or low levels) of food-borne pathogens (e.g. those associated with poor hygiene practices during milking) or harmful chemical or physical substances. Technological attributes relate to the suitability of raw TASFs for preservation and processing. The types of factors that affect the quality of unprocessed TASFs, i.e. the characteristics of the animal and the production system, are summarized in Figure B3. The degree of impact of each factor is further detailed in Table B9.

Genetic selection and livestock husbandry practices directly influence the nutritional content of TASFs and also play a substantial role in other aspects of food quality and safety. The impacts of a given factor on different food-quality attributes may be universally beneficial (synergetic), universally detrimental or combine beneficial and detrimental elements (antagonistic). These associations are discussed further in Subsection 5.3.

Figure B3. **Factors affecting the food-quality attributes of unprocessed terrestrial animal source food**

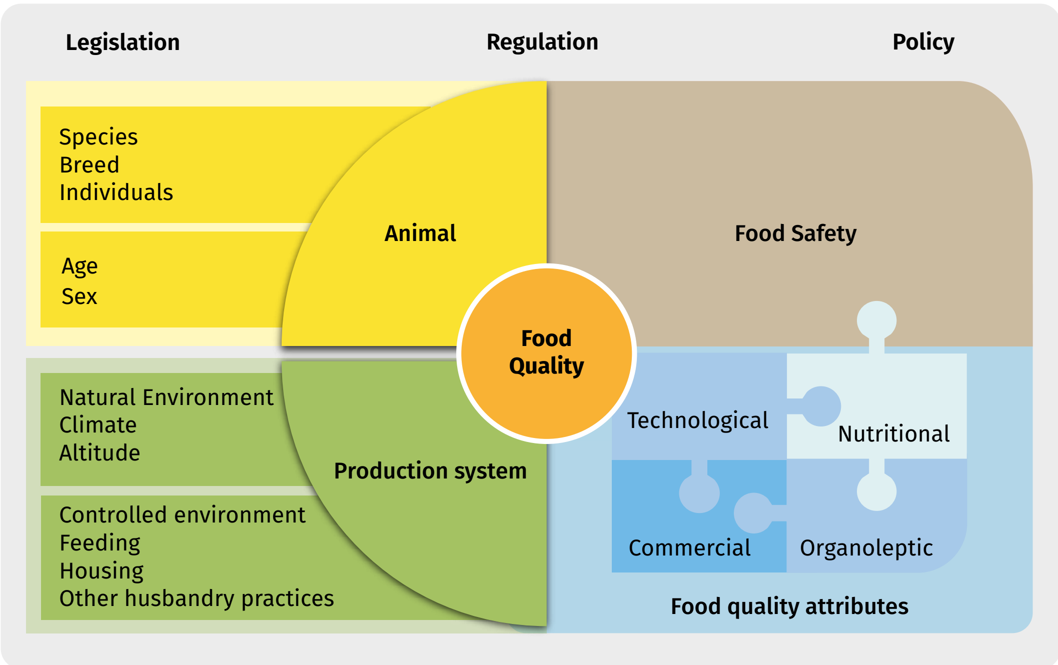


Table B9. Impact of animal characteristics and production practices on food-safety and food-quality attributes

Factors		Food safety	Food-quality attributes			
			Nutritional	Organoleptic	Technological	Commercial
Animal characteristics	Genetic make-up		+	+	++	++
	Sex			+		++
	Lactation stage		+		+	+
	Age at slaughter	+	+	++	++	++
Production practices	Natural environment (climate, altitude)	+	+			+
	Feeding	+	++	++	++	++
	Housing	+	+	+		
	Husbandry practices*	++			+	+
	Transport	+	+	+	++	+

Source: Adapted from Prache, S., Schreurs, N. & Guillier, L. 2021. Review: factors affecting sheep carcass and meat quality attributes. Animal, 16: 100330. https://doi.org/10.1016/j.animal.2021.100330
Note: *Husbandry practices refer to, among others, health care and good hygiene, including biosecurity measures, feed safety, water management, milking management and welfare practices. The crosses indicate whether and how much animal characteristics and production practices impact food safety and food quality attributes: ++ indicates a major impact; + indicates a minor impact; the absence of cross indicates no impact.

5.1 Intrinsic characteristics of animals affecting the nutritional properties and quality of terrestrial animal source food

Protein and fat are the most important macronutrients provided by TASF. The impact of various factors on these nutrients has been studied extensively in livestock species. Micronutrients, such as vitamins, have been studied to a lesser degree. The breed of an animal and its individual genetic traits, as well as other intrinsic characteristics of animals such as age and sex, have been shown to affect the quality of TASFs.

5.1.1 Impact of genetic traits

The influence of genetics on nutrient composition is described below for meat, followed by eggs and milk. Table B10 further details the impact of breed on nutritional quality by species and type of TASF.

With the exception of chickens and to a lesser degree milk, little impact of genetics on the protein content of TASFs has been reported for most livestock species. However, fat content and fatty-acid profile can vary substantially among and within breeds. This has been studied fairly extensively and has been considered in breeding decisions. For example, throughout history genetic improvement schemes have frequently aimed to increase or to decrease the leanness of pig meat to meet market demand. In chickens, commercial broiler lines have been intensely selected for fast growth and leanness. Broiler breeds with slower growth rates are generally fatter and their meat tends to have higher total PUFA content (Baéza, Guillier and Petracci, 2021; Mahiza, Lokman and Ibitoye, 2021).

Products from animals belonging to locally adapted breeds can have different nutrient contents from those belonging to international transboundary breeds subject to intensive selection programmes. For example, the eggs of a local Spanish chicken breed have been found to have higher fat content (by 26 percent) than those from commercial laying hens (Franco *et al.*, 2020). Higher levels of PUFA in TASFs, especially omega-3, and lower omega 6/omega 3 fatty acid ratios are considered better for human nutrition (see Subsection B 3). Meat from some local breeds of sheep (Van Harten *et al.*, 2016), duck (Onk, 2019) and pig (Kim and Kim, 2018) has been found to be more closely aligned with this beneficial fatty-acid profile than meat from international breeds. The higher fat content and specific fatty-acid profile found in Iberico pigs is desired for dry-cured ham processing because of its better technological and organoleptic qualities. Intramuscular fat content in meat from Iberico pigs has been found to be more than twice that of meat from Berkshire pigs (Ali *et al.*, 2021). The omega 6/omega 3 ratio, the PUFA content and the linoleic acid content of Iberico meat were found to be less than half of those of Berkshire meat. A high fat content and a low content of linoleic acid enables slow dehydration during the curing process (Ali *et al.*, 2021; Prache *et al.*, 2020b). The breed effect on nutrient composition needs to be considered along with the feeding system and the geographical area where the animals are raised (Barnes *et al.*, 2012; Belhaj *et al.*, 2020) (see Subsection B 5.2).

Nutritional quality also depends on the cut of the meat. Cuts from the loin or rear legs usually have much lower fat content than cuts from the belly, for example. Comparison of the nutritional value of the same meat cuts can be made between different breeds or species (Barnes *et al.*, 2012). Organ meats are particularly nutrient-dense compared to other meats (see Subsection B 4.3). However, there is limited information on the extent to which the nutritional content of organ meat is affected by differences in breed and animal characteristics. Differences between the fatty acid profiles of kidneys from different sheep breeds were reported by Nguyen *et al.* (2017), with omega-3 DHA content 19 percent higher in pure-bred Merinos than in White Suffolk Corriedale cross-bred animals. However, the total lipid percentage and the fatty-acid profile of liver did not differ between breeds.

Variation in intramuscular fat content, which is related to the palatability of the meat (marbling), has been reported within populations and between breeds in cattle (Park *et al.*, 2018). This affects both the nutritional and the organoleptic qualities. Fat content varies between meat cuts in the carcasses of different breeds, which has an effect on organoleptic qualities (FAO, 2015a; Prache, Schreurs and Guillier, 2021). Differences have been documented between the fatty-acid profiles of subcutaneous and intramuscular fat in beef, with omega-6 and omega-3 PUFA content a minimum of three times higher in intramuscular fat and a higher percentage of MUFA in subcutaneous fat (10–30 percent increase), independent of the diet (concentrate, forage) (Alam, Rana and Akhtaruzzaman, 2017; Indurain *et al.*, 2006; Orellana *et al.*, 2009).The higher the fat content of the carcass, the lower the proportion of omega-6 PUFA in its intramuscular fat.

The fat content and fatty-acid profile of animals' milk is determined by their genetic make-up, and thus varies with species and breed. In most instances, this is a concentration effect. For instance, the Jersey dairy cattle breed has a lower milk productive potential than the Holstein-Friesian, but its milk has higher fat and protein contents (Stocco *et al.*, 2017). However, there are exceptions to this rule. The milk yield of the Simmental breed is both higher in volume and about 10 percent higher in fat content than that of the Italian local breeds Rendena and Alpine Grey (Stocco *et al.*, 2017). Although breed is an important source of variation in fat content, within-breed variation among individual cows and with the stage of lactation tends to have a greater effect on milk-fat composition than breed (Samková *et al.*, 2011). Beyond overall fat content, the composition of fat globules in milk varies between cattle breeds and affects technological quality for butter making (Martini, Salari and Altomonte, 2016) (see Box B5); however, it generally does not affect nutritional quality.

Box B5. Fat globules in the milk affect food quality

Fat globules in milk affect the technological, organoleptic and nutritional quality of milk products (Fleming *et al.*, 2017; Martini, Salari and Altomonte, 2016). The composition of fat globules is influenced by species, breed, stage of lactation and season. The average size of fat globules is generally lower in small ruminants (goats and sheep) than in cattle (Felice *et al.*, 2021). Milk fat globules are associated with potential health benefits (to the immune system) and are used as supplements in infant nutrition (Fontecha *et al.*, 2020). Differences in the diameter and the number of globules cause variation in the total surface area of fat globule membranes, which may have a role in lipid and milk digestion and absorption and have anti-inflammatory action. Milk fat globules are also of particular interest in the manufacture of cheeses, as the interaction between the surface of milk fat globules and the casein matrix influences both the structure and the texture of the product. A larger diameter is better for butter production and certain types of cheese and is found in the milk of Jersey and Norman cattle, for example. The smaller diameter of fat globules in goat's milk contributes to the softer texture of goat's cheese compared to cow's cheese (Martini, Salari and Altomonte, 2016). There is an association between the milk fat content and the average diameter of the milk fat globules.

The nutritional quality of TASFs is controlled by a range of metabolic and genomic pathways (Dadousis *et al.*, 2017; Hocquette *et al.*, 2010; Pegolo *et al.*, 2018). Therefore, traits related to nutritional quality (e.g. protein and fat content, and milk coagulation properties) and organoleptic traits are expected potentially to have a genetic correlation, positive or negative, with many production, reproduction, functional or even adaptive traits (Egger-Danner *et al.*, 2015; Ewaoluwagbemiga *et al.*, 2022; Zhang *et al.*, 2019). Some studies in Australian meat and dairy cattle systems have concluded, on the basis of estimated genetic correlations between adaptive traits and nutritional-quality traits, that selection for one category of trait should have no undesirable effect on the other (Prayaga *et al.*, 2009; Turner *et al.*, 2010).

Certain genes are known to be directly linked to quality traits and are targeted in genetic selection programmes to improve the commercial quality of TASFs. In particular, a mutation of the myostatin gene can be associated with "doubled-muscle" animals, which have muscle hypertrophy (on average 20 percent heavier), lean carcass and meat that is more tender (Allais *et al.*, 2010; De Smet, Raes and Demeyer, 2004; Węglarz *et al.*, 2020). Double-muscled animals are well-represented in the Belgian Blue and Charolais breeds. Reduced development of intramuscular fat is known to occur in animals with a high muscularity (Hocquette *et al.*, 2010). Double-muscled animals have lower total fat, an approximately 50 percent lower proportion of saturated fatty acids and a higher proportion of PUFAs. Genes affecting milk composition have also been studied. A meta-analysis conducted by Bangar *et al.* (2021) showed that the B allele of the kappa casein gene (milk protein) is associated with higher fat percentage in cow's milk than allele A. Improving the traits that underlie meat and milk quality is a major challenge and is further discussed in Subsection 5.3.1.

Table B10. Impact of genetic traits on the nutrient composition of food products by nutrient group, product and species

Nutrient group	Food product	Species	Impact on nutrient composition	Reference
Fat and fatty acids	Egg	Chicken	Higher percentages of SFA (14 percent more) and MUFA (50 percent more) in eggs from a local Italian breed than in a hybrid breed reared in the same environment with the same feeding programme	Ianni *et al.*, 2021
			Higher content of fat (26 percent more) in eggs of a local Galician (Spanish breed) than a hybrid (Isa Brown)	Franco *et al.*, 2020
			No difference in fatty acid profile between 4 local Portuguese breeds and a hybrid population	Lordelo *et al.*, 2020
	Meat	Cattle (*Bos taurus* and *Bos indicus*)	Variation in degree of muscling, intramuscular fat content (linked to marbling score), fatty-acid profile, meat aroma, juiciness and tenderness between breeds selected for dairy and beef production (e.g. Nordic Red Cattle and Aberdeen Angus)	De Smet, Raes and Demeyer, 2004; Iso-Touru *et al.*, 2018; Sevane *et al.*, 2014
			Variability between *Bos taurus* and cross-bred *Bos indicus/Bos taurus* cattle in intramuscular fat content and fatty-acid profile (saturated fatty acids)	Elzo *et al.*, 2012; Rubio Lozano *et al.*, 2021
		Chicken	Commercial hybrids with slower growth rates generally fatter than cross-bred genotypes because they have not been selected for leanness, and tend to have higher total PUFA content in the meat	Baéza, Guillier and Petracci, 2021; Mahiza, Lokman and Ibitoye, 2021
			Lipid content in indigenous pure-bred chickens about one-third of that in hybrid chickens Higher levels of lipid and protein oxidation (which curtails protein bioavailability) in the pure-bred chickens	Dalle Zotte *et al.*, 2020
		Duck	Breast meat of native Turkish ducks 6 percent higher in omega-6 PUFA proportion than Peking ducks	Onk, 2019
		Pig	Higher fat content (twofold), better fatty acid profile, with 20 percent higher level of oleic acid (MUFA), 7 percent higher palmitic acid (saturated fatty acid) and almost 50 percent lower omega-6/omega-3 fatty acids ratio, in meat from Iberico pigs than in meat from Landrace, Yorkshire and Duroc pigs, which has higher saturated stearic acid content	Ali *et al.*, 2021
			Native Korean pigs associated with 57 percent higher PUFA content than cross-bred pigs (Landrace x Yorkshire x Duroc)	Ali *et al.*, 2021
		Sheep	High proportions of PUFA in adipose tissue and gastrocnemius muscle and a 50 percent higher level of omega-3 fatty acids in longissimus dorsi muscle in fat-tailed sheep (compared to non-fat-tailed breeds, e.g. Merino and Dorper)	Alves *et al.*, 2013; Van Harten *et al.*, 2016
			Superior fatty acid profile in Tibetan sheep (from high altitude dryland where pasture is scarce and has low protein content) compared to Small-tailed Han sheep (from northern China)	Jiao *et al.*, 2020

(cont.)

Nutrient group	Food product	Species	Impact on nutrient composition	Reference
Protein and amino acid	Egg	Chicken	Higher protein and higher yolk cysteine content in eggs from an indigenous breed than in eggs from a hybrid population kept in the same environment and given the same feed	Franco *et al.*, 2020; Mori *et al.*, 2020
			Yolk/albumen ratio affected by genetic variability	Prache *et al.*, 2020b
	Meat	Cattle Goat Pig	Little genetic variation observed	Prache *et al.*, 2020b; Suliman *et al.*, 2021
		Chicken	Significantly lower protein content (3–14 percent less) in a high breast-yield strain than in a standard breast-yield hybrid and higher protein content in indigenous chickens	Dalle Zotte *et al.*, 2020; Petracci *et al.*, 2013
			Quality defects such as “white striping” or “wooden breast” associated with a 7 percent to 18 percent decrease in muscle protein content and an increase of up to 11 percent in collagen content with genetic selection for growth rate in broilers	Baéza, Guillier and Petracci, 2021
Fat and protein content	Milk	Cattle Goat Sheep	Fat and protein content higher in milk of Alpine goats than in milk of Saanen goats, and in milk of Norman and Jersey cattle than in milk of Prim’Holstein cattle Individual variability in milk composition (fat and protein) between animals of the same breed and physiological status and on the same feeding; individual variability greater than variation between breeds	Prache *et al.*, 2020b; Samková *et al.*, 2011
		Cattle	Variation of milk fat globule size between breeds (e.g. higher in Jersey cattle – see Box B5)	Martini, Salari and Altomonte, 2016
		Dromedary	Variation of milk fat and protein composition between populations from Jordan, Saudi Arabia and Sudan	Burger, Ciani and Faye, 2019
Vitamin	Milk	Cattle	Variation of vitamin A content in milk between breeds, with the level in Holstein Friesian milk 10-16 percent lower than that in the milk of local breeds	Weir *et al.*, 2017
			Beta-carotene (vitamin A precursor) milk content up to twofold higher in Jersey cattle than in Prim’Holsteins	Prache *et al.*, 2020b
		Sheep	Variation in fat carotenoid content between breeds (differences in absorption, transfer into plasma and storage in body fat)	Macari *et al.*, 2017
	Meat	Cattle	No variation in vitamin E content	Juárez *et al.*, 2021

Notes: DHA = docosahexaenoic. EPA = eicosapentaenoic acid. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. SFA = saturated fatty acid.

5.1.2 Impact of non-genetic differences

Non-genetic differences among individual animals can also affect the nutritional quality of TASFs. The sex of the animal and the time at which the TASF product is harvested are two factors that have been identified. Table B11 summarizes some examples of impacts on nutritional quality by type of TASF and species.

The sex of the animal influences the lipid content of meat products and thus both the nutritional and the organoleptic quality. Females and castrated males have higher intramuscular lipid content. Sex hormones play a role, and their effects are particularly noticeable in the difference between castrated and uncastrated animals. When heated, meat from uncastrated boars may have an unpleasant odour (so-called “boar taint”), which is caused by the presence of skatole and androstenone in the adipose tissue (Lebret and Čandek-Potokar, 2021). Androstenone is a steroidal pheromone produced in the testicles that triggers a urine odour, whereas skatole is produced in the digestive tract and is associated with a faecal odour. Castration of piglets is a growing animal-welfare concern. Research is ongoing on genetic selection of boars with low hormone levels.

Table B11. Impact of genetic traits on the nutrient composition of food products by nutrient group, product and species

Factor	Food product	Species	Impact on nutrient composition	Reference
Sex	Meat	Pig	At the same backfat thickness, lower lipid content and higher proportion of omega-6 PUFA (linoleic acid) in subcutaneous adipose tissue from uncastrated males compared to that from females	Wood *et al.*, 2008
		Goose	Higher contents of PUFA (up to 8 percent), omega-6 PUFA (up to 9 percent), essential alpha-linoleic acid omega-3 (up to 19 percent) in meat from females than from males Lower (up to 9 percent) omega-6 PUFA/omega-3 PUFA ratio values in meat from males	Uhlířová *et al.*, 2019
		Cattle	Lower fat in meat from males than meat from females Higher intramuscular fat in meat from females than meat from castrated and uncastrated males Meat more tender and with higher MUFA content in females	Venkata Reddy *et al.*, 2015
		Goat Sheep	Higher fat deposition, lower total PUFA content (by 27 percent) and lower omega-6/omega-3 ratio (by 37 percent) in meat from castrated males than in meat from intact males	Madruga, Arruda and Nascimento, 1999; de Mello Tavares Lima *et al.*, 2019
		Cattle (*Bos taurus* and *Bos indicus*) Buffalo	Higher PUFA, omega-6 PUFA and omega-3 PUFA content (about 40 percent) in meat from intact males than in meat from castrated males Higher (nearly fivefold) essential omega-3 DHA and lower (by 31 percent) alpha-linolenic acid omega-3 content in meat from castrated males than in meat from intact males	Giuffrida-Mendoza *et al.*, 2015
		Pig	Unpleasant odour due to skatole and androstenone in adipose tissue in meat from uncastrated males	Lebret and Čandek-Potokar, 2021
Stage of lactation	Milk	Buffalo	Decrease in protein and casein percentage in the mid stage (4–5 months) of lactation in Murrah milk compared to earlier and later lactation stages	Arora, Sindhu and Khetra, 2020
		Cattle	Fat and protein content inversely related to milk quantity	Prache *et al.*, 2020b
			Variation of fat composition in milk higher in early lactation (< 100 days)	Samková *et al.*, 2011
		Donkey	Protein and casein content higher in milk during first month of lactation (by 12 percent compared to the 6th and 25 percent compared to the 10th month) No significant variation in milk fat content during lactation	Salari *et al.*, 2019
Laying age	Egg	Chicken Duck	Yolk weight increases with age and albumen weight decreases	Onbaşılar *et al.*, 2014; Prache *et al.*, 2020b
Age at slaughter	Broiler meat	Chicken	Decrease of slaughter age due to genetic selection for growth rate leads to increase in moisture/protein ratio	Baéza, Guillier and Petracci, 2021
	Red meat	Cattle Duck Sheep	Haemoprotein content, especially myoglobin increases with age Higher concentration of myoglobin makes meat darker	Baéza, Guillier and Petracci, 2021; Prache *et al.*, 2020b
		Cattle	Increase in iron and palmitic acid (SFA) content (by 41 and 8 percent, respectively) and decrease in linoleic acid (omega-6 PUFA) content (by 50 percent) with age	Schönfeldt, Naudé and Boshoff, 2010

(cont.)

Factor	Food product	Species	Impact on nutrient composition	Reference
Age at slaughter	Meat	Cattle Sheep	Increase in fat tissue carotenoid concentration with age Age effect on tenderness depends on the muscle (muscles with less collagen show less impact of age) Stronger flavour with age	Prache *et al.*, 2020b; Prache, Schreurs and Guillier, 2021
		Alpaca Cattle Donkey Dromedary Duck Goat	Higher tenderness in young animals	Baéza, Guillier and Petracci, 2021; Guerrero *et al.*, 2017; Kadim *et al.*, 2006; Polidori *et al.*, 2015; Popova *et al.*, 2021; Prache *et al.*, 2020b
		Alpaca Chicken Dromedary Duck Llama Sheep	Generally an increase in fat content with age	Baéza, Guillier and Petracci, 2021; Kadim *et al.*, 2006; Popova *et al.*, 2021; Prache, Schreurs and Guillier, 2021
		Chicken Duck	Increase in fat and MUFA content and decrease in PUFA content with age	Baéza, Guillier & Petracci, 2021
		Sheep	Increase in carotenoid content in the fat tissue and PUFA and iron content with age of the lamb	Prache, Schreurs and Guillier, 2021
		Alpaca	Higher levels of omega-3 PUFAs (EPA, DHA), DPA and total PUFA content in alpacas at age of 18 months compared to older animals (about 10 percent more)	Popova *et al.*, 2021
		Pig	Increase in intramuscular fat with age (30 percent increase between 160 and 220 days) Decrease in omega-6 PUFA (linoleic acid) content (by 30 percent) in intramuscular fat with age	Bosch *et al.*, 2012

Notes: DHA = docosahexaenoic. DPA = docosapentaenoic acid. EPA = eicosapentaenoic acid. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid.

The age of the animal at slaughter influences the fat content, fatty-acid profile and protein content of its carcass. The findings of studies on the impact of age on protein content vary with the age groups studied and the species-specific age at maturity. The fat content of meat generally increases with age. The haemoprotein content in red meat is also higher in the carcasses of older animals (Baéza, Guillier and Petracci, 2021; Polidori *et al.*, 2017; Schönfeldt, Naudé and Boshoff, 2010). Genetic selection for growth rate and carcass yield in chickens has led to a reduction in the slaughter age and thus an increase in the moisture/protein content ratio in the standard retail product (Baéza, Guillier and Petracci, 2021).

As well as affecting the nutritional-quality attributes of food, age can also affect food safety. Chemical residues and environmental pollutants tend to be higher in the carcasses of animals slaughtered at an older age, as the exposure time and thus the risk of accumulation increases with age (Prache *et al.*, 2020b). The potential accumulation of undesirable heavy metals, such as arsenic or cadmium, over the life of the animal, curtails the quality of milk, eggs, meat and offal (Hejna *et al.*, 2018).

5.2

Livestock husbandry practices and production systems

The way in which an animal is raised can have a substantial impact on the quality of the resulting TASFs. Livestock production systems differ substantially in terms of the climate and other geographical aspects of their location, management practices, feed and feeding systems, housing and animal welfare. The nutritional quality of the resulting TASF is mostly influenced by the diet of the animal. Livestock husbandry practices and other aspects of production systems affect safety, organoleptic and technological food-quality attributes more than nutritional content, but some impacts on nutritional content have been reported.

5.2.1 Feed and feeding systems

Whether livestock are fed with grass, forage, cereals or other concentrate feed affects the nutrient content and especially the fatty-acid and vitamin profile of their milk and meat. Table B12 summarizes examples of the findings of studies of the impact of differences in animal feeding and feeding systems on the nutritional quality of TASF. The impact of feed on organoleptic and technological quality is also discussed below.

In general terms, grazing animals have lower milk yield (21 percent) and higher protein content (8 percent) in their milk than animals fed on a diet consisting of grass silage, maize silage and concentrates (O'Callaghan *et al.*, 2018). Higher vitamin A and E contents have been documented in milk and meat from grass-fed ruminants (Juárez *et al.*, 2021; Martin *et al.*, 2004) and higher vitamin E contents in meat from free-range chickens (Baéza, Guillier and Petracci, 2021). Precursors of vitamin E and vitamin A have been reported to be present at levels, respectively, up to four times and seven times higher in beef from pasture-fed systems than in beef from concentrate-fed systems (Duckett *et al.*, 2009; Cabrera and Saadoun, 2014). A comparison of the milk of cows fed on a pasture-based diet to that of cows fed on a concentrate diet showed that the concentration of the precursor of vitamin A was 50 percent higher in the former (Martin *et al.*, 2004). No variation in the protein content of eggs and meat is reported in the literature.

A high PUFA diet improves the content of beneficial fatty acids in milk and meat. Increasing the content of essential fatty acids in TASF (conjugated linoleic acid for ruminants and omega-3 fatty acids) while decreasing omega-6/omega-3 ratio benefits human health. This is of particular interest to researchers and to the processing industry. The omega-6/omega-3 ratio is more affected by the diet of the animals than by their genetic make-up. The PUFA/SFA ratio recommended for the human diet can be achieved in the intramuscular fat of most pig breeds by feeding the animals on an appropriate diet (De Smet, Raes and Demeyer, 2004). The impact of diet differs greatly between monogastrics and ruminants.

The difference in the digestive systems of ruminants and monogastrics means that there are differences in the ways they digest and absorb fats (Ponnampalam, Sinclair and Holman, 2021). In monogastric animals, dietary fatty acids are directly absorbed without biochemical reactions in the stomach, and their composition is reflected in that of the meat. This is not the case in ruminants, as ruminal biohydrogenation[4] of fatty acids decreases their absorption. However, conjugated linoleic acid, a nutritionally beneficial fatty acid, is synthesized in the rumen. This is associated with the ingestion of forages – a major part of the diet of ruminants. Monogastrics (including rabbits and horses) can convert alpha-linolenic acid into PUFA. However, the conversion rate is low. Certain bacterial reactions in monogastrics can further contribute to this synthesis: caecotrophia in rabbits (reingestion of soft faeces issued from bacterial fermentation in caecum) has been shown to increase PUFA content in the meat (Lebas, 2007).

Grazing and high omega-3-dense feed supplements (e.g. linseed) increase PUFA content in milk and meat and thus result in a more nutritionally beneficial fatty-acid profile for human consumption. These effects of grazing are particularly marked when animals feed on leguminous pasture or on forages from diverse grasslands (Hampel *et al.*, 2021; Lourenço *et al.*, 2007; Albenzio *et al.*, 2016). For example, Hampel *et al.* (2021) reported a more than 20 percent increase in PUFA content in meat from lambs fed on tropical legumes compared to meat from grass-fed lambs. Grasses are rich in alpha-linolenic acid, an essential fatty acid and precursor of omega-3 fatty acids, whereas cereal grains have higher levels of linoleic acid, a precursor of omega-6 fatty acids (Prache *et al.*, 2021; Warren *et al.*, 2008). Dietary linseed increases the level of alpha-linolenic acid in the meat of cattle, sheep, pigs, rabbits and chickens (Lebas, 2007; Wood and Enser, 2017), especially if fed in the form of oil rather than whole seeds (Albenzio *et al.*, 2016). Nguyen *et al.* (2017) report that supplementing the diet of sheep with flaxseed increased the content of omega-3 fatty acid (by 18 percent), EPA (by 47 percent) and DPA (by 22 percent)

[4] Biohydrogenation is a process that occurs in the rumen whereby bacteria convert unsaturated fatty acids into saturated fatty acids. This results in highly saturated fatty acids leaving the rumen and limits the PUFA content in tissues.

in the kidneys and alpha-linolenic acid (two times higher) in the liver, with alpha-linolenic acid content in liver being almost three times higher than that in the muscles (Sterk *et al.*, 2011; Van Le *et al.*, 2019).

Complementary feed and use of different local forages, such as hay from Khortane grass, dried olive leaves or hay from *Stipa tenacissima* grass, to supplement scarce pasture grazed by goats in Tunisia had a positive impact on the fatty acid profile (lower omega-6/omega-3 ratio; 30 percent variation) and the vitamin E content of the meat (3.71 mg/kg with olive-leaf supplementation, i.e. almost three times higher than an oat hay-based diet) (Ayeb *et al.*, 2019). In Brazil, milk from dairy goats raised on semi-arid native pasture was found to have a better fatty-acid profile than milk from goats kept in a confined system: the native pasture comprised 71 different plant species, whereas the confined-feeding system was based on hay from Napier grass (*Pennisetum purpureum*) (FAO, 2021c; Neto *et al.*, 2020; Sant'Ana *et al.*, 2019). The feeding system also has an impact on the quality traits and fatty-acid profile of beef. In Uruguay, beef from animals finished on pastures was found to have a higher level of conjugated-linoleic acid (around two times higher) than that from animals finished in feedlots, irrespective whether they were grown in a feedlot or on pasture (Ferrinho *et al.*, 2019). The variety of grass or fodder fed can also affect the nutritional content of animal products, and silage supplementation in grazing cows produces variable responses in terms of milk composition: for example, feeding elephant grass and *Leucaena* silage resulted in higher concentration of fat and lower concentration of lactose in milk than feeding colosuana grass and king-grass morado (Roncallo, Sierra and Castro, 2012).

The biological significance of increases in omega-3 content and conjugated linoleic acid content in TASFs for human health may be debatable given that the PUFA content of TASFs is rather low compared to that of vegetables. However, some clinical studies suggest a potential effect on the blood of consumers and on the regulation of the metabolism. For example, McAfee *et al.* (2011) found a higher concentration of omega-3 PUFA (20 higher omega-3 PUFA/total fatty acid ratio) in the blood of people whose diet included red meat (beef and lamb) derived from grass-fed animals than in the blood of those who ate meat from concentrate-fed animals. Another study (Legrand *et al.*, 2010) found that the EPA and DHA proportions in the fatty acids in the red blood cells decreased significantly in a group that ate standard products, whereas they were maintained in a group whose diet included a high level of omega-3 originating from linseed-fed animals. The conjugated linoleic acid and alpha-linolenic acid contents of sheep's milk are three to four times higher than those of cow's milk (Albenzio *et al.*, 2016). Sofi *et al.* (2010) reported that consumption of conjugated linoleic acid-rich cheese (derived from pasture-fed sheep) rather than a commercially available cow's milk cheese was associated with significant reductions in inflammatory cytokines and platelet aggregation. Intake of 90 g per day of sheep's cheese rich in conjugated linoleic acid and alpha-linolenic acid (three times higher than the control cheese because the sheep's diet was supplemented with linseed) was found to result in significant increases in the plasma concentrations of conjugated linoleic acid and alpha-linolenic acid in consumers and to regulate lipid and energy metabolism (Albenzio *et al.*, 2016; Pintus *et al.*, 2013).

In populations that do not consume significant quantities of fish, meat can contribute meaningfully to omega-3 status, particularly when it comes from pasture-fed animals (Coates *et al.*, 2008; Howe *et al.*, 2006). Australian adults consume six times as much meat as fish and seafood. Howe *et al.* (2006) found that 43 percent of the average intake of omega-3 in the diet of the Australian population came from meat (equivalent to the contribution of fish products). These results can be linked to the livestock husbandry and feeding system in Australia, where most cattle are raised on pasture and grain-fed beef, including beef from systems in which a stage of the production takes place in a feedlot, represents 30 to 40 percent of total beef production (ALFA, 2022). Lenighan *et al.* (2020) found that consumption of grass-fed beef with a higher PUFA content (compared to grain-fed beef) had the potential to improve the quality of dietary fatty acid intake at the scale of the Irish population. Coates *et al.* (2008) showed that the consumption of omega-3-enriched pork can significantly increase omega-3 content in human blood cells. The consumption of animal products derived from animals fed on a linseed diet (associated with a 60 percent reduction in the omega-6/omega-3 ratio in meat and an 86 percent reduction in eggs) led to a more than twofold increase in omega-3 (alpha-linolenic acid) content in the fatty acids in human plasma (Weill *et al.*, 2002).

While TASF with higher PUFA content have a more beneficial fatty-acid profile, this can increase the risk of organoleptic and technological defects caused by a higher level of lipid and protein oxidation. Lipid oxidation in meat induces an unpleasant taste and odour and is associated with a change in colour and with the potential formation of toxic compounds (Prache *et al.*, 2020b). Spontaneous oxidized flavours develop when fats are oxidized in milk and meat. Protein and lipid oxidation leads to a reduction in digestibility and negatively affects bioavailability (Estévez, 2011; Prache *et al.*, 2020b). Feeding broilers on a diet high in omega-3 increases its incorporation into the meat but may compromise meat quality as a result of the oxidation of lipids. The milk and meat of grass-fed animals are reported to have higher antioxidant activity and to contain larger amounts of phytochemicals than those from grain-fed animals (Van Vliet, Provenza and Kronberg, 2021). Adding antioxidants to feed, for example supplementing poultry feed with selenium, can decrease lipid and protein oxidation in meat (Baéza, Guillier and Petracci, 2021). Vitamin E limits lipid and protein oxidation in meat products, and is used during processing.

Because feed is the main variable cost in livestock production, new feed sources are frequently proposed and tested for safety and quality. For example, insect products are increasingly being used. Feeding insect larvae to laying hens, broiler chickens, quails and partridges has been reported to have some effects on the nutrient composition (e.g. fat content) and organoleptic quality of meat, but the results of the limited number of studies that has been conducted are not consistent (Gasco *et al.*, 2019). Laying hens fed black soldier fly larvae produced eggs with higher fat content in their yolks, while organoleptic quality did not change (Bejaei and Cheng, 2020; Tahamtani *et al.*, 2021). Overall, the reported impact of insect larvae feed on TASF quality has been minimal. The use of algae and fish oil as feed ingredients has been found to increase omega 3, EPA and DHA content in meat from cattle, chickens and sheep, although high levels have been found to cause an unpleasant flavour (rancidity) and colour changes in the meat as a result of lipid oxidation (Baéza, Guillier and Petracci, 2021; Prache, Schreurs and Guillier, 2021; Wood *et al.*, 2004).

Replacing human-edible feed crops with plant by-products that cannot be eaten by humans helps to mitigate the environmental impacts of livestock production. A review by Salami *et al.* (2019) documents the environmental impacts and the impacts on the nutritional quality of meat of using a range of different plant by products as feed. Incorporating up to 30 percent distillers' grains with solubles (maize, wheat) or glycerine in the animals' diet has been associated with an increase in the PUFA content of beef and lamb (Salami *et al.*, 2019). Citrus pulp in the diet of lambs does not affect performance or carcass or meat quality and limits rumen biohydrogenation of PUFAs and lipid and protein oxidation (Salami *et al.*, 2019). Other extracts from fruits are of interest as sources of natural antioxidants in animal diets. By-products of potato can increase the PUFA content in subcutaneous fat by 19 percent (Pen *et al.*, 2005). Dietary distillates from rosemary leaves increase PUFA content (by 12 percent) and those from thyme leaves decrease saturated fatty acid content (by 8 percent) in mutton (Nieto, 2013). However, flavour and acceptability need to be further assessed. A recent meta-analysis (Torres *et al.*, 2022) reported that, in addition to mitigating greenhouse-gas emissions, feeding tannins to sheep led to their meat having a higher content of beneficial fatty acids (14 percent increase in omega-3).

Using genetically modified crops as feed and feed ingredients has so far not been shown to affect the safety and quality attributes of TASFs. There has been public concern about the safety of food produced from animals fed with genetically modified crops. However, such concerns are not supported by current scientific evidence. Box B6 presents the current state of knowledge on the impact of genetically modified feed on TASF quality.

Box B6. Impact of genetically modified feed on public health

About 70 to 90 percent of the genetically modified (GM) crops produced globally are used as feed for food-producing animals (Lucht, 2015). According to the European Food Safety Authority GMO Panel Working Group on Animal Feeding Trials, scientific literature on feeding trials with GM crops showed (as of 2008) no evidence of adverse impacts on animals, the nutritional quality of their products or human health (EFSA GMO Panel Working Group on Animal Feeding Trials, 2008). More recently, de Vos and Swanenburg (2018) reported that no scientific publications had demonstrated adverse impacts on public health. FAO (2015a) reported no indication that intact GMO-related proteins or DNA would be transferred to food products of animal origin (fluids or tissue).

Foods produced from animals fed on GM feed are not regulated as such, nor is it mandatory to label these food products as GM foods. However, some national regulations, for example those in France, Germany and the United States of America, cover the use of voluntary claims on food packaging that the animals used to produce the food have not been fed on GM feed.

Table B12. Impact of feed and feeding systems on nutrient composition, by food product and species

Nutrient group	Food product	Species	Feed and feeding system	Reference
Protein content	Milk	Cattle	Animals grazing sown pasture (grass, clover) produce milk with significantly higher concentration of protein (8 percent) and casein (10 percent) compared to animals fed indoors on a grass silage, maize silage and concentrate ration No variation in amino acid profile	Magan et al., 2021; O'Callaghan et al., 2018, 2016
	Egg	Chicken Duck Turkey	No variation	Duckett et al., 2009; Prache et al., 2020b; Schönfeldt, Naudé and Boshoff, 2010; Van Vliet, Provenza and Kronberg, 2021; Bautista et al., 2020
	Meat	Cattle Goat Sheep		
Fatty acid profile and fat content	Milk	Buffalo Cattle Sheep	Diet richer in PUFA results in higher PUFA and omega-3 content (twofold) Pasture grazing results in significantly higher concentrations of fat, PUFA (omega-3) and conjugated linoleic acid compared with silage-concentrate feeding	Gómez-Miranda *et al.*, 2021; O'Callaghan *et al.*, 2018; Rodríguez, Alomar and Morales, 2020; Salzano *et al.*, 2021
			High-fat concentrate diet results in more and larger fat globules	Martini, Salari and Altomonte, 2016
	Egg	Quail	Seeds such as hemp seeds increase omega-3 content in egg yolk (sevenfold increase in alpha-linolenic acid)	Yalcin, Konca and Durmuscelebi, 2018
		Chicken	Higher PUFA (three to fivefold increase) and lower omega-6/omega-3 ratio (by 50 percent, reaching around 5) when hens have access to pasture	Hammershøj and Johansen, 2016
	Meat	Monogastrics (chicken turkey, pig)	Dietary fatty acids directly absorbed without biochemical reactions (and reflected in meat); in ruminants this is not the case	Prache *et al.*, 2020b
		Chicken	Increasing lipid content of feed and decreasing its energy/protein ratio lead to an increase in intramuscular lipid content SFA-rich diet (e.g. palm, copra oil) increases SFA proportion PUFA-dense oil from marine animals increases the proportions of long-chain omega-3 PUFAs	Baéza, Guillier and Petracci, 2021
		Pig	Higher intramuscular fat content (by 28 percent) and PUFA content by (by 10 percent) in free-range Iberian pigs feeding on acorns and grass compared to pigs fed indoors on concentrates	Tejeda *et al.*, 2020
			Feed ingredients derived from chicory reduce skatole in backfat of uncastrated males, thus reducing associated unpleasant odour (boar taint)	Aluwé *et al.*, 2017
		Rabbit	Omega-3 PUFA content doubled in rabbits fed on a diet containing linseed (3 percent linseed)	Petracci, Bianchi and Cavani, 2009
		Ruminants	Higher content of beneficial fatty acids in meat mainly results from plants and other components rich in linolenic acid in the diet	Scollan *et al.*, 2014
		Cattle Goat Lama Sheep	Feeding grass or forages including omega-3 PUFA-rich plants (e.g. linseed, plantain, chicory or legumes, such as pigeon peas) increases content of omega-3 (alpha-linolenic acid and EPA) (around threefold increase in cattle and sheep) and lowers omega-6/omega-3 PUFA ratio by a factor of three to four Grass-fed cattle and sheep have darker meat Grass-feeding increases risk of "off-flavours" in sheep meat	Hampel *et al.*, 2021; Leheska *et al.*, 2008; MacKintosh *et al.*, 2017; Mamani-Linares and Gallo, 2014; Rodríguez, Alomar and Morales, 2020; Scollan *et al.*, 2006; Wood and Enser, 2017
		Cattle	Lower intramuscular-fat content in meat from grass-fed animals compared to concentrate-fed animals and thus higher PUFA levels	Juárez *et al.*, 2021; Latimori *et al.*, 2008
			Diet consisting more of concentrates than of forage associated with a higher level of MUFA (by 20 percent), lower levels of SFA (by 13 percent) and omega-3 (by 73 percent) and a higher omega-6/omega-3 ratio (fourfold)	Leheska *et al.*, 2008

(cont.)

Nutrient group	Food product	Species	Feed and feeding system	Reference
Fatty acid profile and fat content	Meat	Cattle	Grain-based diets produce intramuscular fat with 30 percent less total and saturated fat than that in grass-finished cattle Lower omega-6/omega-3 ratio (by at least 70 percent) in intramuscular fat of grass-fed animals compared to that of grain-finished animals Threefold higher percentage of omega-3 in meat from grass-fed animals than in meat from grain-fed animals in Argentina	Hall, Schönfeldt and Pretorius, 2016; Latimori *et al.*, 2008
			Lower proportions of myristic and palmitic acids in the intramuscular fat of pasture-fed animals than in that of feedlot animals	Rubio Lozano *et al.*, 2021
			Conjugated linoleic acid level two times higher in pasture-fed animals than in concentrate-fed animals (in Central and South American pasture-based systems)	Cabrera and Saadoun, 2014; Ferrinho *et al.*, 2019; Bautista *et al.*, 2020
		Sheep	Ewe's milk fatty-acid profile reflected in fatty-acid profile of meat from suckling lambs Pasture-fed weaned sheep have higher content of omega-3, lower content of palmitic acid and lower omega-6/omega-3 ratio in their meat than lambs fed a concentrate-based diet	Chikwanha *et al.*, 2018; Prache, Schreurs and Guillier, 2021; Ramos *et al.*, 2020
	Offals	Sheep	Flax-seed supplementation increases omega-3 fatty acids (by 18 percent), EPA by (47 percent) and DPA (by 22 percent) in kidney and acid alpha-linolenic omega-3 (twofold higher) in liver, with levels in liver thus almost three times higher than those in muscle	Nguyen *et al.*, 2017; Van Le *et al.*, 2019
			Linseed supplementation leads to better fatty-acid profile and higher proportions of alpha-linolenic acid (threefold increase), EPA (threefold increase) and DPA (twofold increase) in liver	Kim *et al.*, 2007
		Pig	Linseed supplementation decreases omega-6/omega-3 ratio, increases of alpha-linolenic acid content by 70 percent and leads to a threefold increase in EPA content in liver	Enser *et al.*, 2000
Vitamins	Milk	Cattle	Diets based on concentrate or maize silage result in lower vitamin A precursor (carotenoids) content (reduced by 40 percent) and lower vitamin E content (reduced by 30 percent) than grass-feeding	Martin *et al.*, 2004
			Switching from grass silage decreases vitamin E content by at least 30 percent and beta-carotene by 50 percent	Nozière *et al.*, 2006
	Meat	Cattle Goat Sheep	Grass-feeding leads to sevenfold, 60 percent and twofold increases in levels of vitamins A, C and E (or their precursors), respectively	Cabrera and Saadoun, 2014
			High levels of dietary starch reduce vitamin B12 levels in the rumen, leading to reduced vitamin B12 levels in meat	Juárez *et al.*, 2021
			Three times higher concentration of vitamin B1, two times higher of vitamin B2 and more than three times higher of vitamin E in grass-finished than in grain-finished beef	Duckett *et al.*, 2009
		Chicken	Free-range access increases vitamin E content	Baéza, Guillier and Petracci, 2021
Bioactive compounds	Milk	Goat	Supplementation with bioactive compound-rich forages increases total polyphenol, hydroxycinnamic acids and flavonoid concentrations (antioxidant activity)	Delgadillo-Puga and Cuchillo-Hilario, 2021
Pigment	Eggs	Chicken	Yolk colour (affects consumer preference) affected by carotenoids (e.g. yellow: maize, alfalfa, flower extracts; red: paprika) in the diet	Nys and Guyot, 2011; Prache *et al.*, 2020b

Notes: DDPA = docosapentaenoic acid. EPA = eicosapentaenoic acid. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. SFA = saturated fatty acid.

5.2.2 Environmental conditions and climatic zone

Except for certain vitamin and mineral supplements, the diets of livestock are essentially plant based. Climatic conditions, soil type, altitude and season all affect the chemical composition of plants and thus of animal feed and the nutritional-quality attributes of the resulting TASF. All these factors are determined by environmental conditions. Table B13 summarizes key examples of the influence of environmental conditions on the nutritional quality of TASF.

Temperature and day length determine the growing season of plants and thus access to pasture and the quantity and quality of the forage available to grazing animals. Milk produced during the summer contains higher levels of vitamin D, lower levels of fat and higher levels of PUFA than milk produced at other times of year. Liu *et al.* (2013) found no impact of latitude on the vitamin D3 content of lean beef in Australia but found that fat from cattle raised at low latitudes contained higher concentrations of vitamin D3 than fat from cattle raised at high latitudes. The milk and meat of sheep, cattle and yaks raised on high altitude pastures have beneficial fatty-acid profiles (Cividini *et al.*, 2019; Han *et al.*, 2020). The diversity of rangelands and their specificities in terms of soils, biodiversity and terrain allow pastoralists to take advantage of concentrations of nutritious plants (FAO, 2021c). Grazing on combinations of plants specific to particular geographical areas may improve the extraction of nutrients and affect the nutritional content of TASFs. Dromedaries kept by Raika pastoralists in northwestern India feed on 36 different plant species (FAO, 2021c).

Environmental variables can also be important in production systems where feed is harvested rather than consumed directly by grazing animals. Forages should be harvested at the optimal time to ensure maximum quantity and quality

Table B13. Impact of environmental conditions on nutrient composition of terrestrial animal source foods, by food product and species

Factor	Food product	Species	Impact	Reference
Plant composition of pasture	Meat	Sheep	Ten grazing areas in North Macedonia associated with specific fatty acid profiles and fat contents in meat (explained by the plant composition of pastures)	Vasilev *et al.*, 2020
	Milk	Cattle Sheep	Grazing at higher elevation leads to beneficial fatty-acid profile, with increased concentrations of PUFA (up to 87 percent higher), omega-3 fatty acids (e.g. alpha-linolenic) (up to 68 percent higher) and higher milk fat content	Bartl *et al.*, 2008; Cividini *et al.*, 2019; Falchero *et al.*, 2010
		Yak	High altitude associated with higher percentages of PUFA (up to 25 percent higher)	Han *et al.*, 2020
	Meat	Yak	Higher altitudes (from 3 215 m to 5 410 m) associated with 60 percent higher content of vitamin A and 28 percent higher content of vitamin E	Yang *et al.*, 2021
Season	Milk	Cattle Sheep	More vitamin D and calcium, larger fat globules, less saturated fatty acids and more PUFA and omega-3 in spring and summer milk than winter milk	Altomonte *et al.*, 2019; Martini, Salari and Altomonte, 2016; Rutkowska, Adamska and Bialek, 2012; Weir *et al.*, 2017
		Cattle (*Bos taurus*)	Decrease in milk protein contents related to decrease in casein fraction in summer	Bernabucci *et al.*, 2015
		Dromedary	Lower fat content during warmest month	Musaad, Faye and Al-Mutairi, 2013
	Meat	Yak	Increased fat content in season when pasture is abundant	Xiong *et al.*, 2021
		Pig	Slightly lower carcass fatness in pigs born in spring or autumn than in pigs born in winter Muscle lipid content lowest in spring; myoglobin content unaffected PUFA percentage lower in pigs born in autumn than in those born in winter or spring	Lebret *et al.*, 2021

Note: PUFA = polyunsaturated fatty acid.

and consequently optimal nutritional content in resulting TASFs. The proportion of nutrients digestible by ruminants decreases with the age of the plants (Duarte *et al.*, 2019). The concentration of the beneficial conjugated linoleic acid in cow's milk fat is increased by dietary intake of fresh pasture (Kelly *et al.*, 1998). Climatic variations in tropical regions can greatly affect the quality of the grass and hence its nutritional contributions, including minerals (Huerta-Leidenz, 2021; Rubio Lozano *et al.*, 2021). The fatty-acid profile is linked to the climatic zone and feeding system, particularly the combination of pasture management, grass maturity, grass diversity, season and altitude, which influences the concentration of alpha-linolenic acid (precursor of long-chain omega-3) in the diet (Garcia *et al.*, 2016). The selenium content of meat has been reported to be affected by the feeding system, the selenium content in the feed (grains and grass) and the environmental conditions (soil) (Cabrera and Saadoun, 204; Gupta and Gupta, 2000).

5.2.3 Housing conditions and other husbandry practices

Husbandry practices encompass all the methods and measures used by the producer to manage animals up to the time of slaughter. They include feeding, housing, reproductive management, and health and welfare care. Production systems that include grazing or free-range feeding are generally associated with positive impacts on the nutritional contents of TASFs (Prache *et al.*, 2020a).

Housing conditions have been shown to affect the fatty-acid profile and the protein and vitamin content of meat. Pigs raised outdoors have been found to have a lower ratio of omega-6 to omega-3 PUFA than pigs raised indoors on the same diet (Dostálová *et al.*, 2020). The decreased ambient temperature associated with outdoor access was assumed to explain the higher MUFA content of the meat. Ducks raised in irrigated rice fields in China have been found to have higher carcass weight, with higher intramuscular fat, lower protein content and higher concentration of some essential amino acids (valine, methionine, phenylalanine, histidine and arginine) and PUFAs (omega-6 and omega-3), than ducks raised in floor pens (Huo *et al.*, 2021). Sokołowicz, Krawczyk and Dykiel (2018) report that outdoor access was found to have a beneficial effect on the vitamin A content, the proportions of PUFAs and omega-3 fatty acids and the omega-6/omega-3 ratio in egg yolk. A systematic review by Pires *et al.* (2021) highlights conflicting results related to the level of impact of housing system (caged versus free-range) on egg quality, especially egg weight, the most studied quality indicator. As vitamin D is synthesized when animals are exposed to sunlight, housing and indoor rearing decrease the vitamin D content of cow's milk (Weir *et al.*, 2017).

Organic production is increasing in the livestock sector. There are no international common standards of organic production, which hampers comparisons of such production systems and assessments of their effects on the nutritional quality of TASFs. Results differ among studies because of differences in husbandry practices and combinations of factors such as diet, housing and the breed and age of the animals. Nevertheless, attempts have been made to study the impact of organic production systems on the nutritional quality of TASFs. Two meta-analyses reported that certain organic meats (beef, lamb and pork) and cow milk have healthier fatty-acid profiles than their non-organic equivalents (higher concentration of PUFA in meat and milk, higher conjugated linoleic acid and vitamin E concentrations in milk) (Średnicka-Tober *et al.*, 2016a, 2016b). These results may be closely linked to the pasture access and the grazing and forage-based diets prescribed under organic production standards (Średnicka-Tober *et al.*, 2016a). As an illustration, Benbrook *et al.* (2013) reported a 2.5 times higher omega-6/omega-3 ratio in conventional milk than in organic milk.

The production system and, in particular, housing, affect animal welfare, which in turn affects the quality of TASFs. Free-range rearing and pasture-based systems have been shown to improve poultry and cattle welfare (Arnott, Ferris and O'Connell, 2017; Yilmaz Dikmen *et al.*, 2016). Stress factors before slaughtering such as thermal stress, lack of food and water, and transportation over long distances, impair animal welfare and TASF quality, especially technological aspects, as further described in Table B14. Heat stress is already a major challenge for livestock production and animal welfare, a challenge that may become even more serious in the future given global warming and forecasted increases in demand for TASFs in Asia and Africa. Elevated body temperature before slaughter is more frequent in cattle finished on grain than in grass-fed cattle and is associated with high rigour temperature and tougher meat. Stressors associated with poor animal welfare can lead to pale soft exudative (PSE) and dark firm dry (DFD) meat (Alcalde *et al.*, 2017; Carrasco-García *et al.*, 2020). DFD meat is dark in colour, tough and has reduced shelf-life. PSE is light in colour, has poor quality and low water retention, and is hard after cooking. Both types of meat are generally rejected by consumers. Box B7 provides further information on the physiological and metabolic reactions caused by stress and their negative effects on TASF quality.

Studies in Brazil have found around 5 percent of bovine carcasses (Rosa *et al.*, 2016) and 19 percent of pig carcasses (Trevisan and Brum, 2020) to have DFD meat. Higher temperatures are more likely to produce PSE meat, whereas

Box B7. Physiological and metabolic reactions resulting in stress and negative impacts of terrestrial animal source food

Physiological and metabolic reactions to stress have been described in the literature. For example, Terlouw *et al.* (2021) summarized the main effects of stress on the quality of TASFs, and Gonzalez-Rivas *et al.* (2020) reviewed the effects of heat stress on meat quality. Heat stress induces physiological reactions including faster heart rates, higher catecholamine (neurotransmitters) levels and higher metabolic stress, with accelerating muscle glygogenolysis (production of glucose from glycogen stored in muscle) and ultimately high pH in muscles. The extent of the (physiological) pH decline in meat after slaughter depends on the amount of glycogen stored in the muscle before slaughter. Preslaughter stress can have two types of effect:

1. Muscle metabolism continues after death and can be higher if the animal is under acute stress right before slaughter, leading to rapid depletion of glycogen stores and rapid post-mortem pH decline. In this case, the muscle temperature is still high and, when associated with rapid post-mortem pH decline, this can lead to pale soft exudative (PSE) meat (Gonzalez-Rivas *et al.*, 2020; Terlouw et al., 2021). PSE is more frequently observed in pig and poultry meat than in meat from other animals.
2. A low quantity of glycogen in the muscle at slaughter can lead to high ultimate pH and poor meat quality in the form of increased toughness or “high rigour temperature” in carcasses (Gonzalez-Rivas *et al.*, 2020; Terlouw *et al.*, 2021; Warner *et al.*, 2014).

In ruminants and pigs, the most likely effect of chronic heat stress is to trigger dark firm dry meat as a result of lower glycogen reserves in the muscles, lower production of lactic acid and higher ultimate pH (Gonzalez-Rivas *et al.*, 2020; Zhang *et al.*, 2020). In poultry, chronic heat stress reduces feed intake and changes the chemical composition of breast meat, increasing fat, especially intramuscular fat, deposition and reducing protein content (Gonzalez-Rivas *et al.*, 2020). Chronic stress factors also jeopardize the capacity of animals to deal with acute stress during preslaughter handling and transport.

Heat shock proteins (HSP) in ruminants and pigs play a role in muscle tenderness, juiciness and flavour. Heat stress is associated with an increase of HSP expression, which contributes to cellular protection and prevention of protein degradation. Down-regulation of HSP expression is associated with muscle tenderness, whereas up-regulation can lead to tough meat (Gonzalez-Rivas *et al.*, 2020). Archana *et al.* (2018) report that the low expression of the HSP70 gene in the Indian indigenous Salem Black goat reflects the breed’s better adaption to high ambient temperatures than the Osmanabadi, another Indian indigenous goat breed (Archana *et al.*, 2018). However, no impact of heat stress on the protein and fat content of the meat of the two breeds was reported.

Egg weight decreases as the ambient temperature increases above 25 °C, and this is associated with a decline in albumen weight and a delayed decrease in yolk weight. This lower average egg weight is partly explained by reduced protein and energy intake during thermal stress (Renaudeau *et al.*, 2012). The glycogen store in muscles is affected by physical activity and physiological stress, such as that caused by food deprivation (Gonzalez-Rivas *et al.*, 2020; Terlouw *et al.*, 2021). Heat stress also induces oxidative stress, which leads to protein and lipid oxidation and to shorter shelf-life. Lipid oxidation leads to off-flavour and decreases nutritional value. Protein oxidation can modify the digestibility of proteins and decrease the bioavailability of amino acids (Zhang, Xiao and Ahn, 2013). Heat stress also leads to a decrease in milk yield in cattle and decreases the protein and fat content of milk (Gorniak *et al.*, 2014; Liu *et al.*, 2019).

colder temperatures are more likely to produce DFD meat in chickens and turkeys (Leishman *et al.*, 2021). A meta-analysis conducted by Leishman *et al.* (2021) documented the relation betweeen heat stress and poultry-meat quality and noted that it may reach a level sufficient to have an impact if production conditions are extreme, such as those that may occur during transportation, heat waves or periods when apparent temperature is high (e.g. when there is a combination of high air temperature, low air velocity, high humidity and high stocking density).

5.2.4 Husbandry practices and food safety

In addition to nutrient composition, husbandry practices can also affect the safety of TASF. Although public health and food safety are addressed in Section D, some specific aspects of husbandry and food safety are described in this subsection.

To reduce the risk that TASF will contain food-borne contaminants, it is essential to ensure that safe animal husbandry practices are implemented as every stage in the production process up until slaughter, including in the case of home slaughtering (FAO, 2021a). Relevant actions include improving biosecurity measures, traceability, feed safety, disease prevention and control, and animal welfare. The type of hazard and the associated level of risk depend on the type of TASF, the type of production system and the animal management practices and strategies deployed. Free-range and confined systems and small- and large-scale systems will not trigger the same levels of risk, and practices implemented to address food safety along the food chain need to be adapted to the respective system.

Risk assessment based on Codex Alimentarius guidance enables the predominant risk factors for a given type of

Table B14. **Factors affecting animal welfare and the quality and safety of terrestrial animal source food**

Factor	Food product
Heat stress	Acute heat stress before slaughter leads to PSE meat in poultry and pigs Chronic heat stress is more likely to cause DFD meat in ruminants and pigs Chronic heat stress reduces feed intake and changes the chemical composition of breast meat in chickens (increased fat, especially intramuscular-fat, deposition, lower protein content) (Gonzalez-Rivas *et al.*, 2020) Chronic stress factors jeopardize the capacity of animals to deal with acute stress during preslaughter handling and transport Egg weight decreases when ambient temperature increases above 25 °C (associated with a decline in albumen weight and in yolk weight)
Fasting/food deprivation	Fasting and food deprivation increase the risk of DFD meat in pigs (Gonzalez-Rivas *et al.*, 2020) Higher incidence of DFD meat reported during summer in ruminants – related to limited pasture quality and reduced feed intake under high temperature (Gonzalez-Rivas *et al.*, 2020; Kadim *et al.*, 2004) Sheep breeds in temperate climate more likely to withstand reduced feed (and hence nutrient) intake than sheep in tropical arid and semi-arid areas with water scarcity. Impact of water scarcity on meat quality, especially fatty-acid profile, needs further research (Chikwanha *et al.*, 2021)
Rearing and preslaughter conditions – mixing animals	Mixing pigs with unfamiliar individuals during the preslaughter period affects their behaviour, and rearing conditions influence their behavioural reactivity to mixing: mixing outdoor-reared pigs with other animals before slaughter resulted in less fighting and thus less stress in the slaughterhouse, fewer injuries and a lower risk of DFD and PSE meat (higher glycolytic potential) than observed in indoor-reared pigs subject to the same mixing procedure (Terlouw *et al.*, 2015; Terlouw *et al.*)
Density	High stocking density can lead to behavioural stress (e.g. pecking in poultry or cannibalism in pigs), affecting their productivity but also the quality of their meat High stocking density increases occurrence of Salmonella in laying hens (Koutsoumanis *et al.*, 2019) Higher stocking density is considered to be a stress factor in laying hens (Kang *et al.*, 2018) No impact of stocking density on the nutrient content of eggs has been reported Higher stocking density leads to lower feed intake, a lower egg production rate and higher mortality (Geng *et al.*, 2020)
Transport	Poor roads are associated with higher incidence of DFD in lamb and cattle meat when animals have been transported for several hours (Terlouw *et al.*, 2015, 2021) Transportation in high ambient temperature can generate major physiological and muscle metabolic stress in goats (Kadim *et al.*, 2010)
Restraining method	Use of electric prods is documented as being associated with higher incidence of PSE and blood-splashed meat in pigs (Faucitano, 2018) and lower meat tenderness in cattle (Warner *et al.*, 2007)
Individual reaction	Individual reaction to stress varies with species, experience and genetics, even if animals are slaughtered under the same conditions The complexity of the biological response and individual adaptation is not sufficiently well understood to allow prediction of meat quality, and additional factors, such as preslaughter stress conditions, need to be taken into account in predicting models (Terlouw *et al.*, 2021)

Note: DFD = dark firm dry. PSE = pale soft exudative.

TASF to be identified (see Section D). Feed and water are potentially significant sources of contamination in the production system, and interventions to reduce the risk associated with them are critical (FAO and IFIF, 2020). *The OIE/FAO guide to good farming practices for animal production food safety* (FAO and OIE, 2010) recommends a set of practices that can be implemented to reduce the risk of TASF contamination and food-borne diseases. Guidelines are also available to help small-scale producers minimize food-safety risks (FAO, 2021a).

The case of *Salmonella* spp. can serve to illustrate how livestock production affects the safety of TASF and human health. Non-typhoidal *Salmonella* is one of the top food-borne pathogens globally (see Section D). Guidelines on how to control this pathogen have been published (FAO and WHO, 2016), but risk factors and levels of occurrence in livestock production systems in LMICs are not sufficiently documented. In as far as risk factors have been identified (largely in high-income countries), they include inadequate farm management, biosecurity (including pest and rodent management), staff hygiene and carcass handling along production chains (Wilke, Windhorst and Grabkowsky, 2011). For instance, the risk factors for Salmonella contamination along the smallholder pig value chain in northern Viet Nam include situating the pig pen next to human housing, allowing visitors unrestricted access to the farm, locating the slaughter area next to the lairage without biosecurity measures, and failing to take adequate measures to prevent cross-contamination at the slaughterhouse (Dang-Xuan *et al.*, 2019). High stocking density, large farm size and stress increase the occurrence, persistence and spread of *Salmonella* in flocks of laying hens (Koutsoumanis *et al.*, 2019).

Environmental contamination of TASF with heavy metals is closely linked to the feeding system and the feed resources used. Industrial effluents and agrochemicals can affect feed and feed ingredients and the water sources used for livestock production. Further data are needed to assess the level of heavy-metal contamination and toxicological safety in TASFs, for example in the Islamic Republic of Iran (Sarlak *et al.*, 2021), and Nigeria where there is a lack of official monitoring (Njoga *et al.*, 2021). The level of soil contamination can have an impact on TASF. For example, a study that compared egg production systems found that eggs produced by free-range hens had higher concentrations of heavy metals than those from cage-raised hens (Radu-Rusu *et al.*, 2013).

The misuse of veterinary products and the contamination of TASFs with the residues of these products can also give rise to public health risks. The misuse and overuse of antimicrobials, especially antibiotics, and the resulting increase in antimicrobial resistance is a growing concern. Antimicrobials are used in animal production for therapeutic, metaphylactic and prophylactic purposes, and as growth promotors (see Section D). They can be administered through feed and water as a practical method of delivering drugs to a large numbers of animals on a daily basis (FAO and WHO, 2019a).

Use of antimicrobials is affected by legal frameworks. For instance, the European Union has banned the use of antimicrobials as growth promotors since 2006 and forbids routine use of antimicrobials and their use to compensate for poor hygiene, animal husbandry, animal care or farm management; their use for prophylaxis is also forbidden other than in exceptional cases, such as administration to an individual animal or a restricted number of animals when the risk of infection is very high and the consequences are likely to be severe (European Parliament and Council, 2019). Sri Lanka and the Maldives have prohibited the use of all antibiotics as growth promoters and in medicated feed (Goutard *et al.*, 2017). Several other countries are increasingly implementing strategies to reduce antimicrobial use, reporting veterinary antimicrobial sales or introducing specific regulations to address the issue (Tiseo *et al.*, 2020). Importing countries are becoming more likely to require maximum residue limits. Some international standards on veterinary products used in medicated feed are set out in Codex Alimentarius guidelines on the design and implementation of national regulatory food-safety assurance programmes associated with the use of veterinary products in food-producing animals (FAO and WHO, 2014).

Worldwide, antimicrobial use has increased with the expansion of high external input livestock production, and this has put bacteria under high selection pressure (Van Boeckel *et al.*, 2014). The increase in antimicrobial use over the period between 2017 and 2030 is predicted to be greater in pig production than in chicken or cattle production, with pig production expected to account for 45 percent of the total projected increase over this period (Tiseo *et al.*, 2020). Inappropriate use of antimicrobials as growth promotors or to prevent diseases in healthy animals, as well as over-prescription and overuse in animal production, has accelerated the upward trend (WHO, 2017), and this has increased human health risks associated with the development of antibiotic-resistant bacterial strains. However, significant reduction in the use of antimicrobials has been achieved in certain regions of the world over the last ten years (OIE, 2021).

Transfer of resistance genes to pathogenic bacteria or commensal bacteria can occur and may lead to these genes being harboured in the human microbiome for an extended period of time. Food-borne diseases caused by resistant bacterial pathogens may be difficult to treat because antimicrobial treatment options are absent or limited. Antimicrobial resistant micro-organisms can be spread to humans via direct exposure to infected or contaminated animals or via feed, food, animal waste, animal bedding or the environment.

5.3

Drivers of production practices that influence the nutritional quality of terrestrial animal source food

Over recent decades, breeding and husbandry practices have been driven by commercial objectives that have generally not specifically considered the nutritional value of TASFs. Priority is essentially given to the commercial-quality attributes that constitute the primary basis upon which producers are paid, especially in the case of standard commodity TASFs (Prache *et al.*, 2020a). Technological requirements related to the need to meet processing protocols (e.g. for cheese production) and to standardize production to reduce costs may influence genetic selection programmes and influence the characteristics of livestock production systems. Synergies and antagonisms between the various aspects of quality (nutritional, technological, organoleptic and commercial) and food safety may favour or compromise nutritional quality.

5.3.1 Drivers of genetic selection

In a recent review, Prache *et al.* (2021) underlined the priority historically given to commercial qualities in genetic selection (milk and carcass yield and egg production rate). Genetic selection, gene editing and genomic biomarkers usually target productivity, health and longevity, quality attributes, heat tolerance, removal of technological quality defects and elimination of allergens (Van Eenennaam, 2019) (Prache *et al.*, 2021). Markets have generally emphasized payment for quantity of product rather than nutritional composition, and so the latter has historically not been considered in genetic selection programmes. When a trait is not considered in selection programmes, the expectation is that it will remain constant over time unless it is genetically correlated with traits targeted for selection. However, if such a trait has an unfavourable genetic relationship with the traits for which selection is implemented, it will decline over time. In broiler chickens, genetic selection for high growth rate and breast-meat yield has been associated with lower meat quality and the emergence of constraints to processing. For example, “white striping” and “wooden breast” – defects associated with a lower protein content in the muscles and higher collagen content in broiler meat – have become more prevalent in populations selected for increased growth rate. In various livestock species, commercial drivers that have led to genetic selection in favour of higher lean-meat yield and lower fat deposition have led to lower meat tenderness.

The halothane gene in pigs is associated with porcine stress syndrome (PSS), i.e. sudden death of pigs placed under stressful conditions before slaughter, including those associated with transport. Animals affected by a mutation of this gene also tend more frequently to develop PSE meat (a major technological defect described above). The variance of the halothane gene with respect to PSS incidence is also favourably associated genetically with growth rate and production of lean meat. Genetic selection programmes for different breeds and populations have therefore targeted removal or retention of the allele depending on the their objectives, which have included the commercial value (carcass lean-meat content) and the technological quality of the meat, and on the genetic background of the population undergoing selection. Data from South African slaughterhouses showed that 96 percent of the pigs slaughtered did not carry the mutation (Soma, Marle-Köster and Frylinck, 2014). This indicated that the halothane gene was having little effect on the occurrence of PSE meat in the country. Efforts to curtail PSE occurrence therefore focused on other husbandry practices, such as those that decrease stress (Soma, Marle-Köster and Frylinck, 2014).

Quality attributes are strong drivers of some research and genetic-selection programmes. For example, proteomic studies have been conducted to identify proteins associated with the occurrence of DFD meat following preslaughter stress in ruminants (Chikwanha *et al.*, 2021). Recent interest in the nutritional value of TASFs has led to the inclusion of heritable traits affecting nutrient composition in genetic selection programmes. Beta-casein milk protein has two variants: A1 and A2. The A2 variant has been associated with higher milk digestibility than the A1 variant, but current outcomes related to cardiovascular diseases and diabetes are inconclusive (Kuellenberg de Gaudry *et al.*, 2021). This has led to a genetic selection programme in Australia, New Zealand and the United Stated of America that aims to breed animals whose milk contains a higher proportion of variant A2. To reduce allergic reaction triggered by the beta-lactoglobulin protein in milk, gene-editing has been used to prevent the expression of the protein (knockout) and produce hypoallergenic milk (Sun *et al.*, 2019). Debate is still ongoing as to whether this novel technique for producing transgenic animals falls under GMO regulations and is therefore subject to premarket safety assessment (see Box B8).

Box B8. Effects of genetically modified animals on human nutrition and health

Based on the Cartagena Protocol on Biosafety, WHO has defined genetically modified organisms (GMOs) as organisms in which the genetic material has been altered in a way that does not occur naturally, in order to induce or remove a trait.

Regulatory framework and risk assessment policy

The Codex Alimentarius Commission provides internationally harmonized guidance on risk analysis of the safety and nutritional aspects of foods derived from modern biotechnology (FAO and WHO, 2011). A premarket safety assessment should be undertaken on a case-by-case basis and include a comparison between the food derived from modern biotechnology and its conventional counterpart, including extensive comparative studies covering chemical composition, nutritional quality, toxicity and the allergenicity of proteins. Safety assessment should include data and information that can be used to reduce the possibility that the food in question will have unexpected, adverse effects on human health. Careful monitoring of the post-release effects of such products and processes is also essential if continued safety for humans, animals and the environment is to be ensured.

Responsibility for formulating policies and making decisions on genetically modified (GM) food lies with national competent authorities. When requested, FAO provides, advice and technical assistance to strengthen Members' capacities in the field of agricultural biotechnology at national and regional levels. The GM products that are currently on the international market have all passed safety assessments conducted by national authorities. The Organisation for Economic Co-operation and Development (OECD) has established safety assessment processes based on the principle of "substantial equivalence" to ensure that foods derived from GM crops are as safe and nutritious as those from plants obtained through conventional breeding.

Genetically modified animals for human consumption

In 2015, the AquAdvantage® salmon was cleared by the United States Food and Drug Administration and became the world's first GM animal authorized for human consumption. The fish grows to market-size in 18 months instead of the usual 36 months. In June 2021, the company announced the first commercial-scale harvest at its farm in Indiana. The AquAdvantage® salmon was approved for sale by Health Canada in 2015, and the company has announced that its application to Brazil's National Biosafety Technical Commission to sell it in Brazil has been approved.

Labelling requirements for GMOs differ from one country to another. There is no mandatory labelling requirement specific to GMOs in Canada. GMO labelling regulatory requirements came into force in the United States of America in January 2021 but do not apply to restaurants or other parts of the catering industry.

In 2020, the Galsafe® pig became the first terrestrial GM animal authorized for human consumption. The pig lacks the alpha-gal sugar protein, which can trigger allergic reactions in people with alpha-gal syndrome, an allergy to red meat. GalSafe® animals can also be used to produce medicines such as heparin and to solve the problem of rejection of organ transplants. The Food and Drug Administration concluded that the safety of food products originating from GalSafe® pigs is no different from that of food products originating from non-GM pigs. These conclusions were based on toxicological and microbial food-safety evaluations. No nutritional content variation was reported. No testing was conducted on people suffering from alpha-gal syndrome. Potential for the development of antimicrobial resistant bacteria was considered, and ongoing surveillance to monitor for the development of resistance to aminoglycoside is required, in line with Codex Alimentarius Commission guidance (FAO and WHO, 2008).

Research interest in GM animals is supported by the private sector and focuses particularly on disease-resistant animals, faster-growing animals and animals that have therapeutic uses.

Debate is ongoing as to whether organisms obtained by using precise gene-editing biotechnologies should be considered GMOs and thus be covered by GMO regulations and subject to premarket safety assessment if they are going to be released for human consumption. The European Union and New Zealand argue that products originating from genome-edited organisms should be subject to the same regulations as GMOs (Callaway, 2018; Fritsche *et al.*, 2018), whereas Canada and the United States of America are taking a different approach (Canada, 2020; FDA, 2020). Canada considers that food products should be regulated on the basis of their final characteristics rather than the method used to develop them.

Boar taint, which gives meat from male pigs an unpleasant odour and taste, is genetically controlled. Therefore selective breeding to reduce boar taint through genetic markers is ongoing in several countries. This approach is considered to be a more animal-welfare friendly alternative to castration.

5.3.2 Drivers of livestock practices

The standardization of milk (fat content) and meat production (through weight and age of slaughtering) helps to standardize the nutrient content of TASFs that are traded and marketed (Huerta-Leidenz, 2021). This standardization is key to lowering production costs, improving compliance with slaughterhouse equipment (e.g. size and pace of slaughter lines) and processing-industry requirements (e.g. thermal treatment and preservation), and ultimately lowering consumer prices.

The commercial attributes of meat are mainly defined by the carcass grade classification, which determines the payment to the producer. The South African classification targets lean carcasses, and this has increased the emphasis given to this goal in beef breeding and management systems (Hall and

Schönfeldt, 2015). A downward trend in the fat and saturated fatty-acid content of beef has also been documented in the United States of America, where it is in line with national dietary guidance that has been in place since the 1980s (McNeill *et al.*, 2012), and in the European Union. A similar trend has been observed pigs and sheep (Prache *et al.*, 2020b).

Meeting commercial requirements for heavier and leaner carcasses has triggered technological and organoleptic side-effects in poultry and pig production. The reduction in fat content and intramuscular fat brought about by genetic selection and optimization of feeding (e.g. in Pietrain pigs), reduces the flavour and juiciness of cooked meats as well as the suitability of meat for processing (De Smet, 2012). A higher level of PUFA in TASFs can lead to higher levels of lipid and protein oxidation and hence reduce the organoleptic and technological quality (see Subsection 5.2.1). Giving pigs feed that contains high levels of PUFA can lead to off-flavours linked to oxidation. It can also constrain technological processes. For example, firm fat makes meat easier to cure, but higher PUFA content makes meat softer at a given temperature. However, adding antioxidants to a PUFA-rich diet can enhance the technological quality of meat while maintaining the human-health benefits of high PUFA levels.

Chicken meat has been considered a lean alternative to red meat and a nutritional source of omega 3 DHA. Wang (2010) reports that genetic selection and production practices targeting greater weight gain and higher productivity increased the fat content and decreased the omega-3 DHA content of broiler meat in the United Kingdom between 1870 and 2004. Confinement of animals indoors with ad libitum access to high-energy feed and the use of growth promoters are reported to have been contributing factors. In the early twenty-first century, the carcass of a chicken from an international strain contained up to three times more fat energy than protein energy (as compared to less fat energy than protein energy before 1950) (Wang, 2010). In France, genetic selection has led to a 12 percent increase in the leanness of pig carcasses since the 1970s (Bidanel *et al.*, 2020).

Nutritional quality and other characteristics related to perceived sustainability are increasingly demanded by consumers. This demand for quality and safety is associated with rising incomes and needs to be considered as a driver of shifts in livestock production in all countries (Jabbar, Baker and Fadiga, 2010). For instance, the "Bleu-Blanc-Coeur" supply chain, which targets a niche market for cattle milk and meat containing a specific quantity of omega-3 PUFAs and requires that animal diets include a certain quantity of these PUFAs has been extended from France, where it was developed, to several other countries, including Brazil, Malaysia, Saudi Arabia, Taiwan, Province of China, and Tunisia.

Quality can be marketed through certification (Huerta-Leidenz, 2021). Certification and branding often target organoleptic and/or nutritional quality linked to genetic make-up, animal management and geographical origin: for example, the Certified Angus Beef brand in the United States of America, the "poulet bicyclette" in Burkina Faso, the Cabrito de Tete goat in Mozambique, and Ternera de Navarra cattle and acorn-fed Iberico pig in Spain. In these cases, consumers' growing interest in, and demand for, food from particular production areas and types of production system are translated into market value, which in turn influences production practices.

International trade opportunities can also lead the livestock sector include factors such as specific weight, age of slaughter and specific genetics in export specifications in the value chain. Production systems are guided by the need to meet commercial standards and regulations. The commercial standards of importers may differ from the standards of the country of production. Marbling score in beef and pork is linked to meat palatability, an important factor in consumer preference, and is a key quality indicator for export. Required levels of marbling vary across the world (De Smet, 2012; Rubio Lozano *et al.*, 2021; Delgado *et al.*, 2005). Marbling score is associated with intramuscular fat deposition, which gives the meat its flavour and palatability. Subcutaneous fat, in contrast, has less commercial value. Marbling can be improved by adopting on-farm nutritional strategies such as supplementation with conjugated linoleic acid in the fattening stage of pig and cattle production to increase the deposition of intramuscular fat and decrease the deposition of subcutaneous fat (Li *et al.*, 2020).

Rules for export are also based on compliance with international (Codex Alimentarius and WOAH) regulations related to public health. The European Union has import requirements regarding the water–protein ratio in meat cuts. These requirements tackle fraud associated with adding external water to the carcass to artificially increases its weight (Dias *et al.*, 2020). The ratio varies from one country to another in line with national regulations. The maximum residue limits of veterinary products also vary between countries, implying different levels of tolerance and monitoring of management practices on farms that produce for export.

6. Limitations, gaps and needs in the evidence-base

The assessment of nutrient composition and value of TASFs reveals several limitations in the evidence-base. Generally, public-health nutrition has had a narrow focus on single nutrients rather than a more holistic focus on the food matrix and dietary patterns underlying TASF digestibility. As in other sections of this document, evidence from LMICs on nutrient composition of local TASFs is limited. Despite its potential implications for human health, the literature on food from hunting and wildlife farming and on insects, grubs and their products is limited. Gaps and needs in the evidence base include the following:

- Interactions of TASF nutrients and bioactive compounds in the food matrix and dietary patterns:
  Further characterization of the role of TASFs in human nutrition and health requires deeper understanding of the complex interplay of nutrients and foods within dietary patterns. More research is needed on underexplored nutrients (e.g. vitamin K2) and bioactive compounds (e.g. carnitine, anserine) found in TASF.
- Nutrient density and bioavailability metrics and modelling:
  Optimally describing TASFs in relation to environmental impacts and issues of cost and access requires improved metrics for nutrient density and bioavailability. Modelling would then be able to provide robuster evidence on the roles of TASFs.
- Food composition databases:
  There is a need to develop more comprehensive and representative food composition databases that capture information on TASFs from local breeds and species and on dietary patterns in LMICs.
- Insects including grubs and their products:
  Research is needed on the nutrient bioavailability and composition of insects and insect products.
- Influence of nutrient content and quality on animal characteristics and husbandry:
  Robust studies on variation in the quality of TASFs are limited in developing countries, where research and investment efforts are more targeted towards increasing productivity. Reviews and publications tend to cover internationally traded breeds. Further research is required on the impact of the diversity of local breeds, husbandry practices, grazing practices and traditional husbandry systems on TASF quality, including for the following species: dromedary and Bactrian camel, cattle, yak and llama. There is a lack of meta-analysis covering different production systems and husbandry practices. Factors such a genetics, animal nutrition, season, housing conditions and other aspects of the production system need to be studied to identify their individual and combined effects on TASF quality. Nutritional quality indicators should be systematically considered and measured along with organoleptic and technological quality indicators. Literature on the impact of livestock management on the nutritional value of TASFs focuses on nutrient composition. Little is known about variation in the bioavailability of nutrients. Further research is needed to assess links between on-farm interventions, such as the choice of animal diets, and the nutritional quality of TASFs and resulting impacts on human health.

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Section **C**

Effects of terrestrial animal source food on health and nutrition over the life course

Key findings

- Dietary intakes of terrestrial animal source foods (TASFs) can affect nutrition (improved nutrient status, increased anthropometric measurements), health (reduced levels of infectious disease, increased levels of non-communicable diseases, improved immune-system function broadly, improved bone health) and cognition (improved development, improved neuroprotection and neurological-disease prevention).
- Across all life-course phases,[5] there is a stronger evidence base for the relation between milk and dairy products and human health than there is for other TASFs. Beef and eggs follow in terms of the availability of evidence. Pig and poultry meat, meat from wild animals, insects and meat from other minor species have been less studied. Overall, the evidence suggests that TASF intakes at appropriate levels have beneficial effects on several health outcomes.
- Milk and dairy consumption during pregnancy promotes healthy weight of infants at birth and may also benefit birth length and foetal head circumference. The findings of studies on egg, milk and meat consumption in infants and young children have varied depending on overall diet and environmental exposures. Evidence shows that consumption of milk and dairy products by school-age children and adolescents increases height and reduces overweight and obesity. Beef consumption in school-age children may improve cognitive outcomes.
- In adults, there is evidence showing that milk and yoghurt consumption reduces risk of all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. Evidence also shows that egg consumption in adults does not increase risk of stroke or coronary heart disease. High-quality evidence shows that meat intake (85–300 g/day) is positively associated with iron status in adults. Poultry meat has been studied to a limited extent relative to beef, but findings suggest non significant effects on stroke risk, with subgroup analyses suggesting a protective effect in women.
- Unprocessed and processed red meat has been evaluated extensively for non-communicable disease outcomes in adults, largely through prospective cohort studies with risk of bias based on quality assessment of the evidence (e.g. GRADE). The Global Burden of Disease Study has set risk thresholds at 23 g (18–27 g) per day of red meat and 2 g (0–4 g) per day of processed meats. Evidence has shown unequivocally that the consumption of processed red meat increases risk of mortality and chronic disease outcomes (cardiovascular disease and colorectal cancer). Evidence on consumption of unprocessed red meat in modest amounts shows that it presents minimal risk with regards to non-communicable disease outcomes (largely based on studies carried out in high-income countries).
- Epidemiological evidence for the health effects of TASF in older adults comes primarily from high-income countries. A fairly robust evidence base shows that consumption of lean red meat has positive effects on muscle health. Other evidence suggests that milk and dairy products and other TASFs potentially have mitigating impacts on sarcopenia (muscle loss), fractures, frailty, Alzheimer's disease and dementia more broadly.
- Evaluating evidence in any of the life-course phases may be difficult because of heterogeneity in study design with respect to comparator groups (counterfactuals including substitution or replacement foods), dosing and exposure (quantity of TASF intake), and context (high-income countries versus low- and middle-income countries). A preponderance of evidence, for adults particularly, has come from observational studies with moderate-to-serious risk of biases.
- Cow's milk and poultry eggs are among the eight foods that pose allergenic risks to populations, and it is therefore mandatory in many countries to state their presence in foods as part of precautionary allergen labelling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread but does not automatically lead to lactose intolerance, which also greatly varies in severity.
- Findings from the policy review conducted for this study relate to the consumption of TASF in general. Next most common are those related to meat (in general), milk and dairy products, eggs and red meat (especially beef). There is significantly less coverage of offal, poultry and rabbit (as part of white meat), meat from wild animals, and insects.
- Most recommendations on TASF consumption found by the policy review are linked to human micronutrient needs and non-communicable diseases – and target the entire population. Micronutrient-related recommendations tend to be more detailed than those related to non-communicable diseases, providing quantitative indications in terms of daily or weekly intake of TASFs. There are no specific recommendations on TASF consumption to address the risks associated with multiple forms of malnutrition (e.g. coexistence of micronutrient deficiency with overweight, obesity and NCDs). In total, 378 of the recommendations on TASF consumption follow a life-course approach – with

[5] Life-course phases: women during pregnancy and lactation; infants and young children; school-age children and adolescents; adults and older adults.

specific guidance targeting individual life phases, 325 of which are in food-based dietary guidelines (FBDGs) and thus in the most relevant type of policy document. Although the review identified a similar number of qualitative and quantitative recommendations, those in the FBDGs of high- income countries were found to be most detailed.

- Environmental sustainability considerations for TASF consumption were found to be included only in documents from eight upper middle income or high- income countries, with most of them providing qualitative recommendations. Mentions of animal welfare were found only in the FBDGs of Denmark and Sweden, which include specific reference to animal welfare labels providing information to consumers.

Summary

This section presents a review of epidemiological evidence for the effects of TASF intakes on nutrition and health outcomes. Human biology and nutrient requirements vary across the phases of the life course, giving rise to differential needs and affecting the impacts of TASF consumption patterns. The review shows that there is also variation in the quality and quantity of scholarly work on different TASFs within each life-course phase. In sum, the evidence suggests that TASF intakes at appropriate levels have beneficial effects on several health outcomes and lead to non-significant increases in chronic diseases among apparently healthy individuals.

This section commences with an analysis of evidence on the effects of TASF intake during pregnancy and lactation, examining nutrition and health outcomes for the mother, foetus and exclusively breastfed child. Despite being identified as a critical period in the first 1 000 days of life, pregnancy and lactation have been understudied across the full range of TASFs. Literature provides consistent findings that consuming milk and dairy products results in healthier weight at birth and – to a lesser extent – increased birth length. There is some indication that milk consumption during the first trimester of pregnancy confers the greatest nutritional advantages, notably with regard to anthropometric outcomes in the offspring. Some evidence suggests that milk and dairy intakes have a possible effect on foetal head circumference.

Infancy and early childhood have been studied more than other phases of the life course, in part because of the established body of literature indicating that nutrient needs are high this period and that malnutrition during this period has life-long consequences. The findings of studies on egg, milk and meat consumption in infants and young children have varied depending on overall diet and environmental exposures. Generally, results show positive or null effects on anthropometry and child development. School-age children and adolescents grow more slowly but still require TASF to support neurological development, bone health and reproductive health. Evidence again focuses on milk and dairy products and shows that daily consumption increases height and protects against adiposity and overweight and obesity. There is evidence that suggests that beef consumption has positive effects on cognitive outcomes in school-age children.

Among adults, findings suggest that milk and dairy products, do not increase risks of all-cause mortality and some chronic diseases. The published literature indicates that egg consumption is not associated with increased risk of stroke or coronary heart disease. The quality of evidence regarding the effects of unprocessed and processed red meat intakes on negative human health outcomes remains low, with high degrees of heterogeneity and risk of bias. Based on the available evidence, risk analyses indicate that consuming modest amounts of unprocessed red meat (ranging from 9 g to 71 g per day) holds minimal risk with respect to NCDs. However, processed meat consumption does confer an elevated risk of mortality and NCDs, including cardiovascular disease and colorectal cancer. Red-meat intake has been found to be positively associated with iron status in adults. Poultry and other white meats have been studied to a lesser extent for both positive and negative health outcomes.

In older adults, epidemiological evidence for the health effects of TASF comes primarily from high-income countries and may be limited by the co-existence of medical conditions in this segment of the population (impacts of TASF on people affected by medical conditions are beyond the scope of this assessment). There is evidence indicating that consumption of lean red meat has positive effects on muscle health, but the evidence for red meat in general is equivocal. Other evidence suggests milk and dairy products can mitigate negative health outcomes including sarcopenia (muscle loss), fractures, frailty, Alzheimer's disease and dementia more broadly. Poultry and eggs have been studied to a lesser extent.

A total of 123 food-based dietary guidelines (FBDGs), from 95 countries, were reviewed. Out of the 850 recommendations on TASF consumption provided in these guidelines, 695 recommendations were linked to micronutrient intake, followed by 145 recommendations for the prevention of diet-related non-communicable diseases. Environmental sustainability was mentioned nine times and included only in FBDGs published from 2015 onwards. Most of these recommendations target the general public, although many recommendations are provided for specific phases of the life course. In addition, a total of 79 non-communicable disease-related documents, from 51 countries, were reviewed. They provided 167 recommendations on TASF consumption, 154 of which were linked to the prevention of diet-related non-communicable diseases, with only ten recommendations related to micronutrient intake and three linked to environmental sustainability. The great majority of the recommendations from the non-communicable disease-related documents target the general public, with only a few targeting specific groups across the life course. A further 35 documents, including food and agriculture legislation and nutrition policies and programmes, were reviewed and were found to include a total of 52 recommendations related to TASF consumption. These recommendations are mostly of a qualitative nature and targeted the generic public with reference to micronutrient intake.

Most recommendations on TASF consumption are for TASFs in general, followed by recommendations on meat, milk and dairy products, eggs and red meat (especially beef). There is significantly less coverage of offal, poultry, rabbit, meat from wild animals, and insects. Most recommendations are linked to human micronutrient needs and non-communicable diseases and target the entire population. Micronutrient-related recommendations tend to be more detailed than non-communicable disease-related recommendations, providing quantitative indications in terms of daily or weekly intakes of TASFs. Most recommendations do not consider the implications of consumption above or below any specific level of TASF, an important gap given the co-existence of micronutrient deficiencies with undernutrition, overweight, obesity and non-communicable diseases.

In total, the review identified 378 recommendations that follow a life-course approach, 325 of which were found in the FBDGs. While the recommendations in the FBDGs of high income countries were found to be more detailed, overall there was a similar number of qualitative and quantitative recommendations.

Environmental sustainability considerations were found only to be included in documents from eight upper middle and high- income countries and mostly related to qualitative recommendations. Animal welfare was found to be mentioned only in the FBDGs of Denmark and Sweden, which included specific references to animal welfare labels to inform consumers.

1. Introduction

This section provides an overview of evidence on the effects of TASF intake throughout the life course. Various physiological processes and environmental exposures drive human nutrient demands throughout life. Social determinants may influence these pathways and ultimately affect the health of an individual (this will be covered in Component Document 2). Section B summarizes evidence on the nutrient and bioactive-compound compositions of TASFs and their implications for human health, drawing from literature spanning from food chemistry to public-health nutrition.

The section primarily highlights epidemiological evidence on the nutrition and health impacts of TASF intake by life-course phase. TASF-related allergies and policy recommendations on TASF consumption are also discussed. This approach takes into account factors across multiple levels, from the cells of the human body to society, and enables further insights into how TASFs affect human nutrition and health (Mahmudiono, Segalita and Rosenkranz, 2019).

2. Concepts, definitions and methods

One of the original frameworks for nutrition across the life course was published by ACC/SCN (2000) (see adapted as Figure C1). Despite multiple different iterations and adaptations, the framework has largely endured in its original form. Figure C1 visually represents manifestations of malnutrition in each life-course phase, as defined in Box C1. This part of the assessment follows a similar framework, with some minor changes, but narrows the scope to examining the consequences of TASF consumption.

Many causes of all forms of malnutrition share common determinants, including genetics, inadequate infant and young-child feeding, frequent infections during early childhood, unhealthy diets, food insecurity, poor health status, inadequate health or care behaviours, and low physical activity. The double burden of malnutrition in an individual refers to the co-existence of undernutrition (e.g. micronutrient deficiency or stunting) with overweight, obesity and/or NCDs.

The most common combination is micronutrient deficiency with overweight and obesity, which has implications for NCDs. Figure C1 provides an overview of the health implications of both undernutrition and overweight or obesity for each life-course phase, and resulting implications for child development, NCDs, and educational, mental and physical capacity.

Section C partitions the life course into five phases based on nutritional requirements and largely aligned with the published literature. For infants and young child, the review considers TASF consumption during complementary feeding for both breastfed and non-breastfed children (6-23 months). For school-age children and adolescents, in some cases youth older than 18 years of age may be included if they were part of the sample in a study that was evaluated.

Methods for this part of the assessment followed PRISMA guidelines for conducting systematic reviews (Page *et al.*, 2021b, 2021a). PRISMA, which stands for Preferred Reporting Items for Systematic Reviews and Meta-Analyses, is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. Findings are presented below in narrative form.

Box C1. Life course phases relevant for human health

The term "life course" is applied here to encapsulate both biological and social determinants of health, as compared to "life cycle", which generally refers to the biological developmental phases of an organism, and "lifespan", which describes the period from conception to death in temporal terms (Brown, 2019; Herman et al., 2014).

The following life-course phases are distinguished:

- women during pregnancy and lactation, including the needs of the developing foetus and the exclusively breastfed child up to 6 months of age;
- infants and young children (below 5 years of age);
- school-age children and adolescents (5 to 18 years of age);
- adults (men and women in adulthood);
- older adults (above 65 years).

Figure C1. Forms and consequences of malnutrition over the life course

	Forms of malnutrition	*Consequences*
PREGNANT/LACTATING WOMEN	• Overweight • Obesity • Post-partum weight retention • Low-weight gain • Nutrient deficiency	• Gestational diabetes • Increased risk of maternal mortality • Epigenetic changes • Inadequate foetal growth and development (intrauterine growth retardation) • Preterm birth
NEWBORNS	• Large for gestational age • Small for gestational age • Low birth weight	• Increased risk for neonatal mortality and morbidity
INFANTS/ YOUNG CHILDREN	• Overweight • Obesity • Stunting • Wasting • Underweight • Nutrient deficiency	• Inadequate catch-up growth • Inadequate brain development and cognitive impairment • Compromised function of the immune system
SCHOOL-AGE CHILDREN	• Overweight • Obesity • Wasting • Underweight • Nutrient deficiency	• Inadequate brain development and cognitive impairment • Compromised function of the immune system
ADOLESCENTS	• Overweight • Obesity • Underweight • Nutrient deficiency	• Cognitive impairment • Development of neurological disorders and non-communicable diseases
ADULTS	• Overweight • Obesity • Underweight • Nutrient deficiency	• Cognitive impairment • Neurological disorders • Cardiovascular diseases, cancer, diabetes
OLDER ADULTS	• Overweight • Obesity • Sarcopenic obesity • Underweight • Nutrient deficiency	• Cognitive impairment • Neurological disorders • Frailty • Cardiovascular diseases, cancer, diabetes

Using the Population Intervention/Exposure Comparator Outcome (PICO/PECO) framework, the inclusion criteria were as follows:

- Population – apparently healthy populations falling into the respective life-course phases defined above; apparently healthy refers to the absence of disease based on clinical signs and symptoms and function, normally assessed by routine laboratory methods and physical evaluation. Some studies reviewed included sample populations across multiple life-course phases; these findings were considered in various subsections, as appropriate.
- Intervention/exposure – consumption of TASFs and/or their products at varying levels (more versus less; some versus none; one TASF type versus another TASF type).
- Comparator – usual diet (often used as control group); TASF intakes at lower levels; TASF intakes at higher levels; PBF or other foods/diets.
- Outcome – nutrition and health outcomes were evaluated, with some variation depending on life-course phase, on the basis of anthropometry and growth, biomarkers of nutrient and/or health status (e.g. haemoglobin concentration, nutrient biomarkers) infectious and chronic disease morbidities and diagnoses, indicators of food hypersensitivities and allergies, all-cause and cause-specific mortality, and cognition and other domains of neurological function and development.

No single question could be formulated using the PICO/PECO because of the multiple populations, TASFs and outcomes examined. Studies conducted in the last five years were prioritized, but studies dating back to 2000 were also included.

Exclusion criteria were the inverse of the inclusion criteria, with the following specifications. With regard to sample populations, studies examining TASF effects in immunocompromised individuals and people requiring therapeutic diets, as well as medical case reports, were excluded. With regard to intervention/exposure, studies focused on aquatic food only were excluded, although in some studies aquatic foods were part of the overall TASF category and described as such. Also excluded were studies examining isolated TASF components, TASFs as ingredients in processed foods, and fortified TASF products. Some systematic reviews included findings on TASF supplements, but this section reports only on those related to TASFs. It should be noted, however, that some of these products are considered in Section E as part of the discussion of emerging topics.

For Section C, the literature search and screening included peer-reviewed articles and grey literature and used a set of pre-defined search terms across multiple databases, including PubMed, Medline, EMBASE, Google Scholar and various institutional websites (see Box C2).

Box C2. Search terms by database used for Section B

Search terms using Academic Search Complete via EBSCOHost

("animal source food" OR "animal sourced food" OR "animal based food" OR "livestock derived foods" OR "animal derived foods" OR "TASF" OR "meat" OR "milk" OR eggs) AND ("child" OR "Infant" OR "adolescent" OR "adult" OR "elderly" OR "school-age child" OR "child under the age of 5" OR "schoolchildren" OR "older adults" OR "breastfeeding" OR "lactation" OR "teenager") AND ("health" OR "nutrition)

Search terms using PubMed

("animal source food" OR animal source food* OR "animal based food" OR "livestock derived foods" OR "TASF" OR "meat" OR "milk" OR "eggs" OR "dairy" OR "insects" OR "honey") AND ("child" OR child* OR "infant" OR infant* OR "adolescent" OR "adult" OR "elderly" OR "school-age child"* OR "child under the age of 5" OR "older adults" OR "breastfeeding" OR "lactation" OR "teenager") AND ("health" OR "nutrition") AND ("meta-analysis" OR "systematic review" OR "experimental trial" OR "observational study")

Search terms using ScienceDirect

("animal source food" OR "animal sourced food" OR "animal based food" OR "livestock derived foods" OR "TASF" OR "meat" OR "milk" OR "eggs" OR "dairy" OR "insects" OR "honey") AND ("child" OR "Infant" OR "adolescent" OR "adult" OR "elderly" OR "school-age child" OR "child under the age of 5" OR "older adults" OR "breastfeeding" OR "lactation" OR "teenager") AND ("health")

Box C3. Research methods in human nutrition

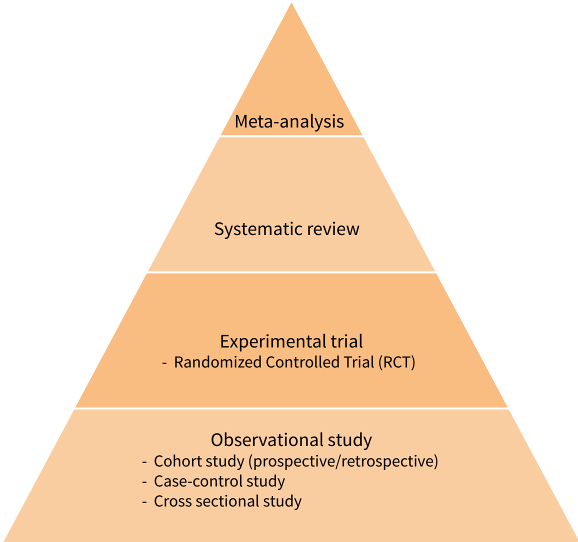
Meta-analysis: a statistical analysis of combined data from a number of independent studies of the same subject, conducted in order to determine overall trends.

Systematic review: analysis of a clearly formulated question that uses systematic and reproducible methods to identify, select and critically appraise all relevant research.

Experimental trial (or intervention trial): study of the effects of an intervention (e.g. risk factor, medical treatment, specific diet) on people who are assigned to different groups. People are randomly assigned to a group in randomized controlled trials. The control group receives no specific intervention or a placebo.

Observational study: study of the effects of an intervention on people who were already exposed to the intervention before the study. A cohort study compares the effect of an intervention on a group of people with shared characteristics (a cohort) who have been exposed to the intervention with the effect on a group of people who have not been exposed. A case-control study compares people with an existing health issue to people without that issue. A cross-sectional study analyses numerous characteristics and variables at once (at a single point in time).

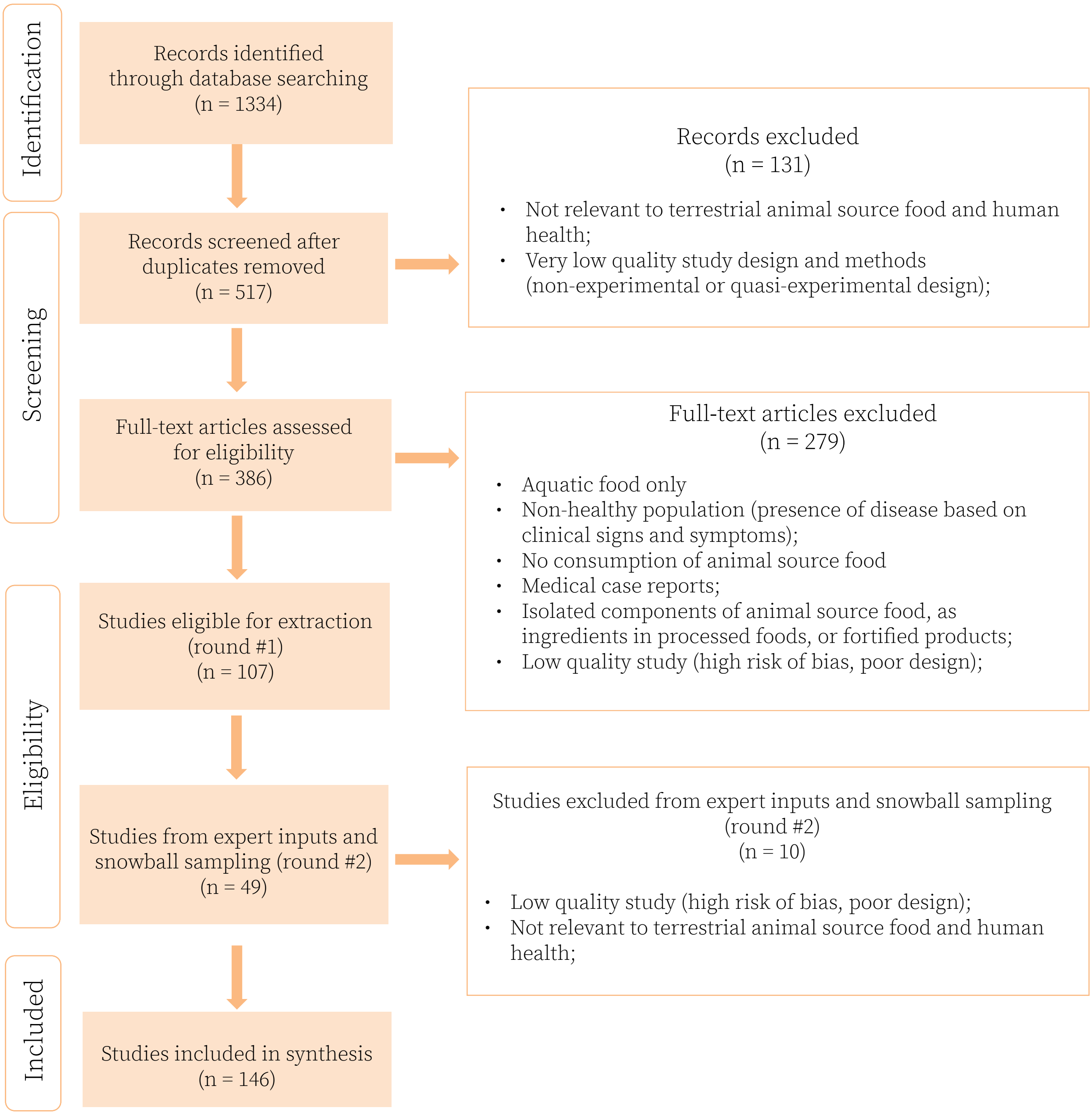
Narrative review: analysis that describes the evidence on a topic but is not systematic and does not follow a specific method.



The articles, documents and reports were categorized by type: systematic reviews; other reviews; intervention trials; observational studies; and grey literature (see Box C3). Studies were assessed for eligibility, relevance and strength of evidence, drawing on the GRADE domains of risk of bias, imprecision, indirectness and publication bias for decision-making on inclusion. In a subsequent phase, snowball sampling was used based on suggestions received from the assessment's scientific advisory committee and other collaborators, again applying the same inclusion criteria as described above.

The flow diagram presented in Figure C2 shows the results of this process. In total, 1 334 records were initially identified. Round 1 yielded 107 studies for extraction of evidence after excluding duplicates and ineligible studies. An additional 49 studies were identified from the round 2 snowball sampling, and eligibility screening ultimately yielding a total of 146 studies.

Figure C2. **PRISMA Flow diagram assessing effects of terrestrial animal source food on health and nutrition over the life course**



Note: Flow diagram following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. For further information see Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med, 6(6): e1000097. doi:10.1371/journal.pmed1000097 and www.prisma-statement.org.

3. Life-course phases

Results of the assessment of TASF effects on nutrition and health outcomes through the life course are described below and summarized in Table C1 and Annex Table C6, giving the following information: TASF; specific findings; sample size; country of study; study design (including number of embedded studies if a systematic review); and reference. For each phase of the life course, sections briefly highlight key requirements and biological processes ongoing in the respective life-course phase and the potential role of TASF, followed by an overview of the epidemiological evidence for impacts on nutrition and health. Each section presents the most robust, high-quality evidence first, including systematic reviews and meta-analyses and experimental trials, followed by well-designed observational studies. Within these categories, to the extent possible given the availability of evidence, the outcomes are presented in the same sequence: nutrition (nutrient status, anthropometry); health (infectious disease, NCDs, bone health); and cognition (development, neuroprotection, neurological-disease prevention). Indicators commonly used to assess the nutritional status of children are defined in Box C4.

Annex Tables C1 to C5 present the contribution of selected animal and plant food items to the recommended nutrient intake for vitamin A, vitamin B12, iron, zinc and calcium during specific life-course phases.

Box C4. Indicators related to the development of children – before, at and after birth

Indicators for the nutritional status of foetuses and infants before and at birth

- Intrauterine growth retardation: impaired growth and development of the foetus and/or its organs during gestation.
- Small-for-gestational age: newborn with a weight below the tenth percentile for the gestational age in comparison with average infant population of the same sex and gestational age.
- Large-for-gestational age: newborn with a weight above the ninetieth percentile for the gestational age in comparison with average infant population of the same sex and gestational age.
- Prematurity/preterm birth: neonates born alive before 37 weeks of pregnancy.
- Low birthweight: weight at birth of below 2 500 g.

Indicators for the nutritional status of children

- Height-for-age z-score: the height of a child in relation to the standardized average height of children of the same age and sex. When a child has low height for its age (< -2 standard deviations of the WHO Child Growth Standards), it is stunted.
- Weight-for-age z-score: the weight of a child in relation to the average weight of children of the same age and sex. When a child has low weight for its age (< -2 standard deviations from the median of the WHO Child Growth Standards), it is underweight.
- Weight-for-length/height z-score: the weight of a child in relation to the standardized average length/height of children of the same age and sex. When a child has low weight for its length/height (< -2 standard deviations of the WHO Child Growth Standards), it is wasted. Child overweight is weight-for-height greater than 2 standard deviations above WHO Child Growth Standards; obesity is weight-for-height greater than 3 standard deviations above the WHO Child Growth Standards.

Table C1. Important nutrients required for health functions during specific life-course phases provided by terrestrial animal source foods

Life-course phase	Key health functions	Nutrients
Infants and young children (6 to 59 months, including 6 to 23 months)	• Healthy growth • Healthy bone growth • Cognitive development • Immune system functioning • Vision health	• Vitamin A • Vitamin B12 • Choline • Calcium • Iron • Zinc • Proteins • Fatty acids (DHA, Ratio Linoleic to Alpha-Linolenic Acids – LA:ALA)
School-age children (5 to 9 years)	• Healthy growth • Immune system functioning • Normal cognitive functioning and brain development	• Vitamin A • Vitamin B12 • Calcium • Iron • Zinc • Proteins • Fatty acids (DHA, LA:ALA)
Adolescents (10 to 18 years)	• Healthy growth • Reproductive maturation • Normal cognitive development and neuroplasticity	• Vitamin B12 • Calcium • Iron • Zinc • Protein • Fatty acids (DHA, LA:ALA)
Women of reproductive age, including during pregnancy and lactation (15 to 49 years)	• Anaemia prevention • Bone preservation • Lower risk of infection • Breastmilk quality • Supporting increasing blood volume • Birth outcomes (prevention of LBW, IUGR) • Full-term infant • Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions	• Folate • Calcium • Iron • Zinc • Protein • Fatty acids (DHA, LA:ALA, cholesterol)
Adults (18 to 65 years)	• Cognitive maintenance and healthy nutrient levels • Immune-system functioning • Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions	• Vitamin B12 • Calcium • Iron • Zinc • Protein • Fatty acids (DHA, LA:ALA, cholesterol)
Older adults (65 + years)	• Bone health • Immune-system functioning • Memory and cognitive preservation • Muscle-mass maintenance • Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions	• Vitamin B12 • Calcium • Zinc • Protein • Fatty acids (DHA, LA:ALA, cholesterol)

Notes: DHA = docosahexaenoic acid; LA = linoleic acid; ALA = alpha-linolenic acid; LBW = low birth weight; IUGR = intrauterine growth restriction.

3.1

Women during pregnancy and lactation, including foetuses and breastfeeding children up to six months of age

Conception initiates the first 1 000-day period, a critical phase in the life course that requires nutrient-dense, healthy diets to support the developing foetus and infant while sustaining the health and well-being of the mother. Offspring growth and development depend not only on diet but also on a wide array of genetic and environmental factors (McDade *et al.*, 2019). Malnutrition in this life-course phase can induce critical consequences for both mother and offspring. For the mother, issues may include compromised nutrient status, impaired bone health, metabolic perturbations and increased overweight and obesity (Black *et al.*, 2013). For the foetus and infant, malnutrition during pregnancy may result in, *inter alia,* intrauterine growth restriction or small size for gestational age, large size for gestational age, low birth weight and height, pre-term birth and long-term health outcomes (Barker, 1997; Chia *et al.*, 2019; Christian *et al.*, 2015). Iron deficiencies, in particular, are increasingly prevalent during pregnancies and can induce a range of complications for the mother and the foetus during gestation, with longer-term impacts on offspring mental health, brain development and cognition (Georgieff, 2020).

In the lactation period, breastmilk composition, particularly levels of fatty acids and some vitamins, depends on maternal diet and body reserves (Bravi *et al.*, 2016; Dror and Allen, 2018; Kovacs, 2016). Required maternal dietary intakes may increase further during breastfeeding as the dependent neonate and infant grows. Calcium and iron requirements, for example, are very high in both pregnancy and lactation (Black *et al.*, 2013; Georgieff, 2020; Hacker, Fung and King, 2012; Kovacs, 2016). Evidence shows that women absorb these nutrients more efficiently during these periods, although their own skeletons may be resorbed to compensate for the high mineral needs of the offspring (Kovacs, 2016). Several other nutrients found to be bioavailable in TASF are also required at higher levels during pregnancy and lactation to sustain increases in blood plasma expansion, foetal growth and development, milk production and multiple other biological processes (Allen, 2013).

Evidence from intervention studies on TASF consumption during pregnancy and lactation has largely focused on milk and dairy products. Two comprehensive systematic reviews were identified for milk and dairy products. Quality observational prospective cohort studies that underline findings from the systematic reviews were also identified.

A recent systematic review and meta-analysis of the effects of milk and dairy products consumed during pregnancy on perinatal nutrition (anthropometry) outcomes (Pérez-Roncero *et al.*, 2020) pooled data on 111-184 pregnant women identified from 14 studies and demonstrated that intake of higher quantities of milk and dairy products, as compared to lower quantities or none, was associated with increased birth weight (mean difference = 51.0 g, 95% CI: 24.7-77.3). The meta-analysis showed that higher milk and dairy intake had a positive effect on infant length (mean difference = 0.33 cm, 95% CI: 0.03-0.64). It was also that found higher milk and dairy intake reduced risk of small size for gestational age (odds ratio = 0.69, 95% CI: 0.56-0.84) and low birth weight (odds ratio = 0.63, 95% CI: 0.4-0.84) and increased risk of large size for gestational age (odds ratio = 1.11, 95% CI: 1.02-1.21). Consuming higher quantities of milk and dairy products was found to have no effect on the standard ultrasound measures of the foetal size.

Another systematic review examined both nutrition (anthropometry and breastmilk composition) and health (birth outcomes). Drawing evidence from 17 studies (three intervention, six prospective-cohort, three retrospective-cohort and two case-control studies), this study produced findings consistent with those of the review described above for a positive association between infant birth weight and length and milk intake during pregnancy (Achón *et al.*, 2019). Evidence was insufficient to draw conclusions regarding the effects of milk and dairy intakes during pregnancy on preterm birth and spontaneous abortion or on breastmilk composition during the lactation period.

Observational studies, when appropriately designed, can also provide evidence for the impacts of TASF consumption during pregnancy and lactation. The Generation R Study and its follow-on Generation R Next in the Netherlands are prospective cohort studies running from the foetal period to young adulthood (Generation R, 2021). One analysis conducted as part of these studies assessed the association between first trimester milk consumption and foetal growth and neonatal complications (n=3405 mothers) (Heppe *et al.*, 2011). Data from a semi-quantitative food-frequency questionnaire showed that consuming three or more glasses of milk per day, compared to one or zero glasses of milk per day, was associated with greater foetal weight gain in the third trimester and an 88 g higher birth weight (95% CI: 39-135 g). Head circumference was also increased by 2.3 cm in the offspring of mothers drinking three or more glasses of milk compared to one or zero. No association was found for length. Another prospective cohort study examined the effects of milk consumption during pregnancy in Danish women on their offspring's nutrition (anthropometry) at birth and health (IGF 1 levels, insulin levels) outcomes over approximately 20 years of follow-up (n=685) (Hrolfsdottir *et al.*, 2013). The investigators found that maternal milk consumption greater than or equal to 150 ml/day at 30 weeks gestational age compared to less than 150 ml was associated with higher birth weight-for-age z-score (0.32, 95% CI: 0.06-0.58) and birth length-for-age z-score (0.34, 95% CI: 0.04-0.64). When the offspring of mothers with higher milk consumption were followed up 20 years later, they showed higher height z-scores, higher levels of IGF-1 and higher insulin levels compared to the offspring of mothers consuming lower milk levels, but differences were not statistically significant.

Other observational studies were identified to improve the population representativeness of the assessment. Pregnant women living in an urban area of South India were studied in a prospective cohort trial (Mukhopadhyay *et al.*, 2018). The effects of dietary intakes of milk and dairy products on birth nutrition outcomes (anthropometry) were examined using a food-frequency questionnaire (n=2036). The study found that total milk and dairy-product intakes and percentage of protein from milk and dairy products in first trimester were positively associated with birth weight (beta=86.8, 95% CI: 29.1-144.6; beta=63.1, 95% CI: 10.8-115.5; $P<0.001$). The percentage of total vitamin B12 intakes from milk products was also examined, but no association with birth weight was found.

An observational study among pregnant Portuguese women (n=98) found a relationship between total dairy intakes in the first trimester and head circumference (beta=0.002, P=0.014) and placental weight (beta=0.333, P=0.012) (Abreu *et al.*, 2017). There was also some indication that increased dairy intakes between the first and second trimesters were associated with lower maternal weight gain during pregnancy (beta=-0.007, P=0.020).

In sum, randomized controlled trials have examined the effects of consuming milk and dairy products during pregnancy and lactation to a greater extent than the effects of consuming other TASFs. Consistent findings show that milk intake has a positive effect on healthy birth weight, with some evidence suggesting greater effects if the intervention starts in the first trimester. Prospective cohort studies adjusting for multiple confounding factors have similarly shown positive association between milk consumption during pregnancy and healthy foetal-growth outcomes. However, there are limitations inherent in drawing conclusions from observational studies. Findings for ultrasound parameters are more equivocal but give some indication that TASF consumption affects head circumference.

3.2 Infants and young children

It is well established that infancy and early childhood are among the life-course phases most vulnerable to malnutrition. This subsection covers TASF in the diets of children aged between six months and 59 months. Complementary feeding is defined as the period when an infant or young child, aged between six month and 23 months, continues to breastfeed but requires other foods to meet daily requirements (WHO, 2021b). TASF may be particularly critical during this period as a source of bioavailable nutrients that can be more efficiently absorbed (Iannotti, 2018; Murphy and Allen, 2003). Infants have limited gastric capacity and therefore need to be fed frequently throughout the day with complementary foods that supply nutrients that can be absorbed efficiently to support rapid growth and neurological development (Bergman, 2013; Brown and Lutter, 2000). At this phase in the life course, immunity is also transitioning from the passive immunity conferred by the mother through pregnancy and lactation to an independent, maturing system in the child. Zinc, which is found concentrated in TASF, is an example of a nutrient that is critically important for the development of adaptive immunity, in particular (Ackland and Michalczyk, 2016).

As described in Section B, certain nutrients and bioactive compounds provided only by TASF or that are more biologically active in TASF than in PBF are critical for growth and development during infancy and early childhood. Vitamin B12 supports neurological development, among many other processes, and can only be obtained through food by consuming TASF (Allen *et al.*, 2018). Zinc and iron deficiencies are highly prevalent in young children, leading to stunting, diarrhoeal morbidities and mortality, and compromised cognition, language and socio-emotional development (Black *et al.*, 2017, 2013). During the complementary-feeding period, the non-breastfed infant may be especially vulnerable to nutrient deficiencies and therefore require nutrient-dense foods, such as TASFs, after six months of age (WHO, 2005). At the other end of the nutrition spectrum, excessive TASF consumption during early childhood may heighten the risk of child and adult overweight and obesity (Lind *et al.*, 2017). Overweight and obesity, acting through multiple mechanisms, are risk factors for NCD outcomes, including cancer (De Pergola and Silvestris, 2013). This subsection reviews the epidemiological evidence, across multiple contexts, for the effects of TASF on nutrition and health outcomes in infants and young children.

A series of systematic reviews have examined the effects of TASF on nutrition outcomes (anthropometry) in young children. It should be noted that the reviews encompass a range of TASFs and different kinds of comparator groups (usual diet, fortified foods, etc.). One review examined the literature on the effect of TASF on growth and development outcomes among children aged between six months and 59 months (Eaton *et al.*, 2019). The authors identified six trials (n=3 036 children) from China, the Democratic Republic of the Congo, Ecuador, Guatemala, Pakistan, the United States of America and Zambia. Three studies showed a significant increase in the change in the height for age z-score or length for age z-score in the intervention group compared to the control. In addition, three studies reported that TASF consumption was associated with significant increases in the change in the weight-for age z-score. All-cause morbidities were assessed, and one study that tested the effect of yoghurt consumption reported a significant reduction in the duration and incidence of diarrhoea and upper-respiratory infections. One randomized controlled trial examining egg consumption during complementary feeding reported an increase in diarrhoea morbidity compared to the control. The review also reported findings from a study examining meat- and dairy-based diets that indicated a significant increase in length for age z-score for meat but not for dairy, and non-significant findings for weight for age z-score (Eaton *et al.*, 2019).

Another systematic review examined the effects of TASF on stunted growth among children aged between six months and 60 months, identifying 21 studies for inclusion (Shapiro *et al.*, 2019). One randomized-controlled trial and one cross-sectional study covered in this review showed significant reductions in stunting. Secondary outcomes of anaemia, height/weight and head circumference were non-significant. Another systematic review and meta-analysis focused only on milk and dairy products and physical growth of children aged between two and 18 years old (de Beer, 2012). Using data from 12 studies conducted in China, Europe, Kenya, Indonesia, India, the United States of America and northern Viet Nam, authors found that for each incremental increase of 245 ml in daily milk consumption, child height increased by 0.4 cm per year compared to children consuming less. The results also showed that children with stunted growth had greater growth benefits from milk consumption than other children did and that the effect of milk on child height was greater than that of other dairy products.

A systematic review focusing on complementary feeding practices within high-resource contexts and their impacts on infant micronutrient status suggested that meat reduced the risk of iron deficiency among breastfeeding infants who had low iron intake or were at risk of having inadequate iron stores during the first year of life. This relationship was, however, less clear for infants with adequate iron stores. There was also limited evidence available examining the impact of meat consumption on infant zinc status during the complementary feeding period (Obbagy *et al.*, 2019).

RCT and other types of experimental trials testing the effects of TASF on child nutrition and health outcomes were included in the systematic reviews described above. A few trials are highlighted here to draw attention to nuances in the findings and the importance of context and the overall dietary pattern. A series of trials tested the effects of introducing eggs early in the complementary-feeding period (at between six and nine months of age) and continuing the egg intervention for six months. One of the early studies, the Lulun Project (Iannotti *et al.*, 2017a), was carried out in Ecuador and showed a relatively large effect on child growth (length-for-age z-score increased by 0.63 (95% CI: 0.38–0.88) and a 47 percent reduction in stunting (prevalence ratio 0.53; 95% CI: 0.37–0.77) (Iannotti *et al.*, 2017a). The trial also found significantly increased concentrations of biomarkers of brain development, including choline and DHA (Iannotti *et al.*, 2017b). When the study was replicated in Malawi (Mazira Project), however, the effect of egg consumption on child growth and development outcomes was found to be non-significant (Prado *et al.*, 2020; Stewart *et al.*, 2019). Important contextual differences were noted. The sample population for the Mazira Project was located near Lake Malawi and was already consuming animal source food in the form of small fish. The staple food was maize, probably high in dietary phytates that can interfere with TASF nutrient absorption. The Lulun sample, by contrast, had limited TASF in the diets, and the staples were potatoes and rice. The diverging findings for these two studies highlight the need to consider child diets more holistically.

There are a limited number of studies assessing the consumption of insects and their products among young children. Caterpillar cereal as a complementary food was tested in the Democratic Republic of the Congo and found to have a positive effect on haemoglobin concentrations and to lead to reductions in anaemia (Bauserman *et al.*, 2015). In a small study in Indonesia, young children aged 24 to 59 months (n=60) were put at random into two groups, one of which received 45 g/day of honey for two months while the other served as a control (Harmiyati *et al.*, 2017). There was some evidence for an effect on anthropometry, with differences evident for height for age z-score, weight for age z-score and weight for height z-score, and this may merit replication in a larger trial.

In sum, while systematic reviews indicate that TASF intake provides some benefits to infants and young children in terms of increased height/length and weight, the diverse findings highlight the importance of considering environmental health and overall child diets when assessing relationships across multiple contexts.

3.3

School-age children and adolescents

As the young child ages into middle childhood and adolescence, nutrition remains an important factor underlying health. The rate of linear growth slows as energy and nutrients are redirected into other developmental processes (Norris *et al.*, 2022). Among primates, *Homo sapiens* has the longest juvenile periods in the life span (Bogin, 2009). Evolutionary biologists posit that the long duration of this period arose for multiple reasons, including to enable learning and brain development (Bogin, 2009). The middle childhood period is characterized by rapid neurogenesis and synapsis formation, which is followed by a period of intense pruning during adolescence (Black *et al.*, 2017). Brain development has high glucose and micronutrient requirements, reaching 50 percent of the body's total basal requirements during childhood, and therefore requires an energy- and nutrient-dense diet (Goyal, Iannotti and Raichle, 2018). Similar to the situation in infancy and early childhood, the nutrients driving brain development during middle childhood and adolescence, including DHA, iron, zinc, choline and B vitamins, are those found in bioavailable form in TASF. In some contexts, infection may interfere (through inflammation) with nutrition-driven neurodevelopment (Suchdev *et al.*, 2017).

Other important biological processes during the school-age and adolescent periods require healthy diets. Growth trajectories follow similar patterns in prepubescent boys and girls (Ruxton and Derbyshire, 2013). Around nine years of age, girls begin their pubescent growth spurt, and boys do so approximately two years later. Differences related to the biological sex of the individual emerge during this phase for adiposity tissue and fat deposits (Ruxton and Derbyshire, 2013). Peak bone mass is reached during adolescence, requiring sufficient supplies of protein, calcium, vitamin D, zinc, phosphorous and magnesium, among other nutrients (Wallace *et al.*, 2020). Evidence clearly supports the need for healthy diets to support bone health during these life-course phases (Golden, Abrams and Committee on Nutrition, 2014). The immune system also continues to develop and interact with dietary intakes and microbial exposures (Norris *et al.*, 2022). Importantly, adolescents enter a phase of rapid reproductive development and changes to the endocrine system that require healthy diets and other health-promoting behaviours. With menarche, girls' iron requirements increase (Brabin and Brabin, 1992). Overall, the nutrient requirements of the school-age child and adolescent point to the ongoing importance of healthy diets, which may include TASF.

TASF consumption has been evaluated in school-age children and adolescents for nutrition (anthropometry), health (bone health) and cognition outcomes. The above-described systematic review and meta-analysis examining milk and dairy products found an increase in height growth of 0.4 cm per year associated with daily consumption of 245 ml of milk/dairy (de Beer, 2012). Data were drawn from samples in China, Europe, Kenya, Indonesia, India, northern Viet Nam and the United States of America. Dairy consumption led to greater height effects in adolescents than in school-age children, and among all children and adolescents, milk intakes led to greater effects on height in those with low heights for their ages than in other children.

Some concerns have been raised about longer-term risks of overweight and obesity associated with child consumption of milk and dairy products. One systematic review examined this question directly (Lu *et al.*, 2016). The authors identified 10 studies (n=46 011 children and adolescents) with an average three-year follow-up period. Children in the groups with the highest dairy intake showed a reduced risk of overweight/obesity compared to those in the lowest intake group (pooled odds ratio = 0.62; 95% CI: 0.49–0.80). The adjusted regression modelling showed that for each additional one serving per day of dairy, the risk of overweight/obesity was 13 percent lower than for children consuming lower quantities (odds ratio = 0.87; 95% CI: 0.74–0.98).

A previous systematic review and meta-analysis showed consistent findings for milk or dairy consumption in relation to adiposity (Dror, 2014).This analysis included data from 36 studies of children across multiple age categories – pre-school, school-age and adolescents – living in high-income countries. It found that milk or dairy intake did not lead to a significant increase in adiposity and that, among adolescents, dairy intake reduced adiposity with an effect size of -0.26 (95% CI: -0.38 – -0.14, P<0.0001).

As well as anthropometry, bone health has been studied in relation to dairy and egg consumption in school-age children and teenagers. A review of randomized controlled trials found eight studies indicating positive effects of dairy consumption on both bone mineral content and bone mineral density (Kouvelioti, Josse and Klentrou, 2017).

Another observational study, in a population in the United States of America, examined egg consumption and bone health among 13 year olds (n=294) (Coheley *et al.*, 2018). The authors found that egg consumption was positively associated with bone mineral content (radium cortical bone mineral) and biomarkers of bone metabolism (osteocalcin).

Although there is compelling evidence for highly active brain development during childhood and adolescence that could be responsive to TASF in the diet, few studies have examined this linkage. One systematic review aimed to examine the effects of consuming beef and beef products on cognitive outcomes in children and young adults (An *et al.*, 2019). It assessed findings from five unique interventions, some of which are covered above in the section on young children (Krebs *et al.*, 2012). Interventions evaluated in the trials compared beef to other TASFs (e.g. a glass of milk) or PBFs. There was only one intervention that compared beef to a usual-diet control group, and this was also the only one that showed positive effects on cognitive outcomes (Neumann *et al.*, 2007).

The series of papers published from a cluster randomized-controlled trial carried out among Kenyan school children (n=911) has been widely cited in the literature on TASF nutrition (Gewa *et al.*, 2009; Hulett *et al.*, 2014; Neumann *et al.*, 2007; Whaley *et al.*, 2003). The papers in question compared the health and development outcomes of four groups: children given meat with githeri stew (maize, beans and greens); children given milk with githeri stew; children given githeri stew alone; and a control group. It was found that children in the meat group showed higher rates of increase in Raven's Progressive Matrices (which reflect fluid intelligence, abstract reasoning, problem solving, perceptual awareness and reasoning) than all the other groups, while only younger children and those stunted at baseline in the milk group showed a greater rate of height gain than other children in the milk group (Neumann *et al.*, 2007). Multiple other health and nutrition outcomes have been reported from this study. Vitamin B12 plasma concentrations were increased in the meat and milk groups (McLean *et al.*, 2007; Siekmann *et al.*, 2003). Arm muscle area and mid-upper arm circumference were significantly higher over time in the meat and milk groups than in the githeri and control groups (Neumann *et al.*, 2013b). Differences were also observed for morbidities, among other outcomes (Neumann *et al.*, 2013a).

In sum, the school-age child and adolescent undergoes critical growth, reproductive, endocrinal and neurodevelopmental changes that require energy and nutrient-dense foods. As with pregnancy and lactation, more synthesized evidence is available on the effects of milk and dairy-product consumption during this period of the life course than on the effects of consuming other TASFs, although meat has been evaluated for cognition, growth and other health impacts. Findings from systematic reviews on milk and dairy consumption show that it is associated with increased height, increased bone mineral content and density, and lower risks of overweight and obesity. Meat and milk intakes were associated with positive health, nutrition and cognitive outcomes in a cluster randomized-controlled trial in Kenya.

3.4

Adults

Healthy diets are important during adulthood for maintaining biological systems, responding to changes that may occur, such as infection or other environmental exposures, and supporting ongoing neurogenesis. Overall anthropometry and body composition differ between men and women, influencing the levels of macronutrients and micronutrients required in the diet to maintain health (Brown, 2019). On average, muscle mass is higher in men than women, while women have higher fat mass, which means that dietary needs differ (Gallagher, Chung and Akram, 2013). Women of reproductive age (15 to 49 years) have additional requirements for nutrients found in TASF (e.g. iron) because of menstruation and other reproductive-health processes.

During adulthood, TASF – within the context of a healthy diet – can protect and promote health. This section provides an overview the benefits and risks associated with dietary intakes of TASF at a range of different levels. Table C2 summarizes the levels of intake given as healthy reference intakes or as risk thresholds, depending on the nature of the analysis, for various TASFs. For example, the healthy reference diet of the EAT-Lancet Commission incorporates daily intake levels for several different TASFs based on nutrient intake adequacies and analyses of the literature (Willett *et al.*, 2019b). Similarly, the Global Diet Quality Score (GDQS) is a food-based metric consisting of 25 food groups, of which 16 are classified as healthy, seven as unhealthy and two (red meat and high-fat dairy products) as unhealthy when consumed in excess. Investigators based the score on the analysis of datasets containing 24 hour dietary recalls across different regions and an analysis of the association of each candidate metric with a range of diet-quality outcomes related to nutrient adequacy and NCD risk. In contrast, the Global Burden of Disease estimates provide thresholds for risk analyses across different types of foods, including processed and unprocessed meats (Afshin *et al.*, 2019b; Murray *et al.*, 2020b). In the Global Burden of Disease 2019, theoretical minimum risk exposure level (TMREL) is reduced to zero, as shown in Table C2.

Very high consumption of red meat can, however, be associated with overweight, obesity and NCDs. The World Health Organization established the Global Action Plan for the Prevention and Control of Non-Communicable Diseases 2013 2020 (WHO, 2013) targeting cardiovascular disease, cancer, chronic respiratory diseases and diabetes. Unhealthy dietary behaviours are among the risk factors targeted for chronic-disease prevention (WHO, 2014). There is a large body of epidemiological evidence available examining the association between red meat consumption and colorectal cancer (Bouvard *et al.*, 2015). In 2015, the International Agency for Research on Cancer Monographs Programme classified consumption of red meat as *"probably carcinogenic to humans"* based on limited evidence and processed meat as *"carcinogenic to humans"* based on sufficient evidence (Boobis *et al.*, 2016; IARC, 2015; Thøgersen and Bertram, 2021). Subsequent analyses have questioned the validity of these conclusions because of a weak effect size, heterogeneity and a lack of dose–response patterns (Alexander *et al.*, 2015).

The biological mechanisms for NCDs vary and depend on a range of factors that extend beyond unhealthy dietary practices and include genetics, physical inactivity, underlying health conditions and comorbidities, and environmental exposures. TASF consumption has been associated with increased levels of low-density lipoprotein cholesterol in the blood, which can in turn, increase risk of atherosclerosis (disease of large arteries) and cardiovascular disease. Dietary intakes of saturated fatty acids can increase low density lipoprotein in the blood, although dietary cholesterol has been shown to have minimal effects on plasma concentrations of low-density lipoprotein cholesterol (Astrup *et al.*, 2020; Fernandez, 2012; Guasch-Ferré *et al.*, 2019). As described in Section B, cholesterol has important functions in the human body, including in cell membrane activity and integrity and as a precursor for steroids such as sex hormones, adrenocortical hormones and vitamin D (Gropper, Smith and Carr, 2021b). Cholesterol in excess may not be catabolized readily, leading to increased risk of atherosclerosis (Schade, Shey and Eaton, 2020).

Potential mechanisms underlying the association of red meat with chronic disease include pro-inflammatory factors, serum ferritin, haem iron, heterocyclic amines, trimethylamine N oxide and saturated fats. Evidence largely derives from observational studies in humans, animal models and cell cultures (Kim, Keogh and Clifton, 2015; Kruger and Zhou, 2018). With regard to processed red meat, reviews examining the mechanisms involved highlight particular compounds that can harm DNA: carcinogenic N-nitroso compounds from the curing meats with nitrite; polycyclic aromatic hydrocarbons from smoking; and heterocyclic aromatic amines from high-temperature cooking (Domingo and Nadal, 2017; Turesky, 2018). Another review of the biological mechanisms underlying the effect of meat on colorectal cancer suggested that *in vitro* studies do not represent normal dietary intakes for haem exposure, in particular (Kruger and Zhou, 2018). This review also found that the types of N-nitroso compounds in the human body after ingestion of red meat are nitrosyl iron and nitrosothiols, which have chemistries that differ from those implicated in the formation of DNA adducts.

As in the case of other life-course phases, milk and dairy products have been studied extensively for nutrition and health outcomes in adults. One metareview compiled this evidence to assess the effect on all-cause mortality (Cavero-Redondo *et al.*, 2019). It included eight meta-analyses, 50 percent of which were considered to meet the criteria for "very good" quality of evidence, while 25 percent were classed as "good" and 25 percent as "acceptable". Relative risks were reported for dairy products, milk, cheese and yoghurt, and no excess risk associated with these products was found for all-cause mortality. Other reviews have parsed the effects of milk and dairy on different chronic disease outcomes. A systematic review and meta-analysis showed one cup of milk (200 ml) per day reduced risk of cardiovascular disease, stroke, hypertension, colorectal cancer, metabolic syndrome, obesity and osteoporosis in a dose-response manner (Zhang *et al.*, 2021). The study also found an increased risk associated with milk for prostate cancer and Parkinson's disease. The findings for colorectal cancer were supported by the World Cancer Research Fund (WCRF), Continuous Updata Report (CUP) 2018, which showed that consumption of dairy probably protects against colorectal cancer (WCRF, 2018b). This report, however, found that evidence showing that high consumption of dairy products increases risk of prostate cancer is limited.

Another systematic review and meta-analysis drew data from 13 cohort studies for coronary heart disease and seven for ischaemic stroke and found that an increase of 200 g/day intake of high-fat milk was positively associated with coronary heart disease, RR 1.08 (95% CI: 1.00-1.16), while an increase of 90 g/day of cheese reduced the risk of coronary heart disease, RR 0.96 (95% CI: 0.93-0.98) (Jakobsen *et al.*, 2021). In another updated systematic review and meta-analysis, investigators focused on risk assessment for dairy products and hypertension only (Heidari *et al.*, 2021). The combined 16 studies showed reduced risks of hypertension for the following types of food: all dairy products, RR 0.90 (95% CI: 0.87-0.94); low-fat dairy products, RR 0.86 (95% CI: 0.77-0.96); milk, RR 0.94 (95% CI: 0.90-0.99); and fermented dairy products, RR 0.95 (95% CI: 0.91-0.99). In subgroup analyses, however, the authors reported differential findings based on sex, region and stage of hypertension.

Milk and dairy products also seem to protect against type 2 diabetes. A systematic review and meta-analysis combined 22 cohort studies to show that each 200 g/day increase in dairy intakes reduced risk of type 2 diabetes, RR 0.97 (95% CI: 0.95-1.00) (Gijsbers *et al.*, 2016). Yoghurt intakes at 80 g/day versus no intake also reduced risk, RR 0.86 (95% CI: 0.83-0.90). However, heterogeneity across the studies was high. A meta-analysis of cohort studies in adults in the United States of America found only yoghurt to be protective against type 2 diabetes, HR 0.83 (95% CI: 0.75-0.92) (Chen *et al.*, 2014). Breast cancer has also been studied in relation to milk and dairy intakes in a systematic review and meta-analysis (Zang *et al.*, 2015). This study also included a total of 22 prospective cohort studies. The authors showed that high and modest intakes of dairy products reduced the risk of breast cancer relative to low intakes, and subanalyses for particular dairy products indicated protective effects for yoghurt and low-fat dairy. The WCRF, CUP 2018 for breast cancer also shows that consumption of dairy products at 200 g/day minimally reduces risk of premenopausal breast cancer, RR 0.95 (CI: 0.02-0.99) (WCRF, 2018a).

Other systematic reviews and meta-analyses have shown that consuming milk and dairy products reduces the risk of metabolic syndrome (Chen *et al.*, 2015), colorectal cancer in men (Ralston *et al.*, 2014), vertebral fracture (Matía-Martín *et al.*, 2019) and hip fracture (for yoghurt only) (Hidayat *et al.*, 2020). One systematic review and meta-analysis showed that dairy intakes reduced the risk of endometriosis (Qi *et al.*, 2021). Those consuming more than 18 servings per week of full-fat dairy products showed a relative risk of 0.68 (95% CI: 0.76-0.96). In stratified analyses by dairy product, the relationship held for cheese but not for whole or reduced-fat/skim milk or yoghurt.

Few studies have systematically examined the effects of TASF substitute or replacement foods. One prospective cohort study over 32 years in the United States of America found that consuming nuts, legumes or whole grains instead of dairy foods was associated with lower mortality and that consumption of red and processed meat instead of dairy was associated with higher mortality (Ding *et al.*, 2019).

Concerns over dietary egg intakes in adults have largely focused on the risk of blood cholesterol with respect to coronary heart disease, stroke and hypertension. However, there is no strong evidence supporting these associations among healthy adults. A systematic review of meta-analyses of randomized-controlled trials examined the impacts of egg consumption on blood pressure in adults (Kolahdouz-Mohammadi *et al.*, 2020). The authors identified fifteen randomized controlled trials (n=748 participants) and found that, overall, egg consumption had no significant effect on systolic blood pressure (weighted mean difference 0.046 mmHg; 95% CI: 0.792-0.884) and diastolic blood pressure (0.603 mmHg; 95% CI: 1.521-0.315). They reported no heterogeneity among the included studies.

An earlier systematic review and meta-analysis evaluated the association between egg consumption and stroke and coronary heart disease (Rong *et al.*, 2013). The authors drew data from 17 reports (3 081 269 person years and 5 847 incident cases for coronary heart disease, and 4 148 095 person years and 7 579 incident cases for stroke). Findings indicated no association for either condition. The relative risks of one egg per day were 0.99 (95% CI:0.85-1.15) for coronary heart disease and 0.91 (95% CI: 0.81-1.02) for stroke. Heterogeneity assessed using I2 (the percent variance from the point estimate attributable to heterogeneity in study design) was 0 percent. A subgroup analysis among diabetic individuals showed that there was an increased risk of coronary heart disease at the highest intake level as compared to the lowest intake level, RR 1.54 (95% CI: 1.14-2.09).

Another systematic review and meta-analysis was carried out in China using the Guangzhou Biobank Cohort Study and included 28 024 participants without cardiovascular disease at baseline (Xu *et al.*, 2019). This study confirmed the findings presented above, showing that there were no significant increases in risk of all-cause mortality, mortality from cardiovascular disease, ischaemic heart disease or stroke associated with high (more than seven eggs per week) relative to low (less than one egg per week) egg consumption. The authors found a small reduction in risk of stroke (HR 0.91, 95% CI: 0.85-0.98) but recommended further study.

Table C2. Healthy reference intakes and risk thresholds of specific terrestrial animal source foods for adults, methods and data sources

Healthy reference intake					
Food	**Study**	**Mean** (range)	**Method for calculating range**	**Analysis or data source**	**Reference**
Red meat	World Cancer Research Fund	350–500 g/week	The recommendation on consumption of red meat identifies the level of consumption that the independent panel of experts judges to provide a balance between the advantages of consuming red meat (e.g. as a source of essential macronutrients and micronutrients) and the disadvantages (e.g. increased risk of colorectal cancer).	Used an integrated approach to the evidence to define an intake consisting of a “modest amount of red meat and little or no processed meat” that reduces the risk of NCDs. More specific guidance is not possible because the exact conversion depends on the cut of meat, the proportions of lean meat and fat and the method and degree of cooking.	WCRF, 2018c
Red meat, unprocessed	Global Dietary Quality Score[b]	9–46 g/day	Categories of consumed amounts: • Low: < 9 g/day • Middle: 9–46 g/day • High: > 46 g/day Classified by the authors as “unhealthy in excessive amounts”.	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Red meat, processed	Global Dietary Quality Score[b]	9–30 g/day	Categories of consumed amounts: • Low: < 9 g/day • Middle: 9–30 g/day • High: > 30 g/day Classified by authors as ”unhealthy”	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Beef and lamb	EAT-Lancet Commission	7 g/day (0–14 g/day)	The authors based the estimates on the assumption that intake of red meat is not essential and appears to be linearly related to total mortality and risks of other health outcomes in populations that have consumed red meat for many years, optimal intake might be 0 g/day, especially if replaced by plant sources of protein. Because data on risk of low intakes of red meat are imprecise, the authors concluded that an intake of 0 g/day to about 14 g/day of beef and lamb is desirable and a midpoint of 7 g/day was used for the reference diet.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence base.	Willett *et al.*, 2019
Pork	EAT-Lancet Commission	7 g/day (0–14 g/day)	The authors based the estimates on the assumption that intake of red meat is not essential and appears to be linearly related to total mortality and risks of other health outcomes in populations that have consumed it for many years, optimal intake might be 0 g/day, especially if replaced by plant sources of protein. Because data on risk of low intakes of red meat are imprecise, the authors concluded that an intake of 0 g/day to about 14 g/day of pork is desirable and a midpoint of 7 g/day was used for the reference diet.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence base.	Willett *et al.*, 2019

(cont.)

Healthy reference intake					
Food	**Study**	**Mean** (range)	**Method for calculating range**	**Analysis or data source**	**Reference**
Chicken and other poultry	EAT-Lancet Commission	29 g/day (0–58 g/day)	The authors based the estimates on evidence that consumption of poultry has been associated with better health outcomes than consumption of red meat and concluded that the optimum consumption of poultry is 0 g/day to about 58 g/day, with a midpoint of 29 g/day.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence base.	Willett *et al.*, 2019
Poultry and game meat	Global Dietary Quality Score[b]	16–44 g/day	Categories of consumed amounts: • Low: < 16 g/day • Middle: 16-44 g/day • High: > 44 g/day Classified by authors as "healthy"	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021y
Low-fat dairy	Global Dietary Quality Score[b]	33–132 g/day	Categories of consumed amounts: • Low: < 33 g/day • Middle: 33–132 g/day • High: > 132 g/day Classified by authors as "healthy"	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
High-fat dairy (in milk equivalents)	Global Dietary Quality Score[b]	35–734 g/day	Categories of consumed amounts: • Low: <35 g/day • Middle: 35–142 g/day • High: 142–734 g/day • Very high: >734 g/day Classified by authors as "unhealthy in excessive amounts (i.e. very high consumption)".	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Whole milk or derivative equivalents (e.g. cheese)	EAT-Lancet Commission	250 g/day (0–500 g/day)	The authors based their estimate on evidence that there is no clear association between intake of milk or its derivatives greater than 0–500 g/day and major health outcomes and competing risks for some types of cancer, a wide range of intakes are compatible with good health. Because consumption of unsaturated plant oils conveys lower risks of cardiovascular disease than dairy fat, optimal intake will usually be at the lower end of this range and 250 g/day was used for the reference diet.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence base.	Willett *et al.*, 2019
Egg	EAT-Lancet Commission	13 g/day (0–25 g/day)	The authors used an intake of about 13 g of egg/day or about 1.5 eggs/week for the reference diet, but a higher intake might be beneficial for low-income populations with poor dietary quality.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence base.	Willett *et al.*, 2019
Egg	Global Dietary Quality Score[b]	6–32 g/day	Categories of consumed amounts (g/day): • Low: < 6g/day • Middle: 6–32 g/day • High: > 32 g/day Classified by authors as "healthy"	Cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021

(cont.)

Risk thresholds					
Food	**Study**	**Mean** (range)	**Method for calculating range**	**Analysis or data source**	**Reference**
Red meat, unprocessed	Global Burden of Disease 2017	23 g/day (18–27 g/day)	20% above/below mean	Comparative risk assessment[d]	Afshin *et al.*, 2019
Red meat, processed	Global Burden of Disease 2017		20% above/below mean	Comparative risk assessment[d]	Afshin *et al.*, 2019
Red meat	Global Burden of Disease 2019[e]		No data	Comparative risk assessment[d]	Murray *et al.*, 2020
Meat, processed	Global Burden of Disease 2019[c]		No data	Comparative risk assessment[d]	Murray *et al.*, 2020

Notes: Foods are named as in the respective reference.

[a] World Cancer Research Fund recommendation: Consumption of red meat should be limited to no more than about three portions per week. Three portions are equivalent to about 350–500g cooked weight. Consumption of processed meat should be restricted to very little, if any.

[b] Global Dietary Quality Score is based only on cross-sectional and cohort data from non-pregnant, non-lactating women of reproductive age in 10 African countries and China, India, Mexico and the United States of America. The classification into healthy, unhealthy in excessive amounts and unhealthy is based on review of the literature on dietary contributors to nutrient intakes and NCD risk globally Intake, Harvard School of Public Health & Instituto Nacional de Salud Pública. 2021. The Global Diet Quality Score: data collection options and tabulation guidance. [Cited 16 February 2022]. https://www.intake.org/news/global-diet-quality-score-data-collection-options-and-tabulation-guidance; Micha, R., Shulkin, M.L., Peñalvo, J.L., Khatibzadeh, S., Singh, G.M., Rao, M., Fahimi, S. et al. 2017. Etiologic effects and optimal intakes of foods and nutrients for risk of cardiovascular diseases and diabetes: systematic reviews and meta-analyses from the Nutrition and Chronic Diseases Expert Group (NutriCoDE). PloS One, 12(4): e0175149. https://doi.org/10.1371/journal.pone.0175149; Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T. et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170): 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

[c] Hard cheese should be converted to milk equivalents using a conversion factor of 6.1 when calculating total consumption of high-fat dairy for the purpose of assigning a GDQS consumption category.

[d] Based on World Cancer Research Fund evidence grading criteria to separately assess the strength of the epidemiologic evidence on the causal relationship between each dietary risk factor and disease endpoint, and including only dietary risk factors for which convincing or probable evidence on their relationship with chronic diseases was found.

[e] The study states that sufficient evidence was found supporting the causal relationship of red meat intake with ischaemic heart disease, breast cancer, haemorrhagic stroke and ischaemic stroke and that these outcomes were added and the dose–response curve of relative risk for red meat and outcomes based on the most recent epidemiological evidence and a newly developed method for characterizing the risk curve. Controversy about the non-transparent methodology has been discussed (WFO (World Farmers' Organization) Scientific Council. 2021. Consumption of unprocessed red meat is not a risk to health. Rome. https://www.wfo-oma.org/wp-content/uploads/2021/07/SC-WFO-Synopsis-Paper-on-Unprocessed-Red-Meat-Consumption_final.pdf)

Meat consumption (including a variety of types) has also been studied in adult samples primarily with a view to understanding effects on chronic diseases, although some studies have examined the effects of muscle tissue ("flesh") meat intakes on nutrient status. As a bioavailable source of haem iron (see Section B), meat may affect iron status and anaemia in adults. One systematic review of studies in adults from high-income countries identified seven high-quality studies examining this question (Jackson *et al.*, 2016). The studies examined intakes of animal flesh foods, defined as muscle tissue of an animal carcass, and included both red and white meats from chicken/poultry, sheep, pig, cattle, goat, fish, seafood, buffalo, kangaroo, camel, deer or rabbit. They included processed meats, such as ham, bacon and sausage, but excluded offal, such as liver and kidney. Five of the studies indicated that meat intake (85 300 g/day) was positively associated with iron status.

Red-meat consumption (processed and unprocessed) in adults has been studied in association with NCDs. Processed meats were typically defined as including those that have undergone changes such as salting, curing, smoking or addition of chemical preservatives. While there is a relatively large evidence base, it has been noted that it has serious limitations in that it is largely based on observational studies with moderate-to-high risk of biases. Analyses have been carried out explicitly to examine the quality of evidence from epidemiological studies evaluating red and processed meat consumption. One such study, looking at processed meat only, found risk of misclassification of exposure, serious risk of confounding and moderate-to-serious risk of biases, including selection, reporting and missing-data biases (Händel *et al.*, 2021). In another assessment, a panel of experts from seven high-income countries was convened to develop recommendations on consumption of processed and unprocessed red meat (Johnston *et al.*, 2019). They used GRADE (Grading of Recommendations, Assessment, Development and Evaluation) to evaluate the body of evidence and recommended that adults should continue current levels of both unprocessed and processed meat consumption (average intakes of two to four servings per week in North America and Europe), but they described the recommendation as weak and based on low-certainty evidence (Johnston *et al.*, 2019).

Two assessments of dietary risk factors using statistical analyses have in recent years been carried out for the Global Burden of Disease Study (GBD) at the Institute of Health Metrics. The GBD 2017 study established thresholds for dietary intake levels based on compilations of epidemiological data (see Table C2) (Afshin *et al.*, 2019). The assessment showed that red and processed meat contributed to global burden of disease calculated as life years lost due to disability or death, although they ranked low relative to other dietary risk factors such as high sodium consumption, low fruit consumption and low consumption of whole grains. The authors noted that the relatively low ranking could be a function of limited evidence compared to other dietary risk factors. For the GBD 2019, the theoretical minimum risk level was reduced to zero, increasing the estimate for the contribution of meat consumption to mortality and burden of disease (Murray *et al.*, 2020b). There may be uncertainty and a lack of representation of LMICs in the data used for both the GBD studies (Beal *et al.*, 2021).

Potential links between red meat consumption and specific NCDs have been examined largely through prospective cohort studies. The prospective cohort study Prospective Urban Rural Epidemiology (PURE) included data from 21 countries, with representation from low-, middle- and high-income populations. It showed that higher intakes of processed red meats (≥ 150 g/week versus 0 g/week) increased risk of total mortality (HR:1.51; 95% CI: 1.08-2.10) and cardiovascular disease (HR:1.46; 95% CI: 1.08-1.98) (Iqbal *et al.*, 2021). There was found to be no significant association between unprocessed red meat or poultry consumption and the various negative health outcomes studied. Another prospective cohort study, in a population of men in the United States of America, found an increased risk of cardiovascular disease for one additional serving of meat per day: total red meat HR 1.12 (95% CI: 1.06-1.18); unprocessed red meat HR 1.11 (95% CI: 1.02-1.21); and processed meat HR 1.15 (95% CI: 1.06-1.25) (Al-Shaar *et al.*, 2020).

As described above, the International Agency for Research on Cancer (IARC) analyses found substantial epidemiological evidence linking meat to colorectal cancer, in particular processed meat (IARC, 2015). The World Cancer Research Fund's Continuous Update Project 2018 also concluded that there is convincing evidence that consumption of processed red meat is a cause of colorectal cancer (WCRF, 2018b). A more recent umbrella review of meta-analyses found suggestive evidence for positive associations between red and processed meat consumption and risk of colorectal cancer: 50 g/day of processed meats RR 1.16 (95% CI: 1.08-1.26) and 100 g/day red or processed meat RR 1.19 (95% CI: 1.10-1.29) (Papadimitriou *et al.*, 2021). Cohort studies have also found associations between red meat consumption and pancreatic and advanced-stage prostate cancers (Bouvard *et al.*, 2015). Another, older, prospective cohort study, carried out in the United States of America, showed a positive association between increased daily servings of unprocessed red meats (430.9 g/day) and processed meats (421.8 g/day) and four-year weight gain (Mozaffarian *et al.*, 2011).

Red-meat consumption has been associated with different forms of diabetes in cohort studies. Marí-Sanchis *et al.* (2018) report that among Spanish women, total meat consumption (highest versus lowest quartile) was associated with increased risk of gestational diabetes mellitus (OR 1.67 [95% CI: 1.06-2.63]), with greater odds observed for red meat (OR 2.37 [95% CI: 1.49-3.78]) and processed meat (OR 2.01 [95% CI: 1.26-3.21]). An older study (Pan *et al.*, 2011) examined red-meat consumption and risk of type 2 diabetes in adults in the United States of America and found that a one serving a day increase in consumption of unprocessed meat (100 g/day) had a relative risk of diabetes of 1.19 (95% CI: 1.04-1.37) and that the equivalent figures for processed meat (50 g/day) were 1.51 (95% CI: 1.25-1.83).

Biomarkers of chronic disease have also been examined in relation to meat. A systematic review and meta-analysis examined the effects of total red meat consumption by comparing pre- and post-values for biomarkers for diet periods with intakes of 0.5 or more servings (35 g)/day of total red meat to those for diet periods with intakes of less than 0.5 servings/day in a series of randomized controlled trials. It found no significant difference in change values for glucose, insulin, Homeostatic Model Assessment of Insulin Resistance or c-reactive protein (O'Connor *et al.*, 2021).

Few studies have examined meat within the context of the overall dietary pattern over the short or longer term. One recent prospective cohort study, however, showed that the level of consumption of fruits and vegetables together with processed meats mattered for cancer risk (Maximova *et al.*, 2020). The reference point used by the authors was high intake levels of vegetables and fruits (> 5 servings/day for women and for men aged 55 years or more, and > 6 servings/day for men aged less than 55 years) or whole grains (> 1.1 servings/day for women and > 1.5 servings/day for men) with low intake levels of processed meat (< 28 g/week for women and < 42 g/week for men) or unprocessed red meat (< 150 g/week for women and < 250 g/week for men). They then estimated hazard ratios and confidence intervals for incidence of all-cause cancer and 15 cancers for different combinations of intake levels of red and processed meat, vegetables and fruits, and whole grains. The highest risk of all-cause cancer and 15 cancers was found to occur when low intake of vegetables and fruits or whole grains was combined with high intake of processed meat (HR men 1.9; HR women 1.4; HR men 1.8; HR women 1.5). When low intake of vegetable and fruits or whole grains was combined with high intake of unprocessed red meat, risk was less pronounced and associations were less consistent.

Replacement or substitution of meat with other foods has also been minimally studied. A meta-analysis compared red meat consumption to consumption of the following list of alternative "protein sources" for a variety of NCD risk factors: high-quality plant protein sources (legumes, soy, nuts); chicken/poultry/fish; fish only; poultry only; mixed animal-protein sources (including dairy); carbohydrates (low-quality refined grains and simple sugars, such as white bread, pasta, rice, cookies/biscuits); or usual diet (Guasch-Ferré *et al.*, 2019). No differences were observed between red meat and the combined category of all alternative diets for changes in blood concentrations of total, low-density lipoprotein or high-density lipoprotein cholesterol, apolipoproteins A1 and B or blood pressure, although there were smaller reductions in triglycerides for the red meat compared to the combined alternatives category (weighted mean difference, 0.065 mmol/L; 95% CI: 0.000-0.129). Red meat resulted in smaller reductions in total cholesterol and low-density lipoprotein compared to high-quality plant-protein sources, while compared to fish, red meat yielded greater reductions in low-density lipoprotein concentrations.

Poultry meat consumption, while sometimes included in analyses of unprocessed meats, has been evaluated to a lesser extent than consumption of red meat and other TASFs. A systematic review and meta-analysis of cohort studies assessing poultry consumption and stroke risk identified seven relevant studies (n=354 718) (Mohammadi *et al.*, 2018). Pooled RRs for total stroke risk were found to be non-significant: highest versus lowest poultry intake categories, RR 0.92 (95% CI: 0.82-1.03); dose-response, RR 1.00 (95% CI: 0.96-1.03). Subgroup analyses provided evidence for inverse relationships in a population in the United States of America and in women. A non-linear association was also revealed for lower risk of stroke at the consumption level of one serving per week.

Evidence is minimal for the effects of insects, grubs and insect products in the diets of adults on health outcomes. One systematic review looked at bee products and cardiovascular risk but was unable to draw conclusions based on the evidence base (Hadi, Rafie and Arab, 2021). Rasad *et al.* (2018) found that honey consumption improved lipid profiles relative to sucrose consumption. In another study, honey was shown not to adversely affect blood lipids in adults (Al-Tamimi *et al.*, 2020). A double-blind randomized controlled trial found evidence suggesting that cricket powder improved gut health and reduced inflammation; however, the authors called for more studies (Stull *et al.*, 2018).

In sum, considerable evidence has accumulated on the health effects of dietary intakes of milk and dairy products. Findings suggest protective effects for several health outcomes: all-cause mortality; hypertension; stroke; breast and colorectal cancers; type 2 diabetes; metabolic syndrome; and fractures. Evidence for the effects of milk and dairy intakes on coronary heart disease is equivocal, and there may be some increased risks in the cases of prostate cancer, Parkinson's disease and iron-deficiency anaemia, but heterogeneity and confounding across the respective studies may lessen the strength of the findings. The evidence for egg consumption largely points to null effects on a range of chronic-disease outcomes in adults. Meat has been studied fairly extensively in adult populations, although limitations related to design heterogeneity, focus on high-income countries and risk of biases preclude definitive conclusions. Consumption of muscle tissue from a range of animals improves iron status and reduces anaemia. While evidence has shown unequivocally that processed red meat consumption increases risk of mortality and chronic disease outcomes (cardiovascular disease and colorectal cancer), recent systematic reviews and meta-analysis have found unprocessed red meat intake to have non-significant effects on health outcomes and biomarkers of chronic diseases. Poultry consumption has been studied to a lesser extent, with evidence indicating that it has non-significant effects on chronic disease. More research is needed on the potential health benefits and risks of consuming meat from hunting and wildlife farming and of consuming insects.

3.5

Older adults

Several physiological processes occur during aging that may alter dietary needs (Solomons, 2013). At the cellular level, senescence or growth arrest of replicating cells commences and leads to altered protein expression and increased oxidative stress due to accumulation of iron and other inflammatory factors. Tissues (e.g. depigmentation of hair or loss of connective tissue in skin) and whole systems may change during aging (Brown, 2019). Inflammatory processes and alterations in blood flow and neurotransmitter metabolism can influence cognition and memory. There has been increasing interest in the potential role of TASF in addressing some of these deficits in older adults, although the evidence base remains minimal compared to that for other life-course phases. One example of a nutrient that is found concentrated in TASF and whose role in healthy aging is attracting interest is choline, which has been shown to improve memory, among other neuroprotective effects (Blusztajn, Slack and Mellott, 2017).

TASFs contain nutrients and bioactive compounds that may be critical for preserving muscle mass and bone health and reducing brain disorders and impaired cognition among older adults (Cardoso, Afonso and Bandarra, 2016). Sarcopenia is the loss of muscle or lean body mass in the aging process (Santilli *et al.*, 2014). Protein metabolism changes with age such that protein synthesis cannot compensate for protein catabolism (Baum, Kim and Wolfe, 2016). Investigators have suggested increasing high-quality protein intakes in older adults to 25 to 30 g per meal (Paddon-Jones and Rasmussen, 2009). Meat containing bioactive compounds such as creatine and carnitine has been hypothesized to counteract some of the above-mentioned problems (Phillips, 2012). One narrative review showed that the consumption of 113 g of meat five times a week would be the optimal dietary intake level in older adults for addressing sarcopenia (Rondanelli *et al.*, 2015). Relatedly, TASF may protect bone health and prevent osteoporosis, which results from the body's inability to replace old bone with new bone tissue. For both men and women, dietary nutrient requirements for some minerals increase after the age of 65 years, notably calcium and magnesium. These minerals, as well as vitamin D, are needed to prevent bone loss and related frailty fractures in aging people (Bonjour *et al.*, 2013). Finally, TASFs that provide DHA, such as eggs, may be important for enhancing memory, preventing macular degeneration and brain disorders, and neuroprotection more broadly (Cardoso, Afonso and Bandarra, 2016).

There is increasing epidemiological evidence, particularly from high-income countries, related to the effects that dietary intakes of TASF have on nutrition and health outcomes among older adults. However, this evidence has limitations. For example, older adults are sometimes grouped with other adults in the literature. Moreover, they experience more medical conditions than people in other life-course phases. Given that this assessment covers studies in apparently healthy populations, the latter factor limits the breadth of evidence available for older adults.

Milk and dairy consumption in older adults, or earlier in the life course with impacts measured in older adults, has been evaluated for nutrition (sarcopenia), health (frailty) and cognitive outcomes (cognitive decline, Alzheimer's). A narrative review examining the effects of dairy intakes on sarcopenia, frailty and cognitive decline among older adults (Cuesta-Triana *et al.*, 2019) found only six relevant studies: five observational prospective cohort studies and one randomized-controlled trial. High consumption of dairy products was found to be associated with reduced frailty and sarcopenia through improved skeletal muscle mass. The authors highlighted two prospective-cohort studies conducted in Japan that demonstrated positive effects on cognition, although across all studies the effects on cognition were equivocal. The Cuesta-Triana review also found that milk consumption in midlife may diminish verbal memory performance later in life. Another literature review examined the effects of milk and dairy consumption in terms of preventing dementia and Alzheimer's disease (Bermejo-Pareja *et al.*, 2021). Again, the two prospective cohort studies from Japan provided evidence supporting an effect – one showing that high milk intake (almost daily compared to less than four times a week) reduced the odds of vascular dementia (Yamada *et al.*, 2003) and the other finding that increased consumption of milk and dairy reduced the risk of Alzheimer's disease (Ozawa *et al.*, 2014).

Another systematic review (Granic *et al.*, 2020), which covered intervention and observational trials examining whole foods, including TASFs, for effects on muscle health and sarcopenia, reported consistent and robust findings for beneficial effects of lean red-meat and dairy-food consumption on muscle mass or lean tissue mass. Evidence for eggs and fish was inconclusive.

Other recent experimental trials not included in the systematic reviews were identified for this assessment. A cluster RCT was carried out in Australia across 60 residential age-care facilities (n=7 195 participants, mean age 86±8.2 years) (Iuliano *et al.*, 2021). Thirty residential facilities received additional milk, yoghurt and cheese as the intervention. Results showed that risks were reduced by 33 percent for all fractures (hazard ratio 0.67, 95% CI: 0.48-0.93; P=0.02), by 46 percent for hip fractures (HR 0.54, 95% CI: 0.35-0.83; P=0.005) and by 11 percent for falls (HR 0.89, 95% CI: 0.78-0.98; P=0.04). Significance was reached for falls by three months of dairy intake and for hip fractures by five months. No difference in mortality risk was observed. Another cluster randomized-controlled trial, also in Australia, tested the effects of lean red meat, 160 g/d consumed six days/week with progressive resistance training, on muscle health (Daly *et al.*, 2014). Compared to the control group, which received progressive resistance training but no lean red meat, the intervention group showed greater gains in total body and leg lean-tissue mass and muscle strength. A similar randomized-controlled trial in a different Australian setting provided some contrasting findings. In a six-month bundled intervention with three-day/week resistance training combined with either two 80 g servings of cooked lean red meat or approximately 225 g of cooked pasta or rice (control) on training days (n=154; age ≥ 65 years), no significant differences were found between the two groups in terms of changes in total body and leg lean mass. There were also no significant differences between the groups in terms of changes in thigh muscle cross-sectional area, leg and back muscle strength, executive and cognitive functioning, systolic blood pressure or physical function. The lean red meat group had greater improvements in arm lean mass, gait speed, muscle density and appendicular lean mass than the control group. The control group had significantly greater improvements for indicators of memory and learning at 12-week and 24-week follow-up points in the study (Formica *et al.*, 2020).

Other small-scale dietary intervention studies have been conducted in older adults – one assessing the effect of replacing meat with a soy-based diet in post-menopausal women (Roughead *et al.*, 2005) and the other comparing a lactovegetarian diet with a meat diet in older men (Haub *et al.*, 2002). Neither showed significant differences between the diets in terms of effects on health outcomes. Another study, carried out in the Netherlands, showed that consuming a fermented milk drink improved bowel habits in older adults (van den Nieuwboer *et al.*, 2015).

A large prospective cohort study (n=16 948) (Jiang *et al.*, 2020) assessed the relationship between consumption of different types of meat (red meat, poultry, fresh fish/shellfish, preserved fish/shellfish) during midlife (mean age at baseline: 53.50±6.23 years) and cognitive outcomes during later life (mean age at endline: 73.18±6.41 years). Based on a cohort from the Singapore Chinese Health Study, the findings indicated that individuals in the highest quartile of red-meat consumption (median intake: 48.61 g/day) had significantly higher odds of cognitive impairment (OR 1.16, 95% CI: 1.01-1.32, P for trend = 0.009) than those in the lowest quartile (11.81 g/day). On the other hand, poultry intake in the highest quartile (median intake: 37.18 g/day) was found to be protective against cognitive impairment, although this relationship was not statistically significant (OR 0.89, 95% CI: 0.78-1.02, P for trend = 0.10).

In sum, epidemiological evidence for the health effects of TASF consumption in older adults comes primarily from high-income countries. There is consistent strong evidence that lean red meat consumption has positive effects on muscle health, while one prospective cohort study examining unprocessed and processed red meat has suggested that consumption increases the likelihood of cognitive impairment, except in the case of organ meat. Other evidence suggests that milk and dairy products and other TASFs have potential in mitigating sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer's disease.

4. Allergies related to terrestrial animal source food

Food allergies vary in prevalence, severity and potency (FAO and WHO, 2021a). They represent a key concern at both individual and food business operator levels (Sicherer and Sampson, 2018; Taylor, 2000). According to the Codex Alimentarius Expert Committee on Food Allergens (FAO and WHO, 2021b), among the many different TASFs analysed, egg and milk were found to pose allergenic risks to the population. It is therefore often mandatory for allergen labelling on food products to indicate the presence of eggs or milk if they are among the ingredients (FAO and WHO, 2020). The rationale behind such rules and the potential risks posed by milk and egg allergies are discussed below.

4.1

Milk sensitivity

Milk sensitivity can be caused by lactose or by milk proteins (Muehlhoff *et al.*, 2013). In the former case the sensitivity is caused by the non-digestion of lactose, the main sugar present in human and other mammals' milks, because of lactase deficiency. In the latter, there is an adverse reaction to proteins. The two types of sensitivity have different symptoms, diagnosis and management or treatment. Box C5 provides a glossary of terms used in this section and explains the differences between them.

Lactase deficiency and lactose malabsorption are not diseases but normal variants of human metabolisms. They thus differ from congenital lactase deficiency, which is a very rare genetic disorder. According to a recent systematic review (Storhaug, Fosse and Fadnes, 2017), the global prevalence of lactose malabsorption among individuals older than ten years is estimated to be 68 percent, with significant differences across regions and among countries (see Figure C3). Some of these variations relate to differences in assessment methods, definitions or thresholds or to limitations associated with the lack or non-representativeness of data from some countries. Lactose malabsorption is

Box C5. Terms related to allergies and intolerances caused by milk

Lactase deficiency: also called lactase non-persistence, is the inability to digest large amounts of lactose. Lactose is digested and absorbed by the body thanks the enzyme lactase, concentrations of which are highest during infancy and decrease after weaning (Misselwitz *et al.*, 2019).

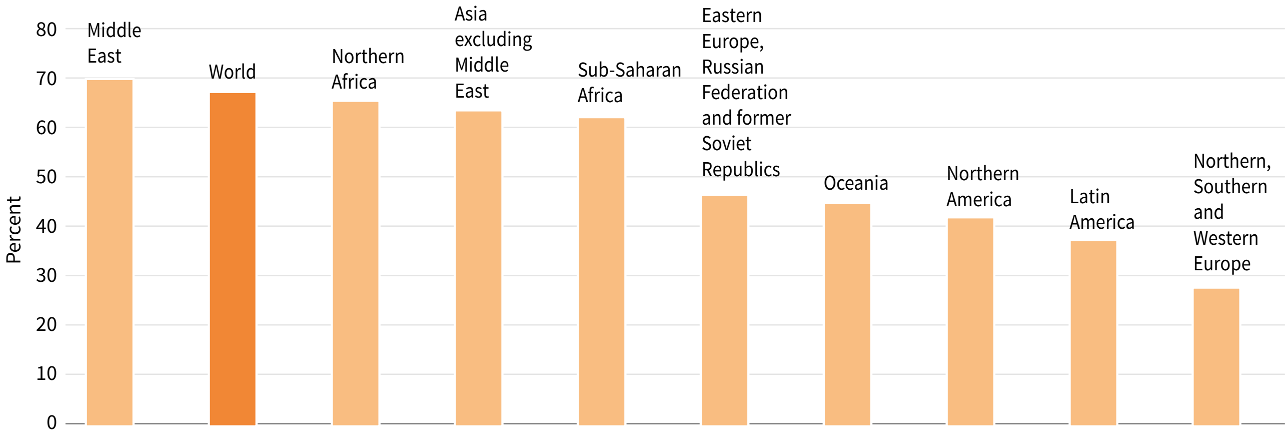
Congenital lactase deficiency: a very rare genetic disorder (e.g. ranges in western European populations are between 1 in 23 000 and 1 in 44 000 births) that appears right after birth and has severe symptoms, such as delayed mental development and death, frequently caused by a fulminant E. coli sepsis (EFSA, 2010).

Lactose malabsorption: refers to failure to digest and/or absorb lactose in the small intestine. Lactose malabsorption can have various causes: primary lactose malabsorption (the most common form) is caused by lactase deficiency, whereas secondary lactose malabsorption can be transitory and be caused, inter alia, by rapid small-intestinal transit or small-bowel bacterial overgrowth (Misselwitz *et al.*, 2019). Not all individuals with lactose malabsorption have lactose intolerance.

Lactose intolerance: indicates symptoms associated with the ingestion of food containing lactose, for example abdominal pain, bloating and diarrhoea. Individuals with lactose intolerance have different levels of tolerance of dairy products. In some people with lactose malabsorption, less than 6 g of lactose can lead to symptoms of lactose intolerance. However, according to the European Food Safety Authority Panel on Dietetic Products, Nutrition and Allergies, the vast majority can tolerate up to 12 g with no symptoms or minor ones (EFSA, 2010). According to a systematic review on the management of lactose intolerance (Shaukat *et al.*, 2010), this figure is between 12 g and 15 g, whereas another review (Deng *et al.*, 2015) indicates that the figure is 20 g in lactase-deficient individuals. Furthermore, the severity of symptoms in people with lactose intolerance depends on the dosage and the type of food consumed as well as on the individual's microbiome and whether visceral hypersensitivity (e.g. irritable bowel syndrome) is present (Misselwitz *et al.*, 2019).

Milk-protein allergy: also called cow's milk allergy, is an immune-mediated adverse food reaction to milk proteins and can be caused by immunoglobulin E (IgE) mediated, non-IgE mediated or mixed reactions (Di Costanzo and Berni Canani, 2018). Around 60 percent of those with cow's milk allergy have the IgE mediated form (Flom and Sicherer, 2019), although there is some variation across populations and age groups. Although cow's milk contains approximately 20 potentially sensitizing proteins (Fiocchi *et al.*, 2010), those involved in cow's milk allergy are mainly β Lactoglobulin and casein (Muehlhoff *et al.*, 2013). Cow's milk allergy is one of the most common food allergies, especially in the first year of life, but tends to be outgrown by patients at around the age of two to five years (Di Costanzo and Berni Canani, 2018). Symptoms of cow's milk allergy include gastrointestinal, skin and respiratory reactions (Fiocchi et al., 2010). Clinical manifestations of IgE-mediated cow's milk allergy are usually immediate (from a few minutes to two hours) and include urticaria and/or angioedema, with vomiting and/or wheezing (Lifschitz and Szajewska, 2015). Mixed and non-IgE mediated cow's milk allergy tend to have delayed onset and mainly involve the gastrointestinal tract and the skin. In general, cow's milk allergy causes mild to moderate reactions; anaphylaxis, a life threatening reaction, is rare (1-2 percent) (Lifschitz and Szajewska, 2015).

Figure C3. Prevalence of lactose malabsorption by region



Source: Storhaug, C.L., Fosse, S.K. & Fadnes, L.T. 2017. Country, regional, and global estimates for lactose malabsorption in adults: a systematic review and meta-analysis. *The Lancet Gastroenterology & Hepatology,* 2(10): 738 746. https://doi.org/10.1016/S2468-1253(17)30154-1

Table C3. Lactose content in milk from livestock species

Species	Lactose (g/100 g milk)
Buffalo	4.4
Cattle	5.2
Mithan	4.4
Yak	4.8
Goat	4.4
Sheep	5.4
Alpaca	5.1
Bactrian camel	4.2
Dromedary	4.3
Llama	6.3
Reindeer	2.9
Donkey	6.4
Horse	6.6

Note: Nutrient values expressed per 100 g edible portion on a fresh weight basis.
Source: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx; Balthazar, C.F, Pimentel, T.C., Ferrão, L.L., Almada, C.N., Santillo, A., Albenzio, M., Mollakhalili, N. *et al.* 2017. Sheep milk: physicochemical characteristics and relevance for functional food development. Comprehensive Reviews in Food Science and Food Safety, 16(2): 247–262. https://doi.org/10.1111/1541-4337.12250; FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov/; Frida. 2021. Frida - Database med fødevaredata udgivet DTU Fødevareinstituttet. [Cited 15 December 2021]. https://frida.fooddata.dk/; Medhammar, E., Wijesinha-Bettoni, R., Stadlmayr, B., Nilsson, E., Charrondiere, U.R. & Burlingame, B. 2012. Composition of milk from minor dairy animals and buffalo breeds: a biodiversity perspective. Journal of the Science of Food and Agriculture, 92(3): 445 474. https://doi.org/10.1002/jsfa.4690; Tabla de Composición de Alimentos Colombianos. 2021. Tabla de Composición de Alimentos Colombianos. In: Portal ICBF - Instituto Colombiano de Bienestar Familiar ICBF. [Cited 3 February 2022]. https://www.icbf.gov.co/bienestar/nutricion/tabla-alimentos.

significant in the Middle East (70 percent of the population, ranging from 56 percent in Israel to 96 percent in Oman), Northern Africa (66 percent, ranging from 53 percent in Western Sahara to 84 percent in Tunisia), Asia (64 percent, ranging from 58 percent in Pakistan to 100 percent in the Republic of Korea) and sub-Saharan Africa (63 percent, ranging from 13 percent in Niger to 100 percent in Malawi and Ghana).

In northern and western Europe, the prevalence of lactose malabsorption is low to moderate (4-36 percent), whereas in eastern Europe it is moderate to high (28-81 percent). The figure for Latin America is 38 percent (ranging from 48 percent in Mexico to 80 percent in Colombia), for Oceania 45 percent (ranging from 10 percent in New Zealand to 99 percent Solomon Islands) and for northern America 42 percent. Interestingly, in Canada and Australia, native populations show different prevalences from the rest of the respective national populations. There is a hypothesis that selection has played a role in maintaining lactase persistence in populations where cattle have been important in order to allow digestion of dairy products. This is the case in Northern Europe (Storhaug, Fosse and Fadnes, 2017) and among pastoralists in Africa, the Arabian Peninsula and Central Asia (Ranciaro *et al.*, 2014). Evershed *et al.* (2022) have linked the evolution of lactase persistence in Europe, beginning in the Early Neolithic period, to both the crisis mechanism, where the selection was driven by famine, and the chronic mechanism based on the increased exposure.

Not all animal milk and dairy products contain the same level of lactose (see Tables C3 and C4). Lactose content in 100 g of milk ranges from 2.9 g in reindeer milk to 6.6 g in horse milk and from as low as zero in ghee and various types of cheese, such as hard cheese and blue/white mould cheese, to around 5 g in buttermilk and yoghurt.

Table C4. Lactose content in dairy products

Dairy product	Lactose (g/100 g milk)
Buttermilk	4.9
Yoghurt	5.1
Milk powder	4.3
Cream	3.7
Sour cream	4.6
Ice cream	4.4
Fresh cheese	2.3
Soft cheese	0.9
Butter	0.03
Blue mould cheese	0
Hard cheese	0
White mould cheese	0

Note: Nutrient values expressed per 100 g edible portion on a fresh weight basis.
Source: Australian Food Composition Database. 2021. Australian Food Composition Database. [Cited 3 February 2022]. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/pages/default.aspx
FoodData Central USDA. 2021. FoodData Central. [Cited 15 December 2021]. https://fdc.nal.usda.gov/.

Live cultures contained in yoghurt and other dairy products with added live cultures are able to support lactose digestion in the gut, thus reducing the likelihood of symptoms associated with lactose intolerance (Muehlhoff *et al.*, 2013).

Individuals with lactose intolerance who avoid milk and dairy products may have reduced intake of calcium, which in turn can cause rickets in young children and low bone mineral density and higher risk of fracture in adults (Hodges *et al.*, 2019). WHO (2019) indicates that calcium intakes lower than 300 mg/day are associated with an almost fivefold increase in the risk of developing rickets.

A number of factors influence tolerance of or sensitization to cow's milk, including genetic predisposition, infections, alteration of intestinal microflora, age at first exposure, maternal diet, antigen transmission through breastmilk, and the nature, quantity and frequency of antigen load (Fiocchi *et al.*, 2010).

According to a recent review (Flom and Sicherer, 2019), the prevalence of cow's milk allergy (CMA) in high-income countries at one year of age ranges between 0.5 percent and 3 percent. The authors focus specifically on IgE mediated CMA and observe that available studies are very heterogeneous, making comparison and estimates difficult. In a review of nine guidelines published between 2012 and 2019, Vincent *et al.* (2022) indicate that existing CMA guidance for infants may lead to caregivers mistaking normal infant reactions to cow milk for CMA, and therefore to overdiagnosis. It seems that 70 percent of children with CMA can tolerate baked foods containing milk if extensively heated (Sicherer and Sampson, 2018). In cross-sectional studies a CMA prevalence of 0.6 percent to 2.5 percent of pre-schoolers, 0.3 percent of older children and teens, and less than 0.5% percent of adults is reported (Fiocchi *et al.*, 2010).

WHO's guiding principles on complementary feeding indicate that there is no evidence that avoiding potentially allergenic foods (such as eggs and milk) after the age of six months can delay or prevent reactions (PAHO, 2003). However, they advise delaying consumption of liquid milk until after 12 months of age because of the risk of contamination wherever hygiene is poor. Diets that completely exclude milk, especially long-term diets of this kind, need to be monitored to control for nutritional adequacy, as there is a risk of negative outcomes, and there should be a passage to normal diets as soon as feasible (Fiocchi *et al.*, 2010).

4.2 Egg hypersensitivity

Egg hypersensitivity is one of the most frequent food allergies and has an estimated prevalence of 1.7 percent (Hasan, Wells and Davis, 2013). It is the most common food allergy in children with atopic dermatitis (Benhamou *et al.*, 2010). While the first studies date back to the 1980s (Hasan, Wells and Davis, 2013), egg hypersensitivity is a complex phenomenon that has only partially been characterized (Benhamou *et al.*, 2010). Ovomucoid, one of the proteins found in egg white, is the dominant allergen, although it only makes up 10 percent of egg-white protein (Benhamou *et al.*, 2010). Unlike other egg proteins, ovomucoid is heat-resistant.

Clinical signs usually appear during the first year of life (Benhamou *et al.*, 2010) and can include hives, wheezing, vomiting, eczema, asthma and, very rarely, anaphylaxis (Hasan, Wells and Davis, 2013). Mild reaction in the past does not exclude severe reactions in the future, and vice versa (Hasan, Wells and Davis, 2013).

Some initial studies related to the resolution of the condition have indicated that the majority of children outgrow egg allergy before they reach school age, while others do so during their late teens (Hasan, Wells and Davis, 2013). Consumption of baked or well-cooked eggs (350 °C for 20 minutes) can accelerate the development of tolerance to eggs (Hasan, Wells and Davis, 2013).

As in the case of eggs, WHO recommendations on complementary feeding advise introducing eggs at six months, as no evidence is available on the benefit of delayed consumption for the purpose of allergy prevention (PAHO, 2003).

5. Policies shaping consumption of terrestrial animal source food

Food and nutrition-related policies inform food consumption patterns at national, regional and global levels (FAO, IFAD, UNICEF, WFP and WHO, 2021). This subsection explores how policy can shape the food system, thereby influencing consumption of common TASFs, such as milk and dairy products, red meat, poultry and eggs.

Food, nutrition and health policies can have a significant impact on the quantity and diversity of TASF consumed by the public (Bechthold *et al.*, 2018). Unlike agricultural and supply-chain policies, which affect the quantity and quality of food produced, food-based policies influence the food system of an entire commodity sector. For example, according to a model developed by Springmann *et al.* (2020), moderation of red-meat consumption, as suggested by contemporary food-based dietary guidelines (FBDGs), could potentially reduce average greenhouse-gas emissions by 13 percent and premature mortality by 15 percent. Miller *et al.* (2021) note that 70 percent of FBDGs encourage increased dairy consumption, while less than 55 percent advocate increased consumption of meat. The authors suggest that these guidelines may have influenced school feeding policies, many of which now aim to reduce or moderate meat consumption while increasing dairy consumption in order to improve health and environmental sustainability.

National, regional and global policies must balance the various implications of TASF consumption (Herforth *et al.*, 2019). This means adjusting consumption recommendations based on their health outcomes in the generic population and among vulnerable groups and concerns over environmental and socio-economic impacts, while accounting for emerging ethical concerns such as animal welfare (Dave *et al.*, 2021). As these policies evolve, it will be important to take stock of the changes made and ensure that recommendations align with the contexts they aim to influence.

In view of the importance of policy, the following five sets of food and nutrition-related instruments (see Box C6)were reviewed as part of this assessment in order to determine trends in global policy on TASF consumption: FBDGs from the FAO FBDG website (FAO, 2021a); NCD policy from the WHO NCD document repository (WHO, 2021a); nutrition policy from the WHO global database on the implementation of nutrition action (GINA) (WHO, 2021); food legislation from the FAOLEX database (FAO, 2021c); and food and agriculture policy decisions from the FAO Food and Agriculture Policy Decision Analysis (FAPDA) Database (FAO, 2021d).

Nutrition policies and programmes are guidance documents or policy frameworks that contain diet-related guidelines and commitments related to healthy diets and nutrition outcomes (WHO, 2018). These documents often aim to address local malnutrition-related issues such as stunting and wasting in children under five years of age. The WHO Global Database on the Implementation of Nutrition Action (GINA) is a repository of such documents.

All documents were reviewed manually to identify policies related to TASF consumption. Documents were considered in all languages, as published. FBDGs from all years available on the FAO food-based dietary guideline website were included in the review. For the other above-mentioned databases, all documents published from 2016 to 2021 were considered. Both the search terms and keywords used in each database are detailed in Box C6. In addition to the search criteria and keywords, the review considered the following for each policy recommendation: country; region; quantitative/qualitative status; target group within the life cycle (general [adults], infants, young children, adolescents, women of reproductive age, pregnant women, lactating women, older men, older women, older adults in general); and document type (FBDG, NCD, nutrition recommendation, policy framework) (see Annex Tables C10-C15). The flow diagram presented in Figure C4 summarizes the process.

The review also considered whether recommendations relate to human micronutrient needs, overweight, obesity or diet-related NCDs such as diabetes, cardiovascular disease and cancer, whether they include environmental sustainability considerations (e.g whether recommended serving sizes are based on environmental considerations) and whether they follow a life-course approach (with a focus on meeting the needs of nutritionally vulnerable individuals). In addition, the review noted references to an emerging topic of concern – animal welfare.

Box C6. Food and nutrition-related policy instruments

Food-based dietary guidelines (FBDGs)

FBDGs are government-endorsed documents that promote healthy diets (Wijesinha-Bettoni *et al.*, 2021). They typically aim to influence the food environment and consumer behaviour, guiding individuals towards choosing/demanding healthier diets (Leroy and Cofnas, 2020). FAO takes a leading role in providing technical support for their development: a full list of national FBDGs is provided on the FAO website (FAO, 2021a).

Non-communicable disease (NCD) policy documents

NCD documents are targets, policies and guidelines that focus on the prevention and treatment of NCDs, such as obesity, diabetes, cardiovascular disease and cancer (Boudreaux *et al.*, 2020). These documents often make dietary recommendations, with the primary goal of either reducing the symptoms of an NCD or supporting healthy lifestyle choices that reduce NCD risk. TASF consumption is a common theme, with lean meat, egg and low-fat dairy intakes suggested as good sources of micronutrients that support growth and prevent undernutrition. Moderating or reducing consumption of fatty meat, processed meat and red meat is suggested as a means of reducing the risk of obesity, cardiovascular disease and cancer (Herforth *et al.*, 2019). The WHO NCD repository contains a rich set of global NCD documents, making it an ideal source for NCD-related national publications.

FAOLEX

FAOLEX is a repository of national laws, regulations and policies on food, agriculture and natural-resources management. Legal and regulatory documents and policy frameworks have strong implications for the food systems within their remit. For example, Mexico's use of fiscal policy to tax soft-drinks has led to a reduction in the consumption of sugar-sweetened beverages among young children and adolescents (Thow *et al.*, 2018). Another example is the mandatory fortification of grain products with folic acid in several countries, which has significantly reduced the prevalence of spina bifida in newborn babies globally (Martinez *et al.*, 2021). Many countries have implemented food policies and legislation related to the consumption of TASF, with legislation often targeting school feeding programmes (Miller *et al.*, 2021).

FAO's database on national policy documents (FAPDA)

Like FAOLEX, FAPDA contains national documentation related to food, agriculture and natural-resources management. FAPDA, however, focuses mainly on policy framework decisions, which define the basis for broad-based strategic, programmatic and financial planning on food systems, including those linked to the consumption of food produced by the livestock sector.

Sources:

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Box C7. Search terms used to search policy databases

Common search terms

(“animal source foods”, “livestock products”, “egg”, “meat”, “poultry”, “milk”, “dairy”, “cheese”, “game”, “bushmeat”, “insect”, “NCD”, “non-communicable disease”, “obesity”, “diabetes”, “cancer”, “cardiovascular”, “sustainability”, “animal welfare”, “red meat”, “white meat”, “micronutrient”, “vitamin”, “mineral”)

Search terms using the WHO NCD database

(“integrated NCD policies”) AND (“cardiovascular disease policies”); (“cancer policies”) AND (“diabetes policies”) AND (“chronic respiratory disease policies”); (“obesity policies”) AND (“diet policies”); (“front-of-pack-labelling policies”) AND (“marketing policies”); (“saturated fat policies”) AND (“integrated guidelines”) AND (“cancer guidelines”); (“cardiovascular guidelines”) AND (“chronic respiratory disease guidelines”); (“diabetes guidelines”) AND (“obesity guidelines”)

Search terms using the FAOLEX database

(“infant food”) AND (“animal production”); (“family farm”) AND (“food security”) AND (“production”); (“nutrition”) AND (“meat”); (“eco production”) AND (“meat”); (“nutrition”) AND (“meat”) AND (“public health”); (“animal welfare”) AND (“animal production”); (“animal welfare”) AND (“animal production”) AND (“eco production”); (“poverty”) AND (“meat”); (“use restrictions”) AND (“meat”); (“food security”) AND (“meat”); (“poultry”) AND (“food security”); (“food sovereignty”) AND (“animal production”); (“school feeding”) AND (“meat”); (“environmental protection”) AND (“animal production livestock”); (“fats”) AND (“labelling”) AND (“public health”); (“insects”) AND (“food security”)

Search terms using the FAPDA database

Policy classification: “consumer oriented” AND “producer oriented” AND “trade oriented”

Food security dimension: “access” AND “access/availability/utilization of food” AND “access/availability of food” AND “access to food” AND “availability” AND “availability/access/utilization of food” AND “availability/access to food” AND “availability of food” AND “utilization” AND “utilization of food”

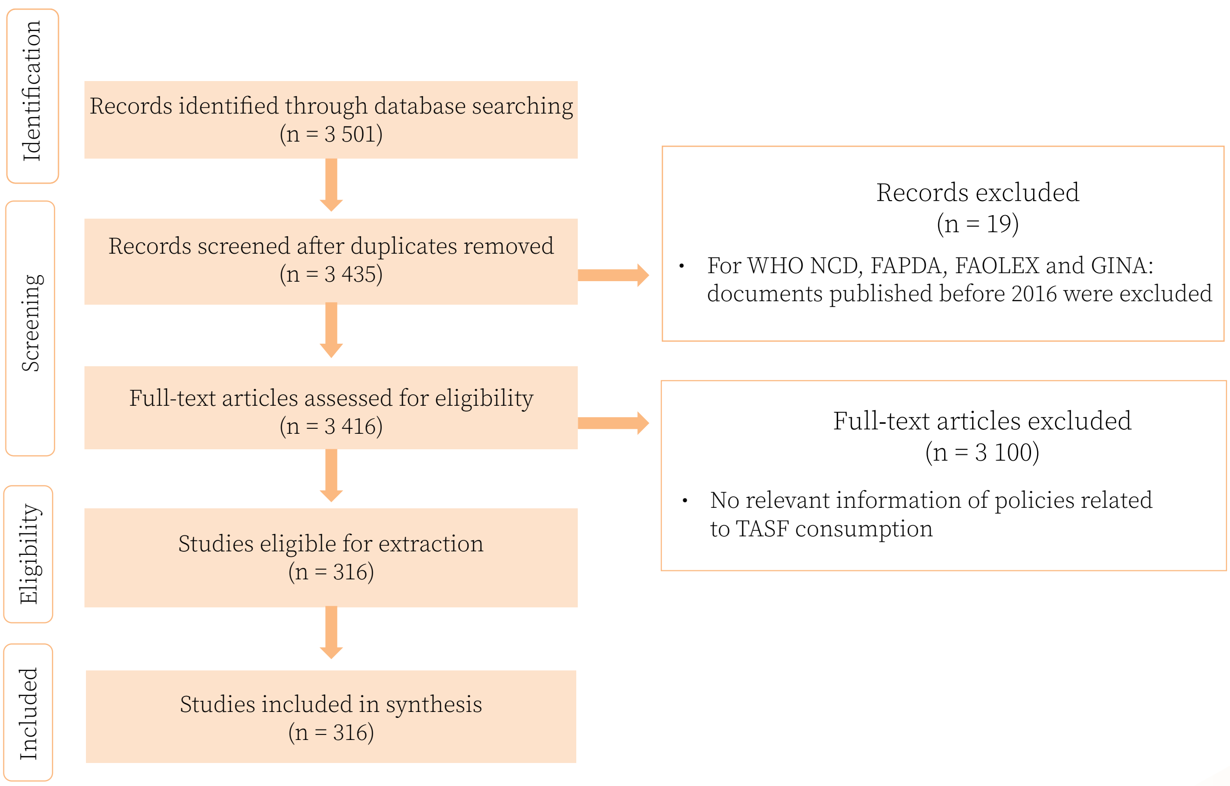
Commodity: “meat and other animal derived products”

Policy frameworks: “food security and nutrition” AND “agricultural and rural development”

Search terms using the GINA database

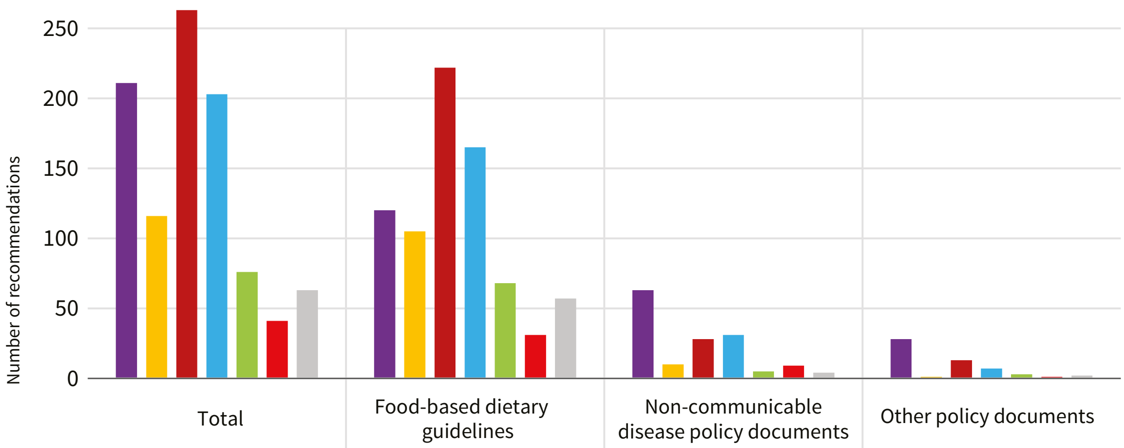
(“animal source foods”, “livestock”, “egg”, “meat”, “poultry”, “milk”, “dairy”, “fish”, “bushmeat”, “insect”, “sustainability”, “animal welfare”)

Figure C4. PRISMA Flow diagram assessing policy trends related to TASF consumption



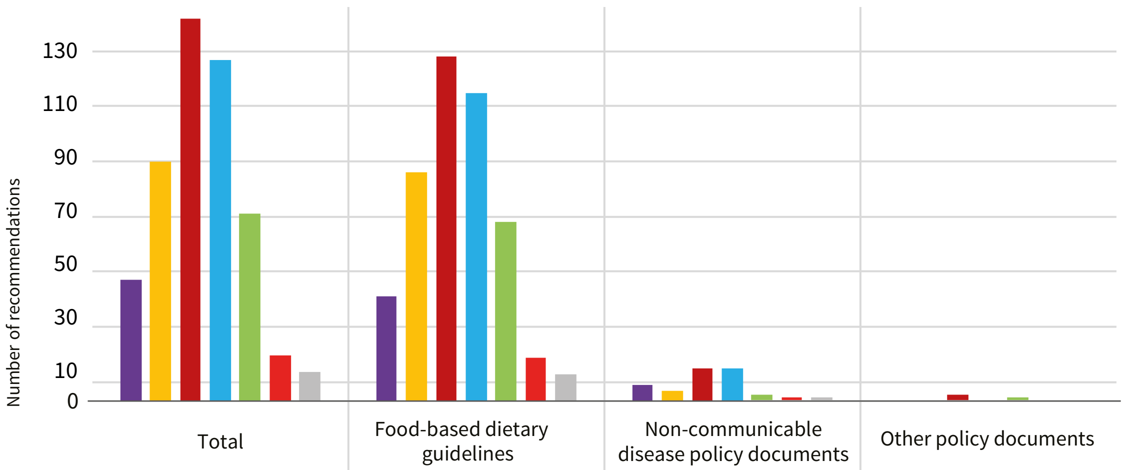
Recommendations on consumption of terrestrial animal source foods: This subsection discusses the collated results obtained from the five databases analysed. Most recommendations are found in the FBDGs, which also contain the highest number of quantitative recommendations, mostly on milk, dairy products, eggs and meat (see Figures C5 and C6). One example of quantitative recommendations is the following from China: "the recommended daily intake for lean meat is 120-200 g" (Chinese Nutrition Society, 2016). The other types of policy document have fewer recommendations, and these are mostly qualitative and largely generic. One example of a qualitative recommendation is the following from Nigeria: "children 25-60 months of age should consume meat, milk and eggs when possible" (Federal Ministry of Health Abuja, 2006).

Figure C5. **Qualitative recommendations on terrestrial animal source food, by type of policy document**



	Total	Food-based dietary guidelines	Non-communicable disease policy documents	Other policy documents
Terrestrial animal source foods	211	120	63	28
Eggs	116	105	10	1
Meat	263	222	28	13
Milk and dairy products	203	165	31	7
Poultry	76	68	5	3
Red meat	41	31	9	1
Others	63	57	4	2

Figure C6. **Quantitative recommendations on terrestrial animal source food, by type of policy document**



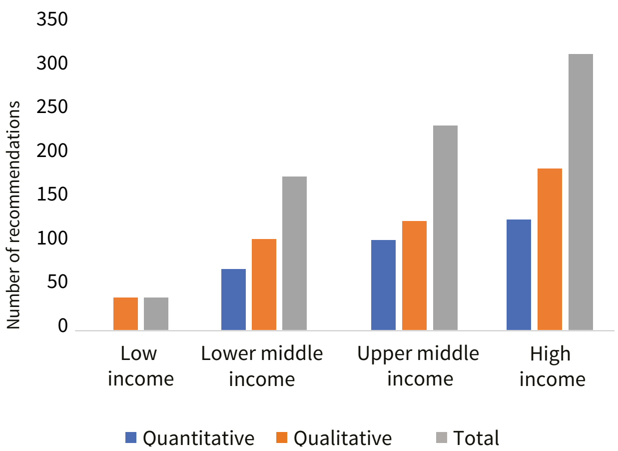
	Total	Food-based dietary guidelines	Non-communicable disease policy documents	Other policy documents
Terrestrial animal source foods	44	38	6	0
Eggs	87	83	4	0
Meat	139	125	12	2
Milk and dairy products	124	112	12	0
Poultry	68	65	2	1
Red meat	17	16	1	0
Others	11	10	1	0

Recommendations related to micronutrients: FBDGs from at least 95 countries acknowledge TASF consumption as part of the daily diet. The nutrient benefits of TASF are also recognized in NCD-related documents and in other legal documents and policy frameworks, with approximately 20 countries linking TASF consumption to a healthy diet.

Micronutrient-related recommendations in FBDGs are evenly distributed across country-income groups. However, the granularity of these recommendations was found to be variable across countries (Figure C7). For example, Sierra Leone's FBDG states that "animal source food tend to be better sources of some micronutrients than plant-source foods, particularly iron, zinc and calcium" (Government of Sierra Leone, 2016) and Kenya's mentions that "foods of animal origin, due to their high bioavailability in micronutrients and as an important source of protein play a key role in improving the nutritional condition of populations" (Kenya Ministry of Health, 2017), while New Zealand's states that "red meat is an excellent source of key nutrients like iron (in an easily absorbed form) as well as zinc; low iron levels are a problem for some New Zealanders, particularly young women" (Ministry of Health New Zealand, 2020) and Belgium's encourages citizens to "have at least three servings of dairy per day, as these are a good source of calcium and vitamin D" (Minister van Sociale Zaken en Volksgezondheid, 2020). Further examples from FBDGs are provided in Annex Table C7.

One instrument found in the FAOLEX database mandates serving dairy in school meals to boost nutritional status: Honduras's Law of the Glass of Milk for Strengthening School Lunch (Legislative Decree No. 452010) requires the serving of "a glass of milk to fortify the school snack" (Gobierno de la República de Honduras, 2018).

Figure C7. Quantitative and qualitative micronutrient recommendations, by country income classification



Quantitative recommendations, such as advice to consume three servings of 250ml of milk per day, are more frequently present in the FBDGs of middle- and higher-income countries than in those from other countries (Cocking *et al.*, 2020). These recommendations are often linked to specific age groups, for example the following statement from a document from New Zealand: "pre-schoolers should have two to three servings of milk and milk products per day" (Ministry of Health New Zealand, 2021). Lower-income countries tend to make more generic qualitative recommendations that indicate TASF as a good source of micronutrients, for example the following instance from Bangladesh: "meat/ poultry/ eggs are good sources of haem iron" (Bangladesh Institute of Research and Rehabilitation in Diabetes, Endocrine and Metabolic Disorders, 2013). Some of the most comprehensive recommendations on TASF consumption, covering specific food groups, vulnerable demographics and daily dietary guidelines, are to be found in FBDGs from high-income countries such as Denmark, New Zealand and the United Stated of America (Wyness, 2016) where average meat intake is well over 150 g/day (FAO, 2021e).

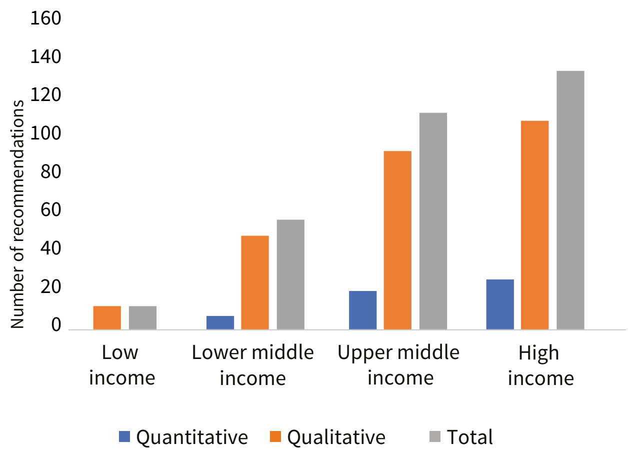
In the case of LMICs, there are some variations by region, with the majority of Latin American countries having some form of quantitative guidelines, while most African countries currently lack FBDGs and do not have TASF recommendations in their policy frameworks and legal documents. Interestingly, small-island developing states in general tend to lack detailed recommendations related not only to TASF consumption but also to most other food groups.

The above findings give rise to the following points for consideration. First, country income status plays a role in the development of more quantitative recommendations on micronutrient-related TASF consumption, but it does not necessarily result in the systematic inclusion of specific recommendations for nutritionally vulnerable groups or recommendations aimed at preventing TASF consumption above agreed levels associated with overweight, obesity and NCDs. Second, the level of detail in recommendations on TASF consumption within FBGDs varies even among lower-income countries, with public-health concerns likely to play a role; for example, overweight and obesity tend to be a growing issue in Latin American countries (Caballero *et al.*, 2017), which may explain the greater emphasis on quantitative recommendations in these countries relative to small-island developing states and African countries.

Recommendations related to non-communicable diseases: While the food legislation and food and agriculture policy decisions reviewed do not discuss NCD risks, the FBDGs and the NCD-related policies contain several recommendations on TASF selection and moderation in the diet. NCD-related recommendations from 55 countries were found, with approximately 317 specific recommendations, which is almost 50 percent less than the number of countries with micronutrient-related recommendations.

As with micronutrient-related recommendations, NCD-related recommendations are evenly distributed across country income groups (Figure C8). For example, Guatemala (Ministerio de Salud Pública y Asistencia Social, 2012) and Ecuador (Ministerio de Salud Pública Ecuador and FAO, 2021) respectively advise the general population to "consume lean meats up to four times per week" and "limit the consumption of red meat and avoid processed meats; do not eat more than 500 g (cooked weight) per week red meat, such as beef, pork and lamb; eat small amounts or no meat and processed meat such as sausages, hams, and bacon", while the United States of America (United States Department of Health and Human Services and United States Department of Agriculture, 2015) and Singapore (Health Promotion Board and Ministry of Health Singapore, 2016) respectively advise them to "reduce saturated fat intake" and note that "non-lean meats and dairy may cause weight gain."

Figure C8. **Quantitative and qualitative non-communicable disease recommendations, by country income classification**



NCD-related recommendations lack granularity, do not adequately target vulnerable groups and do not consider risks associated with the links between NCDs and micronutrient deficiency and overweight and obesity. Many of the frameworks and guidelines reviewed focus solely on reducing animal fat and processed-meat consumption as risk factors for overweight, obesity and NCDs. For example, the risk of obesity due to consumption of meat above specific levels is well-recognized in the French dietary guidelines for children aged below 36 months and for those aged between three and 17 years (Haut Conseil de la santé Publique, 2020), which states that "adolescents should consume no more than 500 g/week of meat." However, there is no acknowledgement of the risk to development or of anaemia associated with a lack of meat consumption. It is also notable that some countries with a recognized problem of the double burden of malnutrition focus only on the obesity, overweight and NCD-related risks associated with TASF consumption.

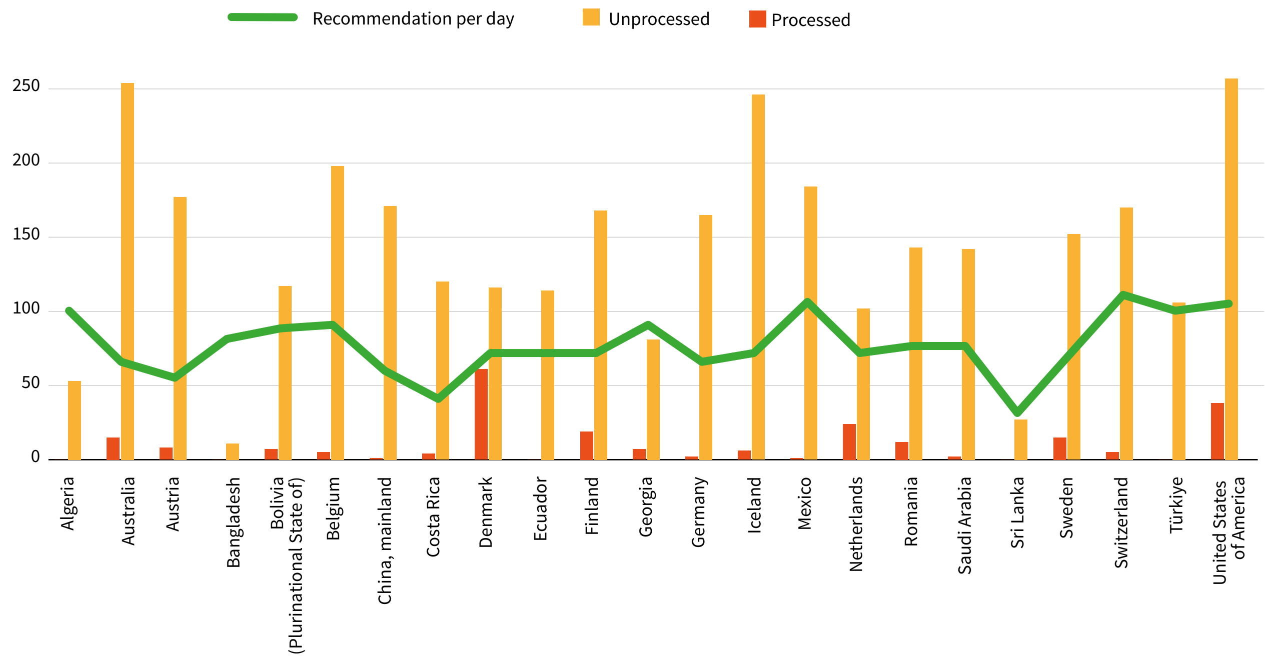
Only three out of the 317 recommendations found in NCD-related policies link TASF intake to undernutrition, including risks of micronutrient deficiencies. These recommendations are from the Dominican Republic (targeting undernourished individuals) (El Despacho de la Primera Dama República Dominicana, 2009), Lesotho (targeting children under five years of age) (Food and Nutrition Coordinating Office Lesotho, 2016) and Slovenia (targeting older adults) (Republic of Slovenia Ministry of Health, 2016).

Recommendations related to meat consumption: The distribution of quantitative recommendations by country for meat are presented in Figure C9. The data were obtained from a review of 123 FBDGs, 61 NCD documents, 41 policy frameworks and five nutrition policy recommendation documents from 127 distinct countries. These were found to contain 139 detailed quantitative meat-related recommendations in total, with variations in the recommended number of grams per capita per day and considerable gaps between the recommended daily intakes for meat and the average daily supply of unprocessed and processed meat for the respective countries as extrapolated from FAOSTAT's supply utilization accounts.

Recommendations related to environmental sustainability: Environmental sustainability concerns associated with livestock farming have come to the fore in recent years. As concerns over climate change have grown, as indicated by renewed commitments from countries at the 26th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in 2021, TASF consumption has come under the spotlight.

However, the review of recommendations on TASF consumption indicates that very few of these recommendations link TASF consumption directly to environmental

Figure C9. Consumption recommendations versus estimated average daily supply of unprocessed and processed meat

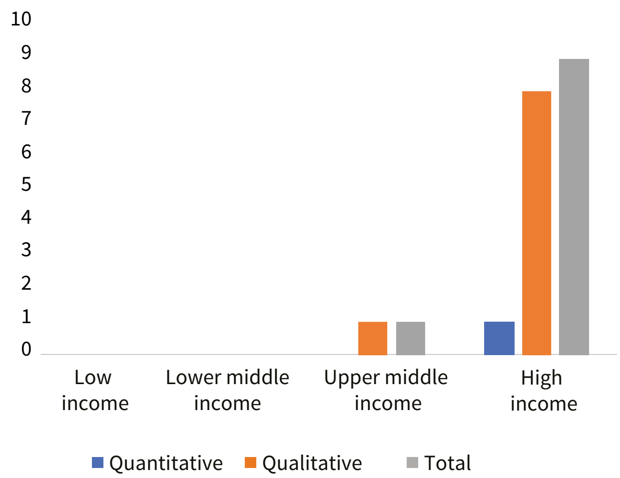


Note: All available quantitative data on recommended meat consumption (recommendations/guidelines specifically referring to "meat" as the target food group) were obtained from national FBDGs; qualitative data were excluded. The data were compared to supply data from FAOSTAT's supply utilization accounts (FAO. 2022. FAOSTAT. [Cited 3 February 2022]. https://www.fao.org/faostat/en/#data/SCL). Items from the element "food supply quantity (g/cap/day)" from 2019 were used. The "unprocessed meat supply (g/cap/day)" category included: meat nes; meat, ass; meat, bird nes; meat, buffalo; meat, camel; meat, cattle; meat, cattle, boneless (beef and veal); meat, chicken; meat, duck; meat, extracts; meat, game; meat, goat; meat, goose and guinea fowl; meat, horse; meat, mule; meat, other rodents; meat, pig; meat, pork; meat, rabbit; meat, sheep; meat, turkey; snails, not sea. The "processed meat supply (g/cap/day)" category included: bacon and ham; meat nes, preparations; meat, beef and veal sausages; meat, beef, dried, salted, smoked; meat, beef, preparations; meat, chicken, canned; meat, dried nes; meat, homogenized preparations; meat, pig sausages; meat, pig, preparations. Across all countries, standard data collection methods were used.

concerns. Only eight countries were found to have recommendations that make this link: Canada, Denmark, the Netherlands, Norway, Italy, South Africa, Sweden and Uruguay (Figure C10). The number of policy recommendations that connect TASF consumption and environmental sustainability is limited, probably because the global climate agenda for food systems is nascent and policy is updated only periodically. Most of the recommendations are qualitative, for example "to reduce the effect on the environment, eat a more plant-based diet and less meat" (Denmark) (Lassen *et al.*, 2020) or "there is evidence supporting a lesser environmental impact of patterns of eating higher in plant-based foods and lower in animal-based foods. Potential benefits include helping to conserve soil, water and air"(Canada) (Health Canada, 2019).

Only one quantitative recommendation was found: "to limit environmental impact, reduce consumption of meat to a maximum of 500 g per week, consume two to three portions of dairy products per day, more is not necessary and eat fish (only) once a week" (the Netherlands) (Stichting Voedingscentrum Nederland, 2020). A list of environmental sustainability recommendations is provided in Annex Table C8.

Figure C10. Quantitative and qualitative sustainability recommendations, by country income classification



TASF consumption can be excessive in high-income countries. A relative reduction in consumption may therefore benefit the environment. However, countries that wish to develop recommendations linked to environmental sustainability should ensure that they reflect local and regional realities. For example, some populations depend on agropastoral livelihoods and animal protein from livestock. Many populations, including those most nutritionally vulnerable, such as children, adolescent girls and pregnant and lactating women, have lower TASF consumption than the average of the national population, especially in low-income settings. At present, recommendations on TASF consumption linked to environmental sustainability are nascent and mostly driven by environmental concerns in high- income countries. If generalized without attention to context, they may run the risk of jeopardizing health (in addition to generating other risks, such as those related to the economy and trade balances). It is suggested that context-specific and granular recommendations are needed in all countries irrespective of their income classification (Adesogan *et al.*, 2020).

Recommendations related to animal welfare: Animal welfare is a contemporary topic in food and nutrition policy (Buller *et al.*, 2018). While the COVID19 pandemic has raised some concerns, most of world's countries do not account for animal welfare in their food and nutrition guidelines. In fact, out of 1 161 recommendations found in the review, there were only two related to animal welfare.

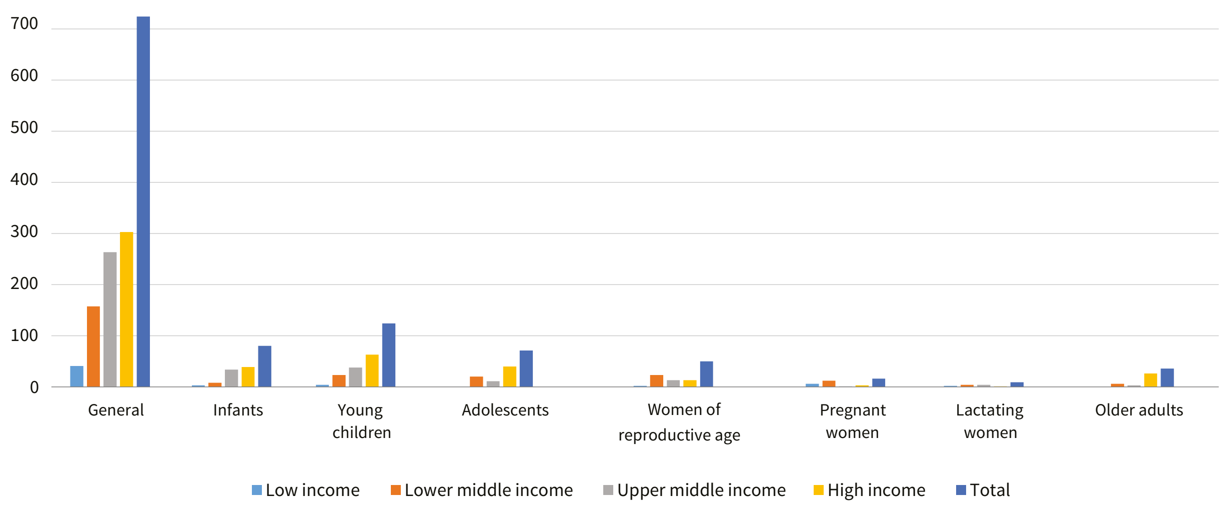
The Danish FBDGs, The official dietary guidelines – good for health and climate, suggest that "the state animal welfare label will enable consumers to select animals that live up to the requirements for animal welfare; this includes milk and milk products" (Lassen *et al.*, 2020). These guidelines recommend that labels including animal-welfare scores should be attached to TASF products to inform consumers about the quality of life had by the animals from which the products come. The Danish FBDGs suggest that consumers select foods that have a high animal-welfare score. Similarly, the Swedish FBDGs, The Swedish dietary guidelines – find your way to eat greener, not too much and be active, suggest that "if you cut back on meat, you'll have enough money for meat produced more sustainably, with attention paid to the welfare of the animals" (Livsmedelverket, 2015).

It remains to be seen whether labelling schemes such as those in Denmark and Sweden will gain traction, and how soon such policies will be adopted in LMICs. However, in planning any such measures it is prudent to consider the economic and nutritional concerns that may be associated them. As with environmental sustainability issues, introduction of animal welfare guidelines requires a multifaceted overview of the entire food system and all its drivers. Non-specific, generic guidelines may risk jeopardizing food and nutrition security.

Life-course analysis for vulnerable groups: Recommendations related to vulnerable groups feature in the FBDGs and in other policy documents. These include recommendations referring to pregnant and lactating women, infants, young children, adolescents and older adults. Of these groups, recommendations for adolescents, young children and infants are the most common. In total, 378 recommendations related to vulnerable groups were found, 325 of which came from FBDGs .

Colombia's FBDGs suggest that "to prevent anaemia, children, teenagers and young women should eat organ meats once a week" (Instituto Colombiano de Bienestar Familiar and FAO, 2020) and Cuba's suggest that "children aged 36 years should consume two servings of meat, poultry or eggs per day" (Ministerio de Salud Pública, 2009), while FBDGs of the Netherlands (Stichting Voedingscentrum

Figure C11. Quantitative and qualitative life-course recommendations, by country income classification



Nederland, 2020) and Latvia (Veselības ministrijas, 2003) respectively suggest that "girls aged 14-18 should consume 600 g per day of milk" and that "pregnant women consume protein-rich products – lean meat, fish, eggs, legumes, nuts and seeds, including three to four servings per day." Further examples are listed in Annex Table C9.

While the life-course related recommendations identified come mostly from high- income countries, a small number of such recommendations from low-income countries were also identified (Figure C11). Within the documents that did make such recommendations, there was found to be a similar number of quantitative and qualitative recommendations.

There are still many countries that lack TASF consumption guidelines, both for the general population and for vulnerable groups. Although clear recommendations on TASF consumption for vulnerable groups should be included in every country's FBDGs, data indicate that – as with other categories of food – other drivers within the food system, such as economic status, food access, agricultural productivity and consumer education, also have a critical influence on TASF consumption (Comerford *et al.*, 2021; FAO, 2021e).

6. Gaps and needs in the evidence base

The above-described evaluation of the literature on the effects of TASF on nutrition and health outcomes reveals that this literature has several limitations. Most evidence comes from observational studies that have limitations with regard to causal inference. These studies were found to have considerable heterogeneity in design with respect to context (high-income countries versus LMIC), intervention/exposure (quantity of TASF intakes) and counterfactual or control groups. In most studies, the comparison group was consuming usual diets that may or may not have been healthy. More data are needed on co-consumption of other foods with TASFs in dietary patterns and on the effects of TASF relative to those of healthy PBFs and other substitution or replacement foods. There was found to be moderate-to-serious risk of bias in the evidence. Some TASFs were found to be overrepresented in the literature relative to other TASFs, which limits the evidence base for particular life-course phases. A summary of the gaps and research needs identified is presented below.

General across all life-course periods:

- Rigorous evidence: Experimental trials are needed for all TASF and human-health outcomes, and these need to have continuity in design, including in terms of the comparator group or counterfactual, the context-specific factors and the dose (quantity of TASF).
- TASF within diets and overall dietary patterns: A holistic examination of animal source foods (terrestrial and aquatic) within broader dietary patterns is needed in relation to health benefits and risks.
- Cognition, neurodevelopment and mental health: Evidence points to positive effects of TASF on cognition and neurodevelopment, especially during childhood, but more evidence is needed across the entire life course. The effects of TASF on mental health are understudied.

Specific life-course periods:

- Pregnancy/lactation: More research is needed on the nutrition and health effects of TASFs other than milk and dairy products. The effects of TASF on the nutrition and health of the mother should also be examined to a greater extent. Research on TASF impacts on foetal, neonate and infant brain development is also needed.
- Infants and young children: There are gaps in the evidence for the nutrition and health effects of consuming meats from pigs, poultry, goats, sheep, wild animals and insects. There is a need for more research on the effects of TASF consumption on bone health, brain development and immune system pathways. Minimum frequency and quantity of TASF needed is another gap in the literature for this life-course phase.
- School-age children and adolescents: Gaps in the literature remain for the effects of egg consumption on school-age children and adolescents and for the effects of consuming other TASFs such as meat from pigs, poultry, goats, sheep, wild animals and insects on these groups. This age-group should be studied for the impacts of TASF consumption on brain development, school performance, endocrine-system functioning and growth plasticity, body composition (bone density, muscle mass, fat mass), and anaemia and iron deficiency.
- Adults: Significant gaps remain for meats other than beef and for effects on nutrition and health outcomes. Additional evidence on the effects of TASF consumption in unhealthy populations (diabetic, overweight/obese) may be merited in view of the high prevalence of these conditions. Confirmative research is needed on the effects TASF consumption on iron and zinc deficiencies. Research gaps remain for the health effects on adults of consuming meats from wild animals and insects.
- Older adults: There is a need to prioritize this life-course phase in view of global demographic trends. Research on the effects of TASF consumption in older adults should further examine bone health, muscle mass (sarcopenia), neurocognitive function, and general health and well-being. As in the case of younger adults, research may be needed on the nutrition and health impacts of TASF consumption in unhealthy populations.

Population representation:

- Greater representation of certain populations globally in studies of the effects of TASF consumption may be needed, particularly populations in certain phases of the life course. For example, more evidence on older adults is needed from LMICs. More research on TASF consumption and overweight/obesity and chronic disease outcomes is needed from low-income countries. There are also gaps in knowledge on TASF intakes and their effects on nutrition and health outcomes among Indigenous Peoples and in countries experiencing humanitarian crises.

7. Implications for food and nutrition policies and programming

Policy recommendations:

- Small-island developing states and many African countries lack updated FBDGs, and TASF-related recommendations are hardly present in food and nutrition policies. Further work in this area is recommended.
- National FBDGs should be updated with a view to adequately considering TASF and specific nutrient requirements during the life course, where these factors are not yet considered. Given the increasing coexistence of micronutrient deficiencies and NCDs, recommendations should take into account the implications of TASF consumption above or below specific levels. Given that the double burden of malnutrition affects most LMICs, recommendations on TASF should not focus only on NCD-related risks but should also consider the role of TASF in the prevention of undernutrition, especially among vulnerable age groups.
- In upcoming policy documents, it is critical that countries make context-specific recommendations, accounting for existing levels of TASF intake, the needs of vulnerable groups based on their life-course stage and other socio-economic factors, the most prevalent forms of malnutrition in both rural and urban areas, and potential trade-offs with the environmental, socioeconomic and cultural dimensions of sustainability.
- Many countries' food and nutrition guidelines and policy frameworks need to be updated to reflect TASF consumption as part of healthy diets, but these documents alone will not guarantee healthy TASF consumption; other factors, such as national programmes, consumer awareness, the quality of the supply chain and food environment also play a significant role.

Programming recommendations:

- When appropriate, animal milk should be promoted – as part of diverse, healthy diets – to improve the nutrition and health of pregnant and lactating women, with adaptations based on context, for example to account for cultural preferences, background nutritional status, dietary patterns or access to TASF.
- Eggs, milk and meat should be promoted – as part of diverse, healthy diets – for infants and young children, school-age children and adolescents, with adaptations based on context, for example to account for cultural preferences, background nutritional status, dietary patterns or access to TASF.
- Meat, in moderate quantities within diverse, healthy diets, should be promoted to reduce iron deficiency anaemia across all life-course phases.
- Healthy diets that include TASF intakes in moderate quantities could be promoted in apparently healthy adults and older adults.

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Section **D**

Food safety and food-borne diseases

Key findings

- One-third of the world's food-borne disease burden is associated with the consumption of contaminated terrestrial animal source food. This is mainly linked to bacterial causes and diarrhoea. While evidence on food-borne disease (FBD) hazards and health outcomes has been documented, as have risk analysis methods, data on the burden (incidence and severity) of these diseases are lacking in many countries. Understanding the main disease-transmission routes along the value chain is crucial if national policies are to be improved, yet these are not well documented.
- Changing agricultural practices, especially the intensification of livestock production and increased use of inputs (e.g. feed and veterinary medicine), the lengthening and broadening of value chains and shifts towards consumption of processed food contribute to increased exposure to food-borne (FBD) disease hazards. Antimicrobial residues present additional challenges.
- Reducing the food-borne disease burden requires improvements to hygiene and sanitation and mitigation of health risks at the animal–human–environment interface, through a One Health approach. Sensitization of the public, including education programmes that target food producers, transporters, processors, storage-facility operators, distributors and consumers, has the potential to improve food safety. Improvements can be achieved by strengthening and enforcing national food-control systems. Verifiable evidence is needed to support such interventions.

Summary

Ensuring safe and nutritious food, especially food of terrestrial animal origin, is a global public-health challenge. The interlinkages between unsafe food, poor nutrition and the absence of food security create a vicious cycle of disease and malnutrition that particularly affects the young, older people, the immunocompromised and the sick. The United Nations Decade of Action on Nutrition 2016–2025 highlights the need to integrate food safety into the global food-security and nutrition agenda if significant progress on improving nutrition is to be made.

Subsection 2 introduces concepts and terms used in the discussion of food safety and FDBs. This includes concepts and terms related to risk assessment, disease-burden metrics (DALYs), zoonoses, markets, food control, food-safety management and surveillance. The methods used to prepare this subsection are also described.

Subsection 3 highlights the significance of risk-based approaches to the mitigation of FDBs. The concepts of food risks and food hazards are presented and differentiated, as is the role of risk assessment, which provides the scientific basis for evaluating known or potential health effects resulting from human exposure to food-borne hazards.

Subsections 4 and 5 discuss food-borne hazards and their impacts. An understanding of hazards and risks is important in risk management. The World Health Organization has reported that, based on a conservative estimate, about 600 million people each year become sick after eating contaminated food, and 420 000 people die – resulting in the loss of 33 million healthy life years. The economic burden of unsafe food is huge. An annual total loss of USD 110 billion has been estimated for LMICs.

The burden of FBDs is not equally distributed. Children have been shown to bear the greatest burden.

Subsections 6 and 7 discuss agrifood systems and associated value-chain activities, including markets. Adopted in 2015, the United Nations Sustainable Development Goals (SDGs) call for transformation in agrifood systems in order to end hunger, achieve food security and improve nutrition by 2030. Sustainable agrifood systems promote food security and nutrition while ensuring that the economic, social and environmental bases needed to provide food security and nutrition for future generations are not compromised. Achievement of several of the SDGs, including zero hunger, health and wellbeing, clean water and sanitation, and responsible production, can be promoted through improved food safety, including that of TASF. In developing countries, a significant proportion of TASF is marketed through informal markets. Such markets, especially wet markets, have been heavily linked to the emer-

gence of important zoonotic pathogens. Public pressure is driving regulators to increase scrutiny of these markets and enforce food-safety standards. Interventions to ensure the safe and hygienic operation of food markets can mitigate risks associated both with live animals and with their products.

Subsection 8 presents factors that should be considered in efforts to mitigate FBDs. These include risk-based approaches to food-safety management, regulations that specify and enforce food-safety requirements, provision of an enabling environment for food safety and adoption of the One Health approach (an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems).

Subsection 9 summarizes current evidence gaps. National food-control systems need to be strengthened to ensure food safety and protect public health. Surveillance systems are required that facilitate the collection of country-specific epidemiological data and support the updating of FDB burden estimates, especially for developing countries. Risk assessment studies that inform prioritization and decision-making are lacking, as are traceability and food-recall tools.

1. Introduction

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996).

Food and nutritional security are realized when food is safe to eat and consumers have confidence in their food supply (Jaffee *et al.*, 2019). According to the work programme of United Nations Decade of Action on Nutrition 2016–2025, integrating food safety into the global food security and nutrition agenda would allow significant progress to be made on improving nutrition (FAO and WHO, 2016).

Food-borne diseases (FBDs) present serious threats to public health globally. More than 200 different FBDs have been identified (Mead *et al*., 1999). The majority of these are caused by diarrhoeal disease agents (WHO, 2015). The relationship between diarrhoea and malnutrition is bidirectional: diarrhoea leads to malnutrition and malnutrition exacerbates diarrhoea (Nel, 2010). FBDs can contribute to undernutrition by increasing nutrient requirements while also causing loss of appetite, reducing food intake and increasing malabsorption and metabolic loss of nutrients (Gross *et al*., 2000). Malnutrition affects the functioning of all body systems (Saunders and Smith, 2010).

The Food-borne Disease Burden Epidemiology Reference Group (FERG) of the World Health Organization (WHO) analysed a total of 31 FBD hazards and estimated that these caused 600 million illnesses and 420 000 deaths globally in 2010, resulting in a burden of 33 million disability-adjusted life years (DALYs) (WHO, 2015). One DALY is equivalent to the loss of one year of healthy life (see Box D1). The study considered 11 diarrhoeal disease agents (one virus, seven bacteria and three protozoa), seven invasive infectious disease agents (one virus, five bacteria and one protozoon), ten helminths and three chemicals. The majority (91.7 percent) of the 600 million cases were caused by diarrhoeal disease agents, such as norovirus (responsible for 124 million cases) and *Campylobacter* spp. (responsible for 96 million cases). Despite these high numbers of cases, diarrhoeal agents accounted for only 55 percent of the FBD burden.

The impact of food-borne metals on the burden of disease are largely overlooked; however, results from a study by FERG indicated that ingestion of arsenic, methylmercury, lead and cadmium resulted in more than 1 million illnesses, over 56 000 deaths, and more than 9 million DALYs worldwide in 2015 (Gibb *et al.*, 2019).

FBD burden is not equally distributed. Children under five years of age bear 40 percent of the DALY burden according to FERG data; geographically, they are most likely to die from FBDs in sub-Saharan Africa, followed by South Asia (Jaffee *et al.*, 2019). African subregions have the highest DALY burden (ranging from 1 200 to 1 300 DALYs per 100 000 population in 2010), followed by Southeast Asian subregions (ranging from 690 to 710 DALYs per 100 000 population in 2010) (WHO, 2015). The North American subregion has the lowest burden: 35 DALYs per 100 000 population in (WHO, 2015).

Livestock and other animals used for food may transfer hazards to TASFs and present significant risks to public health (Abebe, Gugsa and Ahmed, 2020; Haileselassie *et al.*, 2013; Heredia and García, 2018). The burden associated with consumption of contaminated TASFs is estimated at 168 DALYs per 100 000 population (about 35 percent of the global burden of FBDs) (Li *et al.*, 2019).

A World Bank study (Jaffee *et al.*, 2019) estimated that unsafe food costs USD 110 billion per year in LMICs, including productivity losses (USD 95.2 billion) and treatment (USD 15 billion). Improving food safety will facilitate the achievement of several of the SDGs, including zero hunger, health and wellbeing, clean water and sanitation, and responsible production.

Safe food can promote trade and enhance national and regional economies and development. Food-safety standards are intended to protect the health and safety of citizens and ensure fair trade in food and food products, thus providing opportunities to promote national and regional economies (FAO and WHO, 2018b). The Agreement on the Application of Sanitary and Phytosanitary Measures[6] (SPS Agreement) is designed to facilitate trade between developed and developing countries by improving transparency, promoting harmonization and preventing countries from imposing arbitrary food standards. However, effective implementation of the SPS Agreement in developing economies requires commitment to capacity building and appropriate national action (Athukorala and Jayasuriya, 2003). The Standards and Trade Development Facility helps developing

[6] https://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm

Box D1. Disability-adjusted life years

The disability-adjusted life year (DALY) is a standard metric commonly used to measure the impact of diseases on population health. It represents years lived with disability (YLD) (decreased quality of life) and years of life lost (YLL) as a consequence of premature death caused by a given disease or condition at the individual or population level. One DALY can be thought of as one year of "healthy" life lost. The burden of disease can be thought of as a measure of the gap between current health status and an ideal situation in which everyone lives into old age, free of disease and disability (WHO, 2008).

DALYs aggregate morbidity and disability, expressed as YLD, and mortality, expressed as YLL, into a single figure. DALYs are calculated by adding YLL to YLD (WHO, 2015).

DALY = YLD + YLL

Where:

YLD = the number of incident cases × average duration until remission or death × disability weight and

YLL = number of deaths × residual life expectancy at the age at death.

Disability refers to any acute or chronic illness that reduces physical or mental health (Chen et al., 2015). Disability weight reflects the severity of the disease on a scale of zero (perfect health) to one (death).

Both prevalence and incidence approaches can be used in the computation of DALY estimates (WHO, 2015). YLL are strongly influenced by high mortality rate or death at a young age, whereas YLD are influenced by the number of sequelae, high disability weight and long duration (Devleesschauwer et al., 2015). DALY is an established WHO metric with international application, and for this reason it was used by FERG to estimate FBD burden (WHO, 2015).

countries meet SPS standards through capacity building and ensuring trade in safe products. SDGs 8 (decent work and economic development) and 12 (responsible consumption and production) suggest that improving well-being is achievable through trade (Wilson, 2017). Labels and food safety standards may promote or hamper trade and thus affect growth and capacity to attain the relevant SDGs (Wilson, 2017).

FERG data provide the best estimate of FBD burden to date. The burden in developing countries is not fully known, but experts believe that it is higher in these countries than elsewhere (Käferstein, 2003; WHO, 2015). This belief is consistent with the following evidence:

- high levels of hazards are often reported in food in developing countries (Grace et al., 2010);
- high prevalence of potential food-borne pathogens are found in hospital and community surveys of children and adults with diarrhoea in developing countries (Fletcher, McLaws and Ellis, 2013);
- an estimated 2 billion people in the world lack access to safe drinking water (WHO and UNICEF, 2021);
- use of human sewage and animal waste for horticultural production is common in developing countries;
- lack of effective government food-control systems is prevalent in developing countries; and
- developing countries tend to lack adequate checks and balances in relevant areas (e.g. little opportunity for suing if food is unsafe).

A number of factors may contribute to underestimation of FBD burdens. Illnesses often go untreated, and not all treated cases are reported to health authorities; when they are treated, there is usually no laboratory diagnosis or way of telling whether an illness came from food or from another source, and there are no effective FBD-surveillance systems in LMICs. FBD agents can be transmitted to humans via several routes, including food, animal contact, human-to-human contact and water (Hald et al., 2016). Global disease burden estimates include only the share of illness caused specifically by contaminated food. They are based on experts' best and most recent estimates but are obviously less accurate than nationally representative empirical data.

FERG has developed tools and resources to enable countries to carry out national studies of FBD burden. Pilot studies were conducted in four countries (Albania, Japan, Thailand and Uganda), but there were significant data gaps that hindered the estimation of FBD burden. In many countries, provision of the data needed to estimate the burden of FBDs nationally and globally would require improved capacity and surveillance (WHO, 2015). For most countries, and at the global level, the data needed to quantify the attribution of potential FBDs to the major transmission routes do not exist (WHO, 2015). Where this is the case, structured elicitation of scientific judgment can be used (Aspinall, 2010; Pires, 2013).

Food-safety standards are measures enacted by governments to protect the health and safety of their citizens and the environment in which they live. Although the SPS Agreement facilitates trade between developing and developed countries, this largely depends on the ability of developing countries to participate effectively in the implementation of the agreement. However, most LMICs have negligible or no livestock product exports and are increasingly becoming importers of livestock products.

This section discusses not only FBDs (i.e. diseases transmitted through food) but also diseases transmitted through animal–human contact, focusing on animals used for food.

2. Concepts, definitions and methods

According to WHO, FBDs are diseases commonly transmitted through ingested food. These diseases are caused by food hazards, which include microbial pathogens, parasites, chemicals and biotoxins (WHO, 2014). The effects of FBDs on individuals depend on factors such as their health, nutritional status, age and immunological status and the virulence of the pathogen.

This section was prepared by synthesizing available evidence using recent literature reviews and guidance provided by international organizations in the area of food safety, including by FAO, WHO, WOAH and UNEP. It focuses on hazards, risk analysis, policies and regulations affecting food safety, including the One Health approach. The choice of priority hazards was based on recent FERG estimates and on Global Burden of FBD data (WHO, 2015), with additions from the authors given the limitations of FERG evidence.

Box D2. Concepts and methods related to food safety and food-borne diseases

Food hazard is a biological, chemical or physical agent in food with the potential to cause adverse health effects (FAO and WHO, 1997). Codex Alimentarius defines food as any substance, whether processed, semi-processed or raw, that is intended for human consumption, including drink, chewing gum and any substance that has been used in the manufacture, preparation or treatment of "food" but not including cosmetics or tobacco or substances used only as drugs (FAO and WHO, 2001).

Food safety risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food (FAO and WHO, 2001, 2014a). It is possible for hazard contamination to be high yet for the risk to be low, and vice versa.

Risk analysis is a process consisting of three components: risk assessment, risk management and risk communication (FAO and WHO, 2014a).

Risk assessment is a scientifically based process consisting of the following steps:

1. hazard identification;
2. hazard characterization;
3. exposure assessment; and
4. risk characterization (FAO and WHO, 2001, 2014a).

Risk assessment can be qualitative or quantitative, depending on the approach used and the availability of data.

Risk management is the process, distinct from risk assessment, of weighing policy alternatives, in consultation with all interested parties, considering risk assessment and other factors relevant for the health protection of consumers and the promotion of fair trade practices, and, if needed, selecting appropriate prevention and control options (FAO and WHO, 2014a).

Risk communication is the interactive exchange, throughout the risk-analysis process, of information and opinions concerning risk, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk-assessment findings and the basis of risk-management decisions (FAO and WHO, 2014a).

Zoonoses: the *Second Report of the Joint WHO/FAO Expert Committee On Zoonoses* defined zoonoses as those diseases and infections that are naturally transmitted between vertebrate animals and humans. Although some may not make the animal sick, they make humans sick. The infections range from minor, often short-term illnesses, to major life-changing ones that can cause death. Zoonotic pathogens may be bacterial, viral or parasitic, or may involve unconventional agents such as prions, and can spread to humans through direct contact or through food, water or the environment (WHO, 2020a). Prions are transmissible particles that are devoid of nucleic acid and seem to be composed exclusively of a modified protein; spongiform encephalopathy in cattle, scrapie in sheep, and Creutzfeldt–Jakob disease in humans are among key prion diseases (Prusiner, 1998).

Antimicrobial resistance (AMR) is the ability of microorganisms to persist or grow in the presence of drugs designed to inhibit or kill them (FAO, 2021). These drugs, known as antimicrobials, are used to treat infectious diseases caused by microorganisms, such as bacteria, fungi, viruses and protozoan parasites. AMR mainly develops when microorganisms adapt and grow in the presence of antimicrobials (WHO, 2015). It is a major global threat, with implications for public health, food security and the economic well-being of communities.

Informal markets: the informal food sector exists in many forms and finding a clear definition for the concept is difficult given the variety of activities and trades that the term embraces (FAO, 2003). Informal markets include economic activities that occur outside formal regulations (e.g. those related to acquiring licenses, registering business and paying taxes) and are mostly guided by informal norms, values and understandings (Sutter *et al.*, 2017). Informal food businesses are characterized by low capital investments and the absence of specialization, and can exist at various stages of the value chain, including production, distribution and retailing (FAO, 2003).

(cont.)

Food control system: Food control is a mandatory regulatory activity of enforcement by national or local authorities to provide consumer protection and ensure that all foods, during production, handling, storage, processing and distribution are safe, wholesome and fit for human consumption, conform to safety and quality requirements, and are honestly and accurately labelled as prescribed by law (FAO and WHO, 2003). A food control system is the integration of a mandatory regulatory approach with preventive and educational strategies to ensure protection of the whole food chain (FAO and WHO, 2003). A national food control system aims to protect the health of consumers by assuring the safety and quality of foods being traded, both nationally and internationally. FAO and WHO have developed a tool, the Food Control System Assessment Tool, to help member countries assess the effectiveness of their food control systems, demonstrate performance and determine areas that require improvement (FAO, 2020).

Surveillance: WHO defines surveillance as the systematic, ongoing collection, collation and analysis of data and the timely dissemination of information to those who need to know so that action can be taken (WHO, 2001). Animal health surveillance, according to the Terrestrial Animal Health Code of the World Organization for Animal Health, is a tool for monitoring disease trends, facilitating the control of infection or infestation, providing data for use in risk analysis for animal-health or public-health purposes, substantiating the rationale for sanitary measures and providing assurances to trading partners (WOAH, 2021).

Public health surveillance is the ongoing systematic collection, analysis and interpretation of data, closely integrated with the timely dissemination of these data to those responsible for preventing and controlling disease (Thacker and Berkelman, 1988). It provides the scientific and factual data needed to inform decision-making and appropriate action on public health (Nsubuga et al., 2006).

Surveillance for food safety is a systematic effort to collect, analyse and interpret data on food contaminants and food consumption and establish effective links with the public-health system to improve the availability of attributable data on food-borne disease (Bishop and Tritscher, 2012).

An integrated surveillance system is one that links human and animal disease reporting systems. It can help identify and facilitate a response to known and emerging zoonotic diseases (Mauer and Kaneene, 2005).

Residues are traces in food, agricultural commodities or animal feed and result from the use of pesticides or veterinary drugs. Residues of pesticides can include any derivatives of pesticides, such as conversion products, metabolites, reaction products, and impurities of toxicological significance (FAO and WHO, 2016). Veterinary drug residues include the parent compounds and/or their metabolites in any edible portion of the animal product and include residues of associated impurities of the veterinary drug concerned (FAO and WHO, 2016). The maximum residue limit is the concentration that is legally tolerated in a food product obtained from an animal that has received a veterinary medicine (FAO and WHO, 2018a).

Traceability and recall: Codex Alimentarius Commission defines traceability or product tracing as the ability to follow the movement of a food through a specified stage or stages of production, processing and distribution. Traceability within food control systems is used to control food hazards, provide reliable product information and guarantee product authenticity (adapted from FAO and WHO, 2012).

Recall or product recall is defined as the action of removing food from the market at any stage of the food chain, including when possessed by consumers (FAO and WHO, 2012a). Food recall is a fundamental tool in the management of risks in response to food-safety events and emergencies. Reliable identification and traceability systems are essential for effective animal disease control systems, food-safety systems and trade in live animals and animal products.

Food-safety interventions are control measures added to a process to reduce and ultimately prevent or eliminate food-safety risks (Bucknavage and Cutter, 2011). Food-safety interventions can be categorized based on where they occur within the food supply chain: preharvest interventions occur in the field or on the farm, while post-harvest interventions occur as raw materials undergo processing. Food-safety interventions also refer to risk management (see above for definition of this term) (FAO and WHO, 2014a).

3. Hazards versus risks versus risk assessment

A food hazard is a biological, chemical or physical agent in, or a condition of, food with the potential to cause an adverse health effect (FAO and WHO, 2014a). Hazards, when ingested by susceptible consumers, have the potential to cause FBDs, which include any illness arising from consumption of contaminated food (Adley and Ryan, 2016). The global burden of FBDs, many of which are carried by livestock products, was 33 million DALYs in 2010, based on the burden evidence presented by FERG, which is considered the best to date. Of that burden, 40 percent was borne by children under five years of age (WHO, 2015). Together, the hazards caused 600 million food-borne illnesses (95 percent uncertainty interval [UI] 420–960) and 420 000 deaths (95 percent UI 310 000–600 000) in 2010. As explained in the previous subsection, risk considers the probability or likelihood of an adverse health effect occurring and the severity of that effect following exposure, and risk assessment is a scientific process that allows risk to be estimated. A detailed description of hazards, risks and risk assessment is provided below.

3.1

Hazards

Food hazards can be biological, chemical or physical, and more than 250 different food-borne hazards have been recognized (Hoffmann and Scallan, 2017; Todd, 2014). Biological hazards include microorganisms, such as bacteria, viruses, parasites and fungi (Untermann, 1998). Pathogens can enter food anywhere along the value/supply chain – during primary production, processing, distribution, storage or consumption. People with a food-borne illness (or another illness that impacts their immune system) and the environment can also potentially be sources of food contaminants (Schirone *et al.*, 2017). A few bacterial hazards (e.g. *Staphylococcus aureus* and *Clostridium botulinum*) can under certain conditions produce toxins, and it is these toxins that cause rapid-onset food-borne illness (Rhodehamel, 1992). Toxins are problematic because they are not destroyed by cooking.

For most of the many food-borne pathogens known to cause disease there is insufficient evidence to develop credible global estimates of disease burden. FERG selected 31 important hazards (28 biological pathogens) for which there was sufficient evidence to develop global estimates. The most important in terms of burden were (in declining order) lead, non-typhoidal (NT) *Salmonella*, *Salmonella* Typhi, enteropathogenic *Escherichia coli*, norovirus, *Campylobacter* spp., Shiga toxin-producing *Escherichia coli*, methylmercury, *Vibrio cholerae,* and arsenic (Gibb *et al.*, 2019; Havelaar *et al.*, 2015). Together, these ten hazards accounted for nearly 75 percent of the total global burden of FBDs. Their significance may vary depending on geography and the types of foods that comprise the common diets of populations in particular locations. Outbreaks should be assessed in-depth to confirm the presence of the hazards, identify root cause(s), assess trends over time and determine the actions needed to combat future outbreaks (Adley and Ryan, 2016). There is no single clinical syndrome for all FBDs. Diarrhoeal disease agents, particularly norovirus, *Campylobacter* spp., NT *Salmonella* spp. and *E. coli*, are the most frequent causes of FBD (> 90 percent) (Havelaar *et al.*, 2015). Their sources range from contamination during the acquisition of food from the live animal to inadvertent or intentional addition during food production, processing or preparation (Adley and Ryan, 2016). The proportion of human infection with a given pathogen that can be attributed to food will differ depending on the agent, the food, the value/supply chain and the ways the food is handled, with only a few FBDs being transmitted exclusively via foods (Hoffmann and Scallan, 2017).

Chemical hazards include, but are not limited to, naturally occurring components of certain food ingredients (e.g. linarmarin, a cassava cyanide [Cereda and Mattos, 1996]), toxins produced by microorganisms found in the environment (e.g. mycotoxins), pesticide residues, heavy metals (from raw food ingredients or use of improper food-processing equipment or food-packaging materials) and industrial chemicals (FDA, 2012). Chemical hazards in TASF may result from the use of contaminated feed, the uptake of chemical compounds when animals graze on contaminated soil or the use of veterinary medicines. A good example occurred in Germany in 2010 when illegal use of industrial oils led to fats used for animal feed becoming contaminated with dioxin (Kupferschmidt, 2011). Other examples include the use of furazolidone in animal feed and the melamine crisis in China in 2008 (Chen, 2009; Pei *et al.*, 2011).

Physical hazards include, but are not limited to, metal items (wire, needles, etc.), sand, soil, stones, wood, plastic, rubber or glass items, and hair (Asselt *et al.*, 2016; Rhodehamel, 1992). Physical hazards may be introduced into the livestock value chain during the production process (e.g. metal parts of stirring machines, rubber from seals or broken needles). They may also be introduced from packaging materials, especially where these are recycled (Geueke, Groh and Muncke, 2018), or because of their presence in raw materials or the environment.

3.2

Risks

Analysis of hazards occurring in food makes it easier to identify measures that can be used to reduce people's exposure to them. However, proper mitigation of FBDs requires risk-based approaches – hence the need to understand and differentiate food risks from food hazards. As noted by Fazil (2005), risk is a frequently encountered concept: people subconsciously assess risks every day. Understanding FBD risks makes it easier to prioritize and manage them and provides a framework for solving trade-related disputes.

The food value chain is very complex and involves many players. In a system of this kind, many factors will affect both the likelihood that FBDs will occur and their severity if they do (Fazil, 2005). Factors such as failure to observe good production practices, use of unsafe water to clean and process food, poor storage and unhygienic food-handling practices can increase FBD risks, especially when coupled with inadequate or poorly enforced regulatory standards and a lack of industry compliance (Todd, 2020).

A risk profile is a description of the food-safety problem and its context, while a risk estimate is the quantitative outcome of risk characterization (FAO and WHO, 2014a). FBD risks are perceived differently by different categories of people, and this could be related to their levels of food-safety awareness and how well particular risks have been publicized.

3.3

Risk assessment

For over half a century, FAO in collaboration with WHO, has formulated scientific advice that has provided the basis for the international food-safety standards, guidelines and codes of practice developed by the Codex Alimentarius Commission on issues related to the following issues (FAO and WHO, 2018d):

- safety assessments of chemicals such as food additives, veterinary drug residues, pesticide residues, contaminants and natural toxins in food;
- safety assessments of biological agents such as micro-organisms, fungi, parasites and prions in food;
- assessments of practices and technologies used for the production of foods, for example safety assessment of foods derived from biotechnology; and
- issues in human nutrition such as the use of probiotics, human nutrient requirements and food fortification.

Risk assessment is the scientific evaluation of known or potential health effects resulting from human exposure to food-borne hazards (FAO and WHO, 2001) and is the first step in the Codex Alimentarius risk-analysis process. The process consists of the following four steps (FAOHazard identification: the identification of the biological agent that may be present in a particular food or group of foods and capable of causing adverse health effects.

1. Hazard characterization: the qualitative or quantitative, or both, evaluation of the nature of adverse health effects associated with the biological agent that may be present in food, and in such cases a dose–response assessment should be performed if the data are obtainable.
2. Exposure assessment: the qualitative or quantitative, or both, evaluation of the likely intake of the biological agent through food, as well as through exposure from other sources, if relevant.
3. Risk characterization: qualitative or quantitative, or both, estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterization and exposure assessment.

In 2000, FAO and WHO launched a programme on microbiological risk assessment that led to the publication of guidelines on the various steps of the risk assessment process:

- Hazard characterization for pathogens in food and water: guidelines (WHO and FAO, 2003);
- Viruses in food: scientific advice to support risk management activities: meeting report (FAO and WHO, 2008); and
- Risk characterization of microbiological hazards in food (FAO and WHO, 2009a).

The guidelines recognized risk management decision-making and effective risk communication within the risk analysis framework require reliable estimation of risk, combined with appropriate uncertainty analysis. In 2021, a single updated guideline on risk assessment has been developed to remove the need to consult three separate guidelines (FAO and WHO, 2021). The development of the guidelines for risk assessment paved way for a number of microbial risk assessments in commodity–pathogen matrices (LeJeune *et al.*, 2021), such as *Salmonella* in eggs and broiler chickens (FAO and WHO, 2002), *Listeria monocytogenes* in ready-to-eat foods (WHO and FAO, 2004) and *Campylobacter* spp. in broiler chickens (FAO and WHO, 2009b).

4. Biological food hazards and associated public health impacts

TASFs are a good medium for microbial growth and can become contaminated with hazards at any stage along the value chain, from primary production to manufacture, distribution and retailing, or through handling during preparation and consumption. Biological food hazards include pathogenic organisms (bacteria, viruses, parasites, fungi and prions) and their toxins (Abebe, Gugsa and Ahmed, 2020).

Microbial growth in food is influenced by a number of factors, both intrinsic (e.g. pH and nutrient content) and extrinsic (e.g. humidity and storage temperature) (Preetha and Narayanan, 2020). Livestock, farmed wildlife and hunted animals are important reservoirs for many of the pathogens that contaminate TASFs, including meat, dairy and egg-based products (Heredia and García, 2018). Although they provide some micronutrients that are difficult to obtain in sufficient quantities from plants, for instance vitamin B12 (Murphy and Allen, 2003), TASF – like foods of plant origin – are prone to contamination and present significant risks to public health (Haileselassie *et al.*, 2013).

4.1 Bacterial hazards

Among biological food hazards, bacterial hazards present the greatest threat to food safety and human health (Desta Sisay, 2015) and are the most studied and monitored (Newell *et al.*, 2010). The frequency and of seriousness of FBDs vary (Abebe, Gugsa and Ahmed, 2020). Enteropathogenic *E. coli* (EPEC), *Campylobacter* spp., enterotoxigenic *E. coli* (ETEC), NT *Salmonella enterica*, Shiga toxin-producing *E. coli*, *Salmonella enterica* Paratyphi A and *Salmonella enterica* Typhi are among the common bacterial causes of FBDs (WHO, 2015). Some bacteria may cause severe complications, including *Listeria monocytogenes* and *Vibrio cholerae* (Akbar and Anal, 2011). Production of toxins and structural virulent factors is responsible for the pathogenesis of bacteria such as *Salmonella* spp., *Campylobacter* spp., *Staphylococcus aureus* and *Escherichia coli* (Abebe, Gugsa and Ahmed, 2020).

Staphylococcus aureus

Staphylococcus aureus (*S. aureus*) is a gram-positive microorganism that is present as a commensal on the skin, nose and mucous membranes of healthy humans and animals (Lozano *et al.*, 2016; Tessema and Tsegaye, 2017). It is considered an opportunistic food-borne pathogen (Rodríguez-Lázaro *et al.*, 2017; Wang *et al.*, 2017) and can cause diseases with diverse severity in both humans and animals (Abraha *et al.*, 2018; Lozano *et al.*, 2016) as an infectious agent or through its toxins. *S. aureus* is able to grow in a wide range of temperatures (7 °C to 48 °C, with an optimum of 30 °C to 37 °C), pH (4.2 to 9.3, with an optimum of 7.0 to 7.5) and sodium chloride concentrations (up to 15 percent NaCl). These characteristics enable it to survive in a wide variety of foods, especially those that require manipulation during processing, including fermented food products such as cheese (Argaw and Addis, 2015). It has a wide range of hosts, including humans and livestock (Wang *et al.*, 2017).

Contamination of food with *S. aureus* may occur directly from infected animals or because of poor hygiene during production, retail or storage (Massawe, Mdegela and Kurwijila, 2019). Cows with mastitis are a common source of *S. aureus* in raw milk (Tarekgne *et al.*, 2015). *S. aureus* in food products is a serious concern because of the food-borne intoxication caused by enterotoxigenic strains of coagulase-positive staphylococci, mainly *S. aureus* (Tsepo *et al.*, 2016) and very occasionally others species, such as *S. intermedius* (Genigeorgis, 1989; Khambaty, Bennett and Shah, 1994). A variety of food items can be contaminated by staphylococcal enterotoxins, with moist food containing starch and proteins (Wu *et al.*, 2016), unpasteurised milk and dairy products (Beyene *et al.*, 2017; Abunna *et al.*, 2016), pork, beef, mutton, poultry and eggs having been implicated in staphylococcal food poisoning (Wang *et al.*, 2017). *S. aureus* growth and toxin production is influenced by factors such as the composition of the food, the temperature and the time allowed (Hennekinne, De Buyser and Dragacci, 2012), and this provides an indication of areas that should be targeted by efforts to mitigate exposure and improve health.

Many cases of staphylococcal food poisoning have been reported globally (Hennekinne, De Buyser and Dragacci, 2012). Staphylococcal food poisoning results from the ingestion of enterotoxins preformed in food by enterotoxigenic strains of *S. aureus* (Hennekinne, De Buyser and Dragacci, 2012). Staphylococcal enterotoxins are resistant to environmental conditions (freezing, drying, heat treatment and low pH) that easily destroy the enterotoxin-producing strain. They are also resistant to proteolytic enzymes and hence are able to remain active in the digestive tract after ingestion (Hennekinne, De Buyser and Dragacci, 2012). Generally, heat treatments commonly used in food processing do not completely destroy staphylococcal enterotoxins present in the concentrations at which they are expected to be found in food involved in food poisoning outbreaks (0.5–10 μg per 100 ml or 100 g) (Hennekinne, De Buyser and Dragacci, 2012).

The widespread use of antibiotics and the ability of bacteria to acquire antimicrobial resistance have led to the emergence of resistant strains, such as methicillin resistant *S. aureus* (Abraha *et al.*, 2018; Rodríguez-Lázaro *et al.*, 2017; Wang *et al.*, 2017). Methicillin resistant *S. aureus* has been reported in animals (Weese, 2010). Multidrug resistant strains of *S. aureus* have been associated with high mortality and morbidity (Tsepo *et al.*, 2016). Delaney *et al.* (2008) studied a cohort of 1 439 patients with methicillin resistant *S. aureus* and 14 090 patients with no methicillin resistant *S. aureus*; within one year, 21.8 percent of the methicillin resistant *S. aureus* patients had died as compared with 5 percent of the non-methicillin resistant *S. aureus* patients.

Staphylococcal infections have a short incubation period (the time from infection to the manifestation of symptoms) of two to four hours after consumption of contaminated foods (Desta Sisay, 2015). The bacteria can cause symptoms that range from simple skin infections to potentially life-threatening septicaemia, necrotizing fasciitis, infective endocarditis, necrotizing pneumonia and toxic shock syndrome (Che Hamzah *et al.*, 2019; Wang *et al.*, 2017). Staphylococcal infections are characterized by nausea and vomiting, chills and headache (Dhama *et al.*, 2013) and abdominal cramping with or without diarrhoea (Kadariya, Smith and Thapaliya, 2014) but not by fever (Wang *et al.*, 2017). Children and elderly persons are more susceptible (Wang *et al.*, 2017).

Control and prevention of *S. aureus* mainly requires strategies that interrupt its modes of transmission, as the organisms are ubiquitous and impossible to eliminate from the environment (Argaw and Addis, 2015). Preventing contamination and cross-contamination and cooking food thoroughly are effective ways of preventing staphylococcal infections. Improving public awareness of how to handle food safely and cook it well, along with other public health interventions, can be effective means of preventing outbreaks (Kadariya, Smith and Thapaliya, 2014). It is noteworthy that although *S. aureus* is one of the most important food-borne pathogens it was not considered in the FERG study, probably because global data were lacking. This illustrates how the FERG study, still the best available guide to the burden of FBD, underestimates the true burden.

Salmonella species

Salmonella is a gram-negative bacterium that can survive for several weeks in a dry environment and for several months in water. *Salmonella* are divided into typhoidal (*S.* Typhi and *S.* Paratyphi) and non-typhoidal *Salmonella* serotypes (Feasey *et al.*, 2012). Most *Salmonella* serotypes are present in a wide range of hosts and typically do not cause complicated infections that warrant treatment; however, some are host specific, for example *S.* serotype Dublin, which resides in cattle, and *S. enterica* serotype Choleraesuis, which resides in pigs (WHO, 2018a). When these particular serotypes cause disease in humans, it is often invasive and can be life threatening (WHO, 2018a). Non-typhoidal *S. enterica* usually cause gastroenteritis (EFSA and ECDC, 2018; Lane *et al.*, 2014). Globally, *S. enteritidis* and *S. typhimurium* are the two most commonly reported serovars of *Salmonella* spp. transmitted through food (EFSA and ECDC, 2018).

Salmonella is the most common cause of FBD in both developing and developed countries, although incidence rates vary according to the country (Addis *et al.*, 2011). *Salmonella* is one of the four key global causes of diarrhoeal diseases (the others are norovirus, enteropathogenic *E. coli* and *Campylobacter*) (Tadesse and Gebremedhin, 2015; WHO, 2018a). Globally, non-typhoidal *Salmonella* spp. were estimated to cause approximately 78 million cases of illness, 59 000 deaths and 4 million DALYs in 2010 (Havelaar *et al.*, 2015). The numbers were also high in the WHO European Region, where non-typhoidal *Salmonella* spp. occupied the first position in the ranking of DALYs and deaths due to food-borne hazards, causing 107 000 DALYs and 1 854 deaths in 2010 (WHO, 2017b). In 2017, the 28 member states of the European Union reported a total of 93 583 human salmonellosis cases, 91 662 of which were confirmed cases, resulting in an European Union notification rate of 19.7 cases per 100 000 population. This was a slight decrease (0.7 percent) compared with the figures for 2016 (20.4 cases per 100 000 population) (EFSA and ECDC, 2019).

Livestock and other animals used for food are a major reservoir for many food-borne *Salmonella* spp. (Heredia and García, 2018). Humans are the only reservoir of typhoid *Salmonella* (Gal-Mor, Boyle and Grassl, 2014). Non-typhoid *Salmonella* serovars have animals as the main reservoirs (Eng *et al.*, 2015). *S. enterica*, subspecies *enterica* serotypes are principally found in warm-blooded animals, whereas the other, non *enterica*, subspecies are principally found in cold-blooded animals, although there are some exceptions (Lamas *et al.*, 2018). The incidence of diseases caused by non-typhoid *Salmonella* differs from country to country; for example, it is estimated to cause 690 cases per 100 000 population annually in Europe, while the infection rate in Israel is around 100 cases per 100 000 annually (Eng *et al.*, 2015). *S. typhimurium* is the dominant serovar around the world and is associated with food-borne outbreaks in both developing and developed countries (Mohammed, 2017). The transmission of non-typhoidal *Salmonella* infection to humans can occur through the ingestion of food or water contaminated with waste from infected animals, by direct contact with infected animals or by consumption of food from infected animals (Eng *et al.*, 2015; Garedew *et al.*, 2015; WHO, 2018a). This bacterium has been isolated from a wide range of animals – poultry, ovines, porcines, and fish and other aquatic animals – and their food products, and also from some other cold-blooded animals (Flockhart *et al.*, 2017; Nguyen *et al.*, 2016; Zając *et al.*, 2016).

Salmonella spp. infections are characterized by acute onset of fever, abdominal pain, diarrhoea, nausea and sometimes vomiting (WHO, 2018a). Non-typhoidal salmonellosis is usually self-limiting and does not require specific treatment other than oral fluids (WHO, 2018a). *Salmonella* spp. infection can, however, cause severe disease, especially in children, the elderly and immunocompromised people. In invasive salmonellosis, the bacteria enter the bloodstream, resulting in bacteraemia, meningitis, osteomyelitis or septic arthritis and sometimes even death. Treating this type of infection with antimicrobial agents is justified, although antimicrobial resistance in *Salmonella* spp. is increasingly becoming a public health concern (WHO, 2011). Invasive non-typhoidal *Salmonella* is endemic in Africa, and children and human immunodeficiency virus (HIV) infected adults carry most of the burden of invasive disease (Morpeth, Ramadhani and Crump, 2009). A systematic literature review and meta-analysis reported multidrug resistance in 75 percent of non-typhoid *Salmonella* isolates obtained in sub-Saharan African regions after the year 2000 (Tack *et al.*, 2020). In Viet Nam, 71 percent of patients included in a study on invasive non-typhoid infection had HIV (Phu Huong Lan *et al.*, 2016); *S.* Enteritidis (48 percent; n = 102) and *S.* Typhimurium (25 percent) were the main serovars.

To prevent the infection, it is recommended that food should be properly cooked and served when hot, and that hands should be thoroughly and frequently washed, using soap, in particular after contact with pets or livestock and after visiting toilets (WHO, 2018a).

Campylobacter species

Among the 17 species and six subspecies assigned to the genus *Campylobacter*, the most frequently reported in human diseases are *C. jejuni* (subspecies *jejuni*) and *C. coli* (WHO, 2020b). These organisms are found in the environment, and many species are susceptible or act as reservoirs (Gebremichael, Berhe and Amede, 2019; Ogden *et al.*, 2009). Poultry (Desta Sisay, 2015), cattle, sheep, pigs and other animals used for food (Khoshbakht *et al.*, 2016; Silva *et al.*, 2011; Woldemariam, Asrat and Zewde, 2009), as well as wild animals and birds (Gebremichael, Berhe and Amede, 2019), are reservoirs of *Campylobacter*. Companion animals (cats and dogs) and rodents may also act as reservoirs of *Campylobacter* spp. (Woldemariam, Asrat and Zewde, 2009).

Large numbers of *Campylobacter* bacteria can be found in the intestinal tracts of animals (Gölz *et al.*, 2014), although they seldom causes disease in animals. Most often, carcasses or meat are contaminated by *Campylobacter* from faeces during slaughtering. Table eggs are not considered to be an important source of the organism (Dhama *et al.*, 2013). A worldwide meta-analysis study on the prevalence of *Campylobacter* spp. in animal food products reported a pooled prevalence of 29.6 percent (95 percent CI 27.6–31 percent); *C. jejuni* (19 percent) and *C. coli* (9.7 percent) (Zbrun *et al.*, 2020). Poultry flocks are highly colonized with the bacteria (Gölz *et al.*, 2014) and contaminated broiler meat is considered the most important source of *Campylobacter* infection in humans (Abebe, Gugsa and Ahmed, 2020; WHO, 2017b). However, levels of colonization can vary by production system and species. Most reported cases are associated with chickens, especially those raised in organic and free-range systems rather than in intensive production systems, probably because of increased environmental exposure (Hendrixson and DiRita, 2004). A community-based cross-sectional study involving children aged 11 to 13 months conducted in the Haramaya woreda (district), East Hararghe Zone, Oromia Region, Ethiopia found *Campylobacter* prevalence based on child faecal samples to be 50 percent (n = 101) (Chen *et al.*, 2021). The risk of *Campylobacter* spp. presence was found to be significantly higher in children that were currently consuming TASF (in last 24 hours) (OR 4.87; 1.58–17.76). The same study found 12 percent of the children to have diarrhoea.

The withdrawal of chicken and eggs from retail sale following the 1999 dioxin crisis in Belgium resulted to a 40 percent reduction in human campylobacteriosis cases (Vellinga and Van Loock, 2002).

In most cases of campylobacteriosis, the first symptoms occur two to five days after infection. The most common clinical symptoms are diarrhoea (frequently with blood in the faeces), abdominal pain, fever, nausea and/or vomiting (WHO, 2020b). The symptoms typically last three to six days. Treatment other than electrolyte replacement and rehydration is not generally required. Antimicrobial treatment is recommended in invasive cases where the intestinal mucosa cells are invaded and tissue is damaged. Death from campylobacteriosis is rare and is usually confined to very young or older patients or to those with another serious disease such as AIDS (WHO, 2020b). Complications such as bacteraemia, hepatitis, pancreatitis and miscarriage have been reported at varying frequency. Postinfection complications may include reactive arthritis, which can be a long-term (indeterminate) sequela and last more than a two months, and neurological disorders, such as Guillain-Barré syndrome, a form of paralysis that can result in respiratory and severe neurological dysfunction or death in a few cases (WHO, 2011).

A recent review of *Campylobacter* spp. shows that the incidence and prevalence of campylobacteriosis have increased in both developing and developed countries (Kaakoush *et al.*, 2015). According to FERG, in 2010, food-borne *Campylobacter* spp. were responsible for more than 95 million cases of illness and slightly more than 21 000 deaths worldwide. The global burden of this hazard was estimated to be over 2.1 million DALYs per year, consisting mostly of years of life lost (YLL) due to the disease (WHO, 2017b). In the WHO European Region, *Campylobacter* spp. were the second leading hazard in terms of food-borne illness (nearly 4.7 million cases per year), deaths (459 per year) and burden (more than 82 000 DALYs per year). It is undoubtedly a major threat to public health in the region, where the median was nine DALYs (95 percent UI 6 - 13) per 100 000 population in 2010 (Havelaar *et al.*, 2015). In 2017, human campylobacteriosis data were reported by 27 European Union members states, with 246 158 confirmed cases, resulting in an European Union notification rate of 64.8 cases per 100 000 population, a slight decrease compared with 2016 (when there were 66.3 cases per 100 000 population) (EFSA and ECDC, 2018).

The risk factors that contribute to the susceptibility of humans to campylobacteriosis include travelling, consumption of undercooked chicken, environmental exposure and direct contact with livestock (Shad and Shad, 2019). Prevention of disease caused by *Campylobacter* is based on control measures at all stages of the food chain, with the most effective being heating of TASF to temperatures that will completely inactivate all types of *Campylobacter* (WHO, 2020b). Enhancing biosecurity to avoid transmission of *Campylobacter* from the environment to flocks of birds on farm can reduce the prevalence of *Campylobacter* in poultry, but this option is feasible only where birds are kept in closed housing. Hygienic slaughtering practices reduce contamination of carcasses by faeces, although this does not guarantee the absence of *Campylobacter* from meat and meat products. Bactericidal treatment, such as heating (e.g. cooking or pasteurization) or irradiation, is the only effective method of eliminating *Campylobacter* from contaminated foods (WHO, 2020b).

Listeria monocytogenes

Listeria monocytogenes is widely distributed in nature and causes listeriosis in both animals and humans (Derra *et al.*, 2013; O'Grady *et al.*, 2009). *Listeria* spp. are gram-positive, rod-shaped bacteria. *L. monocytogenes* occurs worldwide (Lee *et al.*, 2019). Most cases of listeriosis are sporadic, although outbreaks may occur (Dhama *et al.*, 2015). In general, incidence is relatively low (0.1 to 10 cases per 1 million people per year, depending on the country and region of the world), but hospitalization and fatality rates are high (WHO, 2018).

Unlike most other food-borne pathogens, *L. monocytogenes* can grow in food at fairly low moisture levels, at high salt concentration and at refrigeration temperatures. The ability to persist and multiply in the food environment when other bacteria and pathogens do not grow makes *L. monocytogenes* more difficult to control (Schlech and Acheson, 2000). Unlike other common food-borne pathogens, *L. monocytogenes* is one of the most virulent pathogens of public-health concern globally (Mulu and Pal, 2016). It has a high case-fatality rate of approximately 30 percent, partly because of its ability to cause spontaneous abortion of human foetuses (Odu and Okonko, 2017). Where active surveillance of sepsis and meningitis has been carried out, attack rates of about 0.7 cases per 100 000 population have been reported (Gellin *et al.*, 1991). The infection is much more common in infants (10 cases per 100 000 population) and older persons (1.4 cases per 100 000 population) and has a predominance among males (Schlech and Acheson, 2000).

According to FERG estimates (Havelaar *et al.*, 2015), listeriosis resulted in more than 14 000 cases of illness, over 3 170 deaths and over 118 000 DALYs globally in 2010. The proportion of perinatal cases was approximately 20 percent. In Europe, it is evident that listeriosis has public health impact. The disease caused an estimated 1 781 cases of illness, 399 deaths and almost 15 000 DALYs in the WHO European Region in 2010 (WHO, 2017b). Listeriosis was the fourth leading food-borne hazard in terms of deaths in the region and the fifth in terms of DALYs (WHO, 2017b). There were 2 480 confirmed human cases of listeriosis reported in the European Union in 2017, and a statistically significant increasing trend in cases of listeriosis was observed between 2008 and 2014 (EFSA and ECDC, 2017).

Listeria species are commonly found in raw food, vegetables contaminated by soil and water, and raw animal products (Seyoum *et al.*, 2015; Vaidya *et al.*, 2018). *L. monocytogenes* is frequently isolated from food of animal origin such as ready-to-eat products, ground beef (Pal and Awel, 2014; Şanlıbaba and Uymaz Tezel, 2018), meat and meat products (sausages) (Carrique-Mas and Bryant, 2013; Dhama *et al.*, 2013), fish and fish products (Nayak *et al.*, 2015), and milk and dairy products such as soft cheese and ice cream (Mashhadany *et al.*, 2016; Mulu and Pal, 2016). Occupational exposure from animal sources has been reported in livestock keepers, butchers, poultry workers and veterinary surgeons (Mashhadany *et al.*, 2016; Şanlıbaba and Uymaz Tezel, 2018). Healthy people infected with *L. monocytogenes* may experience febrile gastroenteritis, which is usually mild and self limiting. However, in patients with impaired cell-mediated immunity, *L. monocytogenes* can lead to severe illness, including severe sepsis, meningitis or encephalitis and therefore have lifelong consequences or even lead to death (de Noordhout *et al.*, 2014). In South Africa, an outbreak of listeriosis between January 2017 and July 2018 caused 1 060 confirmed cases and 216 recorded deaths (Tchatchouang *et al.*, 2020). Epidemiological investigations indicated that ready-to-eat processed-meat products from a food-production facility contaminated with *L. monocytogenes* were responsible for the outbreak (Tchatchouang *et al.*, 2020).

Listeriosis occurs mainly in risk groups such as pregnant women, older people, people with AIDS and other immunocompromised conditions, people that have undergone solid organ transplantation, people with diabetes mellitus, cirrhosis or renal failure, foetuses and neonates (Goulet and Marchetti, 1996; Şanlıbaba and Uymaz Tezel, 2018). Infection during pregnancy can result in spontaneous abortion, stillbirth or preterm birth (Chan and Smith, 2018; Maertens de Noordhout *et al.*, 2014). Infants can acquire the infection in two ways: their mothers may consume contaminated food and develop occult sepsis, resulting in chorioamnionitis and delivery of a septic infant or foetus; and infected mothers may contaminate the skin and respiratory tract of their babies during childbirth (Schlech and Acheson, 2000). The infants may then develop bacterial meningitis two to three weeks after exposure at the time of birth (Schlech and Acheson, 2000). In North America, *L. monocytogenes* is the third most common pathogen causing bacterial meningitis among neonates, after Group B streptococcal infection and *Escherichia coli* (Dawson *et al.*, 2018; Goulet and Marchetti, 1996). Food-borne listeriosis can be prevented by controlling the organism at all the stages of the food chain – ensuring good hygienic practices (GHPs), good manufacturing practices (GMPs) and a food-safety system based on hazard analysis critical control points (HACCP), with careful attention to preparation and choice of foods in the household and, in special circumstances, use of antibiotic prophylaxis (WHO, 2018; Schlech and Acheson, 2000).

Escherichia coli

Escherichia coli is part of the normal bacterial flora in the gastrointestinal tract of humans and other warm-blooded animals; most strains are harmless other than in immunocompromised individuals (Kaper, Nataro and Mobley, 2004). However, some strains can cause illness and even severe FBD (Abreham *et al*., 2019; Disassa *et al*., 2017; Taye *et al*., 2013, WHO, 2017b). Transmission of *E. coli* occurs via the oral–faecal route through consumption of contaminated foods. Meat can be contaminated with *E. coli* during slaughter as a result of the carcass and environment becoming soiled with faecal material (Johnson *et al.*, 1996). People can become infected with diarrhoeagenic *E. coli* by consuming or handling contaminated food or water or by contact with infected animals (Abreham *et al.*, 2019; Dhama *et al.*, 2013). Person-to-person transmission is also possible (WHO, 2017b).

E. coli are categorized into groups according to their virulence mechanism (Kaper, Nataro and Mobley, 2004). Diarrhoeagenic *E. coli* groups include enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC) and Shiga toxin-producing *E. coli* (also known as verotoxin-producing *E. coli* [STEC/EHEC]). Cattle and other ruminants are the natural reservoirs of Shiga toxin-producing *E. coli* (Abreham *et al.*, 2019; Bekele *et al.*, 2014; Desta Sisay, 2015; Dhama *et al.*, 2013). Globally, this type of *E. coli* has been associated with several life-threatening food-borne outbreaks, especially in young children and older people (Elmonir, Abo-Remela and Sobeih, 2018; WHO, 2017a). Certain strains of STEC are zoonotic (Fairbrother and Nadeau, 2006). *E. coli* O157 is the most commonly reported serogroup, but other serogroups, such as O26, O103, O145, O91, O146 and O111, can also cause human infection (Assefa and Bihon, 2018; Bedasa et al., 2018; Bekele et al., 2014; İnanç and Mustafa, 2018). TASFs typically associated with Shiga toxin-producing *E. coli* include raw milk and dairy products, and poorly cooked ground-meat products (Abdissa *et al.*, 2017; Ayscue *et al.*, 2009; Bogere and Baluka, 2014). The major factors contributing to

E. coli O157:H7 infection include consumption of undercooked meat and unpasteurised milk, mass catering, complex and lengthy food-supply procedures and poor hygiene practices (Haile, Kebede and Wubshet, 2017).

According FERG's 2010 global estimates (Havelaar *et al.*, 2015), ETEC were the group of *E. coli* that caused the most cases of food-borne illness (86.5 million cases and 26 000 deaths), followed by EPEC (24 million cases and 37 000 deaths) and Shiga toxin-producing *E. coli* (1.2 million cases and 13 000 deaths). The annual DALY burdens caused by ETEC, EPEC and Shiga toxin-producing *E. coli* in 2010 were 2.1 million, 2.9 million and 12 953, respectively (Kirk et al., 2015, FAO and WHO, 2018). In the WHO European Region, Shiga toxin-producing *E. coli* caused more than 150 000 cases of illness in 2010, making it the seventh out of the ten most common causes of food-borne illness (FAO and WHO, 2018, EFSA and ECDC, 2015). The annual burdens of Shiga toxin-producing *E. coli*, EPEC and ETEC in the WHO European Region in 2010 were estimated to be 1 000, 46 and 35 DALYs, respectively (Havelaar *et al.*, 2015). In 2017, 6 073 confirmed cases of Shiga toxin-producing *E. coli* infections were reported in the European Union. The European Union notification rate was 1.66 cases per 100 000 population, which was a 6.2 percent decrease compared to the 2016 figures (FAO and WHO, 2018; EFSA and ECDC, 2015). In the same year, 20 deaths due to Shiga toxin-producing *E. coli* infection were reported, which resulted in a European Union case-fatality rate of 0.5 percent (FAO and WHO, 2018; EFSA and ECDC, 2015). The most commonly reported Shiga toxin producing *E. coli* serogroup in the European Union is O157, although its proportion relative to other serogroups appears to be decreasing (FAO and WHO, 2018; EFSA and ECDC, 2015).

E. coli infection has an incubation period of two to ten days, which is followed by the onset of diarrhoea, abdominal pain, vomiting, haemorrhagic colitis, the more severe form of haemolytic uraemic syndrome, with acute kidney failure, and thrombotic thrombocytopenic purpura, a rare disorder that causes blood clots in small vessels of the body (Abreham *et al.*, 2019; Mersha *et al.*, 2010). Septicaemia (presence of bacteria in the blood with multiplication that can lead to organ damage/death) starts with bacteraemia (presence of bacteria in blood) and ends with toxaemia (presence of bacterial toxins in blood); its severity depends on the effect of bacteria localization in a variety of tissue spaces throughout the body (Desta Sisay, 2015).

Although prevention and control of *E. coli* infections are similar to those of other food-borne bacterial diseases, their severe consequences in young children mean that special precautions are required (Desta Sisay, 2015). Control measures include good sanitation measures during food preparation, handling and transport (Saeedi *et al.*, 2017). In cattle, intervention measures such as probiotics, vaccination, antimicrobials, sodium chlorate and bacteriophages may reduce the prevalence of infection with *E. coli* O157:H7 (Karmali, Gannon and Sargeant, 2010). Measures such as training of food handlers, inspection of food premises and community-based education programmes promoting proper food handling and preparation are effective in reducing public exposure to food-borne pathogens, including *E. coli* (Karmali, Gannon and Sargeant, 2010).

4.2

Viral hazards

Viruses are composed of genetic materials, i.e. DNA or RNA, enclosed by a protein, sometimes combined with lipids to produce one or more membranous coats. Besides being much smaller than bacteria, viruses also differ from them in that they are incapable of reproducing on their own: bacteria can reproduce in any suitable environment, but viruses need to infect a living cell and introduce their genetic material into the cell's replication system (FAO and WHO, 2008). Viruses use the cell's resources to produce more viruses that are then able to invade more cells. As they require living cells in order to replicate, viruses are not able to grow in food and water. The infective dose of most viruses is low (10 to 100 infectious viral particles). Most food-borne or water-borne viruses are relatively resistant to heat, disinfection and pH changes (FAO and WHO, 2008).

Food-borne infection through ingestion of products from an animal infected with a zoonotic virus is rare, but hepatitis E virus has been reported after consumption of pork, wild boar and deer (Ruggeri *et al.*, 2013; Van der Poel, 2014). Hepatitis E virus is a small, spherical and non-enveloped RNA virus of approximately 7.2 kb. It belongs to the family *Hepeviridae* and the genus *Hepevirus*. Hepatitis E virus has emerged as a potential zoonotic threat (Bosch, Pintó and Guix, 2016) and is known to be a major cause of acute human hepatitis in regions with inadequate water supplies and poor sanitary conditions (Guthmann *et al.*, 2006; Purcell and Emerson, 2001). It has been found to be highly prevalent in pigs in countries where hepatitis E virus in humans is rare (BIOHAZ, 2011). Hepatitis E virus variants found in pigs are almost identical to the viruses found in some humans (Meng *et al.*, 1997), a finding that provided the first evidence of zoonotic transmission of hepatitis E virus.

4.3 Parasites

Parasitic organisms affecting humans include protozoa (e.g. *Toxoplsma*, *Giardia*, *Cryptosporidium*, amoebae and *Cyclospora*) and helminths, such as roundworms (e.g. *Trichinella* spp. and *Anisakis* spp.) and tapeworms (e.g. *Diphyllobothrium* spp., *Taenia* spp. and *Echinococcus* spp.) (WHO, 2020a). These parasites are usually transmitted via food, water, soil or person-to-person contact, but some, such as fish-borne trematodes, are only transmitted through food (WHO, 2017b). According to FERG data (WHO, 2015), the parasitic diseases with the largest number of symptomatic incident cases attributable to contaminated food in 2010 were acquired toxoplasmosis and ascariosis. The global burden of 11 parasitic diseases was 8.78 million DALYs, of which an estimated 6.65 million DALYs were attributed to food (WHO, 2015).

Toxoplasmosis

Toxoplasmosis is a food-borne infection caused by the protozoa *Toxoplasma gondii.* Cats are the primary hosts. Other animals, including food animals, are intermediate hosts. Humans can become infected when they come into contact with the faeces of these animals. Human transmission can also occur through consumption of raw or undercooked meat (Attias *et al.*, 2020; WHO, 2020a) and raw milk (Saad, Hussein and Ewida, 2018). In many people, toxoplasmosis does not cause any problems, and no treatment is required. The parasite can reach the foetus through the placenta (Attias *et al.*, 2020). This can result in foetal death if it occurs in early stages of pregnancy and may cause hydrocephalus and blindness in children (McAuley, 2014; Scallan et al., 2011).

According to Scallan et al. (2011), T. gondii infections cause approximately 87 000 illnesses, 4 400 hospitalizations, and 330 deaths each year in the United States of America, making it the second leading cause of food-borne mortality and the third leading cause of food-borne hospitalizations The global burden of toxoplasmosis, both congenital and acquired combined, was 1.68 million (95 percent UI 1.24–2.45 million) DALYs in 2010 (WHO, 2015). Preventative measures include proper cooking of meat to a minimal internal temperature of 70 °C or freezing at –20 °C and avoiding eating food potentially contaminated with oocysts from cat faeces (Mirza Alizadeh *et al.*, 2018; Schmidt and Rodrick, 2003).

Cryptosporidiosis

Cryptosporidium parvum is a zoonotic parasite that is mostly transmitted through contaminated water, food or fomites (Zambriski *et al.*, 2013). Cattle are important reservoirs. A systematic literature review reported a pooled prevalence of 22.5 percent (95 percent CI = 19.6–24.6 percent) for conventional microscopy and 29 percent (95 percent CI = 23.1–35.6 percent) for detections done using the PCR method (Hatam-Nahavandi *et al.*, 2019). Another review, focusing on studies done in the Islamic Republic of Iran, found a prevalence of 14.4 percent (95 percent CI = 11–18.6 percent) (n = 40 studies) (Haghi *et al.*, 2020). *C. parvum* is the species most often responsible for diarrhoeal diseases in animals and humans (Laberge *et al.*, 1996). Infected calves may suffer from watery diarrhoea, inappetence, lethargy and dehydration (Robertson *et al.*, 2020). Lombardelli *et al.* (2019) sampled a total of 1 073 calves and found 26 percent to be positive for oocysts, using microscopic examination.

The major symptoms of *Cryptosporidium* infection in humans are fever, diarrhoea, abdominal pain and anorexia. Gastrointestinal symptoms usually last about seven to 14 days, unusually five to six weeks, while persistent weakness, lethargy, mild abdominal pain and bowel looseness may persist for a month (Casemore, 1990). In young, malnourished children, symptoms may be severe enough to cause dehydration, malabsorption and even death. Illness and oocyst excretion patterns may vary with factors such as immune status, infective dose, host age and the virulence of the organism. In humans, the prepatent period is between seven and 28 days. The mean incubation period is 7.2 days (range 1–12) with a mean duration of illness of 12.2 days (range 2–26) (Jokipii and Jokipii, 1968). Oocyst excretion can continue for two to three weeks after the disappearance of symptoms, creating problems with infection control (Soave and Armstrong, 1986).

The global burden of cryptosporidiosis in 2010 was estimated to be 128.4 per 100 000 population, with a range of 50.3 to 601.6 (WHO, 2015). Cryptosporidiosis mortality was estimated to be 0.015 per 100 000 population, with a range of 0.003 to 0.08 (WHO, 2015). However, the proportion of food-borne cryptosporidiosis burden attributable to TASFs (most commonly dairy products) was less than 10 percent in all subregions (the lowest proportion among all hazards, with a global burden of 0.3 DALYs per 100 000 population) (Li *et al.*, 2019).

Trichinosis

Trichinosis, or trichinellosis, is one of the most widespread global parasitic diseases of humans and animals (Foreyt, 2013). It is a zoonoses caused by the larval stage of parasitic roundworms called *Trichinella* spp. (FAO, WHO and WOAH, 2021). *T. spiralis* is the most important cause of human disease (Gottstein, Pozio and Nöckler, 2009). Trichinosis is mainly associated with the ingestion of contaminated raw or insufficiently cooked pork or wildlife meat. Consumption of meat from horses and other animals can also be a source of human infection, although this depends on cultural, dietary and livestock-husbandry practices and is not common (Foreyt, 2013). For example, in China, outbreaks of human trichinosis attributed to *T. nativa* have been caused by consumption of dog meat (Cui and Wang, 2001). In France and Italy, human infections have been linked to consumption of horse meat (Dupouy-Camet, 2000). *T. spiralis* is the predominant species in the United States of America, but *T. pseudospiralis* and *T. murrelli* have also been identified (Worley *et al.*, 1986). Following the ingestion of meat containing encysted larvae, the cysts dissolve in the intestine, releasing the larvae, which then enter the gastrointestinal tract epithelium. The parasites then mate and deposit larvae in the lymphatic system. The larvae infect other body tissues through lymphatic circulation. Initial symptoms are gastroenteritis, which may be followed by irregular fever (39–41 °C), muscle pain and difficulty in breathing, talking or moving. Duration ranges from 21.5 to 70 days (Murrell and Pozio, 2011). The larvae in muscles can be killed by a number of methods: heating to 65.5 °C or freezing at -15 °C for three weeks or at -30 °C for one day. According to data compiled by Murrell and Pozio (2011), 51 percent of cases of infection in humans are in males and most are in people between 20 and 50 years of age.

Trichinosis is a public health threat (Dupouy-Camet, 2000). In many countries, including the United States of America, decreases in the number of reported cases have been brought about by prohibiting the use of untreated garbage (swill) as pig feed and improving surveillance, public education, livestock-husbandry systems and hygiene (Foreyt, 2013). Trichinosis prevalence of up to 50 percent has been reported in pig herds in Belarus, Croatia, Latvia, Romania, the Russian Federation and Ukraine (Pozio, 2001). In Argentina, Chile, Mexico and the Plurinational State of Bolivia, trichinosis remains endemic and prevalent due to an increase in the number of small farms, which often do not use good management practices, a lack of sanitary regulations and regulations for home slaughter, and the misconception that trichinosis is no longer a disease of concern (Gajadhar and Gamble, 2000). The occurrence of the disease has been attributed to lack of veterinary controls, economic problems and war, changes in livestock husbandry, changes in marketing and distribution systems, complacency and increases in wildlife reservoirs (Pozio, 2001).

Trichinosis can be controlled and prevented through education and improved hygiene in the environment and in the home. Transmission of trichinosis to garbage-fed pigs can be prevented by cooking the garbage (swill) to an internal temperature of 71 °C to inactivate the *Trichinella* larvae (Pozio, 2001). Cooking the meat to 71 °C (Gajadhar and Gamble, 2000) will kill larvae and prevent human infections; however, it is more effective for meat producers and suppliers to prevent infected meat from reaching consumers, for example through meat inspection (van Knapen, 2000). At production level, control can be enhanced by implementing biosecurity measures, controlling rodents and not feeding wastes to pigs (van Knapen, 2000).

4.4

Prions

Prions are infectious pathogens associated with specific forms of neurodegenerative disease (Prusiner, 1998). They are composed of a modified protein and are devoid of nucleic acid (Prusiner, 1998). Bovine spongiform encephalopathy (BSE or “mad cow disease”) is a prion disease of cattle and is thought to have originated as a result of cattle being fed with animal protein derived from scrapie-infected sheep. The disease is associated with the variant Creutzfeldt-Jakob Disease in humans (Campbell, 1998). Consuming bovine products containing specified prion-containing risk material, such as brain tissue, nerve ganglia or spinal tissue, appears to be the most likely route of transmission of the prion agent to humans (WHO, 2020a).

5. Chemical hazards and associated public health impacts

Chemicals have both beneficial and negative impacts on human health (World Health Organization, 2014). Contamination of food can occur at various stages of the value chain. Public health concerns arise when chemicals are present where they should not be or in amounts that are higher than recommended (Rather *et al.*, 2017). The categories of substances involved in food contamination include:

- agrochemicals such as pesticides and herbicides;
- veterinary medicines and residues of veterinary medicines;
- environmental contaminants: mainly heavy metals, persistent organic pollutants, and natural toxins; and
- processing contaminants resulting from cooking, processing or packaging: for example, nitrosamines, chloropropanols, acrylamide, furanes and poly-aromatic hydrocarbons (Nerín, Aznar and Carrizo, 2016).

5.1 Agrochemicals

Residues of pesticides

According to FAO and WHO (2014b), a pesticide is any substance or mixture of substances of chemical or biological ingredients intended for repelling, destroying or controlling any pest or regulating plant growth. At the international level, the Joint Meeting on Pesticide Residues in Food is responsible for assessing risks associated with pesticide residues in food and estimating maximum residue levels compatible with avoiding toxicological risks to health (FAO, 1997). The Codex Alimentarius Commission, through the Codex Committee on Pesticide Residues, aims to reach consensus among governments on the maximum residue limits allowed in food.

Pesticides are used in agriculture to protect plants and ensure that produce is not destroyed by pests, and in public health to control vector-borne diseases (Nicolopoulou-Stamati *et al.*, 2016). Pesticides can be natural or synthetic and include insecticides, pesticides, herbicides and fungicides (Cabras, 2003; Stoytcheva, 2011). Over 1 000 pesticides are known to exist. When not properly used, pesticides can contaminate the environment and negatively affect soil, water, vegetation (Aktar, Sengupta and Chowdhury, 2009) and animals. Public-health concerns relate to their persistence as residues (Aktar, Sengupta and Chowdhury, 2009). Dichloro-diphenyl trichloroethane (DDT) was prohibited as an insecticide in the United States of America in 1973 and its production and use thereafter decreased rapidly in most industrialized countries (Turusov *et al.,* 2002). However, in countries such as India, DDT use is still permitted for the control of malaria-bearing vectors, even though vector resistance has been reported (van den Berg, Manuweera and Konradsen, 2017; Curtis, 2002).

Pesticides used in agriculture can contaminate feeds and be excreted in milk produced by animals that consume these feeds. A study in the United Kingdom found that 21 percent of feed samples contained pesticide residues that could potentially end up in cow's milk (FAO, 2004). Studies in Bundelkhand, India, detected pesticide contamination in 56 percent of 533 feed samples analysed (but many at levels below the regulatory limits) (Nag and Raikwar, 2010) and in 63 percent of 325 milk samples (Nag and Raikwar, 2008). Another study in India, involving peri-urban areas in five states, reported residue prevalence rates of 6.3 to 11.2 percent in milk (Gill *et al.*, 2020).

Most insecticides are neurotoxic and act by attacking the nervous system of target organisms. Chemical compounds that act on the nervous system of insects have similar effects on humans (Costa, 2008). Cancer and asthma are among the diseases associated with pesticide exposure in humans (Kim, Kabir and Jahan, 2017). Health outcomes depend on the type of pesticide, the duration and route of exposure and the health status of the individual affected (Nicolopoulou-Stamati *et al.*, 2016).

Residues of veterinary medicines

Veterinary medicines are used in livestock production to prevent, control or treat disease, improve feed uptake and promote growth. However, the benefits provided come with the risk that food products will be contaminated with residues. Drug residues present at the time of slaughter pose significant health risks to consumers on account of their effects on the evolution of antimicrobial resistance in bacteria, especially if residues exceed recommended levels. In recognition of the public health risk that may arise as a result of the presence of veterinary medicine residues in food, the Codex Alimentarius Commission established the Codex Committee on Residues of Veterinary Drugs in Foods to advise member governments and the Commission on issues related to public-health hazards and barriers to international trade caused by residues in foods of animal origin.

The Joint FAO/WHO Expert Committee on Food Additives has previously held meetings to specifically address the issue of veterinary drug residues in foods of animal origin (FAO and WHO, 2000).

Several studies have documented the prevalence but not the actual levels of veterinary medicine residues in TASF, making it difficult to assess the risk to humans. The results of prevalence studies for veterinary product residues in eggs and beef (Mensah *et al.*, 2014; Omeiza *et al.*, 2012; Omeiza, Ajayi and Ode, 2012) and in milk (Abebew, Belihu and Zewde, 2014) have been reported. Some veterinary medicine residues in TASF occur because of the unintended presence of residues of approved veterinary drugs in food animals as a result of the drugs being carried over in feed (FAO and WHO, 2019).

Hypersensitivity reactions, carcinogenicity, mutagenicity, teratogenicity and disruption of intestinal flora are the main concerns associated with presence of veterinary medicine residues in animal source foods (Tufa, 2015). It is important to sensitize value-chain actors about the need to observe drug withdrawal periods to ensure that products sold are safe for human consumption.

5.2

Environmental contaminants

Dioxins and Polychlorinated biphenyls (PCBs)

Dioxins are widespread contaminants that arise from human activities, especially industrial processes, incomplete combustion processes, such as waste incineration, and improper disposal of transformer oil used in the electrical-distribution industry (Marinkovic, 2010). Over 95 percent of human exposure to dioxins and PCBs is through the ingestion of high-fat foods, including meat and meat products, fish, and milk and dairy products (Zennegg, 2018).

A number of food and animal-feed contamination incidents occurred between 1997 and 2010 in Europe, and these highlighted the need to monitor dioxins and PCBs in food and feed (Zennegg, 2018). An outbreak involving dioxin and PCBs in animal feeds occurred in Belgium in 1999 (van Larebeke *et al.*, 2001). Cattle from extensive farming systems have been found to have higher levels of dioxin-like PCBs (dl-PCBs) than conventionally raised cattle, implying exposure through grazing and indicating that the chemicals are less present in concentrate feed than in silage and green fodder (Zennegg, 2018).

According to WHO (2016), short-term exposure of humans to high levels of dioxins may result in altered liver function and in skin lesions such as chloracne and patchy darkening of the skin. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions.

Heavy metals

The term "heavy metals" is used to describe a number of metals that if present in food or feed beyond a recommended threshold may present a significant risk to human health. Heavy metals can persist for long periods in the environment and have the potential to bioaccumulate in food value chains (WHO, 2007). They interfere with normal body functions and affect health. According to WHO burden estimates (WHO, 2015), ingestion of arsenic, methylmercury, lead and cadmium resulted in 1 122 436 illnesses, 56 192 deaths and 9 164 162 DALYs worldwide in 2015, with the greatest impact in terms of DALYs occurring in WHO's Western Pacific B subregion (Gibb *et al.*, 2019). All the metals were found to give rise to more DALYs per case than other FBD agents, including infectious and parasitic agents (Gibb *et al.*, 2019). Lead, arsenic and methylmercury were found to give rise to more DALYs per 100 000 population than other FBD agents (Gibb *et al.*, 2019).

Lead

Lead (Pb) is the most toxic heavy metal in the environment (Wani, Ara and Usmani, 2015), where it occurs primarily in organic form. Human exposure is mainly via food and water, with some occurring via air and soil. The WHO burden study found that lead accounted for 54 percent of the illnesses, none of the deaths and 60 percent of the DALYs caused by the four above-mentioned heavy metals globally in 2015 (Gibb *et al.*, 2019).

A recent systematic review on the occurrence of lead in TASF over a ten-year period (2010 to 2019) in the Islamic Republic of Iran reported a number of studies that showed concentrations above maximum recommended limits in meat, milk and their products (Sarlak *et al.*, 2021).

A greater proportion of ingested lead is absorbed in children than in adults; it accumulates in soft tissues and – over time – in bones (Wani, Ara and Usmani, 2015). In children, lead exposure affects cognitive functions (Sanders *et al.*, 2009) and may cause abnormal behaviours (Hou *et al.* 2013). Lead and calcium compete for protein: lead can interfere with calcium metabolism and impair bone formation (Dongre *et al.,* 2013). The central nervous system is the main target organ for lead toxicity (Tong, 2000).

Lead has a long half-life in the body, which leads to chronic toxicity (Sanders *et al.*, 2009). Studies have shown a link between blood lead concentration and chronic kidney disease at relatively low blood lead levels (Buser *et al.*, 2016; Harari *et al.*, 2018; Rastogi, 2008).

The Joint FAO/WHO Expert Committee on Food Additives establishes the provisional tolerable weekly intake (PTWI) for lead at the international level (FAO and WHO, 2011a).

Cadmium

Cadmium (Cd) is a heavy metal found as an environmental contaminant as a result of natural occurrence and pollution from industrial and agricultural sources. It has no known biological function in animals or humans. Foods are the main source of cadmium exposure for the non-smoking population (Agency for Toxic Substances and Disease Registry, 2012; UNEP, 2019). The WHO burden study found that cadmium accounted for 1 percent of the illnesses, 4 percent of the deaths and 1 percent of the DALYs caused by the four heavy metals under consideration globally in 2015 (Gibb *et al.*, 2019). Poultry, cattle, horses and wildlife are among the animal bio-accumulators of cadmium (ATSDR, 2012; Raicu, Vlagioiu and Tudor, 2020). Meat normally contains lower levels of cadmium, than animal offals (kidneys and liver) that can have high cadmium concentrations, as these are the organs where the metal particularly accumulates (Drapal *et al.*, 2021). Cadmium absorption after dietary exposure in humans is generally low (3–5 percent), but it is retained in the human kidney and liver and has a very long biological half-life, ranging from 10 to 30 years (ATSDR, 2012). Cadmium exposure has been associated with accumulation in the proximal tubular cells of the kidney over time and may cause renal malfunction and osteoporosis through bone demineralization and neurotoxicity (European Food Safety Authority (EFSA), 2009; Genchi *et al.*, 2020).

Mercury

Mercury (Hg) is widely distributed in the Earth's crust, seawater, freshwater and air. Bioaccumulation of mercury in the food chain in Poland was analysed for a period of ten years (2009 to 2018) by monitoring the muscle tissue and liver of various livestock and game animals (Nawrocka *et al.*, 2020). Most of the results for muscle tissue were below the limits of quantification. However, the mean mercury concentrations in muscle tissue were between 0.6 and 5.6 µg/kg of wet weight and those in liver between 0.8 and 16.4 µg/kg of wet weight, with the lowest levels recorded in chickens and the highest in wild boars; these levels of mercury were not considered to pose a health risk. A recent study in Iraq on the bioaccumulation and toxicity of heavy metals in edible chicken liver found mercury concentrations of 110 +/- 83 µg/kg (Ali *et al.* 2020), while a study in Saudi Arabia found mean mercury levels of 125 µg/kg in sausages (Alturiq and Albedair 2012). Levels as high as these are a public health concern.

Mercury toxicity usually manifests itself mainly as neuronal disorder, immunotoxicity and kidney damage (Clarkson, 2002). People affected by a mercury poisoning incident in a small fishing town near Minamata, Japan, in the 1950s suffered muscle weakness, paralysis and speech and hearing problems. Over 40 percent of those exposed died, and others suffered permanent damage. This poisoning incident was the worst in Japan in the 1950s (Kessler, 2013; Onuki, 2020).

Arsenic

Arsenic (As) is a heavy metal that occurs in various inorganic and organic forms. It is very prevalent in the environment, where it occurs both naturally and as a result of human activity. It can easily enter the agrifood system through contaminated soil or water. The WHO burden study found that arsenic accounted for 20 percent of the illnesses, 96 percent of the deaths and 14 percent of the DALYs caused by the four heavy metals under consideration globally in 2015 (Gibb *et al.*, 2019).

A study that evaluated the role of milking cattle and poultry as sources of arsenic in the human food chain in West Bengal, India, showed that milk, poultry egg yolk and albumen and all poultry organs from arsenic-endemic zone had higher levels of contamination than those from control areas (Datta *et al.*, 2012). It was concluded that consumption of eggs and milk might be a factor in the arsenicosis cases occurring in the area (Datta *et al.*, 2012). Another study, also in India, assessed arsenic levels in different kinds of chicken meat and found that the highest levels of accumulation were in breast meat, followed by stomach meat, with lower levels in leg and heart meat (Mondal, 2020). These levels imply that if a person eats 60 g of chicken meat daily, they may be consuming 0.186 to 0.372 µg of total arsenic per day (Mondal, 2020).

The main health effects associated with long-term exposure to inorganic arsenic in humans are skin lesions and cancer (Hong, Song and Chung, 2014; Naujokas *et al.*, 2013). A causal link between oral exposure to arsenic and skin, lung and bladder cancers has been established; there are also indications for liver, kidney and prostate cancers (Hong, Song and Chung, 2014). Other effects related to chronic ingestion of arsenic include cardiovascular diseases, developmental toxicity, abnormal glucose metabolism, type 2 diabetes and neurotoxicity (FAO and WHO, 2011b).

Nitrates and nitrites

Nitrate (NO_{3-}) is a polyatomic anion that can form salts with a number of elements. These salts occur naturally in the environment and in most foods (plant and animal tissue). Nitrates are involved in the nitrogen cycle and large deposits build up in some locations, especially in the form of sodium nitrate ($NaNO_3$) (EFSA, 2020). Dietary nitrate is converted to nitrite by symbiotic bacteria in the oral cavity and stomach, then to nitric oxide (NO) (Ma *et al.*, 2018).

Nitrates and nitrites have various uses in food and agriculture, for example in the production of fertilizers and food preservatives. The European Union has authorized the use of nitrites (sodium nitrite – E249, potassium nitrite – E250) and nitrates (sodium nitrate – E251, potassium nitrate – E252) as food additives under Commission Regulation (EU) No. 1129/2011. Their use as food additives to stabilize various types of processed meat, to keep it red and give flavour is permitted in some countries; nitrates are used to prevent certain cheeses from bloating during fermentation (EFSA, 2017).

The major human health risk associated with exposure to nitrates is considered to be production of methaemoglobin, a molecule with very limited oxygen carrying capacity. Clinical symptoms include anoxia, tachycardia, dyspnoea, muscle tremors, reduction in blood pressure, weakness, vomiting, unstable gait, cyanosis (manifested by brown-coloured arterial blood), polyuria, lethargy and death (Bruning-Fann and Kaneene, 1993).

Studies have shown that when it reacts with secondary amines under acidic conditions, nitrite can form N-nitrosamines (Gupta *et al.*, 2010; Robles, 2014). This reaction may potentially be of toxicological significance because some of the dialkyl- or cyclic N-nitrosamines are genotoxic and carcinogenic. Nitrosating agents produced from nitrite under acidic conditions in the stomach can react readily with nitrosatable compounds, especially secondary amines and amides, to form N-nitroso compounds, some of which are potential carcinogens (Shephard, Schlatter and Lutz, 1987).

Natural toxins

Natural toxins are toxic compounds that are naturally produced by living organisms (WHO, 2018b). These toxins, though not harmful to the organisms themselves, may be toxic to other organisms, including humans. They may be produced by plants as a natural defence mechanism against insects or microorganisms or in response to climate stresses such drought or extreme humidity, or they may be a consequence of infestation with microorganisms such as moulds. Microscopic algae and plankton in oceans and lakes may produce natural toxins that are not toxic to the fish or shellfish that eat these organisms but are toxic to humans. The natural toxins affecting livestock production and livestock products are described below.

Mycotoxins are chemical metabolites of food- and feed-borne fungi that can cause toxic and carcinogenic effects in humans and animals (WHO, 2018). In the context of livestock production, animals can be exposed to mycotoxins through contaminated feed, and humans can in turn be exposed to a subset of these mycotoxins by eating food obtained from animals.

Although mycotoxins, particularly aflatoxins, are responsible for a large burden of human disease worldwide, causing more than 600 000 DALYs and 19 000 deaths per year (WHO, 2015) as well as substantial economic losses to farmers, most of these losses occur as a result of exposure to mycotoxins in crops such as cereals and nuts. Crop-based exposure gives rise to a variety of mycotoxin-related health risks in humans, spanning cancers, acute liver failure, immunosuppression, gastrointestinal illness and growth impairment (Wu, Groopman and Pestka, 2014). In the case of human exposure through TASF, only two mycotoxins – aflatoxin M1 (AFM1) and ochratoxin A (FAO and WHO, 2018c) – pose potential risks (Chen and Wu, 2017).

AFM1 is a metabolite of aflatoxin B1 (AFB1), the most toxic and carcinogenic of aflatoxins. Aflatoxins (B1, B2, G1, G2) are a group of chemicals produced primarily by the fungi *Aspergillus flavus* and *A. parasiticus* in food and feed crops such as maize, groundnut, tree nuts and oilseeds. Aflatoxin was first discovered in 1960, following the death of over 100 000 turkey poults that had consumed aflatoxin-contaminated peanut meal (Kensler *et al.*, 2011). In the subsequent decades, it was discovered that aflatoxin causes hepatocellular carcinoma – liver cancer – in humans and numerous animal species (IARC, 1993). AFB1 is biotransformed in the liver into multiple metabolites, including AFM1, by cytochrome P450 enzymes. When dairy animals consume AFB1 in their feed, they secrete AFM1 in their milk, and this can lead to human exposure to AFM1 via the consumption of milk and milk products.

Saha Turna and Wu (2021) provide an overview of AFM1 occurrence in different forms of milk, including raw milk, and resultant AFM1 exposure based on milk consumption data country by country. They report exposures ranging from 0.0021 to 125.6 ng/kg bodyweight per day.

Unsurprisingly, the highest exposures to AFM1 were found to occur in countries where animal feed is highly contaminated with aflatoxin and where humans consume large quantities of milk, for example India, Pakistan and several sub-Saharan African countries. A recent study by Saha Turna *et al.* (2022) found that AFM1 exposure through consumption of liquid milk does not substantially increase liver cancer risk in humans.

The question is whether AFM1 exposure gives rise to any human health risk. AFM1 is much less carcinogenic than its parent compound AFB1. Only two studies have demonstrated that AFM1-related tumours can be induced in mammalian species (Cullen *et al.*, 1987; Lutz *et al.*, 1980). To date, no epidemiological study has linked AFM1 exposure in humans to liver cancer. In the absence of human data, the Joint FAO/WHO Expert Committee on Food Additives (1998) used existing animal studies to estimate that the cancer potency of AFM1 was one-tenth that of AFB1. Using this cancer potency factor, it was estimated that AFM1 exposure through milk consumption would cause, at maximum, only 13 to 32 additional liver cancer cases worldwide per year (Saha Turna *et al.*, 2022). However, other potential health effects of AFM1 exposure remain to be examined. A small number of studies suggests that AFM1 exposure through breastmilk may predispose infants to growth impairment (Khlangwiset, Shephard and Wu, 2011), although the evidence is mixed.

Ochratoxin A (OTA) is found in a wide variety of foodstuffs and is produced primarily by the fungi *Aspergillus ochraceus* and *Penicillium verrucosum* (FAO and WHO, 2007). It has been found in dairy and meat products worldwide. Ochratoxin A secretion in the milk of ruminants is, however, limited because of the action of ruminal microflora (Sorrenti *et al.*, 2013). A study involving dairy farms in Norway found ochratoxin A in six of the 40 (11–58 ng/l) conventional and in five of the 47 (15–28 ng/l) organic milk samples analysed (Skaug, 1999). A study involving 132 French farms (Boudra *et al.*, 2007) found three out of 264 milk samples to be ochratoxin A positive at levels of 5.0 to 6.6 ng/l. Contamination of cheese with ochratoxin A was reported by Altafini *et al.* (2021). A study in Türkiye found mean ochratoxin A contamination levels to be 137±57 ng/l in raw milk, 135±8 ng/l in pasteurized milk and 85±4 ng/l in UHT milk (Turkoglu and Keyvan, 2019).

Jørgensen (1998) reported ochratoxin A contamination (mean 0.05 µg/kg) in organic pork in Denmark (four out of seven samples tested were above the limit of detection). A recent study in the United States of America (Mitchell *et al.*, 2017) found ochratoxin A exposure from pork to be highest in 12 month to 5-year-old children; the mean was 0.16 ng/kg bodyweight per day and 0.6 ng/kg bodyweight per day in heavy consumers of pork. The same study found milk-based ochratoxin A exposures in adult average and heavy milk consumers to be 0.02 and 0.04 ng/kg bodyweight per day, respectively.

There is little evidence for human health risks as a result of ochratoxin A exposure through animal source food consumption (Bui-Klimke and Wu, 2015). Ochratoxin A exposure on the whole has, however, been associated with renal diseases in both livestock and human populations (Cabañes, Bragulat and Castellá, 2010). The International Agency on Research on Cancer (IARC, 1993) has classified ochratoxin A as a Group 2B possible human carcinogen: a classification assigned because suggestive evidence for ochratoxin A-related cancers has been found in animal studies but no such evidence exists in human studies.

6. Changing agrifood systems

Climate change affects the social and environmental determinants of human, animal and plant health. Impact is reflected in the form of novel, emerging and re-emerging diseases (vector-borne, soil-borne, water-borne and food-borne) that threaten the health of vulnerable groups of people and aggravate economic and social inequalities (FAO, 2018). Higher local temperatures are also associated with increased rates of antimicrobial resistance (Blair, 2018).

Agrifood systems have transformed rapidly as a result of factors such as rising incomes and rapid urbanization, and this has led to nutritional shifts as consumption patterns have changed (FAO, 2017b). Consumption of processed and imported foods has increased, posing challenges in terms of meeting food-safety and nutrition standards.

Food-safety issues have been linked to traditional agrifood systems where technological advancement is limited. However, the development of modern agrifood systems has brought new risks. Intensive production and extensive international transfers of animals and animal products facilitate long-distance pathogen transmission (Dury *et al.*, 2019). Intensification of production has given rise to waste management challenges, especially in LMICs. Much of the waste produced, which contains large quantities of pathogens, is disposed of on land without any requirement for pretreatment, posing an opportunity for human contact and transmission to wild animals, both avian and mammalian (Nachman *et al.*, 2005; Zheng *et al.*, 2006). Large-scale, high-input livestock production systems tend to bring humans and animals into close contact with each other, and this has led to the emergence or spillover of zoonotic diseases such as Nipah virus infection in 1999, severe acute respiratory syndrome (SARS) in 2002 and highly pathogenic avian influenza (HPAI) (Hassan 2014; Greger 2007), although none of these examples are FBDs.

FBDs occur mainly as a result of the consumption of contaminated animal products, vegetables and fresh fruits (Dury *et al.*, 2019). Consumption of these foods is increasing in urban settings, and supply chains are getting longer. Various activities within agrifood systems may make food less safe. In rural areas, the significance of post-harvest activities as means of preparing produce for market is increasing as society becomes more urbanized and economies become more market oriented. Although post-harvest activities enhance product storage and transportation, and improve foods' organoleptic, nutritional and sanitary qualities, they can be a source of contamination.

Food is important to many people's sense of identity and belonging to a particular community. Cultural differences mean that different societies process food products in different ways, and this variation needs to be considered when designing FBD interventions.

Since the early 1930s, antibiotic use has intensified in veterinary and human clinical settings, household products and agricultural production, bringing various benefits to patients, producers and consumers (Allen *et al.*, 2013). In livestock production, antibiotics are used to treat, control and prevent disease and in growth promotion (Allen *et al.*, 2013), with the aim of increasing production and hence economic benefits. Repeated use of antimicrobial agents in livestock, including the use of non-therapeutic doses for growth promotion, is reported to significantly contribute to the development of antimicrobial resistance (Agyare, 2016; Elliott, Kenny and Madan, 2017; Lekshmi *et al.*, 2017). The emergence of drug-resistant infection has led to substantial costs in terms of human and animal health. Use of antimicrobials in livestock may result in the presence of residues in foods such as milk, meat, eggs and their products, and this may cause health-related problems. The rise in antimicrobial resistance may also make FBDs more common (O'Neill, 2014; Sachi *et al.*, 2019). There is thus an urgent need to significantly reduce antimicrobial use in agrifood systems in order to combat rising levels of drug resistance. Global efforts to combat antimicrobial use and resistance are prominent in the One Health approach promoted by the Tripartite FAO/WHO/WOAH Joint Secretariat (WHO, 2012).

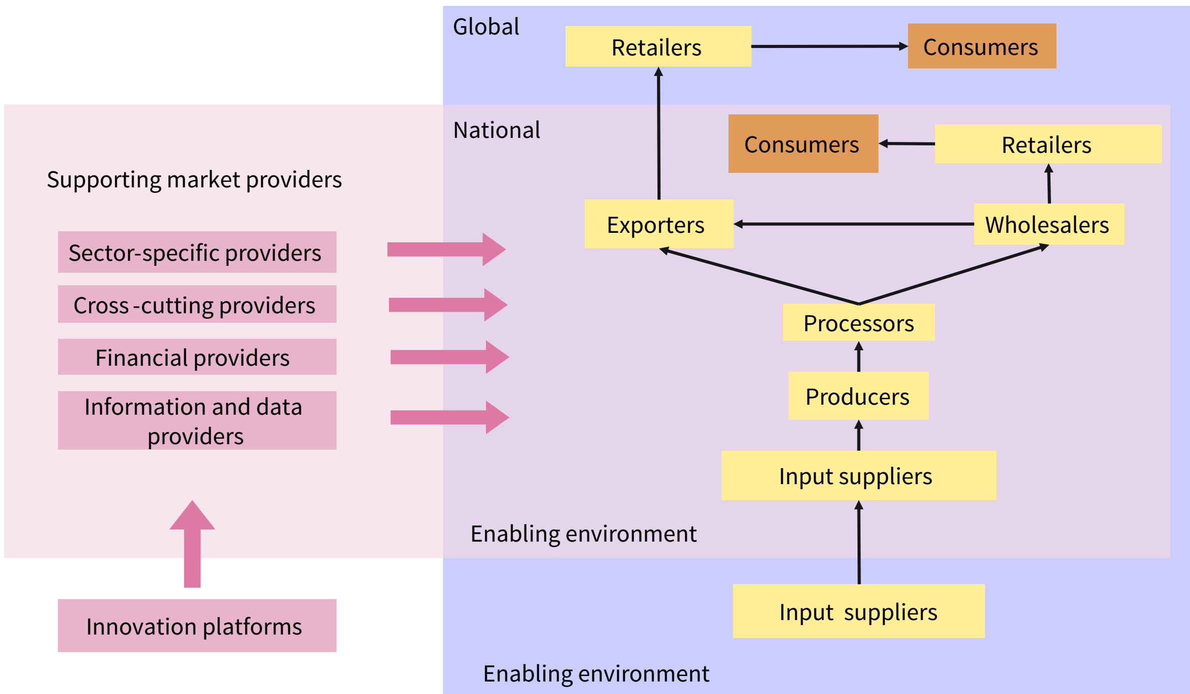
7. Food markets

TASFs are vital components of the diets and livelihoods of many people globally (Staal, 2015). They are frequently traded in formal, regulated markets and in local, unregulated markets. Consumption of these foods tends to be higher in cities than in rural areas (AGRA, 2020). Informal markets, which are common in many developing countries, are not necessarily dangerous, although they can pose significant health risks to consumers (Roesel and Grace, 2014). Formal markets are also not necessarily safe. In both cases, care must be taken to ensure that the products sold are safe. Both types of market are discussed in this subsection.

Marketing of livestock and livestock products is a dynamic process (Alexandratos and Bruinsma, 2012) and largely driven by demand, although other factors play a role (Staal, 2015). Formal markets are managed on the basis of international standards and are driven by demand beyond local boundaries. Consumer demand is driving a move towards higher standards, and this is being channelled through increasingly integrated production and supply chains in which the role of supermarkets is growing. Regulators, in turn, are responding to public pressure by increasing food-safety standards and scrutiny of their implementation (Staal, 2015). Many formal markets comply, or try to comply, with government regulations where these exist and are sufficiently well known, but generally there is a lack of effective food-safety management systems in developing countries. Food safety in these countries is largely driven by the private sector, with government establishing and enforcing the legal framework under which the sector operates (AGRA, 2020).

Formal food markets need to address the complexity of handling and regulating highly perishable animal products, which at times have greater human health implications than crop products (Staal, 2015). They involve regulatory infrastructure along the value chain that links the producer to the consumer (Baltenweck, 2014) (Figure D1).

Figure D1. Formal food markets and global value chains



Source: Adapted from Kula, O., Downing, J. & Field, M. 2006. Globalization and the small firm: an industry value chain approach to economic growth and poverty reduction. Washington, DC, USAID. https://www.fao.org/sustainable-food-value-chains/library/detalles/es/c/265236/.

Food markets in the informal sector play a vital role in the livelihoods of the poor in developing countries. Informal markets (also called traditional markets)[7] provide affordable, accessible and diverse food for the urban poor, while at the same time supporting the livelihoods of millions of small-scale producers, traders and vendors (Resnick, 2017), who include youth and women. They are convenient, accessible and play critical roles in nutrition and livelihoods. In Zambia, for example, the informal sector is a major source of employment and livelihoods, and almost 80 percent of the country's informal workers are employed in agriculture-related activities (Mwango *et al.*, 2019). However, the conditions under which the informal sector operates raise concerns about the safety and quality of the food sold, including TASF. The informal sector focuses on the sale of fresh food, while supermarkets and other formal stores supply more processed products (Romanik, 2008). Traditional food markets have also been associated with important food-borne and zoonotic disease outbreaks, including most recently COVID-19 (Pekar *et al.*, 2022; Worobey *et al.*, 2022; WHO, 2021).

A safe and healthy traditional food market should provide people with food that is not only safe but also nutritionally adequate (WHO, 2021). Factors that need to be considered if this is to be achieved include physical layout and facilities, hygiene practices and food handling, including that of ready-to-eat food. A combination of diverse interventions, encompassing research, regulation and education and operating at different stages of the food chain, has the potential to yield the best results (WHO, 2021). In addition, informal markets, especially those in developing countries, should be monitored to ensure food safety is maintained (Baltenweck, 2014).

The term "wet market" is defined differently by different authors. The definitions also differ by location or region, especially with respect to the range of products sold within such markets. A "wet market" can be defined as a public market that sells, among other products, eggs, meat and fish in an open-air setting (Zeng, 2016).

Emerging and re-emerging zoonotic infections have increased in frequency in the past centuries (Bengis *et al.*, 2004). A number of factors contribute to zoonotic disease transmission: population size, population mobility, intensification of production, urbanization, deforestation, wildlife trade, climate change and improper disposal of faeces, among others (Horby *et al.*, 2014; National Research Council (US) Committee on Achieving Sustainable Global Capacity for Surveillance and Response to Emerging Diseases of Zoonotic Origin, 2009; Sosbey *et al.*, 2006). The increased demand for and trade in meat from wildlife increase the chances of exposure to the pathogens that these foods may carry. The increasing human population has led to greater contact between humans and animals as a result of growing demand for foods of animal origin and greater encroachment on wildlife habitats for human activities and settlement (Naguib *et al.*, 2021).

Wet markets in China and meat from wild animals in Africa are strongly implicated in many recent zoonotic transfers and spillovers (Haider *et al.*, 2020; Pekar *et al.*, 2022; Worobey *et al.*, 2022). Such zoonotic diseases exert a significant burden on human health and have considerable socioeconomic impact globally. The interaction of humans, live domestic animals awaiting sale, food products and wild and scavenging animals increases the threat from emerging infectious diseases. SARS-CoV-2 was initially associated with a wet market in Wuhan province, China (Rabi *et al.*, 2020). One leading theory is that the virus "jumped" from a bat to a pangolin or other wild animal, which was in turn sold in a wet market (Rabi *et al.*, 2020). Similar theories have been reported in the past for the origin of Ebola and other diseases, including HIV-AIDS (Zhang *et al.*, 2020). Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) have also been reported to have originated from wet markets (Peiris, Guan and Yuen, 2004; Hui *et al.*, 2020). In addition, the 2003 to 2006 avian influenza H5N1 outbreak, which culminated in 113 human deaths was linked to contact with infected poultry (Naeem *et al.*, 2007). It is important to understand the epidemiology and pathogenesis of such pathogens, which may move into humans directly from the original host species or via intermediate or amplifier hosts.

There is no doubt that a lack of action to make wet markets safer and more hygienic may endanger already-fragile agrifood systems, human health and human rights, and ultimately sustainable development at global scale (Akhtar, 2012). Several strategies have been instituted to minimize the public health impacts arising from such markets. The Convention on Biological Diversity has called for a move to reduce the number of live animals in wet markets and for stricter controls on the sale and consumption of wild species (Everard *et al.*, 2020). In 2021, WHO has developed

[7] Traditional food markets include wet markets, informal markets and farmers' markets that sell foods of animal origin/non-animal origin/dried goods and where live animals are sometimes housed and slaughtered on site (WHO, WOAH and UNEP, 2021).

food-safety and hygiene standards for wet markets (WHO, 2021). Calls to ban wet markets may be met by local or national resistance in countries where such markets abound, thereby blocking opportunities to target the types of wet markets that actually pose serious risks to people or biodiversity.

In order to reduce the risk of further pandemics, there is a need to reconsider guidelines on biosecurity and hygiene at wet markets, especially in high-risk regions. Measures such as installing handwashing facilities and toilets, requiring adequate drainage, separating live animals from meat and produce, and implementing protocols for food cleaning and animal slaughtering can help reduce pathogen exposure and transmission. Other options include strengthening zoning and land-use planning, developing appropriate legislative frameworks, integrating healthy design standards into infrastructure, improving the quality and distribution of public spaces, and strengthening the regulation and surveillance of agrifood systems. Science-based risk assessment of the zoonotic risks associated with wet markets is recommended (Naguib *et al.*, 2021). One Health should be integrated into risk assessment frameworks, incorporating data on ecosystem health, animal disease and human health (Naguib *et al*., 2021). In addition, policies should focus on minimizing harmful disruptions to communities while mitigating future health and biodiversity risks posed by emerging and re-emerging zoonoses and FBDs.

All of these solutions would stand to benefit from a clearer classification of the different types of wet market that exist and the differential risks they pose. Lin *et al.* (2021) have provided a typology whereby "wet markets sell consumption-oriented, perishable goods in a non-supermarket setting. While wildlife markets sell non-domesticated wild animals, either captive-bred or wild-caught, dead or alive, and live-animal markets sell live animals." Failure to differentiate between different types of wet market or treating wet markets as the only source from which pandemics may arise could lead to unfeasible or ineffectual policy decisions. Outright banning of wet markets could destroy the livelihoods of people that depend on them or even drive the development of even riskier black markets facilitated by corruption (Aguirre *et al*., 2020). Banning wet markets carries the risk that they will evade public scrutiny, making them even harder to quantify, regulate and reform (Roe *et al.*, 2020). A middle ground could be to allow informal markets to operate with improved food-safety and hygiene standards, less animal crowding, regular inspections and increased surveillance focused on reducing the risk of emerging zoonotic diseases and the impact of FBDs.

In low-income countries, government enforcement of regulations tends to be weak and the informal sector tends to be large, providing more than 70 percent of total employment in emerging market and developing economies (Ohnsorge and Yu, 2022). In such countries, many market actors are not licensed and do not pay taxes, traditional processing, products and retail prices predominate, and effective health and safety regulations are often evaded (Roesel, 2018). Failure to taxes affects revenue collection and governments' ability to provide services (Ohnsorge and Yu, 2022). The informal sector accounts for up to 39 percent of local gross domestic product (Roesel, 2018). More than 80 percent of the TASF produced in poor countries is marketed through informal markets (Mwango *et al*., 2019). Thus, measures should be put in place to safeguard the sector as food systems change while also ensuring product safety and protecting public health.

8. Food-safety management

Current evidence highlights the need to invest in food safety through education and strong food-control systems. Food safety is closely linked to the way agrifood supply and distribution chains are organized – a factor that needs to be considered in future mitigation efforts. Agriculture is key to meeting the SDGs, and this has led to increased investment in intensification and diversification of production (Vipham, Chaves and Trinetta, 2018). Improving food safety requires broad stakeholder participation that to ensures that good practices are followed during production (farmers and pastoralists), transportation, processing (manufacturers) and distribution (traders) (Oloo, 2010). Agribusiness firms are restructuring their production processes and distribution systems by transforming their contractual relations from market-based arrangements (e.g. traditional arms-length transactions) to integrated supply systems (e.g. vertical integration, formal contract or preferred supplier) and from food markets with no quality or safety standards to ones that use publicly or privately provided standards (Abebe, Bijman and Royer, 2016). National food-control systems are critical in ensuring better consumer health and supporting trade (FAO, 2020). Care of slaughter animals in production, transportation, markets and abattoirs is central to the provision of safe and good-quality meat.

Food-safety decision-making premised on risk analysis provides a framework for assessing food-safety risks, managing such risks and communicating both risks and decisions taken on how to mitigate them (FAO, 2017a). Policymakers and risk managers should always consider the complexity and dynamic nature of the various factors that can influence food-safety decisions.

Risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard or hazards. Risk analysis is an international approach to improving food safety. It is based on science and provides a basis for international trade in food products. Countries require an effective and efficient food-safety system based on scientific risk assessment and management. However, resources are limited. The desired outcome of a risk assessment is a measure of the probability of effects on human health attributable to a specific hazard, food, process, region, distribution pathway or some combination of these (Häsler *et al.*, 2017).

The Codex Alimentarius Commission and other bodies, such as the Codex Committee on General Principles, the Joint Expert Committee on Microbiological Risk Assessment, the Joint FAO/WHO Expert Committee on Food Additives and the Joint FAO/WHO Meeting on Pesticide Residues, have adopted a risk-analysis approach to food safety that consists of three stages – risk assessment, risk management and risk communication (FAO and WHO, 2014a). The process of assessing risk is divided into four steps (hazard identification, hazard characterization, exposure assessment and risk characterization) that are applied throughout the food chain to determine the risks a hazard poses to human health and capture the dynamics in the chain (see Subsection 3.3).

Effective communication of information and scientific opinion on risks associated with real or perceived hazards in food is an essential and integral component of the risk-analysis process. Risk communication may originate from official sources at international, national or local levels or from other sources, such as industry, trade, consumers or other interested parties (FAO and WHO, 1999).

The major challenges to food safety centre around, but are not limited to, inadequacies, inconsistencies, inequities and inefficiencies in the entire agrifood system (Vipham, Chaves and Trinetta, 2018) and this also includes livestock systems. Food-safety systems – both the policy and the operational aspects of food-safety management – at the national level require a solid foundation of epidemiological data, which often is lacking (FAO and WHO, 2003). In many developing countries, especially in sub-Saharan Africa, unsafe water is usually associated with diarrhoeal illness; reviews of water, sanitation and hygiene (WASH) programmes have reported varying figures (20–60 percent) for the percentage of diarrhoea that can be attributed to unsafe water (Engell and Lim, 2013).

In most developing countries, there is a lack of infrastructure for laboratory testing and a lack of resources for routine monitoring and/or enforcement (e.g. properly trained inspectors), and this represents a big gap in food-safety systems (Bartoloni and Gotuzzo, 2010). Although some governments have incorporated Codex Alimentarius guidance into their national health plans, lack of infrastructure makes operationalization of standards difficult.

There are also inconsistencies in standards, regulations and certification in food-safety systems worldwide (e.g. formal market versus informal market standards and controls, and food production for domestic use versus food production for export) (Vipham, Chaves and Trinetta, 2018).

Inconsistencies exist both within countries and between countries and are highly influenced by trade agreements, customer willingness to pay and government priorities.

Failures in food safety have highlighted the need for new regulations to safeguard human health. A number of meat-related standards have therefore been developed by governments in many developing countries. These standards are intended to achieve a workable balance between food safety, consumer health and the concerns of various stakeholders in the market portion of the value chain, including producers, commercial transporters and traders.

FAO and WHO established the Codex Alimentarius Commission to address the safety and nutritional quality of foods and develop international standards to promote trade among countries. The Commission develops standards for microbiological specification in foods, maximum limits for contaminants and toxins, maximum residue limits for pesticides and veterinary products, and maximum levels for food additives. The standards are intended to protect consumer health and ensure fairness in food trade. At national level, governments develop food-safety legislation to enforce standards and monitor compliance with official standards[8] through approaches such as HACCP, food inspections, prerequisite programmes and GHPs. However, in regions such as sub-Saharan Africa, there is need to create awareness among local government regulators and private-sector value-chain actors of the existence of standards and to enforce them. Standards can be adapted for particular countries (see Table D1). The future of food-safety surveillance will see the processing industry and regulators embracing data-collection and analysis technology in a quest for greater depth, specificity and accuracy (Detwiler, 2020).

Table D1 Localized risk-management standards in Uganda

Standard	Description
Handling and transportation of slaughter animals (US 733:2007 standard)	• Labelling (coding of animals coming in and going out) • Use of designated cattle transport trucks • Separation of young and adult animals • Avoidance of overcrowding (animals are often crammed into vehicles; many are injured or trampled to death) • Avoidance of exhaustion and dehydration (animals can be in transit for days, often suffering extremes of temperature and lacking sufficient food, water or rest; many die as a result) • Avoidance of pain and stress (animals are sentient beings and feel pain and stress just like we do)
Design and operation of abattoirs and slaughterhouses (US 734:2007 Standard)	• Availability of equipment for stunning, bleeding, skinning and processing • Use of hygienic machines that are easy to clean • Use of well-designed structures • Use of food-grade colours • Use of appropriate floor and drainage channels
Hygienic requirements for butcheries (US 736:2007 standard)	• Use of a clean environment (butcheries) • Use of clean hygienic clothing • Maintenance of good personnel hygiene • Use of refrigerated trucks for meat transporting • Use of food-grade colours • Use of chillers and freezers
Hygienic requirements for the production of packaged meat products (processed or manufacture) (US 737:2007 standard)	• Use of food-grade packaging materials • Use of disposable paper towels • Use of acceptable material cutting boards
Requirement for animal stock routes, check points and holding grounds (US 778:2007 standard)	• Use of gazetted livestock routes for movement between production sites, marketing or other user sites or areas, and terminal market destinations • Designation of animal species and the area they occupy (also referred to as the carrying capacity) • Designation of accredited animal and/or meat inspectors • Placement of permanent animal check points along major stock routes

[8] https://www.fao.org/fao-who-codexalimentarius/codex-texts/en/

One Health

Although One Health is not a new concept, it was defined in 2022 by FAO, WOAH, WHO and UNEP[9] as follows:

> *One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems.*
>
> *It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent.*
>
> *The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development* (see Figure D2).

The term is used to refer to approaches to tackling zoonotic diseases that consider all components that might lead to or increase the threat of disease (Cunningham, Daszak and Wood, 2017). The One Health approach was first described in 2004 (Atlas 2013) and has become increasingly important given the emergence and re-emergence of zoonotic infections. It has been shown that 61 percent of human infections and over 70 percent of emerging infections are zoonotic (Jones *et al.*, 2008; Taylor, Latham and Woolhouse, 2001).

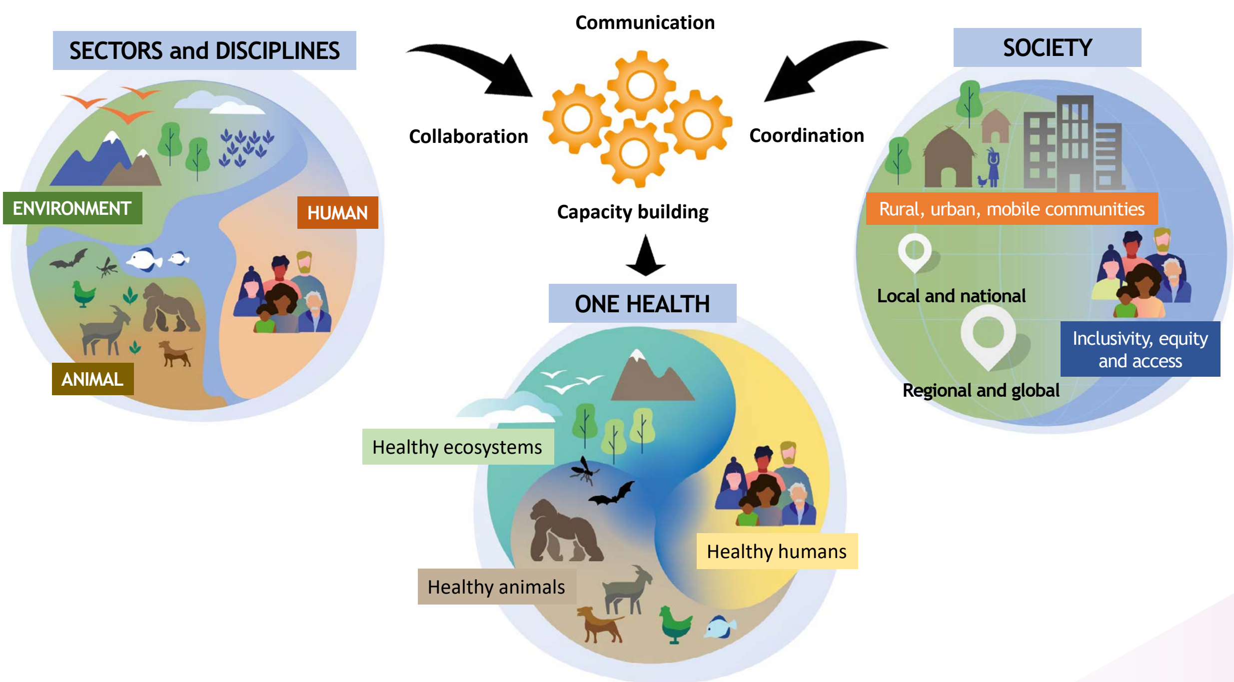
Understanding the complex nature of food-borne pathogens requires a One Health, transdisciplinary approach involving microbiologists, pathologists, epidemiologists, veterinarians and animal, plant and environmental scientists (Garcia, Osburn and Jay-Russell, 2020).

Summa, Henttonen and Maunula (2018) reported finding human noroviruses in 31 out of 115 wild-bird faecal samples (27 percent), two out of 100 rat faecal samples and zero out of 85 mouse faecal samples collected from animals at a dump site in southern Finland. Wildlife intrusions into cultivated fields are a threat to the safety of preharvest produce (Garcia, Osburn and Jay-Russell, 2020). For example, wildlife such as pigs, birds and rodents can move from garbage sites to fields, spreading faecal pathogens in the process.

One Health is being implemented – to varying degrees – in a variety of settings and at local, national and international scales. Its use in the prevention and control of zoonotic diseases with pandemic potential has gained momentum as governments and other stakeholders have increased their emphasis on health risks that emerge at human–animal–ecosystem interfaces as part of longer-term strategies to prepare for severe outbreaks of human disease (Nabarro and Wannous, 2014).

One Health plays a major role in the formulation and adaptation of policies promoting sustainable, safe and equitable livestock-rearing practices (Nabarro and Wannous, 2014). The approach encourages a systematic focus on the links between agricultural livelihoods (especially those of

Figure D2. One Health



Note: The environment includes plants.
Source: FAO, WOAH, WHO & UNEP. 2021. Tripartite and UNEP support OHHLEP's definition of 'One Health'. [Cited 6 February 2022]. https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

[9] https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

small-scale producers), animal health and welfare, wildlife conservation, human food security and nutrition, and both local and global public health. It requires constant attention to climate change adaptation and mitigation, land tenure, efficient and safe use of water, access to energy and infrastructure, and maintenance of environmental services.

The critical feature of One Health is that it is a multisectoral strategy for addressing public health concerns, which is very important in food-safety management. Hence, governments should look for ways to link their efforts to increase the productivity and efficiency of agrifood systems, promote infrastructure development and access to energy, water and affordable health care, and sustain environmental services (including mitigation of climate change) (Nabarro and Wannous, 2014). In the context of food-safety management, when animals are healthy and TASFs are safe, people are also safe and healthy. When the environment in which people, plants and animals live is safe, then animals, plants and people are safe. It is therefore crucial that all stakeholders in the livestock sector address food-safety issues. Food-safety management systems must strongly embrace the notion of One Health. The approach is vital to sustainable livestock production and to improving the quality and safety of TASFs.

9. Gaps and needs in the evidence-base

The global emergence and re-emergence of food-borne pathogens have increased the importance of microbiological safety and food quality to public health (Odeyemi and Bamidele, 2016; Odeyemi and Sani, 2016). International trade and travel increase the spread of FBDs and contribute to the emergence of new hazards, creating additional challenges for disease prevention, control and surveillance (WHO, 2017b).

The WHO initiative that estimated global and regional burdens of FBDs was an important step for food safety. Reports by FERG are comprehensive sources of information on the status of FBDs, globally and regionally (WHO, 2015, 2017b). This information indicates the importance of preventing and mitigating risks to food safety. It also guides the development and implementation of food-safety policies and the strengthening of food-safety systems (WHO, 2017b). However, the FERG reports indicate that the FBD incidence and burden data they present are probably underestimates given the limitations of surveillance systems, possible errors in diagnosis and the fact that not all sick people seek medical care (WHO, 2015). Furthermore, the WHO analysis was based on modelling and expert attribution of the roles of food in disease. Developed-country studies that make more use of clinical data generally suggest that these roles are greater than estimated in the WHO reports (Grace, 2017).

Comparing the European regional rankings with those of other regions reveals major differences in the burden of FBDs. For instance, apart from non-typhoidal *Salmonella* spp., the ten leading food-borne causes of DALYs in the European region are hazards that are systematically ranked lower at global level (WHO, 2017b). The burden in the European region is dominated by invasive infectious diseases, while the burden at global level is dominated by diarrhoeal diseases. Microbial pathogens are responsible for a significant part of FBD burden in developed countries, where they cause 20 to 40 percent of intestinal disease and a similar or greater burden of non-intestinal manifestations of FBDs (Kirk *et al.*, 2014; Scallan *et al.*, 2011; Tam *et al.*, 2014; Thomas *et al.*, 2013). The proportion of diarrhoea caused by food in LMICs remains unknown (Grace, 2015b).

Evidence on FBDs in LMICs is still limited (Grace, 2015b). However, recent studies have increased concerns about them, particularly those caused by biological hazards. A few studies in Southeast Asia have relied on the opinion of victims to determine whether disease is food-borne: these also suggest high levels of FBDs (Ho *et al.*, 2010). One survey in China reported FBDs as the second greatest risk people faced in daily life (after earthquakes), with 92 percent of respondents reporting that they expected soon to become a victim of food poisoning (Alcorn and Ouyang, 2012). Consumption of fresh, perishable foods sold in informal markets increases the risk of FBDs in developing countries (Grace, 2015b). Research gaps in food safety have been reported to include:

- data on FBDs at country level that would allow evidence-based prioritization of FBDs;
- diagnostic and reporting systems that would allow more accurate assessments of FBDs, including FBDs in the community; and
- ways to raise awareness of the importance of FBDs through more effective risk communication (Grace, 2017).

FBD has been increasing in some developed countries and is likely to increase in developing countries as a result of massive increases in the consumption of TASF, the lengthening and broadening of value chains, greater bulking of food from different sources and increases in the distance between production and consumption (Grace, 2015b). Over the years, FBD outbreaks attributed to unsafe raw food, poor storage practices, inadequate cooking, poor personal hygiene, improper handling methods and cross contamination have been reported (Lamuka, 2014; Odeyemi and Bamidele, 2016; Odeyemi and Sani, 2016). There is a need to continuously sensitize both food handlers and consumers about the need for personal hygiene and food-safety awareness, as studies have shown that there is a strong correlation between food-safety awareness and food-safety attitudes (Baş, Şafak Ersun and Kıvanç, 2006; Parry-Hanson Kunadu *et al.*, 2016). In Kenya's milk value chain, preharvest activities are recognized to have implications for post-harvest food safety, particularly for milk, because of their effects on microbial, adulterant and aflatoxin contamination and antimicrobial residues. Capacity building on aspects of milk safety for various stakeholders so that they will be better able to detect food-safety issues and take action to address them has been suggested (Kang'ethe *et al.*, 2020). A study on improving the productivity, quality and safety of milk in Rwanda and Nepal reported that weaknesses of food-safety concern in the milk value chain included suboptimal hygiene, problems with milk cooling, lack of proper cleaning through all the phases of milk processing and lack of basic dairy-management education (De Vries, Kaylegian and Dahl, 2020). The authors of this study also recommended training all stakeholders on food safety in the milk value chain.

In developing countries, the structure of agrifood systems compounds the problem of FBDs. The food-control systems in most of the developing world are heterogeneous, fragmented and involve many actors (Grace, 2015b). Structural challenges are exacerbated by generally poor capacity to enforce regulation. Governance challenges in food-systems regulation include inadequate policy and legislation, multiple organizations with overlapping mandates, outdated, fragmented or missing legislation, inappropriate standards, lack of harmonization and alignment of standards, failure to cover the informal sector, limited involvement of civil society, and limited enforcement (Jaffee *et al.*, 2019). In China and Viet Nam, for example, changing industry structure, rapid market development, rapidly changing prices for products and inputs, low profit margins, lack of bargaining power on the part of key players and lack of government support to stabilize markets all exert pressure on value-chain actors to cut corners and sacrifice food safety (Grace, 2015b). Lack of standardization of food controls and methods of assessment across jurisdictions is another major gap that requires greater attention.

In developed countries, considerable investments have been made in food safety. Despite this, the European Union region and the United States of America have experienced FBD incidents (EFSA and European Centre for Disease Prevention and Control [ECDC], 2014; CDC, 2014). One argument is that investments in food safety have had limited impact not because the strategies were ineffective but because risk has increased as a result of factors such as globalization, changes in eating habits and changes in farming practices (Newell *et al.*, 2010). In Europe and the United States of America, food safety was an issue of intense concern during the periods when they were most rapidly industrializing and urbanizing, and this concern is now evident in more rapidly industrializing developing countries, many of which are undergoing rapid agricultural intensification, which may increase the risk of FBDs (Jones *et al.*, 2013). A review of agricultural intensification and human health in the Greater Mekong region found links between irrigation and fish-borne parasitosis, between livestock manure and contaminated produce, between antimicrobial use and the transfer of resistant bacteria through food, and between pesticide use and food contamination (Richter *et al.*, 2015). A multicountry review found that a 1 percent increase in crop output per hectare was associated with a 1.8 percent increase in pesticide use and that pesticides were weakly regulated in countries undergoing intensification, implying greater risk of food contamination (Schreinemachers and Tipraqsa, 2012).

Some developed countries have succeeded in reducing the burden of FBDs over relatively short periods of time (Grace, 2015a), for example the decline of nontyphoidal *Salmonella* achieved in the United Kingdom through legislation, food-safety advice and a voluntary, private sector-led vaccination programme (O'Brien, 2013). In Denmark, *Salmonella* was reduced to below 5 percent in broiler flocks, below 2 percent in layer flocks and below 1 percent in pork products by monitoring herds and flocks, eliminating infected animals, and differential processing depending on *Salmonella* status. This resulted in savings of USD 25.5 million in 2001 (Wegener *et al.*, 2003). In these examples, control was achieved by taking action along the value chain, with emphasis on reducing disease in the animal reservoir rather than in retailed products. Although these control approaches are more feasible in industrialized countries that have intensive farming systems and good enforcement capacity, they are likely to be useful in developing countries as well (Grace, 2015a). Control measures along the value chain are particularly important. This is because not all food handlers and consumers understand the roles they need to play to protect their health and that of the wider community, such as adopting basic hygienic practices when buying, selling and preparing food (FAO and WHO, 2003). Developing countries often cite the lack of information on the cost of FBDs as a major reason for the lack of engagement by national policymakers. Country-level data on the cost of FBDs are important and should ideally be integrated with assessments of health burden; standardized methods for assessing the economic costs of FBDs in developing countries would also be helpful, as use of different methods leads to wide variations in estimates (Grace, 2017).

Legislation and policies on food may fail to achieve their objectives if they do not account for the concerns of key stakeholders. A study monitoring improvements to food safety in the largest abattoirs and meat markets in Nigeria found that policies had become ineffective partly because the authorities had attempted to move butchers to an abattoir that was more modern and hygienic but was also more distant, a step that was resisted by the butchers and led to riots. It was concluded that an enabling environment and stakeholder collaboration in efforts to improve food safety are important (Grace, Dipeolu and Alonso, 2019). According to WHO (WHO, 2017b), responsibility for addressing and tackling FBDs should be shared by stakeholders along the food chain from production to consumption. Collaboration between government, the food industry, academia and civil society is essential, as is awareness raising among all stakeholders and consumer education about food safety risks and how to prevent and reduce them.

A number of factors contribute to the presence of hazards in foods, including inappropriate livestock-production practices, poor hygiene at all stages of the livestock food chain, lack of preventive controls in food processing and preparation, misuse of chemicals, especially veterinary drugs, contamination of raw materials and water, and inadequate food storage (Birlouez-Aragon *et al.*, 2010). Concerns about food hazards have usually focused on microbiological hazards, pesticide residues, misuse of food additives, chemical contamination (including contamination with biological toxins), and adulteration; each of these issues needs to be fully addressed by legislation at relevant levels (FAO and WHO, 2003).

Increasing international trade, an expanding world economy, liberalization of food trade, growing consumer demand and developments in food science and technology mean that food-safety systems and control measures for food hazards remain complex (FAO and WHO, 2003). Focusing on food safety, especially food safety in developing countries, is vital to efforts to enhance cross-border trade. Creating and sustaining demand for food products in world markets relies on building the trust and confidence of importers and consumers in the integrity of agrifood systems (Unnevehr and Ronchi, 2014). The Codex Alimentarius Commission plays an important role in coordinating food standards at the international level and ensures that the health of consumers is protected and that fair practices in food trade are fully exercised (FAO and WHO, 2003). Governments should therefore use Codex Alimentarius standards to determine and refine policies and regulations within their national food-control systems.

To strengthen food-control systems, there is a need to strengthen food-safety programmes addressing the management of risks associated with physical and chemical food hazards. The main role of food control is to enforce food standards protecting consumers from unsafe, impure and fraudulently presented food by prohibiting the sale of food that is not of the nature, substance or quality demanded by the purchaser – and this increases consumer confidence (Havelaar *et al.*, 2015). FBD outbreaks involving agents such as *E. coli* and *Salmonella* and chemical contaminants have led consumers to conclude that modern farming systems, food processing and marketing need to provide better safeguards for public health (FAO and WHO, 2003).

Surveillance and traceability of hazards are very important. For example, within dairy value chains most chemical and physical hazards are controlled via quality assurance systems on the farm and at the dairy factory. Table D2 provides a summary of gaps and needs in the evidence base.

Table D2. Summary of gaps and needs in the evidence base for food safety and food-borne disease

Gaps	Needs
Inadequacy in monitoring of food-borne diseases and food safety hazards	Strong monitoring systems at both the policy and the operational levels of food-safety management
Inadequate epidemiological data	Continuous collection of data for implementing food-safety programmes across agricultural value chains
Insufficient food legislation enforcing food safety and reducing food hazards	Development of relevant and enforceable food laws and regulations
Codex Alimentarius standards not fully adapted into national legislation	Action by national governments to take full advantage of Codex Alimentarius standards
Inadequacies in value-chain engagement, laboratory capacity and training	Capacity building combined with targeted global efforts to train and educate farmers, transporters, processors, distributors and consumers about food-safety principles and their application
Lack of a systematic way of controlling food-safety hazards	Design and implementation of food-safety programmes that are adaptable to local contexts based on hazard analysis critical control points
Lack of clean water and reliable energy sources	Investment by national governments in water and power infrastructure
Wars or ethnic conflicts and civil unrest	Ensuring that conflicts are resolved peacefully
Inadequate laboratory services for food monitoring	Investment and training in laboratory and testing services for food safety, as required
Lack of incentives	Provision by national governments of incentives for value-chain actors that comply with food-safety requirements and regulations

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Section **E**

Emerging topics related to terrestrial animal source food

Key findings

- While cost and access remain a barrier, milk powder has been used extensively as an ingredient in fortified and blended foods. There is evidence that this is an effective option when used as a therapeutic supplement in the management of severe acute malnutrition in infants and young children. Egg powder and fish powder have been significantly less used as ingredients in fortified and blended foods, probably because of palatability and shelf-life issues and the processing techniques involved.
- The science related to alternatives to terrestrial animal source food (TASF), including plant-based foods and cell-cultured "meat", is relatively new. Evidence suggests that these products cannot replace TASF in terms of nutritional composition. Microalgae are highly regarded as a TASF alternative because of their rich nutritional composition and the advantages they may offer as a natural carbon sink. Plant-based meat alternatives that are widely available on the market have been found to be deficient in some essential nutrients and rich in saturated fat, sodium and sugar. Further research is needed to complete the food safety risk assessment for cell-cultured "meat" in the context of industrial-scale production.
- While insects can provide many essential nutrients – and there is some evidence relating to nutrition outcomes – cultural barriers and individual preferences currently constrain their consumer acceptability. The environmental sustainability of using insects as human food seems compelling, and demand for them may increase in the coming years. Nevertheless, food-safety concerns need to be considered in the scaling up of insects as food or feed.
- Current "omics" applications offer promise in terms of the characterization of nutritional quality and safety, development of precision or personalized nutrition, especially for defined targeted groups of people (e.g. young children), and comparison of the nutritional composition of alternatives to TASF.
- Microbiome science has recently revealed that some effects of the diet on health may be mediated by the gut microbiome – the trillions of microorganisms that live in the human gut. Various TASFs, including meat and fermented dairy products, affect the composition and function of the gut microbiome and hence might affect human health via the production of microbial metabolites. High intake of red and processed meat and saturated animal fats may have deleterious effects, while fermented dairy products seem to be associated with reduced inflammation. Positive or negative impacts on health may be modulated by the overall quality of the diet (in terms of fats, sugars and fibre).
- Assessment of the contribution of TASF to sustainable healthy diets needs to consider regional variation in natural resources, background health and nutrition, nutritional needs over the life course, the availability and accessibility of food, and the ecosystem roles of livestock. Emerging evidence on the sustainability of diets shows that the diversity of species (plants, and terrestrial and aquatic animals) in the diet contributes to higher nutrient adequacy.

Summary

This section addresses emerging and ongoing scientific themes related to the contribution of terrestrial animal source food (TASF) to healthy diets for improved nutrition and health outcomes.

A large and diverse range of TASF products are now available on the market or used by international aid and development projects as part of fortified and blended products. It is difficult to establish direct causal links between the consumption of TASF ingredients and human-health outcomes, but there are compelling findings indicating an association between small-quantity lipid supplements that include milk powder and improved child growth. The science of alternatives to TASF is relatively new, but evidence suggests that alternative products cannot replace TASF with respect to nutritional composition. Insect and insect products may hold greater promise in terms of contributing to nutritional requirements and offsetting the environmental impacts of other TASF.

The emerging topic of "omics" has the potential to yield an increasingly nuanced understanding of how components of TASF interact with other foods in the diet. It may allow deeper insights into how TASF interact with the genome, epigenome and metabolome, and ultimately affect human health.

Evidence on the relationships between TASF and the gut microbiome has increased rapidly in recent years. The gut microbiome has been shown to mediate the effects of meat consumption and fermented dairy-product consumption on human health.

Emerging research addressing TASF and sustainable healthy diets is vital in the context of discourse and action on climate change.

This section is not intended to be exhaustive in its discussion of each emerging topic. Ongoing investments in all these fields of research are needed in order to provide a deeper understanding of the roles TASFs play in human nutrition and health.

A comprehensive overview of current scientific evidence is summarized in Sections B, C and D, and gaps in research and policy are identified. This section draws on existing reviews and reports to provide a brief description of some emerging topics related to TASF, nutrition and health. The search strategy and methods used to evaluate the quality of the evidence were similar to those described in Section C. Some topics are covered in other sections (e.g. insects), so only novel aspects are highlighted here. It is acknowledged that the section does not cover the full range of emerging issues.

1. Terrestrial animal source food products

With advances in biotechnology and food science, a range of TASF products or TASF-related products have been developed. Two categories of product are discussed in this section: 1. fortified or blended foods containing TASFs as ingredients; and 2. TASF alternatives (plant-based and cell-cultured products and others). There are various motivations for the development of such products. In the case of the first category, the intention has largely been to improve the nutritional quality of products used, particularly in the context of food aid and/or supplementary feeding targeting vulnerable individuals. The development of products in the second category is motivated by environmental and health concerns, largely in the context of high-income countries.

Fortified and blended foods containing TASF as ingredients

Fortified foods are foods to which micronutrients have been added, generally with the aim of improving nutrient composition. Blended foods may combine several different food ingredients into single products, such as pastes, cereals or biscuits. TASF, specifically milk powder, has been used for decades to improve the nutritional quality of food-aid products and supplements, and there is some evidence that this is effective in the management of severe acute malnutrition (Hoppe *et al.*, 2008; Iannotti, Muehlhoff and Mcmahon, 2013; Scherbaum and Srour, 2018). Ready-to-use therapeutic foods (e.g. Plumpy'Nut) that combine peanut paste with milk powder, oil, sugar and other fortificants have been used for community-based treatment of children with severe acute malnutrition. More recently, small-quantity lipid-based nutrient supplements (e.g. Nutributter) with similar ingredients (notably the milk powder) have been used as supplements to prevent malnutrition. A meta-analysis of 14 randomized controlled trials among children aged between six and 24 months (n = 37 066) showed that such products reduced stunting by 12 percent, wasting by 14 percent and underweight by 14 percent (Dewey *et al.*, 2021). Cost and access to milk powder remain significant barriers to large-scale production and wider distribution and use, especially in LICs and in contexts where acute malnutrition burdens are high (Potani *et al.*, 2021).

Other TASFs have been used to a lesser extent than milk powder to enhance the nutritional quality of foods. Egg and fish powders have been used as ingredients in fortified blended foods used as food aid or nutritional supplements, although palatability and shelf-life may be issues (Chitrakar, Zhang and Adhikari, 2019). The processing involved in producing such foods may also lead to changes in the nutrient and bioactive composition of the TASF ingredients.

A relevant systematic review and meta-analysis of TASFs (including aquatic foods) and supplements (fortified supplements containing fish or milk powder, milk formula-based supplementation) was identified. The study (Pimpin *et al.*, 2019) examined the impacts of such interventions on mothers and on preterm and term infants (defined as born after 37 weeks gestation) and on growth outcomes at birth and during early childhood. Investigators synthesized evidence from 62 trials involving over 30 000 individuals across samples and found greater evidence for effects on weight than on height outcomes. Maternal supplementation with fortified blended foods or TASF increased the weight of the child at birth by 60 grams. Supplementation of infants (aged 6 to 12 months) and young children with fortified blended foods or TASF increased weight by 0.14 kg. Weight-for-length z-score was increased in food supplementation trials by 0.06 among term infants. TASF supplementation increased height-for-age z-score by 0.06 and reduced odds of stunting by 13 percent.

TASF alternatives: plant-based and other products

TASF alternative products have emerged in some markets around the world, primarily for commercial reasons related to growing consumer interest in healthy food, reducing environmental footprints and improving animal welfare (He *et al.*, 2020; Ismail, Hwang and Joo, 2020; Kyriakopoulou, Dekkers and van der Goot, 2019; Lee *et al.*, 2020). Despite claims about these products, substantial gaps remain in the empirical evidence base related to them (Rubio, Xiang and Kaplan, 2020; Santo *et al.*, 2020). It is unclear whether they reduce environmental impacts – especially in high-income contexts where the livestock-related environmental issues are predominant – or adequately meet nutritional requirements for human health. Life-cycle analyses suggest that greenhouse gas emissions from the production of plant-based meat alternatives are lower than those from the production of beef finished in feedlots but not lower than those from the production of beef from cattle finished on well-managed pastures (van Vliet, Kronberg and Provenza, 2020). Demand for plant-based alternative products is growing in some regions, and they are being incorporated into some niche diets such as flexitarian, vegetarian and

Box E1. Nutritional quality of cell-cultured "meat" and related food-safety issues

Cell multiplication to produce cell-cultured "meat" requires a growth medium containing nutrients such as vitamins, amino acids, minerals, glucose, growth factors and hormones. Some of the additives in the medium are substrates needed for cell development and viability. The most efficient and widely used medium is derived from bovine blood. Research is ongoing on how to replace it with a medium derived from plants (Chriki and Hocquette, 2020).

The nutrient content of the resulting tissue should reflect that of the growth medium, but the uptake of different micronutrients by cells remains to be fully understood, including the uptake of essential micronutrients that are only found in TASF (e.g. conjugated linoleic acid produced in the rumen, heme-iron and vitamin B12) (Post and Hocquette, 2017). Laboratory production conditions can affect nutrient content in the cells: a low-oxygen environment is needed to enable myoglobin expression, and iron uptake by the cell requires further research (Post and Hocquette, 2017). There is no current evidence on the bioavailability of micronutrients in cultured cells as compared to those in meat (Chriki and Hocquette, 2020; Warner, 2019).

The aseptic conditions and environmental control required for the production of cell-cultured "meat" is likely to reduce the risk of contamination with food-borne pathogens (Warner, 2019), especially microbiological hazards (e.g. *Salmonella* spp. and *Listeria monocytogenes*). However, the use of animal-blood components as growth medium (foetal bovine serum has been widely used to date) can be a source of hazards (e.g. viruses and prions) (Hadi and Brightwell, 2021). The addition of biochemical compounds to the medium to enable cell growth and of antimicrobials to impair bacterial infection of the resulting tissue needs further risk analysis for each such compound, both in terms of toxicity to the consumer and in terms of antimicrobial resistance (Post and Hocquette, 2017). The potential occurrence of unexpected dysregulation of biological mechanism (e.g. cell multiplication similar to that of cancer cells), which has also been reported, needs to be included in human health risk assessment (Chriki and Hocquette, 2020). The potential use of genetic engineering (improvement of the means of production, potential use of exogenous genes) triggers a need for continuous risk assessment (Hadi and Brightwell, 2021).

Despite the growing literature on cultured cells, evidence on nutritional value and food-safety outcomes remains more theoretical than practical. Further research is needed to complete food-safety risk assessment, especially in the context of industrial-scale production and to enable regulators to address public-health issues.

vegan diets (Chriki and Hocquette, 2020; Rizzo and Baroni, 2018). Box E1 summarizes the current state of knowledge on the nutritional quality of cell-cultured "meat" and related food-safety issues.

TASF alternative products may use fungal or plant derivatives, such as mycoprotein and soy leghaemoglobin (for the meat alternatives) and nuts or soy (for milk alternatives). Mycoprotein, which is found in some products such as sausages or patties, is a protein-rich food made of filamentous fungal biomass. The organism *Fusarium venenatum* is used, together with egg albumen, colour and flavour compounds, to produce mycoprotein. The use of agro-industrial residues as a substrate for mycoprotein production may reduce environmental impacts below those of other TASF alternatives (Souza Filho *et al.*, 2019). Soy leghaemoglobin, developed by Impossible Foods, Inc., is used to emulate the taste and texture of beef. One review of the literature found no evidence for risk of allergenicity or toxicity for leghaemoglobin or other host proteins (Jin *et al.*, 2018). Microalgae are another TASF alternative and have received attention particularly for their rich content of long-chain n-3 and n-6 fatty acids. In addition to the advantages they may offer as a natural carbon sink, they have been recognized for their value in human food and animal feed. Species of *Chlorella*, *Arthrospira* and *Aphanizomenon* contain quality proteins, while *Haematococcus* and *Dunaliella* are dense in antioxidants, including carotenoids (Kusmayadi *et al.*, 2021).

TASF alternatives are relatively new to global food markets, and the literature on their health impacts is therefore limited. Some studies have analysed the nutrient composition of plant-based meat alternatives relative to TASF and human requirements. One analysis compared the food chemistry of plant-based products (Beyond Meat Burger, Impossible Foods Burger and Morning Star's Black Bean Burger) to that of meats and found sodium and saturated fat content to be higher in the plant-based products (Swing *et al.*, 2021). Moreover, while essential amino acid levels were higher, some nutritionally important ones – methionine and lysine – were unavailable in the plant-based alternatives. Another study underscored some of these findings by modelling a reference omnivore diet compared to flexitarian, vegetarian and vegan diets using traditional and novel plant-based foods (Tso and Forde, 2021). Nutrient intakes in the novel plant-based substitute diet were found to be below daily requirements for vitamin B12, zinc, calcium, potassium and magnesium. Intake levels for saturated fat, sodium, and sugar were found to be higher in the novel plant-based substitute diet than in the reference omnivore diet. Plant-based milk alternatives, which often contain sugar and micronutrient fortificants, may not be able to completely replace animal milk with regard to nutrient composition and flavour (Tangyu *et al.*, 2019).

Few experimental trials have examined the impacts of TASF alternatives on human health. One small crossover randomized trial (n = 36 adults) studied the effect of consuming plant-based meat alternatives on serum trimethylamine-N-oxide (TMAO) and other biomarkers and on anthropometric outcomes (Crimarco *et al.*, 2020). It found that consuming the plant-based products was associated with significantly lower TMAO concentrations than consuming TASF. TMAO has been implicated as a cardiovascular risk factor in adults, but some questions have been raised regarding its specificity and responsiveness to diet, and its significance in infant and child health is unknown (Blesso, 2015; Hamaya *et al.*, 2020; Landfald *et al.*, 2017). A randomized control trial based on a sample of adults in the United Kingdom (n = 155) evaluated the impact of a four-week intervention with TASF alternatives and messaging on the benefits of consuming less meat on meat intake, consumption of TASF alternatives, and a set of nutrition and health outcomes (Bianchi *et al.*, 2019, 2022). The study found significant reductions in meat consumption for the intervention group relative to the control group – reductions of 63 g/d and 39 g/d at four-week and eight-week follow-ups, respectively.

Acceptability of TASF alternatives and consumer behaviour will be covered in Component Document 2, but relevant findings are described here. One systematic review (Onwezen *et al.*, 2021) examined the consumer acceptance of what the authors termed “alternative proteins”. These included pulses, algae, insects, plant-based alternatives and cultured meats. The acceptability of cell-cultured meat was found to be low, ranking only above insects (which are discussed below). Important determinants of acceptance across all alternative foods were social norms, familiarity, taste and health motives, attitudes, food neophobia and disgust. Another recent review of the literature (Lonkila and Kaljonen, 2021) concludes that the ethics of TASF alternatives need to be explored in greater depth.

2. Insects: novel products, acceptability and scalability

Insects have been consumed by humans for millennia. It is estimated that almost a quarter of the world's population consumes insects, across 1 900 species, most commonly from the orders Coleoptera (beetles), Lepidoptera (butterflies and moths), Hymenoptera (bees, ants and wasps), Orthoptera (grasshoppers, locusts and crickets) and Hemiptera (cicadas, leafhoppers, planthoppers, scale insects and true bugs) (Huis, 2013) (see Figure B1). However, urbanization and increased access to other TASFs means that in many societies insect consumption is no longer widespread. In recent years, consumer demand for environmentally friendly, nutrient-rich foods has led to a return to consuming insects, this time in the form of novel products.

As discussed in Section B, insects can fulfil requirements for many essential nutrients (Orkusz, 2021). Depending on the species and the stage of maturation, they may be especially rich in protein, polyunsaturated fats, vitamin C, dietary fibre and several minerals, including zinc, iron, copper, magnesium, manganese, phosphorous and selenium (Rumpold and Schlüter, 2013). While epidemiological evidence for health impacts associated with consuming insects remains limited, their potential was noted in recent narrative review (Nowakowski *et al.*, 2021). Small-scale intervention studies are highlighted in Section C of this document and suggest positive effects on the nutrition of young children living in low-resource settings (Bauserman *et al.*, 2015; Harmiyati *et al.*, 2017).

Cultural barriers and individual preferences interfere with broad acceptance and with bringing some products to scale (Jantzen da Silva Lucas *et al.*, 2020; Onwezen *et al.*, 2021). However, commercial companies have developed products from insects such as mealworms, crickets, locusts and black soldier flies that have higher acceptability, including powders, patties, bars, breads, pastas and snacks. Food-safety concerns should be considered in the scaling up of insects as food or feed. Contaminants may be biological (bacteria, viruses, fungi or parasites) or chemical (mycotoxins, pesticides, heavy metals or antimicrobials), and allergenic risks have also been described (FAO, 2021).

The environmental sustainability appeal of using insects as human food seems compelling and may increase demand in the coming years. Insects' high feed conversion rates (their efficiency in transforming feed into human food) have been particularly noted (Nowakowski *et al.*, 2021). One analysis showed that for the same protein yield, crickets need six times less feed than cattle, four times less than sheep, and two times less than pigs and broiler chickens (Rumpold and Schlüter, 2013). Insects also produce less greenhouse-gas emissions than livestock and can be grown on organic waste. Another analysis compared production systems for conventional TASFs, insects and TASF alternatives (plant-based and cell-cultured "meats") for agricultural land requirements and showed that insects have high potential, particularly relative to conventional TASF production (Alexander *et al.*, 2017). Insects can efficiently transform agricultural by-products and food waste into edible food, and this merits more research and future investment.

3. Foodomics as it relates to terrestrial animal source food, diets and effects on health

Foodomics was first defined by Cifuentes (2009) as "a discipline that studies the food and nutrition domains through the application and integration of advanced omics technologies to improve consumer's well-being, health, and knowledge." It is a scientific approach to studying the relationship between food and health through the application of "omics" approaches: genomics, proteomics, metabolomics, metagenomics and transcriptomics (Gunn, 2020). This subsection also addresses two nutrition-specific fields of research: nutrigenomics and nutrigenetics. All these disciplines use various methods to characterize and quantify molecules that contribute to human health (see Box E2).

This subsection briefly describes the application of "omics" to TASF nutrition subsection (Mayneris-Perxachs and Swann, 2019; Rådjursöga *et al.*, 2018). The science of "omics" can be applied to broader fields of livestock management and health (Banerjee, Pal and Ray, 2015; Bergen, 2017; Goldansaz *et al.*, 2017; Menchaca, 2021; Nowacka-Woszuk, 2020; Rothschild and Plastow, 2014; Sun and Guan, 2018), but the discussion here is restricted to its use in relation to TASF and human health.

To date, the various "omics" methods have been primarily used to examine the nutrient and bioactive components of TASF, as relevant to topics covered in Section B. For example, a study on bovine milk that used metabolomics analyses from nuclear magnetic resonance, liquid chromatography-mass spectrometry and inductively coupled mass spectrometry found 296 metabolites and

Box E2. What are "omics"?

Omics is a scientific discipline or field of research that analyses complete genetic or molecular profiles in humans and other organisms. Depending on the specific component analysed, omics is commonly divided into the following categories:

- genomics: the study of the genome (the complete set of DNA);
- transcriptomics: the study of the transcriptome (the complete set of RNA);
- proteomics: the study of the structure, function and interactions of proteins produced by the genes of a particular cell, tissue or organism; and
- metabolomics: the study of the set of metabolites within an organism.

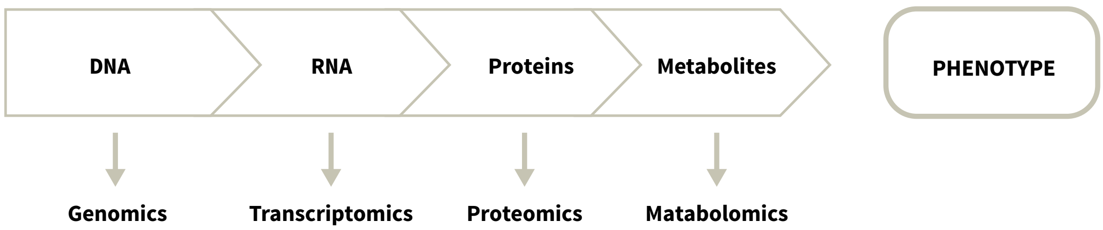
These components, in interaction with the environment, determine the phenotype (observable characteristics) of an individual.

Two areas of research focus on the relationship between human genes and nutrition:

- nutrigenetics: the study of gene variants linked to differential response to specific nutrients and the relation of this variation to different diseases, for example obesity and non-communicable diseases; and
- nutrigenomics: the study of the effects of nutrients and other components of food on gene expression and of how genetic variations may affect human health. Nutrigenomics is important in the study of the prevention and treatment of non-communicable diseases.

Systems biology is increasingly being used to understand the constellation of factors influencing human nutrition. This trend, along with improvements in analytical methods, such as 1H nuclear magnetic resonance spectroscopy and mass spectrometry, and major advances in big data science, has created a growing evidence base for "omics" and human nutrition.

Overview of omics



metabolite species (Foroutan *et al.*, 2019). Metabolomics can be used to identify biomarkers of the nutritional quality and safety of TASF. One study identified the following candidate biomarkers for potential use in the fields of milk quality, safety and traceability: choline, citrate, valine, hippuric acid, 2-butanone, lactate and some fatty acids (Zhu *et al.*, 2021). Another study (van Vliet *et al.*, 2021) used metabolomics to compare plant-based TASF alternatives to ground beef from grass-fed production systems and revealed substantial differences in metabolite abundances (171 out of 190 profiled metabolites; false discovery rate adjusted $p < 0.05$). Only the beef samples contained DHA, niacinamide (vitamin B3), glucosamine, hydroxyproline and several anti-oxidants, while only the plant-based TASF alternatives contained vitamin C, phytosterols and several phenolic anti-oxidants. Proteomics and transcriptomics have been used to study proteins in milk (Anagnostopoulos *et al.*, 2016; Bertram and Jakobsen, 2018; Manoni *et al.*, 2020; Soggiu, Roncada and Piras, 2018) and eggs (Gautron *et al.*, 2010). Scientists have described the potential application of nutrigenomics and nutrigenetics to animal milks in order to enable precision or personalized nutrition, both for humans and animals (Benitez, Nunez and Ovilo, 2017; Bordoni and Gabbianelli, 2019, 2021).

Application of "omics" in experimental, population-based studies of the effects of TASF on human nutrition and health has been more limited. Targeted metabolomics was used for the studies described in Section C of eggs in the nutrition of young children in Ecuador (Lulun Project) and Malawi (Mazira Project). In the Lulun Project, a hypothesized set of metabolites was tested using liquid chromatography–mass spectrometry to assess the effects of eggs on biomarker concentrations in child plasma. The study found that eggs improved the concentrations of several metabolites in the methyl group metabolism pathway (Iannotti *et al.*, 2017). Findings from the Mazira study, using both targeted and untargeted metabolomics, are still being analysed. One small cross-over design study ($n = 32$) compared serum metabolites using nuclear magnetic resonance across three diets: vegan, ovo-vegetarian and omnivore (Rådjursöga *et al.*, 2018). It found that betaine, choline and creatine concentrations were higher in the omnivore diet, while 3-hydroxyisobutyrate, carnitine, proline and tyrosine concentrations were higher in the ovo-vegetarian diets. The application of "omics" and precision nutrition may be promising and appropriate for well-defined targeted groups of people (e.g. young children), but it is not yet feasible as a population-health solution.

4. Terrestrial animal source food and the human microbiome

Over the past 15 years, there has been a growing awareness of the role of the gut microbiome in interconnections between food and human health. The term microbiome refers to the microbial community (bacteria, archaea, protozoa, fungi and viruses) and its "theatre of activity" (genome, proteins and metabolites) in a given environment (Berg *et al.*, 2020). Most studies on the human gut microbiome examine the bacterial population found in the human colon. Recent progress in DNA sequencing and "omics" technologies (see Box E2) has revolutionized capacity to investigate the microbial communities that live in symbiosis with humans. It is now possible to know which species of microbes are present (even unculturable species), their functional potential and their metabolic activity at a given time in the gut.

The gut microbiome is involved in several host functions: synthesis of certain vitamins; nutrient and xenobiotic[10] metabolism; maintenance of gut barrier integrity; and protection against pathogens. Its action is not limited to local effects in the gut. Microbial metabolites – diet-dependent or diet-independent – can reach the bloodstream and act on other parts of the body, modulating several important host functions (glucose and lipid metabolism, systemic immunity, bone metabolism and even lung physiology and brain function) (Cryan *et al.*, 2019).

Increasing amounts of evidence from both animal and human studies show that aberrant (dysbiotic) gut microbiomes are associated with, and may even contribute to, the pathogenesis of various common metabolic disorders (including obesity, type 2 diabetes, cardiovascular diseases, undernutrition, obesity, cancer, auto-immune diseases and even neurodegenerative diseases [reviewed in Fan and Pedersen, 2020; Morais, Schreiber and Mazmanian, 2020; Ruff, Greiling and Kriegel, 2020]). High species diversity and gene richness, as well as high abundance of short-chain fatty acid (SCFA)-producing bacteria and low abundance of potential pathogens, are features usually associated with health.

Multiple environmental and host factors shape the human gut microbiome, with diet being one of the main drivers across the lifetime. Both specific nutrients and whole diets may modify the composition of the microbiome and its function, with possible consequences for health (reviewed in Zmora, Suez and Elinav, 2019). As microbiome science is still a new field, evidence for impacts on health comes from converging studies, both in humans (observational and randomized control trials) and in animal models, that provide mechanistic explanation and help to elucidate causality. Only data related to TASF are discussed in this subsection. Subsection 4.1 presents the impact of TASF products on the composition and function of the gut microbiome, and Subsection 4.2 discusses possible consequences for health.

4.1

Effect of terrestrial animal source food on the gut microbiome

Data suggest that TASF have contributed to shaping the gut microbiome over the course of human evolution. For example, people in hunter-gatherer and some rural communities have a very low level of Actinobacteria, including low levels of *Bifidobacterium* (Afolayan *et al.*, 2019; De Filippo *et al.*, 2017; Martínez *et al.*, 2015; Schnorr *et al.*, 2014), while in adults from urban environments *Bifidobacteria* commonly make up 1 percent to 10 percent of the gut microbiome population. Lack of *Bifidobacterium* in pre-agriculture communities may be caused by the absence (or low levels) of dairy products in their diets (De Filippo *et al.*, 2017). In vegan populations, the representation of Actinobacteria and *Bifidobacterium* is very low (Matijašić *et al.*, 2014; Zimmer *et al.*, 2012). Losasso *et al*. (2018) report that among human cohorts omnivores had lower gene richness (alpha diversity) than long-term vegetarians. However, duration of the diet may be important, as Zhang *et al.* (2018) observed a low effect on overall microbiome composition after a three-month vegetarian intervention. Losasso *et al.* (2018) found that differences between cohorts (vegan, vegetarian and omnivore) were greatest at the genus and species level and relatively minimal with respect to broader compositional features such as diversity and richness. At the species level, *Faecalibacterium prausnitzii,* a major SCFA producer, has been found to be distinctly more prevalent in vegetarians than in omnivores (Matijašić *et al.*, 2014).

[10] Xenobiotics are chemical substances, mostly synthetic, that are not normally present in the environment of living organisms. The gut microbiome has a strong metabolizing capacity and is capable of biotransforming xenobiotics. It can modify the half-lives of xenobiotics and their potential biological effect (inactivate drugs or increase or alleviate toxicity) in the human host.

Bacteroides spp., *Bifidobacterium* spp., *Escherichia coli* and *Enterobacteriaceae* spp. have been found to be present at significantly higher levels in omnivores than in vegans and vegetarians (Zimmer *et al.*, 2012). There are also clear changes at functional level (genes, proteins and metabolites) (De Angelis *et al.*, 2020; do Rosario, Fernandes and Trindade, 2016).

High animal protein intake (tested in urban populations) modifies the gut microbiome and is highly associated with a gut microbiome dominated by the enterotype *Bacteroides* (Wu *et al.*, 2011). In a short-term intervention in humans, a diet based on TASF was shown to increase the abundance of bile-tolerant microorganisms (*Alistipes*, *Bilophila* and *Bacteroides*) and to decrease the levels of *Firmicutes* that metabolize dietary plant polysaccharides (*Roseburia*, *Eubacterium rectale* and *Ruminococcus bromii* – SCF-producing bacteria) (David *et al.*, 2014). Long-term adherence to diets based on TASF has been shown to increase the abundance of pro-inflammatory species, including those related to *Ruminococcus gnavus* and *Collinsella* spp. (van Soest *et al.*, 2020).

Protein origin seems to influence the gut microbiome (Lang *et al.*, 2018; Zhu *et al.*, 2015). The faecal bacterial communities of rats fed with meat proteins (red meat [beef and pork] or white meat [chicken and fish]) had a similar overall structure to those of rats fed with non-meat proteins (casein and soy) (Zhu *et al.*, 2015). However, the beneficial genus *Lactobacillus* was present at a higher level in the white-meat protein group than in the red-meat or non-meat protein groups (Zhu *et al.*, 2015). In both mice and humans, beef consumption has been found to increase the relative abundance of *Proteobacteria* and *Firmicutes* and to a decrease that of *Bacteroidetes* (Zhang, Li and Tang, 2019; Zhu *et al.*, 2015). Overall, studies in humans and animals have found that consumption of dairy products (milk, yogurt, kefir) has a positive impact on the gut microbiome, increasing bacterial diversity and the abundance of the beneficial genera *Lactobacillus* and *Bifidobacterium* (Aslam *et al.*, 2020). Consumption of dairy products during childhood determines the acquisition of methanogenic archaea such as *Methanobrevibacter smithii* (van de Pol *et al.*, 2017). *M. smithii* seems to play an important role in human physiology. Its depletion has been associated with both obesity and severe acute malnutrition in children (Million *et al.*, 2012, 2016).

TASF preparation may affect the gut microbiome. In humans, fried-meat intake has been found to lower microbial community richness (Gao *et al.*, 2021; Partula *et al.*, 2019) and to decrease *Lachnospiraceae* and *Flavonifractor* abundances while increasing *Dialister*, *Dorea*, and *Veillonella* abundances (Gao *et al.*, 2021). Those changes were associated with increased levels of intestinal endotoxin and systemic inflammation, but some of the effects may also be related to saturated fats (Gao *et al.*, 2021). Processed meat has been shown to be inversely correlated with *Roseburia*, a butyrate-producing bacteria (Yu *et al.*, 2021). A study on mice, found that feeding raw rather than cooked meat had no discernible effect on the animals' gut bacterial populations (Carmody *et al.*, 2019). Fermented TASFs (sausages, cheese, yogurt, kefir) are sources of food-borne microorganisms, mainly lactic-acid bacteria, that can be found in the gut microbiome and are usually associated with positive health outcomes (David *et al.*, 2014; Firmesse *et al.*, 2007, 2008; Pasolli *et al.*, 2020). The most frequently detected are starter cultures for fermented foods, such as *Streptococcus thermophilus* and *Lactococcus lactis*. Traditionally prepared TASF (e.g. dried raw meat prepared by Inuit people) may also be a source of environmental microorganisms (Hauptmann *et al.*, 2020).

As well as being a source of bacteria, fermented products can also modulate the resident microbiome via other mechanisms. For example, cheese consumption has been found to be negatively associated with *Akkermansia muciniphila* abundance (Partula *et al.*, 2019). In patients with irritable bowel disease (IBD), consumption of fermented milk (rather than non-fermented milk) led to a decrease in the abundance of *Bilophila wadsworthia* (a bacterial species associated with interabdominal infections and inflammation) and an increase in that of butyrate-producing bacteria and SCFA (Veiga *et al.*, 2014).

Differences observed between the effects of different TASFs on the gut microbiome may be caused by the fact that they vary in amino-acid composition, branched-chain amino acids (BCAAs), taurine, choline and carnitine. In addition to amino-acid composition, different protein sources vary in their content of other macronutrients, such as fats and fibres. For example, red and processed meats are rich in saturated fatty acids (SFAs) (Lang *et al.*, 2018). In addition, processing (e.g. fermentation) and cooking also influence the content of foods and the accessibility of nutrients.

Finally, TASF may contain exogenous components such as food additives and the residues of veterinary drugs used in livestock production. Antibiotics at therapeutic doses have a strong impact on the microbiome, with consequences for health. Effects of antimicrobial drugs at residual level deserve further study. Food additives commonly used in processed meat, such as potassium sorbate and sodium nitrite, have been shown to disturb the gut microbiome in animal models (reduced diversity and increase of proteobacteria) (Cao *et al.*, 2020). More data are needed to determine impacts on health.

4.2

Microbial metabolism of terrestrial animal source food and health

The type and quantity of TASF consumed influence the composition of the microbiome and the microbial metabolites it produces, with potential consequences for human health (O'Keefe, 2016; Singh *et al.*, 2017). Importantly, the overall quality of the diet may compensate for, or exacerbate, some of the effects described in this section.

Protein metabolism and health

TASFs are a major source of proteins. Undigested dietary proteins can reach the large intestine and are broken down by proteolytic bacteria and subsequently used by bacteria as a source of amino acids for making their own proteins or fermented by proteolytic fermentation as an energy source. Bacterial metabolism of dietary proteins produces several types of metabolite. Like fibre fermentation, protein fermentation produces beneficial SCFA, but lower quantities are produced. Fermentation of aromatic amino acids by the gut microbiome is also particularly important biologically, as it generates a wide range of bioactive end products, such as phenol and p-cresol (derived from tyrosine) and indole and skatole (derived from tryptophan). The microbial-derived uraemic toxins p-cresol sulfate, indoxyl sulfate and indole 3-acetic acid are derived from p-cresol and indole and are associated with kidney diseases (Chen *et al.*, 2019). Indole and its derivative may have both negative and positive impacts, promoting neurodevelopmental or psychiatric diseases but possibly protecting against multiple sclerosis (Diether and Willing, 2019). Protein fermentation by the gut microbiome releases potentially toxic nitrogenous and sulfur metabolites, such as ammonia, amines, nitrates, nitrites and hydrogen sulfide (Diether and Willing, 2019; Madsen *et al.*, 2017). Branched-chained fatty acids are reliable markers of proteolytic fermentation, as they are produced exclusively through the fermentation of BCAAs. In mice, an animal-based diet has been found to lead to higher production of branch-chained fatty acids (David *et al.*, 2014). However, little is known about the effects of branch-chained fatty acids on host physiology.

The gut microbiome also plays a role in amino-acid availability and circulation levels in the human host, and this has possible consequences for health. For example, BCAAs are essential amino acids found in several TASFs. Elevated levels of circulating BCAAs have been associated with health problems such as type 2 diabetes and obesity in humans (Newgard *et al.*, 2009). The gut microbiome is involved in both BCAA degradation and BCAA biosynthesis (Gojda and Cahova, 2021). In human trials, insulin resistance has been found to be positively correlated with the abundance of genes encoding enzymes involved in BCAA synthesis (Pedersen *et al.*, 2016). Microbiomes of obese individuals have higher potential to produce BCAAs, and their BCAA degradation pathways are depleted (Liu *et al.*, 2017). Interestingly, diet influences bacterial BCAA metabolism. A study in humans found that vegan and vegetarian groups had lower levels of circulating BCAAs, correlating with higher expression of genes involved in microbial BCAA degradation pathways, than an omnivorous group (Wang *et al.*, 2019). However, in animal studies BCAA supplementation has been found to affect the composition of the gut microbiome, with a potential anti-obesigenic effect (Yang *et al.*, 2016; Yu *et al.*, 2016). More studies are needed to characterize the interconnections between dietary BCAAs, gut microbiome and human health.

TASF and inflammation

Several studies in animals and in humans have shown an association between diets rich in TASF and pro-inflammatory bacteria in the gut (David *et al.*, 2014; Devkota *et al.*, 2012; Gao *et al.*, 2021; van Soest *et al.*, 2020). In a large participant prospective study, high total protein intake, especially animal protein (fish and meat, not eggs and dairy products), was found to be associated with a significantly increased risk of IBD (Bisanz *et al.*, 2019). In mice, interactions between dietary protein of animal origin and gut microbiota increase sensitivity to intestinal inflammation (such as colitis) by promoting pro-inflammatory response of monocytes (Kostovcikova *et al.*, 2019). Some studies have reported that animal fats may be associated with pro-inflammatory change in the gut microbiome in animals and humans (Caesar *et al.*, 2015; Wan *et al.*, 2019). Conversely, in a rat model, processed meat enriched with prebiotic inulin decreased pro-inflammatory bacterial populations (Fernández *et al.*, 2019). In humans, high intake of fermented food (mix of dairy and plant products) has been shown to reduce inflammation via modulation of the gut microbiome (Wastyk *et al.*, 2021; Marco *et al.*, 2021). Yoghurt supplemented with *Bifidobacterium* probiotic could help maintain a normal microbiota composition during the ingestion of a meat-based diet (Odamaki *et al.*, 2016). High intake of cheese and yoghurt has been shown to decrease the risk of cardiovascular disease, type 2 diabetes and cancer (meta-analysis) (Barengolts *et al.*, 2019; Gille *et al.*, 2018; Zhang *et al.*, 2019b, 2019c), which might be partially explained by a reduction in the low-grade inflammation associated with several NCDs.

TASF and cancer

Data suggest that several substances present in red and processed meat could play a role in carcinogenesis, with some of the effects being mediated by the gut microbiome. Heterocyclic amines (HCAs) are generated from amino acids in red meat during cooking at high temperatures and during preservation processes. Some HCAs can be taken up by bacteria and converted by the enzyme β-glucuronidase into activated mutagenic intermediates (Zhang *et al.*, 2019a). Red meat is rich in heme. A study in a mouse model showed that a heme-rich diet increased the abundance of mucin-degrading bacteria, leading to impaired intestinal barrier function and inducing cell hyperproliferation (Ijssennagger *et al.*, 2015). Data also suggest that the microbiota may play a role in the heme-induced promotion of colorectal carcinogenesis by contributing to heme-induced lipoperoxidation (Martin *et al.*, 2015). The bacteria *Fusobacterium nucleatum* have been strongly associated with colorectal cancer. Diets rich in red and processed meat have been found to be associated with *F. nucleatum* positive tumours but not with *F. nucleatum* negative tumours (Liu *et al.*, 2018). *F. nucleatum* has the ability to produce hydrogen sulfide (from cysteine) (Basic *et al.*, 2017), a substance that could induce carcinogenesis in the colon, as it can damage the epithelium, induce chronic inflammation and influence epithelial proliferation/differentiation (Abu-Ghazaleh, Chua and Gopalan, 2021). Hydrogen sulfide is involved in the pathogenesis of ulcerative colitis, a risk factor for colorectal cancer. *Bilophila wadsworthia* may also produce hydrogen sulfide from taurine (Peck *et al.*, 2019). This species has been found to be positively correlated with intake of dietary fat and meat (David *et al.*, 2014). Diets high in certain animal proteins and fats may also promote colorectal cancer by selecting for bacteria capable of converting primary host bile acids into toxic, tumour-promoting secondary bile acids, such as deoxycholic acid (Ridlon, Wolf and Gaskins, 2016). P-cresol may also induce DNA damage and alter cell cycles (Al Hinai *et al.*, 2019).

O'Keefe *et al.* (2015) compared diet and faecal microbiota in African Americans, a population with a high incidence of colorectal cancer, to those in rural South Africans, a population with a low incidence of colorectal cancer. Higher levels of proteolytic fermentation products were observed in the rural South Africans, but this was accompanied by increased carbohydrate fermentation and a lower incidence of colorectal polyps. When metabolic networks are examined, BCAA fermentation appeared to be higher in the African diet. Data suggest that high fibre intake may alter protein fermentation pathways and protect against inflammation and the disruption of cell cycles (Diether and Willing, 2019; O'Keefe *et al.*, 2015). In human clinical trials, consumption of maize starch has also been found to prevent the promutagenic effect of red meat and to correlate with changes in the gut microbiome (Le Leu *et al.*, 2015). Polyphenol from cranberries has been found to attenuate the impact of a TASF-based diet on microbiota composition, bile acids and SCFA (Rodríguez-Morató *et al.*, 2018). There is also experimental evidence that *Lactobacillus* probiotics may directly bind to heterocyclic amines and therefore potentially protect the host from the induction of DNA damage (Vernooij *et al.*, 2019; Zsivkovits *et al.*, 2003).

TASF, trimethylamine N-oxide and health

The metabolite trimethylamine N-oxide (TMAO) has attracted attention because recent meta-analysis has shown that, in humans, higher circulating TMAO concentration aggravates or increases the risk of several NCDs, including cardiovascular events (Farhangi, Vajdi and Asghari-Jafarabadi, 2020; Tang *et al.*, 2021), diabetes (Zhuang *et al.*, 2019), chronic kidney disease (Zeng *et al.*, 2021), liver steatosis (Flores-Guerrero *et al.*, 2021; León-Mimila *et al.*, 2021) and obesity (Dehghan *et al.*, 2020), as well as all-cause mortality (Farhangi, 2020). TMAO production results from the fermentation by the gut microbiota of dietary nutrients such as choline, phosphatidylcholine and L-carnitine (mostly present in protein-rich food of animal origin), which are transformed into trimethylamine, which is in turn converted into TMAO by hepatic enzymes.

Tang *et al.* (2013) found that, in humans, ingestion of phosphatidylcholine produces a post-prandial peak in circulating TMAO levels but that this did not happen if the intestinal microbiota had been depleted by broad-spectrum antibiotics. Several taxa of bacteria (Clostridia, *Proteus*, *Shigella*, *E. coli* and *Aerobacter*) can produce trimethylamine. In humans, diets that are high in animal proteins increase production of TMAO (Crimarco *et al.*, 2020; Ijssennagger *et al.*, 2015; Mitchell *et al.*, 2019; Park *et al.*, 2019). Long-term (more than one year) vegans/vegetarians have been found to have lower levels of circulating TMAO than omnivores and a markedly reduced capacity to produce TMAO from oral carnitine (contained for example in red meat) (Koeth *et al.*, 2018; Wu *et al.*, 2016; Zhang *et al.*, 2018). Bacteria responsible for TMAO production are enriched in omnivore microbiomes, and frequent exposure to L-carnitine or phosphatidylcholine induces the gut microbiota's capacity to produce TMAO (Koeth *et al.*, 2013, 2018; Wu *et al.*, 2019, 2020; Zhang *et al.*, 2018). Different animal-protein sources affect plasma TMAO differently: red meat (carnitine) increases TMAO (Wang *et al.*, 2019; Zhu *et al.*, 2020), while white meat, eggs, dairy products (Burton *et al.*, 2020) and phosphatidylcholine (Cho *et al.*, 2020) are not correlated with higher TMAO levels.

A study of the so-called Palaeolithic diet (high meat and egg consumption but no dairy products) found that it increased TMAO levels relative to a control diet, while TMAO levels were found to be inversely associated with whole-grain intake (low in the Palaeolithic diet) (Genoni *et al.*, 2020). Removing red meat from the diet reduces plasma TMAO within four to eight weeks (Crimarco *et al.*, 2020; Wang *et al.*, 2019). Burton *et al.* (2020) report that TMAO postprandial response is lower after consumption of fermented dairy products than after consumption of non-fermented dairy products but that daily consumption of dairy products was found to have no effect on TMAO levels. In a recent cross-sectional study in Hispanics/Latinos in the United States of America (Mei *et al.*, 2021), TMAO was found to be associated with a higher risk of cardiovascular disease. The same study found fish, red meat and egg intakes to be major dietary factors associated with serum TMAO; it also found the association between red meat and TMAO to be dependent on microbial TMA production from dietary carnitine but found the fish–TMAO association to be independent of gut microbiota. Jaworska *et al.* (2019) proposed that TMA (directly produced by bacterial metabolism) might have a more negative impact on health than TMAO. Fibre intake might modulate serum TMAO, higher intake being inversely correlated with TMAO levels (Genoni *et al.*, 2020; Leal-Witt *et al.*, 2018; Li *et al.*, 2017).

Studies in animal models have provided mechanistic insights into how diet-induced TMAO production by the microbiome may be involved in various health conditions (exacerbation of hepatic steatosis [Ji *et al.*, 2020], atherosclerotic development [Gregory *et al.*, 2015] and thrombosis [Zhu *et al.*, 2016]). More data are needed to confirm TMAO effects in humans.

4.3 Terrestrial animal source food and microbiome over the life course

Most studies on the effects of TASFs on the gut microbiome have been done in adults, but some data suggest that impacts may vary with age. The first 1000 days of life (from conception to two years of age) are critical for child development and for the establishment of the gut microbiome. In one cohort, intake of red and processed meat during pregnancy was found to be associated with high content of beneficial *Bifidobacterium* in the child microbiome (Lundgren *et al.*, 2018). In another cohort, maternal intake of animal protein, but not total protein, contributed to a change in the maternal and the child gut microbiomes and correlated with child health outcomes (García-Mantrana *et al.*, 2020). Infants from mothers with higher intake of animal protein and saturated fat were found to have a higher BMI by the age of 18 months than infants from mothers with higher intakes of plant-based products (García-Mantrana *et al.*, 2020).

Few studies have looked at the introduction of TASFs as complementary foods. A study of breastfed infants found that the effect on the gut microbiome of introducing meat as a complementary food differed from that of introducing cereal food (Krebs *et al.*, 2013). Another study found *Enterobacteriaceae* to be more abundant in infants given meat as a complementary food than in those given cereal but that the relative abundance of *Bifidobacteriaceae* did not differ from that in the cereal groups (Qasem *et al.*, 2017). In formula-fed infants, introduction of meat was found to induce more changes than dairy products (Tang *et al.*, 2019), which was to be expected given that most formula are based on cow's milk.

Two independent studies on cohorts of children from the United States of America and Europe, respectively, showed that an unbalanced TASF consumption in the first year of life was associated with asthma (Hose *et al.*, 2021; Lee-Sarwar *et al.*, 2019). More specifically, asthma correlated positively with high daily meat consumption associated with low milk/yoghurt consumption in the Hose *et al*. (2021) study and with fried and processed meat in the Lee-Sarwar *et al*. (2019) study. In both cases, there were correlations with changes in gut microbiome composition and function. The deleterious effect of unbalanced TASF consumption was reduced by increased duration of breastfeeding but increased by prolonged formula feeding (Hose *et al.*, 2021).

In contrast to studies on early life, two studies in older adults showed that dietary interventions that increased animal-protein consumption had little impact on the microbiome or on levels of protein-fermentation products (Dahl *et al.*, 2020; Mitchell *et al.*, 2020).

In conclusion, numerous studies – both animal models and human cohort studies and randomized controlled trials – have shown that diverse TASFs affect the gut microbiome. Data support the view that the microbiome has a potential mediating role between TASF and human health. Red and processed meat, as well as animal fats, may damage health via the production of detrimental microbial metabolites (e.g. TMAO and hydrogen sulfide). Fermented dairy products are associated with positive changes. The impact of TASF on the gut microbiome may be modulated by the overall quality of the diet. More data on humans are needed to confirm the role of the gut microbiome in TASF–health interconnections.

5. Terrestrial animal source food and sustainable healthy diets

Links between TASFs and planetary health constitute another critical emerging topic where evidence is accumulating. As noted in the introduction to this document, the topic will be addressed in Component Documents 2 and 3 of the assessment. However, some threads of research emerging under the broader category of TASF intake and sustainable healthy diets (described in the introduction to this section) are discussed here.

Livestock are essential components of agroecosystems – and are contributing to the agroecological transition of our food systems. Based on the ten elements of agroecology defined by FAO (2018a) and approved by member states, livestock have been shown to contribute to agroecological transition not only by enhancing diversity (Dumont *et al.,* 2013; Soussana *et al.,* 2015), synergies (Bernués *et al.*, 2011; Swagemakers *et al.*, 2017; Martin et al., 2016) and recycling on farms (Bonaudo *et al*., 2014; Magne *et al*., 2019) but also by contributing to cultural and food traditions (Alexandre *et al.*, 2014; Nyantakyi-Frimpong *et al.*, 2018), to circular economy (Bona *et al.*, 2020; Ramirez *et al.*, 2021) and to the overall efficiency and resilience of food systems (Dumont *et al.*, 2018; Billen *et al.*, 2021; Morais *et al.*, 2021). For example, they generate a variety of products adapted to local cultural values and food traditions. Specific markets for such products – some of which may become more popular with consumers as incomes rise – provide an opportunity to add value and improve livelihoods and to conserve animal genetic resources by keeping them in profitable use.

The need to achieve balance between human nutrition, food consumption and sustainability has led to discussion of the links between dietary patterns and planetary health (Ridoutt, Baird and Hendrie, 2021; Springmann *et al.*, 2018; Van Mierlo, Rohmer and Gerdessen, 2017; Willett *et al.*, 2019). It has been suggested that TASF consumption should be limited in order to reduce the greenhouse-gas emissions and other environmental impacts caused by livestock production. However, it has also been argued that to address sustainability, consideration should be given to regional variation in resources, background health and nutrition (Capper, 2013). Others argue that the proposed changes in diets to improve planetary health may not meet all human nutritional requirements, particularly in the case of women and children, and that some foods in the healthy reference diet of the EAT-Lancet Commission may not be available or accessible in certain contexts (Adesogan *et al.*, 2020; Capper and Bauman, 2013; Chen, Chaudhary and Mathys, 2019; Hirvonen *et al.*, 2020; Perignon *et al.*, 2017). Livestock play a crucial role in enhancing the food security and nutrition of the public at large and the rural and urban poor in particular, providing access to nutrient-dense TASFs such as meat, milk and eggs. In addition, if managed sustainably, they can contribute to important ecosystem functions, such as nutrient cycling, soil carbon sequestration and the conversation of agricultural landscapes (FAO, 2018b).

Another emerging theme related to TASF and sustainable healthy diets is the important contribution that biodiversity makes to public health and nutrition. Livestock include a diverse range of species and breeds raised in a variety of production systems (FAO, 2018b). Reduction in breed diversity has so far been greatest in HICs, where a limited number of widely used, high-output breeds have become dominant. All human health depends on ecosystem services that are made possible by biodiversity. Biodiversity can therefore be considered the foundation for human health. Biodiversity conservation, the sustainable use of biodiversity and the equitable sharing of benefits derived from biodiversity are thus global responsibilities at all levels and across all sectors (FAO, 2012). Efforts are underway to blend disciplines such as environmental science, agricultural science, genetics and human nutrition in the application of metrics across different sectors and the creation of novel metrics for measuring TASF impacts on the environment. For example, dietary diversity could be reframed and re-evaluated using indicators of biodiversity and metrics from the field of ecology. A study that analysed 24-hour recalls from seven LMICs to examine relationships between biodiversity indicators (species richness, Simpson's index of diversity and functional diversity) and human dietary diversity (Lachat *et al*., 2018) found that species richness, defined as the number of different species consumed per day, positively correlated with nutrient adequacy and dietary diversity among women and children in rural areas. FAO has published a food-composition database (INFOODS) for biodiversity that reports the value of nutrients and bioactive components for foods with information available below the species level, including genus, species, subspecies and variety/cultivar/breed (Charrondiere *et al*., 2017).

Efforts are underway to develop metrics that account for nutrient density when measuring the impacts of TASFs and other foods, and this may present a different picture with respect to dietary recommendations for planetary health. Evidence for TASF in sustainable food systems in LMICs is also emerging and allowing a fuller analysis that will help provide a basis for meeting nutritional needs while safeguarding human health, livestock biodiversity and the environment.

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Glossary

Glossary

Agrifood system	Framework that covers the journey of food from farm to table – including when it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. It also encompasses non-food products that constitute livelihoods and all of the people as well as the activities, investments and choices that play a part in getting us these food and agricultural products. (FAO, 2021a)
Agrifood system, sustainable	System delivering food security and nutrition for all in such a way that the economic, social and environmental bases for the food security and nutrition of future generations are not compromised, i.e. a productive and prosperous, equitable and inclusive, empowering and respectful, resilient, regenerative, and healthy and nutritious system. (adapted from FAO, 2018)
Agroecology	An integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems, seeking to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system. (adapted from FAO, 2021b)
Amino acid	Organic compound that forms a protein.
Anaemia	Condition in which the number of red blood cells or the haemoglobin concentration within them is lower than normal, decreasing the capacity of the blood to carry oxygen to the body's tissues. (adapted from WHO, 2022)
Animal welfare	Physical and mental state of an animal in relation to the conditions in which it lives and dies. (WOAH, 2022)
Antimicrobial resistance	Ability of microorganisms to persist or grow in the presence of drugs designed to inhibit or kill them. (FAO, 2021c)
Balanced diet	Food intake that provides an adequate amount and variety of food to meet a person's energy, macronutrient and micronutrient needs for a healthy and active life. (adapted from FAO, 2004)
Bioavailability	Proportion of nutrient intake that is absorbed and metabolized. (adapted from FAO and WHO, 2018)
Biotechnology	Technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for a specific use. (UN, 1992)
Compound, antinutritional	Substance that naturally occurs in plant and animal source foods and interferes with the absorption and/or metabolism of nutrients, also called antinutritional factor or antinutrient.
Compound, antioxidant	Factor that prevents or delays cell and DNA damage arising from free radicals or oxidation.
Compound, bioactive	Substance that modulates metabolic functions leading to beneficial outcomes, also called bioactive factor.
Compound, biochemical	Substance found in living organisms and made of carbon, hydrogen and oxygen (e.g. carbohydrates, lipids, proteins).
Dietary pattern	Combination of foods consumed over a period of time.
Dietary pattern, healthy/ appropriate	Combination of food consumed over a period of time that meets but does not exceed energy and nutrient requirements for growth and development and for health maintenance across the life course.
Digestible Indispensable Amino Acid Score	Metric used to rate protein quality: the percentage of digestible indispensable amino acids compared with a reference protein.

Disability-adjusted life year (DALY)	Standard metric commonly used to compare the impacts of diseases on population health, expressed as the number of years lost due to ill-health, disability or early death, one DALY being equivalent to one year of healthy life that is lost. (adapted from WHO, 2008)
Disease, food-borne	Disease transmitted through ingested food: caused by food hazards, such as microbial pathogens, parasites, chemicals and biotoxins.
Disease, vector-borne	Disease caused by an infectious pathogen (parasite, bacterium or virus) transmitted by vectors (e.g. mosquitoes, ticks, flies).
Disease, zoonotic	Infectious disease that can be spread between animals and humans: can be spread by food, water, fomites or vectors; also called zoonoses. (adapted from FAO, OIE and WHO, 2019)
Experimental trial	Study of effects of an intervention (e.g. risk factor, medical treatment or diet) on people assigned to different groups, the control group receiving no specific intervention or a placebo; also called an intervention trial.
Fat globule (in milk)	Emulsion composed of lipids and proteins secreted from milk-producing cells.
Fatality rate	Proportion of deaths from a certain disease out of the total number of people diagnosed with the disease in a particular period; also called lethality.
Fatty acid	Primary component of lipids, classified in various ways (e.g. length, saturation).
Food balance sheet	Comprehensive picture of the pattern of a country's food supply during a specified reference period. (FAO, 2001)
Food control system	A mandatory regulatory activity with preventive and educational strategies that protect the whole food chain through enforcement by national or local authorities to provide consumer protection and ensure that all foods during production, handling, storage, processing and distribution are safe, wholesome and fit for human consumption, conform to safety and quality requirements, and are honestly and accurately labelled as prescribed by law. (adapted from FAO and WHO, 2003)
Food group	Set of foods that share similar nutritional properties or biological characteristics.
Food hazard	Biological, chemical or physical agent in food with the potential to cause adverse health effects. (FAO and WHO, 1997)
Food insecurity	Lack of regular access to enough safe and nutritious food for normal growth and development and an active and healthy life. (FAO, 2000)
Food matrix	Physical domain where nutrients and non-nutrients of food interact to provide a performance different from that provided by the components in isolation or a free state. (adapted from Aguilera, 2019)
Food quality	Attributes of food that influence its value and that make it acceptable or desirable to the consumer. (FAO and WHO, 2003)
Food safety	Assurance that food will not have adverse health effects on the consumer when it is prepared and/or eaten according to its intended use. (FAO and WHO, 2020)
Food security	Condition in which all people, at all times, have physical and economic access to sufficient, safe and nutritious foods to meet their dietary needs and food preferences for an active and healthy life. It includes six dimensions: availability, access (economic, social and physical), utilization (nutritional uptake), stability, agency (capacity to act independently) and sustainability. (adapted from FAO *et al.*, 2020)
Food value chain	All the stakeholders and activities involved in the coordinated production and value-adding activities that are needed to make food products. (FAO, 2022a)

Food, fortified	Food to which micronutrient fortificants have been added with the aim of improving its nutritional composition.
Food, processed	Substance intended for human consumption that has been altered by mechanical or chemical operation.
Food-based dietary guidelines	National advice and principles on healthy diets and lifestyles that are rooted in sound evidence and respond to a country's public health and nutrition priorities, food production and consumption patterns, sociocultural influences, food composition data, and accessibility, among other factors. (adapted from FAO, 2022b)
Genetically modified organism	Organism in which the genetic material has been altered in a way that does not occur naturally, in order to induce or remove a trait. (adapted from European Union, 2022)
Hazard ratio	Ratio between the probability of the occurrence of a hazard (such as death) in groups of people exposed to an event and the probability of the occurrence of the hazard in those not exposed to the event (such as consumption of terrestrial animal source food), a higher risk being above 1.
Healthy diet	Healthy diets: 1) start early in life with early initiation of breastfeeding, exclusive breastfeeding until six months of age, and continued breastfeeding until two years of age and beyond combined with appropriate complementary feeding; 2) are based on a great variety of unprocessed or minimally processed foods, balanced across food groups, while restricting highly processed food and drink products; 3) include whole grains, legumes, nuts and an abundance and variety of fruits and vegetables; 4) can include moderate amounts of eggs, dairy, poultry and fish, and small amounts of red meat; 5) include safe and clean drinking water as the fluid of choice; 6) are adequate (i.e. reaching but not exceeding needs) in energy and nutrients for growth and development and meet the needs for an active and healthy life across the life cycle; 7) are consistent with WHO guidelines for reducing the risk of diet-related non-communicable diseases and ensuring health and well-being for the general population; and 8) contain minimal levels of, or if possible no, pathogens, toxins or other agents that can cause food-borne disease. According to WHO the characteristics of a healthy diet include the following: less than 30 percent of total energy intake comes from fats, with a shift in fat consumption away from saturated fats towards unsaturated fats and the elimination of industrial transfats; less than 10 percent of total energy intake comes from free sugars (preferably less than 5 percent); at least 400 g of fruits and vegetables are consumed per day; and not more than 5 g of salt (which should be iodized) are consumed per day. (FAO *et al.*, 2022)
Healthy diet, sustainable	Diet that promotes all dimensions of individuals' health and wellbeing, has low environmental pressure and impact, is accessible, affordable, safe and equitable, and is culturally acceptable. (adapted from FAO and WHO, 2019)
Healthy population	Population in state of complete physical wellbeing based on clinical signs and symptoms and function, normally assessed by routine laboratory methods and physical evaluation. (adapted from FAO and WHO, 2001)
Height-for-age z-score	Height of a child in relation to a standardized average height for children of the same age and sex; when a child has a low height-for-age z-score (more than 2 standard deviations below the WHO Child Growth Standards median), it is stunted. (based on WHO, 2006)
Incubation period	Period between the infection of an individual by a pathogen and the manifestation of the symptoms.
Indigenous Peoples	No single definition but a consensus on the following criteria: priority in time with respect to occupation and use of a specific territory; the voluntary perpetuation of cultural distinctiveness, which may include aspects of language, social organization, religion and spiritual values, modes of production, laws and institutions; self-identification, as well as recognition by other groups, or by state authorities, as a distinct collectivity; and an experience of subjugation, marginalization, dispossession, exclusion or discrimination, whether or not these conditions persist. (FAO, 2022c)

Informal market	Market having specific characteristics such as absence of specialization, very low capital investment, interlinkage between production and consumption, absence of bank accounts and non-payment of all or some taxation, predominance of households and micro-enterprises with varying and limited purchasing power, importance of virtually free labour in the form of apprentice help or family members who are fed but receive no or little pay, and relationships with the rural sector that often enable the provision of raw materials at lower cost. (CFS, 2018)
Insect	Animal belonging to zoological class Insecta or Hexapoda: insects have segmented bodies, six jointed legs and external skeletons (exoskeletons); grubs are insects in the larval phase of their life cycle. (adapted from Britannica, 2022)
Intrauterine growth retardation	Impaired growth and development of the foetus and/or its organs during gestation. (adapted from Wu *et al.*, 2006)
Iron-haemo protein	Protein that contains iron as part of a haem group (e.g. haemoglobin); haemo protein is essential for human health, as it transports oxygen in the blood.
Lactase deficiency	Inability to digest large amounts of lactose; also called lactase non-persistence. (adapted from Misselwitz *et al.*, 2019)
Lactose intolerance	Condition generally caused by a lack of lactase enzyme resulting in the inability to digest lactose; symptoms may include abdominal pain, bloating and diarrhoea. (adapated from EFSA, 2010)
Lactose malabsorption	Failure to digest and/or absorb lactose in the small intestines.
Large-for-gestational age	Term used to describe a newborn with a weight above the ninetieth percentile for the gestational age in comparison with average infant population of the same sex and gestational age. (adapted from WHO, 1995)
Life course	Succession of life stages that refers to the biological and social determinants of health of an individual: infants and young children (below 5); school-age children and adolescents (5 to 18); adults; older adults (older than 65). (adapted from Brown, 2019; Herman *et al.*, 2014)
Life cycle	Succession of life stages that refers to the biological developmental phases of an individual. (adapted from Brown, 2019; Herman *et al.*, 2014)
Life-cycle assessment	Compilation and evaluation of inputs, outputs and potential environmental impacts of a product system across the course of its life cycle. (ISO, 2006)
Life span	Succession of life stages that refers to the temporal aspects of an individual from conception to death. (adapted from Brown, 2019; Herman *et al.*, 2014)
Low birthweight	Weight at birth below 2 500 g. (WHO, 2022b)
Malnutrition	Abnormal physiological condition caused by inadequate, unbalanced or excessive intake of macronutrients and/or micronutrients. (FAO *et al.*, 2022)
Meat from wild animals	Meat derived from hunting of wild animals and wildlife farming; also called bushmeat, wild meat or game meat.
Meat, poultry	Meat derived from domesticated avian species including chicken, duck, Muscovy duck, goose, guinea fowl, turkey, quail and pigeon. (adapted from FAO and WHO, 2022)
Meat, processed	Meat products that have undergone treatment such as salting, curing, smoking, marinating, drying or cooking. (adapted from FAO and WHO, 2022)
Meat, red	Meat that is dark brown in colour after it has been cooked and is derived from mammalian ruminant and monogastric livestock species such as: cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse, donkey, yak. (adapted from FAO and WHO, 2022)

Meat, white	Meat that is pale in colour before and after cooking and is derived from rabbits and avian livestock species (including chicken, duck, Muscovy duck, goose, guinea fowl, turkey, quail, pigeon, pheasant, ostrich). (adapted from FAO and WHO, 2022)
Meta-analysis	Statistical analysis of combined data from a number of independent studies of the same subject in order to determine overall trends. (EXS290 Research Guide, 2022)
Metabolite	Molecule used or produced during metabolism: for example, glycine and L-arginine are precursor amino acids of the biosynthesis of creatine, which is the final metabolite.
Microbiome	Community of microorganisms (such as fungi, bacteria and viruses) that exists in a particular environment. In humans, the term is often used to describe the microorganisms that live in or on a particular part of the body, such as the skin or gastrointestinal tract. (NIH, 2022)
Micronutrient deficiency	Lack of essential vitamins and/or minerals that the human body requires in small amounts; also called hidden hunger.
Monogastric	Animal with a one-compartmented stomach (e.g. avian species, pig, rabbit, horse).
Morbidity	Symptom arising from a disease or condition and usually presented as a prevalence calculated by dividing the number of affected individuals by the total number of individuals within a specific population. (Hernandez and Kim, 2021)
Mortality	Deaths caused by a disease, injury or disability: may be communicated as an absolute number or as a rate calculated by dividing the number of deaths in a given time in a given population by the total population. (Hernandez and Kim, 2021)
Non-communicable disease	Illness that is the result of a combination of genetic, physiological, environmental and behavioural factors; also known as chronic disease: examples include cardiovascular diseases (e.g. heart attacks and strokes), cancers, chronic respiratory diseases (e.g. obstructive pulmonary disease and asthma) and diabetes. (WHO, 2021)
Non-significant	A result from a statistical test that does not allow the conclusion to be drawn that the differences in the data are valid and consistent. Non-significant results do not necessarily imply that there is no association between the exposure and the outcome. Any observed differences in results may be attributable to chance alone or to random factors. For example, when studying a factor in relation to human nutrition, non-significance could indicate that there is no association in the sample population, but it could also indicate that the study size is too small to identify an association that does exist in the sample population.
Nutrient	Substance that is required by the body for optimal growth, development and maintenance of good health.
Nutrient density	Amount of nutrients per calorie, food volume or serving size.
Nutrient requirements	Recommendations to consumers on nutrient intakes, amount of nutrients needed to maintain health in an otherwise healthy individual or group of people; nutrient requirements are periodically updated based on new evidence.
Nutrient, essential	Nutrient that cannot be produced by the body in sufficient quantities to meet physiological requirements and must therefore be supplied from foods or other sources (e.g. supplements).
Nutrient, macronutrient	Energy-containing nutrient needed in substantial quantities, typically above 10 g per day (e.g. carbohydrates, proteins and fats).
Nutrient, micronutrient	Nutrient required in small amounts, usually below 2 g per day (e.g. vitamins and minerals).
Nutrient, non-essential	Nutrient that can be synthesized by the body under normal conditions and is thus not required in the diet.
Offal	Organ meat and blood from mammalian and avian species, e.g. liver, kidney, heart, lungs and intestines. (adapted from FAO and WHO, 2022)

Omics	Scientific discipline or field of research that analyses complete genetic or molecular profiles in humans and other organisms.
One Health	Integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent. (One Health High-Level Expert Panel (OHHLEP) *et al.*, 2022)
Overweight and obesity	Body weight that is above normal for height as a result of an excessive accumulation of fat. It is usually a manifestation of expending less energy than is consumed. In adults, overweight is defined as a BMI of 25 kg/m^2 or more, and obesity as a BMI of 30 kg/m^2 or more. In children under five years of age, overweight is defined as weight-for-height greater than 2 standard deviations above the WHO Child Growth Standards median, and obesity as weight-for-height greater than 3 standard deviations above the WHO Child Growth Standards median. (FAO, IFAD, UNICEF, WFP and WHO 2022)
PCR (polymerase chain reaction) method	Method used to amplify specific segments of DNA into numerous copies; one of its applications is to identify infectious agents.
Plant source food	Food derived from plants (e.g. vegetables, fruits, legumes, seeds, nuts).
Protein quality	Protein quality relates to the ability of a protein source to support healthy growth, development and maintenance of body mass. To be considered a “high-quality” or “complete” protein, a protein must contain all the essential amino acids (building blocks of proteins) in the right proportion and be easily digested. The Protein Digestibility-Corrected Amino Acid Score (PDCAAS) measures and compares the protein quality of various food sources. Those with a score of 1.0 are considered “high-quality” or “complete” proteins. (Nutrition & Biosciences, 2022)
Public health	Science that promotes and protects the health of people and communities, generally by applying a population-based approach to disease prevention: subfields include epidemiology, biostatistics, health policy, global health and environmental health.
Residues	In the context of food safety, residues are traces of substances such as pesticides or veterinary drugs in food, agricultural commodities or animal feed.
Review, narrative	Analysis that describes the evidence on a topic but is not systematic and does not follow a specific method.
Review, systematic	Analysis focusing on a clearly formulated question that uses systematic and reproducible methods to identify, select and critically appraise all relevant research. (adapted from BMC, 2022)
Risk	A measure of the probability and severity of adverse effects; human health risk is the probability that a given exposure or series of exposures will damage the wellbeing of individuals.
Risk analysis	Process consisting of three components: risk assessment, risk management and risk communication. (FAO and WHO, 2014)
Risk assessment	Human health risk assessment is a process intended to estimate the risk to a given person, system or (sub)population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system.
Ruminant	Hoofed herbivorous grazing or browsing mammal that is able to acquire nutrients from plant-based food by fermenting it in a specialized stomach principally through microbial action (e.g. cattle, buffalo, goat, sheep).
Shelf-life	Time, under defined storage conditions, during which food remains safe, retains desired sensory, chemical, physical and biological characteristics and complies with any label declaration. (Decker, 2010)
Small-for-gestational age	Term used to describe a newborn with weight below the tenth percentile in comparison with average infant population of the same sex and gestational age. (adapted from WHO, 1995)
Study, case control	Observational study that compares people with an existing health issue to people without the issue.

Study, cohort	Observational study where a group of individuals with shared characteristics (cohort) exposed to an intervention and a group who are not exposed to the intervention are followed over time (often years) to determine the occurrence of disease. The incidence of disease in the exposed group is compared with the incidence of disease in the unexposed group.
Study, cross-sectional	Observational study that analyses numerous characteristics and variables at once (at a single point in time).
Study, observational	Study of the effects of an intervention on people who were already exposed to the intervention before the study.
Stunting	Low height-for-age, reflecting a past episode or episodes of sustained undernutrition. In children under five years of age, stunting is defined as height-for-age more than 2 standard deviations below the WHO Child Growth Standards median. (FAO, IFAD, UNICEF, WFP and WHO 2022)
Surveillance	Systematic ongoing collection, collation and analysis of data and the timely dissemination of information to those who need to know so that action can be taken. (adapted from WHO, 2001)
Terrestrial animal source food	Food derived from terrestrial animals.
Traceability	The ability to follow the movement of a food through a specified stage or stages of production, processing and distribution. (FAO, 2022d)
Wasting	Low weight-for-height, generally the result of weight loss associated with a recent period of inadequate dietary energy intake and/or disease. In children under five years of age, wasting is defined as weight-for-height more than 2 standard deviations below the WHO Child Growth Standards median. (FAO, IFAD, UNICEF, WFP and WHO 2022)
Weight-for-age z-score	Weight of a child in relation to the standardized average weight of children of the same age and sex; when a child has low weight for its age (more than 2 standard deviations below the WHO Child Growth Standards median), it is underweight. (based on WHO, 2006)
Weight-for-length/height z-score	Weight of a child in relation to the standardized average length/height of children of the same age and sex; when a child has low weight for its length/height (more than 2 standard deviations below the WHO Child Growth Standards median), it is wasted; child overweight is weight-for-height more than 2 standard deviations above the WHO Child Growth Standards median; obesity is weight-for-height more than 3 standard deviation above the WHO Child Growth Standards median. (based on WHO, 2006)

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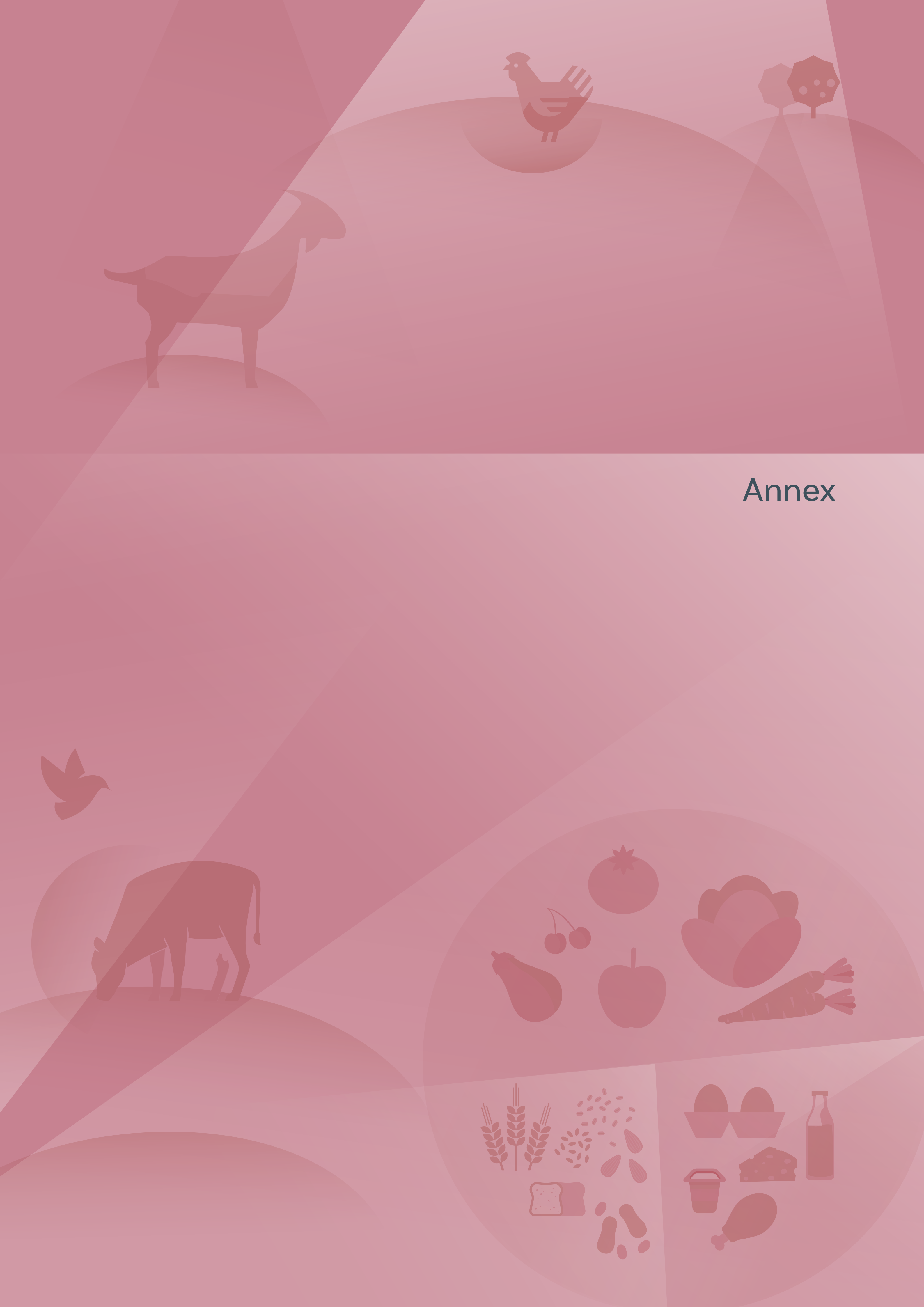
Annex



Tables Section B

Table B1. Recommended nutrient intake by life-cycle phase: vitamins

Life-cycle phase	Water-soluble vitamins									Fat-soluble vitamins			
	Vitamin C (mg/day)	Thiamine (mg/day)	Riboflavin (mg/day)	Niacin (a) (mg NE/day)	Vitamin B6 (mg/day)	Pantothenate (mg/day)	Biotin (µg/day)	Vitamin B12 (µg/day)	Folate (b) (µg RE/day)	Vitamin A (c,d) (µg RE/day)	Vitamin D (µg/day)	Vitamin E (e) (mg α-TE/day)	Vitamin K (µg/day)
Infants, 7–12 months	30	0.3	0.4	4 (f)	0.3	1.8	6	0.7	80	400	5	2.7	10
Children, 1–3 years	30	0.5	0.5	6	0.5	2	8	0.9	150	400	5	5.0	15
Children, 4–6 years	30	0.6	0.6	8	0.6	3	12	1.2	200	450	5	5.0	20
Children, 7–9 years	35	0.9	0.9	12	1	4	20	1.8	300	500	5	7.0	25
Adolescent females, 10–18 years	40	1.1	1	16	1.2	5	25	2.4	400	600	5	7.5	35–55
Adolescent males, 10–18 years	40	1.2	1.3	16	1.3	5	25	2.4	400	600	5	10	35–55
Adult females, 19–50 years (premenopausal)	45	1.1	1.1	14	1.3	5	30	2.4	400	500	5	7.5	55
Adult females, 51–65 years (menopausal)	45	1.1	1.1	14	1.5	5	30	2.4	400	500	10	7.5	55
Adult males, 19–65 years	45	1.2	1.3	16	1.3 (19–50 yrs.) 1.7 (50+yrs.)	5	30	2.4	400	600	5 (19–50 yrs.) 10 (51–65 yrs.)	10	65
Older females, 65+ years	45	1.1	1.1	14	1.5	5	nd	2.4	400	600	15	7.5	55
Older males, 65+ years	45	1.2	1.3	16	1.7	5	nd	2.4	400	600	15	10	65
Pregnant women	55	1.4	1.4	18	1.9	6	30	2.6	600	800	5	(g)	55
Lactating women	70	1.5	1.6	17	2	7	35	2.8	500	850	5	(g)	55

Notes: Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population. (a) NE = niacin equivalents. (b) DFE = dietary folate equivalents; mg of DFE provided = [mg of food folate + (1.7 × mg of synthetic folic acid)]. (c) Vitamin A values are "recommended safe intakes" instead of RNIs. (d) Recommended safe intakes as mg retinol equivalent (RE)/day; conversion factors are as follows: 1 mg retinol = 1 RE; 1 mg β-carotene = 0.167 mg RE; 1 mg other provitamin A carotenoids = 0.084 mg RE. (e) Data were not sufficiently robust to formulate recommendations; the figures in the table therefore represent the best estimate of requirements. (f) Preformed niacin. (g) not specified in the source; nd = no data available.

Source: Adapted from WHO and FAO, 2004

Table B2. Recommended nutrient intake by life-cycle phase: minerals

Life-cycle phase	Calcium (mg/day)	Selenium (µg/day)	Magnesium (mg/day)	Zinc (mg/day)			Iron (mg/day)				Iodine (µg/day)
				50% High bioavailability	30% Moderate bioavailability	15% Low bioavailability	15% bioavailability	12% bioavailability	10% bioavailability	5% bioavailability	
Infants, 7–12 months	400	10	54	2.5 (d)	4.1	8.4	6.2 (a)	7.7 (a)	9.3 (a)	18.6 (a)	90 (b)
Children, 1–3 years	500	17	60	2.4	4.1	8.3	3.9	4.8	5.8	11.6	90 (b)
Children, 4–6 years	600	22	76	2.9	4.8	9.6	4.2	5.3	6.3	12.6	90 (b)
Children, 7–9 years	700	21	100	3.3	5.6	11.2	5.9	7.4	8.9	17.8	120 (6–12 yrs.)
Adolescent females, 10–18 years	1300 (10–18 yrs.)	26 (10–18 yrs.)	220 (10–18 yrs.)	4.3 (10–18 yrs.)	7.2 (10–18 yrs.)	14.4 (10–18 yrs.)	9.3 (11–14 yrs.) (c)	11.7 (11–14 yrs.) (c)	14.0 (11–14 yrs.) (c)	28.0 (11–14 yrs.) (c)	150 (13–18 yrs.)
							21.8 (11–14 yrs.)	27.7 (11–14 yrs.)	32.7 (11–14 yrs.)	65.4 (11–14 yrs.)	nd
							20.7 (15–17 yrs.)	25.8 (15–17 yrs.)	31.0 (15–17 yrs.)	62.0 (15–17 yrs.)	nd
Adolescent males, 10–18 years	1300	32	230	5.1	8.6	17.1	9.7 (11–14 yrs.)	12.2 (11–14 yrs.)	14.6 (11–14 yrs.)	29.2 (11–14 yrs.)	150 (13–18 yrs.)
							12.5 (15–17 yrs.)	15.7 (15–17 yrs.)	18.8 (15–17 yrs.)	37.6 (15–17 yrs.)	nd
Adult females, 19–50 years (premenopausal)	1000	26	220	3	4.9	9.8	19.6	24.5	29.4	58.8	150
Adult females, 51–65 years (menopausal)	1300	26	220	3	4.9	9.8	7.5	9.4	11.3	22.6	150
Adult males, 19–65 years	1000	34	260	4.2	7	14	9.1	11.4	13.7	27.4	150
Older females, 65+ years	1300	25	190	3	4.9	9.8	7.5	9.4	11.3	22.6	150
Older males, 65+ years	1300	33	224	4.2	7	14	9.1	11.4	13.7	27.4	150
Pregnant women, first trimester	(d)	(d)	220	3.4	5.5	11	e	e	e	e	200
Pregnant women, second trimester	(d)	28	220	4.2	7	14	e	e	e	e	200
Pregnant women, third trimester	1200	30	220	6	10	20	e	e	e	e	200
Lactating women, 0–3 months	1000	35	270	5.8	9.5	19	10	12.5	15	30	200
Lactating women, 3–6 months	1000	35	270	5.3	8.8	17.5	10	12.5	15	30	200
Lactating women, 7–12 months	1000	42	270	4.3	7.2	14.4	10	12.5	15	30	200

Notes: Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population. nd = no data available. (a) Bioavailability of dietary iron during this period varies greatly. (b) Recommendation for the age group 0–4.9 years. (c) Pre-menarche. (d) Bioavailability of dietary iron during this period varies greatly. (e) It is recommended that iron supplements in tablet form be given to all pregnant women because of the difficulties in correctly assessing iron status in pregnancy; in non-anaemic pregnant women, daily supplements of 100 mg of iron (e.g. as ferrous sulphate) given during the second half of pregnancy are adequate; in anaemic women higher doses are usually required.

Source: Adapted from WHO and FAO, 2004

Table B3. Nutrient composition of poultry eggs

Nutrient	Chicken		Duck	Chicken egg yolk		Chicken egg white		Goose	Quail	Turkey
	Avg.	Range	Avg.	Avg.	Range	Avg.	Range	Avg.	Avg.	Avg.
Energy (kcal/kJ)	135/566	127–143/533–599	185/776	318/ 1331	313–322/ 1311–1350	50/207	47–52/197–216	185/775	158/663	171/716
Carbohydrates (g)	0.5	0.3–0.7	1.5	1.9	0.2–3.6	0.6	0.4–0.7	1.4	0.4	1.2
Lactose (g)	0.13	0–0.25	nd	0.04	0–0.07	0.04	0–0.07	nd	nd	nd
Protein (g)	12.6	nd	12.8	15.8	15.6–15.9	11.1	10.9–11.2	14.0	13.0	13.7
Fat (g)	8.5	8.5–9.5	13.8	27.4	26.5–28.2	0.1	0–0.2	13.0	11.1	11.9

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

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Table B4. Vitamin content of poultry eggs

Vitamin	Chicken		Duck	Chicken egg yolk		Chicken egg white		Goose	Quail	Turkey
	Avg.	Range	Avg.	Avg.	Range	Avg.	Range	Avg.	Avg.	Avg.
Vitamin A (µg) RAE*	145	130–160	194	415	381–449	-	-	187	156	166
Vitamin E (alphatocopherol) (mg)	1.4	1.1–1.7	1.3	5.1	2.6–7.9	-	-	1.3	1.1	nd
Vitamin D (µg)	1.7	1.4–2.0	1.7	11.2	5.4–17.0	-	-	1.7	1.4	nd
Vitamin K (phylloquinone) (µg)	0.3	nd	0.4	0.7	nd	-	-	0.4	0.3	nd
Vitamin C (mg)	-	-	-	-	-	-	-	-	-	-
Thiamin (mg)	0.06	0.04–0.07	0.16	0.18	0.17–0.19	-	-	0.15	0.13	0.11
Riboflavin (mg)	0.44	0.43-0.46	0.40	0.46	0.40–0.53	0.42	0.41–0.44	0.38	0.79	0.47
Niacin (mg)	0.04	0–0.08	0.20	0.01	0–0.02	0.05	0–0.11	0.19	0.15	0.02
Pantothenic acid (mg)	1.52	1.50–1.53	1.86	4.10	2.99–5.20	0.21	0.19–0.22	1.76	1.76	1.89
Vitamin B6 (mg)	0.09	0.01–0.17	0.25	0.26	0.16–0.35	-	0–0.01	0.24	0.15	0.13
Folate DFE** (µg)	79	47–110	80	133	120–146	7	4–7	76	66	71
Vitamin B12 (µg)	1.15	0.89–1.40	5.40	2.98	1.95–4.00	0.05	0–0.09	5.10	1.58	1.69

Notes: *Vitamin A content expressed in retinol equivalents (RAE). **Dietary folate equivalent. Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = vitamin not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B5. **Amino acid composition of milk from mammalian livestock species and humans**

Amino acid (g)	Human		Buffalo	Cattle		Yak	Goat		Sheep	Reindeer	Donkey
	Avg.	Range	Avg.	Avg.	Range	Avg.	Avg.	Range	Avg.	Avg.	Avg.
Alanine	0.04	nd	0.03	0.11	nd	0.03	0.12	nd	0.27	0.03	0.03
Arginine	0.04	nd	0.03	0.09	nd	nd	0.12	nd	0.20	0.03	0.05
Asparagine	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Aspartic acid	0.08	nd	0.07	0.27	nd	0.07	0.21	nd	0.33	0.06	0.09
Cystine	0.02	nd	0.08	0.02	nd	0.01	0.05	nd	0.04	0.00	0.00
Glutamic acid	0.17	nd	0.21	0.69	nd	0.16	0.63	nd	1.02	0.20	0.22
Glutamine	nd	nd	nd	nd	nd	0.17	nd	nd	nd	nd	nd
Glycine	0.03	nd	0.02	0.07	nd	0.03	0.50	nd	0.04	0.02	0.01
Histidine	0.02	nd	0.03	0.10	nd	nd	0.09	nd	0.17	0.03	0.02
Isoleucine	0.06	nd	0.05	0.18	0.16–0.20	0.04	0.21	nd	0.34	0.04	0.05
Leucine	0.10	nd	0.09	0.31	0.29–0.33	0.12	0.31	nd	0.59	0.09	0.08
Lysine	0.07	nd	0.08	0.28	0.26–0.31	0.07	0.29	nd	0.51	0.08	0.07
Methionine	0.02	nd	0.02	0.08	nd	0.03	0.08	nd	0.16	0.02	0.02
Phenylalanine	0.05	nd	0.05	0.17	nd	0.05	0.16	nd	0.28	0.04	0.04
Proline	0.08	nd	12.00	0.32	0.31–0.33	0.03	0.37	nd	0.58	0.09	0.09
Serine	0.04	nd	0.05	0.19	nd	0.04	0.18	nd	0.49	0.05	6.13
Threonine	0.05	nd	0.04	0.14	0.13–0.15	0.04	0.16	nd	0.27	0.04	0.04
Tryptophan	0.03	0.02–0.05	0.00	0.04	nd	0.02	0.04	nd	0.08	0.01	nd
Tyrosine	0.05	nd	0.05	0.15	nd	0.03	0.18	nd	0.28	0.05	0.04
Valine	0.06	nd	0.06	0.22	0.20–0.23	0.06	0.24	nd	0.45	0.05	0.07

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources.

Sources: Australian Food Composition Database, 2021; Balthazar *et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar *et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021

Table B6. Fat and fatty acid composition of milk from ruminant and monogastric livestock species and humans

Fat/Fatty acid (g)	Human		Livestock species																			
			Buffalo		Cattle	Yak		Goat	Sheep		Bactrian camel		Donkey		Dromedary	Llama		Horse		Reindeer	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Avg.	Range	Avg.	Avg.	Range	Avg.	Range	Avg.	Avg.	Range	Avg.	Range	Avg.	Range
SFA	1.99	1.98–2.01	5.80	4.20–8.80	2.84	1.86–5.00	5.81	2.58	2.50–2.60	4.60	2.23	1.84–2.50	0.3	0.24–0.38	2.08	2.90	1.50–2.60	0.55	0.32–0.75	11.20	nd
SFA 4:0	-	-	0.29	0.23–0.38	0.07	0.06–0.12	nd	0.13	0.13–0.14	0.20	nd	nd	-	0.02–0.04	-	0.09	nd	-	-	0.95	0.50–1.30
SFA 6:0	-	-	0.16	0.11–0.27	0.07	0.05–0.09	nd	0.10	0.09–0.10	0.15	nd	nd	0.01	0.00–0.01	0.01	0.11	nd	-	-	0.32	0.10–0.40
SFA 8:0	-	-	0.11	0.07–0.18	0.04	0.03–0.08	nd	-	0–0.10	0.14	nd	nd	0.06	0.05–0.08	0.01	0.10	0.00–0.08	0.03	0.01–0.05	0.08	0.03–0.12
SFA 10:0	0.06	0.05–0.06	0.31	0.11–1.2	0.08	0.07–0.10	0.06	0.26	0.26–0.28	0.40	nd	nd	0.09	0.07–0.11	0.01	0.11	0.00–0.01	0.07	0.03–0.10	0.1	0.06–0.15
SFA 12:0	0.24	0.22–0.25	0.20	0.14–0.33	0.10	0.08–0.10	0.09	0.13	0.12–0.13	0.24	0.02	0.02	0.04	0.04	0.03	0.07	0.03	0.07	0.04–0.16	0.15	0.09–0.21
SFA 14:0	0.31	0.3–0.32	0.92	0.68–1.2	0.35	0.30–0.40	0.42	0.34	0.32–0.33	0.66	0.29	0.23–0.34	0.03	0.02–0.03	0.33	0.48	0.13–0.48	0.08	0.06–0.11	1.70	1.10–2.50
SFA 16:0	0.96	0.92–1.01	2.5	2.06–3.50	0.96	0.83–1.08	1.89	0.95	0.91–0.99	1.62	1.04	0.78–1.90	0.06	0.04–0.07	0.88	1.30	0.61–1.15	0.26	0.15–0.31	5.20	3.70–6.90
SFA 18:0	0.31	0.29–0.33	0.92	0.55–1.20	0.37	0.37–0.40	0.96	0.44	0.48–0.44	0.9	0.78	0.72–0.86	0.01	0.00–0.01	0.78	0.43	0.72–0.86	0.01	0.08–0.02	2.10	1.30–2.70
MUFA	1.56	1.43–1.66	2.10	1.30–2.70	1.25	0.78–2.5	1.18	1.08	1.00–1.15	1.72	1.3	0.89–1.60	0.08	0.06–0.01	2.20	1.20	1.7–2.5	0.43	0.21–0.64	2.70	1.90–3.10
MUFA 16:1	0.12	0.11–0.13	0.15	0.07–0.25	0.06	0.05–0.06	0.01	0.09	0.09	0.13	0.17	0.10–0.21	nd	nd	0.29	0.29	0.17–0.36	0.07	0.06–0.09	nd	nd
MUFA 18:1	1.38	1.30–1.48	1.80	1.10–2.20	0.77	0.70–0.81	1.10	1.02	0.97–1.07	1.56	1.10	0.76–1.40	0.05	0.04–0.06	nd	nd	nd	0.23	0.06–0.39	2.40	1.70-2.90
MUFA 20:1	0.02	0.01–0.04	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	0.01	nd	-	0.00–0.01	nd	nd
MUFA 22:1	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA	0.49	0.48–0.50	0.45	0.27–0.45	0.16	0.09–0.30	0.15	0.14	0.10– 0.16	0.31	0.15	0.12–0.17	0.08	0.06–0.10	0.28	0.15	0.23–0.32	0.56	0.30–1.02	0.50	0.20–0.80
PUFA 18:2	0.38	0.37–0.39	0.1	0.07–0.10	0.09	0.07–0.12	0.09	0.11	0.11–0.12	0.18	nd	nd	nd	nd	0.11	0.06	0.97–0.12	0.12	0.06–0.20	nd	nd
PUFA 18:3	0.04	0.03-0.05	0.05	0.01–0.10	0.08	0–0.75	0.06	0.04	0.04	0.13	0.06	0.05–0.06	nd	nd	0.08	nd	0.05–0.12	0.18	0.12–0.25	nd	nd
PUFA 18:4	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 20:4	0.02	0.02–0.03	nd	nd	-	-	nd	-	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 2:5 n-3 (EPA)	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 22:5 n-3 (DPA)	0.01	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 22:6 n-3 (DHA)	0.01	-	-	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	0.10	nd	nd	nd
Fatty acids, total trans	-	0.1	0.52	0.39–0.7	0.12	0.11–0.13	0.02	-	-	nd	0.02	0.02–0.07	nd	nd	nd	0.18	nd	nd	nd	0.46	0.44–0.48
Cholesterol (mg)	14	14–15	nd	nd	12	10–14	nd	13	11–15	27	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Choline (mg)	nd	nd	nd	nd	14	nd	nd	16	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Notes: Nutrient values are expressed per 100-gram edible portion on fresh weight basis. SFA = saturated fatty acid. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. Slaughter weight and degree of maturity at slaughter weight influence fat composition. nd = no value in common data sources; - = fatty acid not contained.

Sources: Australian Food Composition Database, 2021; Balthazar *et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar *et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021

Table B7. Mineral composition of milk from livestock species and humans

Mineral		Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Human	Avg.	33	3	15	53	16	0.03	0.2	0.1	0.03	1.0	4.3
	Range	32–34	3	14–15	50–58	15–18	0–0.07	0.2–0.3	0–0.1	0.03	1.0–1.9	3.1–7
Buffalo	Avg.	191	12	185	112	47	0.17	0.5	-	nd	nd	4.0
	Range	147–220	2–16	102–293	nd		nd	nd	nd	nd	nd	nd
Cattle	Avg.	114	11	91	143	43	0.07	0.5	-	-	2.0	10.7
	Range	113–120	10–12	84–95	132–153	43–49	0.20	0.4–0.8	0–0.3	-	1.3–3.7	10.7–22.9
Mithan	Avg.	88	nd	147	nd	nd	nd	nd	nd	nd	nd	nd
Yak	Avg.	129	nd	nd	nd	nd	0.57	0.9	0.4	nd	nd	nd
	Range	119–134	nd	nd	nd	nd	0.15–0.98	0.7–1.1	nd	nd	nd	nd
Goat	Avg.	129	14	105	195	50	0.06	0.3	0.1	0.02	1.0	nd
	Range	120–134	14	100–111	180–204	50	0.10	0.3–0.4	0–0.1	0.02	1.0	nd
Sheep	Avg.	193	18	158	137	44	0.10	0.5	0.1	0.02	2.0	nd
	Range	195–200	17–23	139–142	136–140	32–46	0.10	0.5–0.7	0.1	6.15–8.15	0.7–2.7	nd
Bactrian camel	Avg.	154	8.1	132	186	66	nd	0.7	nd	nd	nd	nd
	Range	152–155	nd	117–146	181–191	61–72	nd	nd	nd	nd	nd	nd
Dromedary	Avg.	114	13	86	151	66	0.21	0.6	0.2	106.00	nd	nd
	Range	105–120	12–14	83–90	124–173	59–73	0.17–0.26	0.4–0.6	0.1–0.2	60–180	nd	nd
Llama	Avg.	195	19	270	156	48	nd	1.1	nd	nd	nd	nd
	Range	170–220	nd	nd	nd	46–50	nd	nd	nd	nd	nd	nd
Reindeer	Avg.	320	19	270	156	48	nd	1.1	nd	nd	nd	nd
	Range	nd	nd	nd	nd	46–50	nd	nd	nd	nd	nd	nd
Donkey	Avg.	91	4	61	50	22	nd	nd	nd	nd	nd	nd
	Range	68–115	nd	49–73	nd	nd	nd	nd	nd	nd	nd	nd
Horse	Avg.	95	7	58	51	16	0.10	0.2	0.1	nd	nd	nd
	Range	76–124	4–12	43–83	25–87	13–20	0.03–0.15	0.2–0.3	0.1	nd	nd	nd

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = mineral not contained.

Sources: Australian Food Composition Database, 2021; Balthazar *et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar *et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021

Table B8. Vitamin composition in dairy products

Product	Vitamin A RAE* (µg)	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE** (µg)	Vitamin B12 (µg)
Buttermilk	47	0.1	1.3	0.3	-	0.05	0.17	0.09	0.38	0.04	5	0.46
Yoghurt	37	0	-	0.2	0.3	0.03	0.19	0.04	0.38	0.03	17	0.44
Milk powder	350	0.9	0.6	nd	41.0	0.20	1.60	-	nd	0.19	117	0.70
Cream	120	0.1	1.1	1.7	0.8	0.02	0.19	0.09	0.44	0.04	2	0.14
Sour cream	154	0.6	-	1.5	0.5	0.01	0.14	-	0.30	-	32	0.16
Ice cream	111	0.3	0.2	0.3	3.0	0.04	0.24	0.14	0.72	0.05	11	0.39
Butter	758	2.2	0.2	7.0	-	-	0.04	0.57	0.06	-	5	-
Ghee	860	2.0	1.2	nd	-	-	0.01	-	nd	-	-	-

Notes: *Vitamin A content expressed in retinol equivalents (RAE). **Dietary folate equivalent. Average values provided for vitamin content. Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = vitamin not contained. Cheeses have been excluded due to the large diversity.

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B9. Mineral composition in dairy products

Mineral	Buttermilk	Butter	Cream	Ice cream	Milk powder	Sour cream	Yoghurt
Calcium (mg)	115	21	91	119	850	92	152
Magnesium (mg)	10	2	9	14	80	7.5	16
Phosphorus (mg)	85	20	92	104	810	74	126
Potassium (mg)	135	24	136	212	1300	75	197
Sodium (mg)	105	710	72	72	310	25	60
Iron (mg)	0.03	0.01	0.05	0.57	0.00	0.04	0.03
Zinc (mg)	0.4	0.1	0.3	0.5	2.3	0.3	0.6
Copper (mg)	0.03	-	0.01	0.04	nd	0.01	0.01
Manganese (mg)	-	-	0.01	0.08	nd	-	-
Selenium (µg)	4	1	5	2	12	2	2
Iodine (µg)	nd	8.8	nd	nd	120.0	15.3	25.0

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = mineral not contained. Cheeses have been excluded due to the large diversity.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B10. Vitamin composition of milk from ruminant and monogastric livestock species and humans

<table>
<tr><th rowspan="3">Vitamin</th><th rowspan="2">Human</th><th colspan="10">Livestock species</th></tr>
<tr><th>Buffalo</th><th>Cattle</th><th>Goat</th><th>Sheep</th><th>Bactrian camel</th><th>Donkey</th><th colspan="2">Dromedary</th><th colspan="2">Horse</th></tr>
<tr><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Avg.</th><th>Range</th><th>Avg.</th><th>Range</th></tr>
<tr><td>Vitamin A (µg) RAE*</td><td>62</td><td>69</td><td>43</td><td>34</td><td>44</td><td>97</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin E (alphatocopherol) (mg)</td><td>0.1</td><td>0.2</td><td>0.1</td><td>0.1</td><td>nd</td><td>0.2</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin D (µg)</td><td>0.1</td><td>nd</td><td>0.1</td><td>0.1</td><td>nd</td><td>1.6</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin K (phylloquinone) (µg)</td><td>0.3</td><td>nd</td><td>0.3</td><td>0.2</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin C (mg)</td><td>4.7</td><td>2.5</td><td>0.8</td><td>1.2</td><td>4.2</td><td>3</td><td>nd</td><td>6.7</td><td>2.5–18.4</td><td>4.3</td><td>1.7–8.1</td></tr>
<tr><td>Thiamine (mg)</td><td>0.01</td><td>0.05</td><td>0.01</td><td>0.04</td><td>0.07</td><td>0.01</td><td>0.06</td><td>nd</td><td>nd</td><td>0.03</td><td>0.02–0.04</td></tr>
<tr><td>Riboflavin (mg)</td><td>0.04</td><td>0.11</td><td>0.18</td><td>0.14</td><td>0.36</td><td>0.12</td><td>0.03</td><td>0.06</td><td>nd</td><td>0.02</td><td>0.01–0.03</td></tr>
<tr><td>Niacin (mg)</td><td>0.19</td><td>0.17</td><td>0.11</td><td>0.28</td><td>0.42</td><td>nd</td><td>0.09</td><td>nd</td><td>nd</td><td>0.07</td><td>nd</td></tr>
<tr><td>Pantothenic acid (mg)</td><td>0.24</td><td>0.15</td><td>0.37</td><td>0.31</td><td>0.41</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin B6 (mg)</td><td>0.01</td><td>0.33</td><td>0.05</td><td>0.05</td><td>0.06</td><td>0.05</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Folate DFE** (µg)</td><td>5</td><td>1</td><td>8</td><td>1</td><td>7</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
<tr><td>Vitamin B12 (µg)</td><td>0.10</td><td>0.50</td><td>0.50</td><td>0.10</td><td>0.70</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td><td>nd</td></tr>
</table>

Notes: *Vitamin A content expressed in retinol equivalents (RAE). **Dietary folate equivalent. Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = vitamin not contained.

Source: Australian Food Composition Database, 2021; Balthazar *et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar *et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021.

Table B11. Amino acid composition of meat from ruminant and monogastric livestock species

Amino acid	Cattle	Buffalo	Sheep	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
Alanine (g)	1	nd	nd	0.54	0.53	1.23	1.25	1.43	0.96	1.22	1.34	1.42	1.11	1.44	1.08	1.13
Arginine (g)	1.15	1.28	nd	1.03	0.60	1.40	1.30	1.65	1.00	1.28	1.38	1.43	1.17	1.45	1.11	1.24
Aspartic Acid (g)	1.31	2.03	nd	0.58	nd	2.10	1.49	2.13	1.59	1.81	1.81	2.28	1.70	2.23	1.46	1.84
Cystine (g)	0.23	0.32	nd	0.25	0.10	0.30	0.26	0.26	0.11	0.21	0.38	0.31	0.25	0.35	0.31	0.26
Glutamic acid (g)	2.12	2.96	nd	0.92	1.41	3.12	3.21	3.34	2.44	3.07	2.82	3.48	2.78	3.56	2.27	3.09
Glycine (g)	1.24	0.79	nd	1.01	0.42	1.03	1.08	1.18	0.86	0.97	1.44	1.04	0.93	1.27	1.16	1.01
Histidine (g)	0.44	0.68	nd	0.29	0.38	0.82	0.72	1.14	0.53	0.61	0.83	0.94	0.50	0.60	0.66	0.64
Isoleucine (g)	0.58	1.02	nd	0.63	0.44	1.01	1.09	0.91	0.57	0.65	1.19	1.32	0.96	1.17	0.96	1.09
Leucine (g)	1.20	1.76	nd	1.08	0.76	1.70	1.66	1.95	1.22	1.57	1.87	2.00	1.52	1.92	1.50	1.55
Lysine (g)	1.16	1.61	nd	0.99	0.82	1.82	1.79	2.01	1.31	1.87	1.90	2.16	1.53	1.95	1.53	1.75
Methionine (g)	0.43	0.51	nd	0.33	0.25	0.47	0.55	0.566	0.40	0.59	0.69	0.69	0.49	0.62	0.55	0.57
Phenylalanine (g)	0.64	0.82	nd	0.48	0.38	0.88	0.81	0.94	0.58	0.73	0.94	0.92	0.77	0.954	0.76	0.82
Proline (g)	0.92	0.78	nd	0.64	0.37	0.99	0.89	1.18	0.67	1.22	0.80	0.86	0.84	1.12	0.64	0.85
Serine (g)	0.57	0.88	nd	0.29	0.39	0.82	0.95	0.97	0.72	0.90	1.06	1.01	0.79	0.98	0.85	0.71
Threonine (g)	0.47	0.98	nd	0.61	0.41	0.96	1.04	1.08	0.69	0.82	1.09	1.18	0.87	0.97	0.53	0.87
Tryptophan (g)	0.17	0.25	nd	0.20	0.11	0.265	0.27	nd	0.12	0.24	0.30	0.33	0.24	0.32	0.27	0.24
Tyrosine (g)	0.38	0.82	nd	0.79	0.37	0.67	0.75	0.81	0.49	0.67	1.01	0.77	0.68	0.87	0.81	0.70
Valine (g)	0.92	1.08	nd	0.70	0.47	1.11	1.11	1.07	0.59	0.72	1.18	1.30	0.96	1.19	0.95	1.02

Notes: Nutrient values expressed per 100-gram of average edible portion on fresh weight basis. nd = no value in common data sources.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B12. Fat and fatty-acid composition of meat from livestock species

Fat/Fatty acid	Cattle	Buffalo	Sheep	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
SFA (g)	18.74	0.46	27.18	12.5	22	1.44	1.22	0.95	4.73	0.46	2.31	1.24	2.02	2.79	4.40	0.64
SFA 4:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 6:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 8:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 10:0 (g)	nd	nd	nd	nd	0.05	nd	nd	-	nd	0	nd	-	nd	-	nd	-
SFA 12:0 (g)	nd	nd	nd	nd	0.05	0.01	nd	-	nd	0	nd	0.05	nd	0.03	nd	0.01
SFA 14:0 (g)	nd	0.01	nd	nd	0.83	0.17	nd	0.02	nd	0.01	nd	0.03	nd	0.03	nd	0.02
SFA 15:0 (g)	nd	nd	nd	nd	0.04	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
SFA 16:0 (g)	nd	0.25	nd	nd	13.6	1.08	nd	0.41	nd	0.29	nd	0.75	nd	1.47	nd	0.42
SFA 18:0 (g)	nd	0.19	nd	nd	7.07	0.16	nd	0.51	nd	0.14	nd	0.36	nd	0.92	nd	0.18
SFA 20:0 (g)	nd	nd	nd	nd	0.12	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
SFA 4:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 6:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 8:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 10:0 (g)	-	nd	nd	-	0.05	nd	-	-	-	0	-	-	-	-	-	-
SFA 12:0 (g)	-	nd	nd	-	0.05	0.01	0.01	-	-	0	0.02	0.05	0.02	0.03	-	0.01
SFA 14:0 (g)	1.65	0.01	1.99	0.06	0.83	0.17	0.10	0.02	0.15	0.01	0.02	0.03	0.03	0.03	0.08	0.02
SFA 16:0 (g)	10.18	0.25	11.88	5.18	13.6	1.08	0.9	0.41	3.53	0.29	1.57	0.75	1.20	1.47	3.22	0.42
SFA 18:0 (g)	6.05	0.19	11.93	5.97	7.07	0.16	0.205	0.51	0.98	0.14	0.63	0.36	0.62	0.92	1.09	0.18
MUFA (g)	18.43	0.42	22.41	8.31	28.00	1.61	1.05	0.67	9.30	0.48	2.9	1.17	2.73	1.85	8.40	0.68
MUFA 14:1 (g)	nd	nd	nd	nd	0.02	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
MUFA 16:1 (g)	nd	0.03	nd	nd	1.28	0.31	nd	0.03	nd	0.04	nd	0.2	nd	0.27	nd	0.09
MUFA 18:1 (g)	nd	0.37	nd	nd	26.30	1.3	nd	0.63	nd	0.42	nd	0.96	nd	1.58	nd	0.57
MUFA 20:1 (g)	nd	nd	nd	nd	0.48	nd	nd	-	nd	0.01	nd	-	nd	-	nd	0.01
MUFA 22:1 (g)	nd	nd	nd	nd	nd	nd	nd	-	nd	0	nd	-	nd	-	nd	-
MUFA 16:1 (g)	1.58	0.03	0.74	0.53	1.28	0.31	0.12	0.03	0.86	0.04	0.42	0.20	0.19	0.27	1.56	0.09
MUFA 18:1 (g)	15.94	0.37	21.16	7.52	26.30	1.30	0.89	0.63	8.36	0.42	2.44	0.96	1.93	1.58	6.78	0.57
MUFA 20:1 (g)	0.07	nd	nd	-	0.48	nd	0.01	-	-	0.01	0.02	-	0.01	-	0.03	0.01
MUFA 22:1 (g)	-	nd	nd	-	-	nd	-	-	-	-	-	-	-	-	-	-
PUFA (g)	1.08	0.27	3.18	0.58	13.20	0.65	0.805	0.47	4.55	0.41	1.87	0.62	0.76	0.90	2.30	0.59
PUFA 18:2 (g)	1.55	0.16	1.63	0.38	11.80	0.29	0.61	0.31	4.11	0.34	1.58	0.54	0.65	0.80	1.93	0.40
PUFA 18:3 (g)	0.24	0.04	1.25	0.14	0.59	0.36	0.13	0.07	0.24	0.017	0.095	0.08	0.06	0.1	0	0.02
PUFA 18:4 (g)	-	nd	nd	0.06	-	nd	nd	-	nd	-	nd	nd	-	nd	nd	nd
PUFA 20:4 (g)	-	0.07	-	-	0.18	nd	0.07	0.1	0.1	0.03	0.11	-	0.04	-	0.11	0.07
PUFA 2:5 n-3 (EPA) (g)	-	nd	nd	nd	-	nd	nd	-	-	-	0.01	-	-	-	0.01	0.01
PUFA 22:5 n-3 (DPA) (g)	-	nd	0.14	0.08	0.05	nd	0.02	-	-	0	0.01	-	-	-	0.05	0.02

(cont.)

Fat/Fatty acid	Cattle	Buffalo	Sheep	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
PUFA 22:6 n-3 (DHA) (g)	-	nd	-	-	0.02	nd	-	-	-	-	0.02	-	-	-	0.02	0.03
Fatty acids, total trans (g)	3.02	nd	5.16	4.12	0.60	nd	0.01	nd	nd	-	0.06	nd	0.03	nd	0.11	nd
Cholesterol (mg)	135	46	70	93	72	52	62	85	143	67	85	66	94	84	87	63
Choline (mg)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Notes: Nutrient values are expressed per 100-gram edible portion on fresh weight basis. SFA = saturated fatty acids. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. Slaughter weight and degree of maturity at slaughter weight influence fat composition. nd = no value in common data sources. - = fatty acid not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B13. Mineral composition of meat from ruminant and monogastric livestock species

Mineral		Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Cattle	Avg.	246	13	206	219	41	3.48	2.26	0.03	0.01	10.4	2.2
	Range	6–485	9–17	87–324	180–277	25–57	1.30–5.67	0.94–3.58	0-0.06	0–0.02	0–20.7	nd
Buffalo	Avg.	12	32	197	297	53	1.61	1.93	0.15	nd	9.0	nd
Goat	Avg.	13	7	129	255	64	2.41	2.60	0.14	0.02	7.2	11
	Range	nd	nd	78–180	125–255	45–82	2.00–2.83	1.20–4.00	0.04–0.26	0–0.04	5.6–8.8	nd
Sheep	Avg.	8	7	72	111	28	0.59	0.76	-	-	5.0	0
	Range	5–10	6–8	56–88	91–130	22–33	0.41–0.77	0.54–0.99	nd	nd	0–10	nd
Deer	Avg.	5	23	202	318	51	3.40	2.09	0.25	0.04	9.7	nd
Horse	Avg.	6	24	221	360	53	3.82	2.90	0.14	0.02	10.1	nd
Pig	Avg.	14	6	84	333	47	0.26	0.60	0.07	0	9	nd
Rabbit	Avg.	11	23	212	350	23	1.28	1.58	0.11	0.01	24.4	nd
	Range	9–13	19–26	210–213	300–370	41–53	1.00–1.57	1.57–1.60	0.07–0.15	0–0.03	23.7–25	nd
Chicken	Avg.	187	12	132	104	40	1.22	1.90	0.07	0.02	15.7	nd
Duck	Avg.	9	19	186.5	270.5	82.5	2.10	1.95	0.25	0.1	19.45	-
	Range	7–11	nd	170–203	270–271	74–91	1.80–2.40	1.90–2.00	0.25–0.25	0–0.02	13.9–19.5	-
Goose	Avg.	13	24	312	420	87	2.57	2.34	0.31	0.02	16.8	nd
Guinea fowl	Avg.	11	24	169	220	69	0.77	1.20	0.04	0.02	17.5	nd
Pheasant	Avg.	13	20	230	262	37	1.15	0.97	0.07	0.02	16.2	nd
Pigeon	Avg.	13	21.5	234	218	59.5	3.45	2.45	0.59	0.02	13.4	1.3
	Range	nd	18–25	161–307	199–237	51–68	2.4–4.51	2.20–2.70	nd	nd	13.3–13.5	nd
Quail	Avg.	10	25	259	369	48	2.91	1.72	0.35	0.01	16.2	nd
	Range	6–13	24–25	210–307	237–369	45–51	1.30–4.51	0.74–2.70	0.1–0.59	0–0.02	15–17.4	nd
Turkey	Avg.	11	27	190	235	118	0.86	1.84	0.08	0.01	22.6	nd

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = mineral not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B14. Vitamin composition of meat from ruminant and monogastric livestock species

Vitamin		Vitamin A RAE* (µg)	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE** (µg)	Vitamin B12 (µg)
Cattle	Avg.	-	0.7	1.0	nd	-	0.04	0.08	2.27	0.27	0.30	5	2.7
	Range	-	nd	nd	nd	nd	0–0.07	0.05–0.11	2.00–2.55	0.279–0.28	0.29–0.30	5–10	2.6–2.9
Buffalo	Avg.	-	nd	nd	nd	-	0.04	0.2	5.97	0.16	0.53	8	1.7
Sheep	Avg.	42	0.9	0.7	nd	-	-	0.07	3.50	0.45	0.10	2	1.5
	Range	34–64	0.7–1.1	nd	nd	nd	nd	nd	2.00–5.00	0.43–0.46	nd	0–4	0.1–2.9
Goat	Avg.	33	3.7	2.0	nd	-	0.07	0.26	2.62	0.14	0.02	13	1.3
	Range	0–66	nd	nd	nd	nd	0.03-0.11	0.03–0.49	1.50–3.75	nd	nd	5–20	1.1–1.5
Deer	Avg.	-	0.2	nd	1.1	-	0.22	0.48	6.37	nd	0.37	4	6.3
Horse	Avg.	-	nd	nd	nd	1.0	0.13	0.1	4.60	nd	0.38	nd	3
Pig	Avg.	26	0.4	1.7	-	-	0.16	0.09	2.63	0.43	0.14	-	0.7
Rabbit	Avg.	5	0.9	1.6	nd	-	0.08	0.11	7.38	0.67	0.38	8	6.2
	Range	0–10	nd	nd	nd	nd	0.06-0.1	0.06–0.15	7.27–7.50	0.53–0.80	0.25–0.50	nd	5.3–7.2
Chicken	Avg.	45	nd	nd	nd	2.0	0.1	0.14	5.25	nd	0.28	5	0.3
Duck	Avg.	21	0.6	0.2	2.8	2.9	0.34	0.33	4.90	1.50	0.22	12.5	0.6
	Range	18–24	0.4–0.7	0.1–0.2	nd	0–5.8	0.32–0.36	0.2–0.45	4.5–5.30	1.40–1.60	0.10–0.34	0–25	0.4–0.7
Goose	Avg.	12	nd	nd	nd	7.2	0.13	0.38	4.28	1.97	0.64	31	0.5
Guinea fowl	Avg.	12	nd	nd	nd	1.7	0.07	0.11	8.78	0.94	0.47	6	0.4
Pheasant	Avg.	50	nd	nd	nd	6.0	0.08	0.15	6.76	0.96	0.74	6	0.8
Pigeon	Avg.	51	0.3	0.6	nd	6.1	0.25	0.25	6.45	0.79	0.47	7	0.4
	Range	28–73	nd	nd	nd	nd	0.21–0.28	0.22–0.29	6.05–6.86	nd	0.41–0.53	6–7	0.4–0.5
Quail	Avg.	19	0.8	0.6	nd	7.2	0.19	0.39	7.40	1.14	0.60	4	0.8
	Range	17–20	nd	nd	nd	nd	0.1–0.28	0.29–0.51	6.60–8.20	0.78–1.50	0.53–0.68	0–7	0.5–1.2
Turkey	Avg.	9	0.1	0.2	-	-	0.05	0.19	8.10	0.84	0.65	7	1.2

Notes: *Vitamin A content expressed in retinol equivalents (RAE). **Dietary folate equivalent; nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = vitamin not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021

Table B15. **Amino acid composition of selected offals from ruminant and monogastric livestock species**

Amino acid	Large ruminant	Small ruminant	Monogastric				
	Cattle liver	Sheep kidney	Pig liver	Pig kidney	Chicken liver	Turkey liver	Goose liver
Alanine (g)	1.16	0.85	1.28	1.04	0.99	0.99	0.95
Arginine (g)	1.24	0.91	1.32	1.01	1.09	1.09	1.00
Aspartic Acid (g)	1.93	1.36	1.94	1.55	1.59	1.59	1.56
Cystine (g)	0.38	0.18	0.40	0.36	0.27	0.27	0.22
Glutamic acid (g)	2.61	1.71	2.78	1.96	2.09	2.09	2.12
Glycine (g)	1.16	0.92	1.24	1.04	0.85	0.85	0.95
Histidine (g)	0.63	0.40	0.58	0.40	0.51	0.51	0.44
Isoleucine (g)	0.96	0.63	1.08	0.88	0.81	0.81	0.87
Leucine (g)	1.91	1.18	1.91	1.48	1.51	1.51	1.48
Lysine (g)	1.61	1.02	1.65	1.18	1.33	1.33	1.24
Methionine (g)	0.54	0.32	0.53	0.35	0.43	0.43	0.39
Phenylalanine (g)	1.08	0.73	1.05	0.78	0.82	0.82	0.82
Proline (g)	0.96	0.81	1.15	1.02	0.73	0.73	0.81
Serine (g)	0.91	0.73	1.16	0.87	0.74	0.74	0.71
Threonine (g)	0.87	0.74	0.91	0.68	0.73	0.73	0.73
Tryptophan (g)	0.26	0.21	0.30	0.21	0.18	0.18	0.23
Tyrosine (g)	0.80	0.55	0.73	0.59	0.65	0.65	0.58
Valine (g)	1.26	0.92	1.32	0.95	0.10	1.00	1.03

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources; - = amino acid not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B16. Fat and fatty acid composition of selected offals from ruminant and monogastric livestock species

Fat/fatty acid	Large ruminant		Small ruminant	Monogastric				
	Cattle liver	Cattle kidney	Sheep kidney	Pig liver	Pig kidney	Chicken liver	Turkey liver	Goose liver
SFA (g)	1.23	0.87	1.00	1.17	1.04	1.45	1.66	1.59
SFA 4:0 (g)	-	-	nd	-	-	-	-	nd
SFA 6:0 (g)	-	-	nd	-	-	-	-	nd
SFA 8:0 (g)	-	-	nd	-	-	-	-	nd
SFA 10:0 (g)	-	-	nd	-	-	-	-	-
SFA 12:0 (g)	-	-	0.01	-	0.01	0	0	0
SFA 14:0 (g)	0.02	0.02	0.03	0.02	0.04	0.01	0.01	0.01
SFA 16:0 (g)	0.31	0.39	0.42	0.44	0.58	0.88	0.89	0.80
SFA 18:0 (g)	0.86	0.37	0.52	0.7	0.41	0.66	0.66	0.76
MUFA (g)	0.48	0.59	0.63	0.52	1.07	1.16	0.82	0.81
MUFA 16:1 (g)	0.04	0.04	0.04	0.03	0.09	0.11	0.11	0.06
MUFA 18:1 (g)	0.42	0.54	0.55	0.46	0.97	1.13	1.13	0.74
MUFA 20:1 (g)	0.01	0.01	-	-	0.02	0.02	0.02	0.01
MUFA 22:1 (g)	-	-	0.01	-	-	-	-	-
PUFA (g)	0.47	0.55	0.55	0.87	0.26	1.01	1.68	0.26
PUFA 18:2 (g)	0.30	0.29	0.21	0.35	0.17	0.44	0.48	0.18
PUFA 18:3 (g)	0.02	0.01	0.07	0.03	0.01	0.01	0.01	0.01
PUFA 18:4 (g)	-	-	nd	-	-	-	-	nd
PUFA 20:4 (g)	0.14	0.23	0.14	0.44	0.08	0.32	0.33	0.07
PUFA 2:5 n-3 (EPA) (g)	-	-	0.05	-	-	nd	-	-
PUFA 22:5 n-3 (DPA) (g)	-	-	0.04	0.03	-	-	-	-
PUFA 22:6 n-3 (DHA) (g)	-	-	0.03	0.02	-	-	-	-
Fatty acids, total trans (g)	0.17	0.1	nd	nd	nd	0.07	0.07	nd
Cholesterol (mg)	275	411	337	301	319	345	345	515
Choline (mg)	333	nd	nd	nd	nd	nd	nd	nd

Notes: Nutrient values are expressed per 100-gram edible portion on fresh weight basis. SFA = saturated fatty acids. MUFA = monounsaturated fatty acid. PUFA = polyunsaturated fatty acid. slaughter weight and degree of maturity at slaughter weight influence fat composition. nd = no value in common data sources. - = fatty acid not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B17. Mineral composition of selected offals from ruminant and monogastric livestock species

Mineral		Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Large ruminant	Cattle liver	5	18	387	313	69	4.90	4.0	9.80	0.30	39.7	nd
	Cattle kidney	13	17	257	262	182	4.60	1.92	0.40	0.10	141.0	nd
Small ruminant	Sheep kidney	13	17	246	277	156	6.38	2.24	0.40	0.10	127.0	nd
Monogastric	Pig liver	9	18	288	273	87	23.30	5.76	0.68	0.30	52.7	nd
	Pig kidney	9	17	204	229	121	4.89	2.80	0.60	0.12	190.0	nd
	Chicken liver	6	19	299	230	69	5.20	3.10	0.40	0.30	54.6	1.4
	Turkey liver	20	19	297	230	71	8.94	3.40	0.50	0.26	54.6	nd
	Goose liver	43	24	261	230	140	30.50	3.10	7.52	-	68.1	nd

Notes: Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = mineral not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B18. Vitamin composition of selected offals from ruminant and monogastric livestock species

Vitamins		Vitamin A (µg) RAE*	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE** (µg)	Vitamin B12 (µg)
Large ruminant	Cattle liver	4970	0.4	1.2	3.1	1.3	0.19	2.76	13.20	7.17	1.08	290	59.3
Small ruminant	Cattle kidney	419	0.2	1.1	0	9.4	0.36	2.84	8.03	3.97	0.665	98	27.5
Monogastric	Sheep kidney	95	nd	nd	nd	11.0	0.62	2.24	7.51	4.22	0.22	28	52.4
	Pig liver	6500	nd	nd	nd	25.3	0.28	3.00	15.30	6.65	0.69	212	26.0
	Pig kidney	59	nd	nd	nd	13.3	0.34	1.70	8.21	3.13	0.44	42	8.5
	Chicken liver	7650	0.6	-	-	18.0	0.31	1.78	9.73	5.62	0.85	1019	16.6
	Turkey liver	8060	0.7	-	-	17.90	0.31	1.78	9.73	6.23	0.85	677	19.7
	Goose liver	9310	nd	nd	nd	4.50	0.56	0.89	6.50	6.18	0.76	738	54.0

Notes: *Vitamin A content expressed in retinol equivalents (RAE). **Dietary folate equivalent. Nutrient values expressed per 100-gram edible portion on fresh weight basis. nd = no value in common data sources. - = vitamin not contained.

Sources: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Tables Section C

Table C1. Contribution of selected foods to recommended nutrient intake of vitamin A

Life-cycle phase	Vitamin A (a,b) (μg RE/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infant (7–12 months)	400	0	18	5	0	5	82	104	35	0	9	0
Children (1–3 years)	400	0	18	5	0	5	82	104	35	0	9	0
Children (4–6 years)	450	0	16	5	0	4	73	93	31	0	8	0
Children (7–9 years)	500	0	15	4	0	4	66	84	28	0	8	0
Adolescent females (10–18 years)	600	0	24	7	0	6	109	139	47	0	13	0
Adolescent males (10–18 years)	600	0	24	7	0	6	109	139	47	0	13	0
Adult females (19–50 years) (premenopausal)	500	0	29	9	0	7	131	167	56	0	15	0
Adult females (51–65 years) (menopausal)	500	0	29	9	0	7	131	167	56	0	15	0
Adult males (19–65 years)	600	0	24	7	0	6	109	139	47	0	13	0
Older females (65+ years)	600	0	24	7	0	6	109	139	47	0	13	0
Older males (65+ years)	600	0	24	7	0	6	109	139	47	0	13	0
Pregnant women	800	0	18	5	0	5	82	104	35	0	9	0
Lactating women	850	0	17	5	0	4	77	98	33	0	9	0

Notes: For infants and children the seving was 50 g while for the other life phase groups the serving was 100 g. (a) Vitamin A values are "recommended safe intakes" instead of RNIs. (b) Recommended safe intakes as mg retinol equivalent (RE)/day; conversion factors are as follows: 1 mg retinol = 1 RE; 1 mg β-carotene = 0.167 mg RE; 1 mg other provitamin A carotenoids = 0.084 mg RE.

Sources: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021

Table C2. **Contribution of selected foods to recommended nutrient intake of vitamin B12**

Life-cycle phase	Vitamin B12 (μg/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infant (7–12 months)	0.7	195	82	33	nd	31	674	0	0	0	0	0
Children (1–3 years)	0.9	152	64	26	nd	24	524	0	0	0	0	0
Children (4–6 years)	1.2	114	48	19	nd	18	393	0	0	0	0	0
Children (7–9 years)	1.8	76	32	13	nd	12	262	0	0	0	0	0
Adolescent females (10–18 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adolescent males (10–18 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult females (19–50 years) (premenopausal)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult females (51–65 years) (menopausal)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult males (19–65 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Older females (65+ years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Older males (65+ years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Pregnant women	2.6	105	44	18	nd	17	363	0	0	0	0	0
Lactating women	2.8	98	41	17	nd	16	337	0	0	0	0	0

Notes: For infants and children the serving was 50 g, while for the other life-cycle phase groups the serving was 100 g. nd = no data available. Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population.

Sources: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C3. Contribution of selected foods to recommended nutrient intake of iron

Life-cycle phase	Iron (mg/day) 15% bioavailability	Iron (mg/day) 10% bioavailability	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants (7–12 months) (a)	6.2	9.3	28	15	1	433	0	8	2	9	33	3	19
Children (1–3 years)	3.9	5.8	45	23	1	688	0	13	3	14	54	4	31
Children (4–6 years)	4.2	6.3	41	22	1	639	0	12	2	13	49	4	28
Children (7–9 years)	5.9	8.9	29	15	1	455	0	9	2	9	35	3	20
Adolescent females (11–14 years) (b)	9.3	14.0	37	20	1	289	0	11	2	12	45	3	25
Adolescent females (11–14 years)	21.8	32.7	16	8	0	123	0	5	1	5	19	1	11
Adolescent females (15–17 years)	20.7	31.0	17	9	0	130	0	5	1	5	20	2	11
Adolescent males (11–14 years)	9.7	14.6	36	19	1	277	0	11	2	11	43	3	24
Adolescent males (15–17 years)	12.5	18.8	28	15	1	215	0	8	2	9	33	3	19
Adult females (19–50 years) (premenopausal)	19.6	29.4	18	9	0	137	0	5	1	6	21	2	12
Adult females (51–65 years) (menopausal)	7.5	11.3	46	24	1	358	0	14	3	15	55	4	32
Adult males (19–65 years)	9.1	13.7	38	20	1	295	0	11	2	12	45	3	26
Older females (65+ years)	7.5	11.3	46	24	1	358	0	14	3	15	55	4	32
Older males (65+ years)	9.1	13.7	38	20	1	295	0	11	2	12	45	3	26
Pregnant women	c	c	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lactating women (0–3 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24
Lactating women (3–6 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24
Lactating women (7–12 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24

Notes: Bioavailability of TASF = 15%. Bioavailability of plant source foods = 10%. For infants and children the serving was 50 g while for the other life-cycle phase groups the serving was 100 g. nd = no data available. Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population. (a) Bioavailability of dietary iron during this period varies greatly. (b) Pre-menarche. (c) It is recommended that iron supplements in tablet form be given to all pregnant women because of the difficulties in correctly assessing iron status in pregnancy. In non-anaemic pregnant women, daily supplements of 100mg of iron (e.g. as ferrous sulphate) given during the second half of pregnancy are adequate. In anaemic women higher doses are usually required.

Sources: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C4. Contribution of selected foods to recommended nutrient intake of zinc

Life-cycle phase	Zinc (mg/day) High bioavailability (50%)	Zinc (mg/day) Moderate bioavailability (30%)	Zinc (mg/day) Low bioavailability (15%)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Carrot (%)	Tuna (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants (7–12 months) (b)	3	4	8	45	24	10	317	12	1	12	2	22	1	0
Children (1–3 years)	2	4	8	47	25	10	330	12	1	13	2	22	1	14
Children (4–6 years)	3	5	10	39	21	8	273	10	1	10	2	19	1	12
Children (7–9 years)	3	6	11	34	18	7	240	9	1	9	2	17	1	10
Adolescent females (10–18 years)	4	7	14	53	28	11	368	14	2	14	3	26	1	16
Adolescent males (10–18 years)	5	9	17	44	24	9	311	12	1	12	2	22	1	14
Adult females (19–50 years) (premenopausal)	3	5	10	75	40	16	528	20	2	20	4	38	1	24
Adult females (51–65 years) (menopausal)	3	5	10	75	40	16	528	20	2	20	4	38	1	24
Adult males (19–65 years)	4	7	14	54	29	11	377	14	2	14	3	26	1	17
Older females (65+ years)	3	5	10	75	40	16	528	20	2	20	4	38	1	24
Older males (65+ years)	4	7	14	54	29	11	377	14	2	14	3	26	1	17
Pregnant women, first trimester	3	6	11	66	36	14	466	17	2	18	3	34	1	21
Pregnant women, second trimester	4	7	14	54	29	11	377	14	2	14	3	26	1	17
Pregnant women, third trimester	6	10	20	38	20	8	264	10	1	10	2	18	1	12
Lactating women (0–3 months)	6	10	19	39	21	8	273	10	1	10	2	19	1	12
Lactating women (3–6 months)	5	9	18	43	23	9	299	11	1	11	2	21	1	13
Lactating women (7–12 months)	4	7	14	53	28	11	368	14	2	14	3	26	1	16

Notes: TASF: high bioavailability. Plant source foods: low bioavailability. For infants and children the serving was 50 g, while for the other life-cycle phase groups the serving was 100 g. Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population. (a) Not applicable to infants exclusively breastfed.

Sources: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C5. Contribution of selected food to recommended nutrient intake of calcium

Life-cycle phase	Calcium (mg/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants, 7–12 months	400	31	6	14	9	19	1	4	15	15	1	7
Children, 1–3 years	500	25	5	11	7	15	1	3	12	12	1	5
Children, 4–6 years	600	20	4	9	6	13	1	3	10	10	0	4
Children, 7–9 years	700	18	4	8	5	11	1	2	8	9	0	4
Adolescent females, 10–18 years	1300	19	4	9	5	12	1	3	9	9	0	4
Adolescent males, 10–18 years	1300	19	4	9	5	12	1	3	9	9	0	4
Adult females, 19–50 years (premenopausal)	1000	25	5	11	7	15	1	3	12	12	1	5
Adult females, 51–65 years (menopausal)	1300	19	4	9	5	12	1	3	9	9	0	4
Adult males, 19–65 years	1000	25	5	11	7	15	1	3	12	12	1	5
Older females, 65+ years	1300	19	4	9	5	12	1	3	9	9	0	4
Older males, 65+ years	1300	19	4	9	5	12	1	3	9	9	0	4
Pregnant women, first trimester	a	a	a	a	a	a	a	a	a	a	a	a
Pregnant women, second trimester	a	a	a	a	a	a	a	a	a	a	a	a
Pregnant women, third trimester	1200	20	4	9	6	13	1	3	10	10	0	4
Lactating women, 0–3 months	1000	25	5	11	7	15	1	3	12	12	1	5
Lactating women, 3–6 months	1000	25	5	11	7	15	1	3	12	12	1	5
Lactating women, 7–12 months	1000	25	5	11	7	15	1	3	12	12	1	5

Notes: For infants and children the serving was 50 g, while for the other life-cycle phase groups the serving was 100 g. Recommended nutrient intake (RNI) is the daily intake that meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population. (a) Not specified.

Sources: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C6. **Evidence for health effects of terrestrial animal source food by life-cycle phase**

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Women during pregnancy and lactation, including foetus and breastfeeding child through 6 months						
Milk, dairy products	Lower or no intake of milk and dairy products.	For mothers with higher intakes of milk and dairy products during pregnancy: • increased BW; • increased infant length; • reduced risks for small-for-gestational age; • reduced risks for low BW; • increased risk for large-for-gestational age; • no effect of milk and dairy on standard ultrasound measures of the foetal size.	111 184 pregnant women	Canada, China, Denmark, India, Malawi, Netherlands, New Zealand, Spain, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (14 studies: 1 quasi randomized trial; 4 retrospective cohort; 9 prospective cohort)	Pérez-Roncero *et al.*, 2020
	Various (lower intakes of milk; fortified milk; varying fat levels of dairy; total and median dairy intake).	1. Maternal milk intake during pregnancy positively associated with infant BW and length. 2. No conclusion drawn on relation to preterm deliveries, spontaneous abortion and lactation due to limited evidence.	>237 555 women	China, Denmark, India, Iran (Islamic Republic of), Italy, Malawi, Netherlands, Portugal, Spain, Sweden, United States of America	Systematic review (17 studies: 3 intervention; 6 prospective cohort; 3 retrospective cohort; 2 case-control)	Achón *et al.*, 2019
	0–1 glass of milk per day.	For mothers who consumed ≥ 3 glasses of milk per day: • greater foetal weight gain in third trimester of pregnancy; • higher BW by 88 g; • larger foetal head circumference by 2.3 cm; • no associations found between milk consumption and femur length; • maternal protein intake from milk was associated with offspring BW.	3 405 pregnant women	Netherlands	Observational (prospective cohort study)	Heppe *et al.*, 2011
	< 150 ml/day of milk.	1. For mothers who consumed ≥ 150 ml of milk per day: • higher z-scores for BW (by 0.32 z-scores); • higher z-scores for birth length (by 0.34 z-scores). 2. For offspring of mothers who consumed ≥ 150ml of milk per day, at 20 years of follow-up: • higher z-scores for height (by 0.19 z-scores); • higher levels of insulin-like growth factor-1 (IGF-1); • higher levels of insulin.	809 pregnant women	Denmark	Observational (prospective cohort study)	Hrolfsdottir *et al.*, 2013
	Intake of milk, gram per day.	1. Positive association between intake of milk products during the first trimester of pregnancy and infant BW. 2. Positive association between % intake of protein from milk products and infant BW. 3. Positive association between intake of milk products during the third trimester of pregnancy and GWG. 4. Positive association between % intake of protein from milk products during the third trimester of pregnancy and GWG. 5. No associations between % intake of vitamin B12 from milk products and infant BW nor GW.	2 036 live births	India	Observational (prospective cohort study)	Mukhopadhyay *et al.*, 2018
	Intake of milk, gram per day.	1. Positive association between maternal dairy intake in first trimester and head circumference of offspring. 2. Increased dairy intakes between first and second and first trimester associated with lower maternal weight gain during pregnancy.	98 pregnant women	Portugal	Observational (prospective cohort study)	Abreu *et al.*, 2017
	Parallel group design: milk with folic acid supplement; folic acid supplement alone; milk alone; control.	1. Increased serum folate (vitamin B9) concentrations at 16 and 32 weeks of pregnancy and cord blood at birth.	4 052 pregnant women	China	Parallel randomized trial	Li *et al.*, 2014

(cont.)

[1] Including number of embedded studies if systematic review.

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Infants and young children						
Non-specific	Various (cereal-based foods, no intervention).	1. Significant increases in change in height-for-age z-score or length-for-age z-score in intervention groups compared to controls associated with TASF consumption (3 studies). 2. Significant increases in change in weight-for-age z-score associated with TASF consumption (3 studies). 3. Yoghurt associated with significant reduction in duration and incidence of diarrhoea and upper respiratory infections. 4. Eggs during associated with increase in diarrhoeal morbidity compared to control. 5. Meat- and dairy-based diets: • associated with increases in length-for-age z-scores; • no significant associations with weight-for-age z-scores.	3 036 children	China, Democratic Republic of the Congo, Ecuador, Guatemala, Pakistan, United States of America, Zambia	Systematic review (6 studies: all randomized controlled or quasi-randomized controlled trials)	Eaton *et al.*, 2019
	Various (usual diet, fortified and non-fortified cereals).	1. Reduced stunting associated with TASF consumption (2 studies). 2. Non-significant associations with anaemia, height/weight, and head circumference.	Average sample size per region: Latin America and the Caribbean = 1 367; Sub-Saharan Africa = 6 749; South Asia = 5 343; East Asia and the Pacific = 2 904	Bangladesh, Cambodia, China, Ecuador, Indonesia, Jamaica, Kenya, Mexico, Myanmar, Nepal, Peru, Senegal, Uganda	Systematic review (21 studies: 7 randomized controlled trials; 14 observational–longitudinal cohort and cross-sectional studies)	Shapiro *et al.*, 2019
Milk, dairy products	Intake of milk, ml per day.	1. Increases in child height by 0.4 cm per year for increases in 245 ml of milk consumed daily. 2. Increased growth as a consequence of milk consumption for children with stunted growth. 3. Greater effect of milk on height compared to other dairy products.	Range: 36 to 757 participants	China, India, Indonesia, Kenya, Viet Nam, United States of America, Europe	Systematic review and meta-analysis (12 studies: 7 randomized controlled trials; 5 non-randomized controlled trials)	de Beer, 2012
	Parallel design: • FVF group (3.5 g fat/dl; 100% vegetable fat from palm, coconut and soybean oil); • LF milk (1 g cow's milk fat/dl); • SF (3.5 g cow's milk fat/dl); • PVF (3.5 g fat/dl: 50% vegetable fat from rapeseed oil, 50% milk fat).	1. Higher amounts of plasma LA in (4) FVF group compared to LF and SF milk groups. 2. Higher amounts of plasma ALA in group PVF compared to SF milk for triglycerides and cholesterolesters. 3. Higher amounts of plasma ALA in group PVF milk compared to LF milk for phospholipids and cholesterolesters. 4. Similar amounts of plasma AA and plasma DHA in phospholipids and cholesterolesters across milk groups. 5. Lower plasma trans fatty acids in cholesterolesters for PVF and FVF milk groups compared to SF. 6. Higher plasma concentrations of α-tocopherol in FVF group compared to other groups.	37 1-year-old children	Sweden	Parallel randomized trial	Svahn *et al.*, 2002
Meat	Various (fortified cereal, low meat, no intervention).	1. Meat consumption associated with reduced risk of iron deficiency among breastfeeding infants who had low iron intake or were at risk of inadequate iron stores during the first year of life. 2. Limited evidence for meat's impact on infant zinc status during complementary feeding.	1 792 children (studies on meat only)	Australia, Austria, Canada, Colombia, Denmark, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, New Zealand, Portugal, Spain, Sweden, United Kingdom, United States of America	Systematic review (15 studies specifically on meat consumption: 8 randomized controlled trials; 7 prospective cohort studies)	Obbagy *et al.*, 2019
Eggs	No intervention.	1. Increased length-for-age by 0.63 for children in egg intervention group. 2. Stunting reduced by 47% from egg intervention. 3. Increased plasma concentrations of DHA and choline.	163 children	Ecuador	Randomized controlled trial	Iannotti *et al.*, 2017a, 2017b

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Eggs	No intervention.	4. No significant effect of eggs on growth. 5. No significant effect of eggs on developmental outcomes.	660 children	Malawi	Randomized controlled trial	Prado *et al.*, 2020; Stewart *et al.*, 2019
Meat	Fortified cereal.	1. No significant differences in linear growth velocity between meat group and comparator. 2. No significant differences in anaemia between meat group and comparator.	532 infants	Democratic Republic of the Congo, Guatemala, Pakistan, Zambia	Randomized controlled trial	Krebs *et al.*, 2012
Insects, insect product	No intervention (usual diet).	• At 18 months old: • no difference in stunting prevalence at between the intervention (caterpillar cereal) and control groups; • increased haemoglobin levels in the intervention group compared to control; • significantly lower anaemia prevalence in intervention group compared to control group; • no difference in estimates of iron stores between the intervention and control groups.	175 infants	Democratic Republic of the Congo	Cluster-randomized trial	Bauserman *et al.*, 2015
Honey	Intervention group: honey as much as 45 g per day for 2 months with drinking dose 3x1. Control group: formula milk, as much as 8 boxes of milk (60 cc per day 3x1 doses) for 2 months.	4. For children receiving 45 g of honey per day (15 g, 3x1 doses) for 2 months: • significantly higher weight, height, weight-for-height z-score, weight-for-age z-score and height-for-age z-score compared to control.	60 children	Indonesia	Quasi-experimental design	Harmiyati *et al.*, 2017
School-age children and adolescents						
Milk, dairy products	Lowest level of dairy intake or each 1 serving/day increment in dairy consumption.	1. For children in the highest group of milk consumption: • 38% reduced risk of overweight/obesity compared to the lowest intake group of dairy consumption; • reduction in body fat by 0.65% for every unit increase in daily serving of dairy; • 13% reduction in risk of obesity/overweight for every unit increase in daily serving of dairy.	46 011 children and adolescents	Australia, China, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (10 cohort studies)	Lu *et al.*, 2016
	Evidence associations between dairy intake and adipositas in pre-schoolers, school-age children and adolescents.	1. No significant association between dairy intake and adiposity. 2. Inverse association between dairy intake and adiposity in adolescents.	N/A	Australia, Canada, Hong Kong, Iran (Islamic Republic of), Italy, New Zealand, Portugal, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (36 studies for systematic review; 22 studies for meta-analysis)	Dror, 2014
	Various (specifics not reported).	1. Significant relationship between dairy consumption and bone mineral content and bone mineral density (BMD) (8 studies). 2. Average of 8% increase in BMD after 16 months of dairy consumption (8 studies). 3. No significant relationships between dairy consumption and body size and composition (significant relationships for body size only found in 2 out of 14 trials measuring body size; significant relationships found only in 1 out of 11 trials measuring body composition).	N/A	Chile, China, Finland, Germany, Iran (Islamic Republic of), New Zealand, United States of America, United Kingdom	Systematic review (15 randomized controlled trials)	Kouvelioti, Josse and Klentrou, 2017
Eggs	No egg consumption.	1. Positive correlation between egg intake and radius and tibia cortical bone mineral content (Ct.BMC), total bone area, cortical area, cortical thickness, periosteal circumference, and polar strength strain.	294 children (9-13-year old)	United States of America	Cross-sectional	Coheley *et al.*, 2018
Meat	Various (3 studies with no food as control: fortified cereal, milk snack; meal without beef; wheat and soy biscuits).	1. One intervention with a non-feeding control arm found beef consumption to improve cognitive abilities compared to the control. 2. Inconsistent results on cognition for studies comparing beef consumption to other food-specific comparators.	N/A	Democratic Republic of the Congo, Guatemala, Kenya, Pakistan, United States of America, Zambia	Systematic review (8 studies)	An *et al.*, 2019

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat	Control group with no food; variations of githeri stew (maize, beans, and greens): meat with githeri stew, milk with githeri stew, githeri stew alone.	1. Children in the meat group performed better in terms of increased cognitive function compared to milk or control groups. 2. Increased vitamin B12 plasma concentrations in the meat and milk groups compared to control. 3. Significantly increased arm muscle area and mid-upper arm circumference over time for meat and milk groups compared to the githeri only and control groups. 4. Significantly greater decrease in probability of morbidity outcome (PMO) for total and severe illnesses, malaria, poor appetite, reduced activity, fever and chills in meat group and githeri only group. 5. For meat group, significant declines in PMO for gastroenteritis (diarrhoea) and typhoid compared with the control group, for jaundice compared with the githeri only group, and for skin infection compared with the milk group. 6. Greatest declines in PMO for upper respiratory infection in milk group.	911 school children	Kenya	Randomized controlled trial	Gewa *et al.*, 2009; Hulett *et al.*, 2014; McLean *et al.*, 2007; Neumann *et al.*, 2007, 2013; Whaley *et al.*, 2003
Adults						
Milk, dairy products	Increases of 200 g/day of dairy consumption; increases of 200–244 g/day of milk consumption; increases of 10-50 g/day of cheese consumption.	1. No association between dairy consumption and all-cause mortality.	Ranges: 24 466 participants reporting 5 092 mortality cases to 938 817 participants reporting 126 759 mortality cases.	N/A	Meta-review (8 meta-analyses)	Cavero-Redondo *et al.*, 2019
	Increases of 200 ml/day of milk.	1. For every 200ml/day increase in milk consumption: • lower risk of cardiovascular disease, stroke, hypertension, colorectal cancer, metabolic syndrome, obesity, diabetes, Alzheimer's disease, and osteoporosis; • increased risk of prostate cancer, Parkinson's disease and acne.	N/A	N/A	Metareview (41 meta-analyses)	Zhang *et al.*, 2021
	Increases of 200 g/day of high-fat milk consumption; increases of 90 g/day of cheese.	1. Increase of 200 g/d intake of high-fat milk intake positively associated with coronary heart disease. 2. Increase of 90 g/d of cheese associated with reduced the risk of coronary heart disease.	N/A	Denmark, Finland, Greece, Iran (Islamic Republic of), Netherlands, Spain, Sweden, United Kingdom, United States of America of America	Systematic review and meta-analysis (13 cohort studies)	Jakobsen *et al.*, 2021
	Increases of 200 g/day of dairy consumption; increases of 30 g/day of cheese (when servings are not reported); dose-response.	1. Decreased risk of hypertension with increased consumption of dairy, low-fat dairy, milk and fermented dairy. 2. Increased risk of hypertension for women and Americans with increased consumption of dairy. 3. Non-linear relationship between total dairy product and milk consumption and risk of hypertension. 4. Linear association between low-fat dairy intake and hypertension.	N/A	N/A	Systematic review and meta-analysis (16 studies)	Heidari *et al.*, 2021
	Lower or no intake of dairy products.	1. Each 200 g/d increase in dairy intake reduced risk of type 2 diabetes. 2. Yoghurt intakes at 80 g/d versus no intake associated with reduced risk of type 2 diabetes.	79 832 individuals and 43 118 cases with type 2 diabetes	N/A	Systematic review and meta-analysis (22 cohort studies)	Gijsbers *et al.*, 2016

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Milk, dairy products	One serving increment per day of different dairy products.	1. Yoghurt found to be protective against type 2 diabetes. 2. Total dairy consumption not associated with risk of type 2 diabetes. 3. Neither low-fat nor high-fat dairy intake appreciably associated with risk of T2D.	41 436 men in the Health Professionals Follow-Up Study; 67 138 women in the Nurses' Health Study; 85 884 women in the Nurses' Health Study II	United States of America	Meta-analysis (3 cohort studies)	Chen *et al.*, 2014
	Increment in dairy consumption of one serving/d.	1. Higher dairy consumption significantly associated with reduced risk of metabolic syndrome.	N/A	N/A	Systematic review and meta-analysis (15 cross-sectional studies; 1 case-control study; 7 prospective cohort studies)	Chen *et al.*, 2015
	Low dairy consumption < 400 g/day.	1. High and modest dairy consumption (> 600 and 400–600 g/day, respectively) significantly reduced the risk of breast cancer compared with low dairy consumption. 2. Linear relationship between dairy consumption and breast cancer risk. 3. Yoghurt and low-fat dairy associated with reduced the risk of breast cancer. 4. Reduced risk of breast cancer for participants in the United States of America and Asia, and in participants followed for 10 years, in association with dairy consumption.	1 566 940 participants (cohort studies); 33 372 participants (case-control studies).	China, Finland, France, Iran (Islamic Republic of), Japan, Netherlands, Norway, United Kingdom, United States of America	Systematic review and meta-analysis (22 prospective cohort studies; 5 case-control studies)	Zang *et al.*, 2015
	Lowest category of intake ranging from 0 to < 407, < 2.5 to < 30 and 0 to < 32 g/day for non-fermented milk, solid cheese and fermented milk, respectively.	1. Reduced risk of colorectal cancer in men consuming highest intake of nonfermented milk (average of 525 g/day) 2. No association found between consumption of non-fermented milk and rectal cancer in men nor non-fermented milk and colon or rectal cancer in women. 3. No protective association found between consumption of solid cheese or fermented milk and colorectal cancer.	Over 900 000 subjects and over 5 200 colorectal cancer cases	Finland, France, Norway, Switzerland, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (15 prospective cohort studies)	Ralston *et al.*, 2014
	Lowest consumption or for each increment in dose of exposure of dairy.	1. Compared to comparator: • non-significant, reduced risk of osteoporotic fractures for highest intake of dairy; • reduced risk of hip fractures for highest intake of dairy; • reduced risk of vertebral fractures; • 1.7–3% lower hip bone mass density in young and postmenopausal women with poor intake of milk in their youth.	N/A	France, Sweden, Switzerland, United States of America	Systematic review and meta-analysis (13 studies, with 9 used for meta-analysis)	Matía-Martín *et al.*, 2019
	Lowest intake of dairy; increment of 1 glass per day of milk.	1. Higher consumption of yoghurt associated with reduced risk of hip fractures. 2. Higher consumption of milk associated with reduced risk of hip fractures in the United States of America of America but not in Scandinavian countries.	9 564 hip fracture events among 363,383 participants	Scandinavian countries, United States of America	Systematic review and meta-analysis (9 articles)	Hidayat *et al.*, 2020
	No dairy intake or less-frequent dairy intake.	1. Total dairy intake associated with the reduced risk of endometriosis. 2. Decreased risk of endometriosis when intake of dairy products was over 21 servings/week. 3. Possible reduced risk of endometriosis with high cheese intake.	N/A	Belgium, Iran (Islamic Republic of), Italy, United States of America	Systematic review and meta-analysis (5 case-control studies)	Qi *et al.*, 2021
	Consumption of nuts, legumes or whole grains; consumption of red and processed meat Total dairy consumption (quintiles – lowest quintile: mean of 0.8 servings per day).	1. Lower risk of mortality associated with consumption of nuts, legumes or whole grains instead of dairy foods. 2. Consumption of red and processed meat instead of dairy associated with higher mortality.	168 153 women and 49 602 men without cardiovascular disease	United States of America	Prospective cohort study (3 cohort studies)	Ding *et al.*, 2019

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Eggs	Various, usual diet, no eggs, egg substitutes, lower eggs, choline supplements, lean animal protein, bagels, oatmeal.	1. No significant effect of egg consumption on systolic or diastolic blood pressure.	748 participants	Australia, Colombia, Mexico, Thailand, United States of America	Systematic review and meta-analysis (15 randomized controlled trials)	Kolahdouz-Mohammadi *et al.*, 2020
	Various, lower egg consumption.	1. No significant association between egg consumption and coronary heart disease nor stroke. 2. Increased risk of coronary heart disease for persons with diabetes in association with egg consumption.	N/A	Japan, United States of America	Meta-analysis (8 articles: 17 reports)	Rong *et al.*, 2013
	Low egg consumption (less than one egg per week).	1. For high egg consumption (more than seven eggs per week), no significant increases in risk for all-cause mortality, mortality from cardiovascular disease, ischemic heart disease or stroke compared to low egg consumption. 2. Small reduction in stroke risk associated with egg consumption.	28 024 participants without cardiovascular disease at baseline	China	Meta-analysis (Guangzhou Biobank Cohort Study)	Xu *et al.*, 2019
Meat, red and white meat from chickens/poultry, sheep, pigs, cattle, goats, fish, seafood, buffaloes, kangaroos, camels, deer or rabbits, processed meat	Various (vegetarian, vegan, low-meat, alternative protein sources, usual diet, etc.).	1. Positive association between animal flesh intake (85–300 g/day) and iron status (5 studies).	N/A	Australia, Austria, Belgium, Canada, Czechia, Demark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Republic of Korea, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America	Systematic review (49 studies: 41 observational; 8 experimental)	Jackson *et al.*, 2016
Meat, animal husbandry, not direct consumption	Various.	1. Intervention trials targeting poultry production showed a positive effect on anaemia among women. 2. Observation studies demonstrated that chicken ownership increased risk for anaemia in young children, potentially arising from increased risk of enteric pathogen exposures.	N/A	Afghanistan, Bangladesh, Burkina Faso, Cambodia, Chad, China, Equatorial Guinea, Ghana, Haiti, Kazakhstan, Kenya, Nepal, Philippines, Thailand	Systematic review (23 articles)	Lambrecht, Wilson and Jones, 2019
Meat, processed and unprocessed red meat	0 g of meat/week.	1. Higher intakes of processed red meats (≥ 150 g/week versus 0 g/week) associated with increased risk of total mortality. 2. Non-significant findings for unprocessed red meat and poultry on the negative health outcomes.	134 297 individuals	21 low-, middle- and high-income countries	Cohort study	Iqbal *et al.*, 2021
	Alternative proteins: plant protein sources (nuts, legumes, and soy); dairy; fish, eggs, poultry. Total red meat, processed red meat and unprocessed red meat consumption (quintiles).	1. Increased risk of cardiovascular disease for one additional daily serving of total red meat, unprocessed red meat and processed meat. 2. Lower risk of cardiovascular disease for intake of one serving per day of combined plant protein sources (nuts, legumes and soy), compared to total red meat, unprocessed red meat and processed red meat. 3. Substitution of whole grains and dairy products for total red meat and of eggs for processed red meat associated with lower cardiovascular disease risk.	43 272 men without cardiovascular disease or cancer at baseline	United States of America	Prospective cohort study	Al-Shaar *et al.*, 2020

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat, processed and unprocessed red meat	Total red meat, processed red meat and unprocessed red meat consumption (quintiles).	1. For every increase of 100 g/d in unprocessed meat consumption and 50 g/d in processed meat consumption, there was an increased risk of type 2 diabetes.	37 083 men in the Health Professionals Follow-Up Study (1986–2006); 79 570 women in the Nurses' Health Study I (1980–2008); and 87 504 women in the Nurses' Health Study II	United States of America	Meta-analysis (3 prospective cohort studies)	Papadimitriou *et al.*, 2021
Meat, red and processed	Evaluation of epidemiological data regarding the association between red and processed meat consumption and cancer.	1. Classification of processed meat consumption as "carcinogenic to humans" (Group 1) on the basis of sufficient evidence for colorectal cancer 2. Positive association with the consumption of processed meat was found for stomach cancer 3. Classification of red meat consumption as "probably carcinogenic to humans" (Group 2A) 4. Positive association between consumption of red meat and colorectal cancer and the strong mechanistic evidence 5. Consumption of red meat was also positively associated with pancreatic and with prostate cancer	More than 800 epidemiological studies	Many countries, from several continents, with diverse ethnicities and diets	Monograph critical review	Bouvard *et al.*, 2015
Meat, processed and unprocessed	Increments of daily servings of unprocessed red meats (430.9 g/d) and processed meats (421.8 g/d).	1. Positive association between increased daily servings of unprocessed red meats (430.9 g/d) and processed meats (421.8 g/d) with four-year weight gain.	120 877 women and men	United States of America	Prospective cohort study	Mozaffarian *et al.*, 2011
	Total meat consumption (in quartiles).	1. Total meat consumption, processed meat consumption, and unprocessed meat consumption in the highest quartile was significantly associated with a higher risk of gestational diabetes.	3 298 healthy women	Spain	Prospective cohort study	Marí-Sanchis *et al.*, 2018
Meat, processed	High vegetable and fruit with low processed-meat intakes.	1. Low co-consumption of fruit and vegetables with high levels of processed meat increased risk of all-cause and 15 cancers compared to high vegetables and fruit with low processed meat intakes.	26 218 adults	Canada	Prospective cohort study	Maximova *et al.*, 2020
Meat, red meat	Less that 0.5 servings (35 g)/day of total red meat intake.	1. No significant differences in changes for levels of glucose, insulin, Homeostatic Model Assessment of Insulin Resistance, or c-reactive protein.	N/A	N/A	Meta-analysis (24 articles from randomized controlled trials)	O'Connor *et al.*, 2021
	Alternative protein sources: high-quality plant protein sources (legumes, soy, nuts); chicken/poultry/fish; fish only; poultry only; mixed animal protein sources (including dairy); carbohydrates (low-quality refined grains and simple sugars, such as white bread, pasta, rice, cookies/biscuits); usual diet.	1. No differences between red meat and the combined category for all alternative diets for changes in blood concentrations of total, low-density lipoprotein, or high-density lipoprotein cholesterol, apolipoproteins A1 and B, or blood pressure. 2. Lesser decreases in triglycerides for red meat compared to alternative protein sources. 3. Lesser decreases in total cholesterol and low-density lipoprotein compared to high-quality plant protein sources. 4. Greater decreases in low-density lipoprotein compared to fish.	1 803 participants	N/A	Meta-analysis (36 randomized controlled trials)	Guasch-Ferré *et al.*, 2019

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat, poultry	Lowest category of poultry intake (quintile; never consumed). Increments of one serving per week.	1. Reduced, but non-significant total risk of stroke for highest category of poultry intake. 2. No association between increments of one serving per week of poultry and risk of stroke. 3. For studies in the United States of America and for women, reduced total risk of stroke for highest category of poultry intake. 4. Lower risk of stroke at consumption of ~1 serving of poultry per week.	354 718 participants	China, Iran (Islamic Republic of), Japan, United States of America	Systematic review and meta-analysis (7 cohort studies)	Mohammadi *et al.*, 2018
Insects, insect products	Outcomes of interventional studies: effects of the consumption of bee products on CVD risk factors.	1. Possible association between natural honey consumption and improved lipid profile as well as anthropometry. 2. Possible association between propolis supplementation and improved lipid profile and glycaemic markers. Inconclusive findings on bee products and cardiovascular risk.	N/A	Brazil, Chile, Iran (Islamic Republic of), Japan, Slovenia, Taiwan, Province of China, Türkiye	Systematic review (23 interventional studies)	Hadi, Rafie and Arab, 2021
	Control: sucrose intake (70 g/day).	1. For intervention group receiving 70 g/d of honey: • Decrease in total cholesterol, triacylglycerol, and LDL cholesterol, whereas these parameters increased in the control group. • Increase in HDL cholesterol, whereas these parameters increased in the control group.	60 healthy subjects	Iran (Islamic Republic of)	Randomized controlled trial	Rasad *et al.*, 2018
	Trial 1: sucrose intake providing 1.2 g of carbohydrate per kg of body weight per day. Trial 2: clover honey providing 1.2 g of carbohydrate per kg of body weight per day.	1. In both trials, no effects on serum concentrations of insulin, total cholesterol, low density lipoprotein-cholesterol, or high density lipoprotein-cholesterol. 2. Significantly reduced intake of carbohydrates, sugars, and saturated fats in honey trial. 3. Increases in serum triglycerides for both trials. 4. Transient increase in body weight for honey trial.	37 healthy adults	United States of America	Randomized crossover trial	Al-Tamimi *et al.*, 2020
	Breakfast meals without cricket powder.	1. 25 g/day whole cricket powder found not to be toxic. 2. Increase in probiotic bacterium, Bifidobacterium animalis by 5.7-fold for intervention group. 3. Cricket powder associated with Tumour Necrosis Factor-alpha (TNF-α)–biomarker of systemic inflammation.	20 adults	United States of America	Randomized controlled trial	Stull *et al.*, 2018
Older adults						
Milk, dairy products	Various, lower quantities of milk/dairy; total dairy intake.	1. No firm conclusion between milk/dairy consumption and cognitive impairment. 2. Consumption of milk at midlife may be negatively associated with verbal memory performance. 3. High intakes of dairy desserts and ice cream associated with cognitive decline in old women. 4. Inverse relation between dairy intake and development of Alzheimer disease among older individuals (1 study). 5. Possible reduced risk of frailty with high consumption of low-fat milk and yoghurt. 6. Possible reduced risk of sarcopenia associated with consumption of dairy products.	N/A	France, Japan, Mexico, Spain, United States of America	Systematic narrative review (6 studies: 5 observational prospective cohort studies and 1 randomized controlled trial)	Cuesta-Triana *et al.*, 2019
	Various.	1. Data from 2 long Japanese cohorts indicate that milk and dairy intake could prevent dementia and Alzheimer's. 2. No definite conclusions on milk and dairy as preventative against dementia and Alzheimer's.	N/A	Australia, Congo, France, Japan, Netherlands, Republic of Korea, Sweden, Switzerland, United Kingdom, United States of America	Systematic review (2 ecological surveys, 1 complex document, 28 cross-sectional studies and 7 cohort surveys; 2 randomized control trials)	Bermejo-Pareja *et al.*, 2021
	Less than four cups per week of milk intake.	1. Almost daily intake of milk compared to less than four cups per week during midlife reduced the odds of Alzheimer's. 2. Low milk intake during midlife associated with vascular dementia.	1 174 subjects	Japan	Longitudinal cohort study	Yamada *et al.*, 2003

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Milk, dairy products	Total milk consumption (quartiles).	1. Milk and dairy intake are associated with reduced risk of dementia.	1 081 subjects	Japan	Prospective cohort study	Ozawa *et al.*, 2014
	Usual diet [700 (247) mg/day calcium and 58 (14) g/day protein (0.9 g/kg body weight)].	1. For groups receiving additional dairy products with usual diet [(166) mg/day calcium and 12 (6) g/day protein achieving a total intake of 1142 (353) mg calcium/day and 69 (15) g/day protein (1.1 g/kg body weight)]: • Reduced risks of all fractures by 33% compared to control • Reduced risks of hip fractures by 46%for hip fractures • Reduced risks of falls by 11%. No differences in mortality risk	7 195 participants	Australia	Cluster randomized controlled trial	Iuliano *et al.*, 2021
	No comparator.	1. Consumption of fermented milk containing *Lactobacillus* casei Shirota increased percentage of stool types per week and reduced diarrhoea. 2. No significant impact on bowel movement.	135 participants	Netherlands	Intervention study (non-randomized)	van den Nieuwboer *et al.*, 2015
Eggs Meat (lean red meat)	Various.	1. Consistent and robust findings for beneficial effects of lean red meat consumption and dairy foods on muscle mass or lean tissue mass. 2. Inconclusive evdence for eggs on muscle mass or lean tissue mass.	N/A	Australia, Finland, France, Ghana, India, Japan, , Mexico, Republic of Korea, Russian Federation, Spain, South Africa, United Kingdom, United States of America	Systematic review (19 observational studies; 9 intervention studies)	Granic *et al.*, 2020
Meat, lean red meat	Control: progressive resistance training with [1 serving pasta or rice/d].	For groups receiving ~160 g cooked lean red meat in addition to progressive resistance training: • Greater protein intake • Greater gains in total body and leg lean tissue mass and muscle strength	100 women	Australia	Cluster randomized controlled trial	Daly *et al.*, 2014
	Control: ~225 g of cooked pasta or rice with resistance training. Intervention: two 80 g servings of cooked lean red meat with resistance training.	1. No significant differences were found in changes for total body and leg lean mass. 2. The intervention did not significantly affect changes in thigh muscle cross-sectional area, leg and back muscle strength, executive and cognitive functioning, systolic blood pressure, and physical function. 3. Individuals assigned to the lean red meat group had greater improvements in arm lean mass, gait speed, muscle density, and appendicular lean mass. 4. Greater improvements for indicators of memory and learning in control group.	154 subjects	Australia	Randomized controlled trial	Formica *et al.*, 2020
Meat	Control: 25 g of meat protein Intervention: 25 g of isoflavone soy protein.	1. Non-significant differences in indicators of bone or cardiovascular health. 2. Non-significant differences in calcim intake or calcium retention	13 post-menopausal women	United States of America	Controlled feeding study	Roughead *et al.*, 2005
	Control: lacto-ovo-vegetarian diet (0.6 g protein per kg of body weight per day) with resistance training. Intervention: beef-containing diet (0.6 g protein per kg of body weight per day) with resistance training.	1. No significant difference between groups in body composition, resting energy expenditure, and concentrations of muscle creatine, phosphocreatine, and total creatine.	21 men	United States of America	Randomized controlled trial	Haub *et al.*, 2002

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Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat, red meat, poultry	Total meat consumption g/day (in quartiles).	1. Increased risk of cognitive impairment in highest quartile of red meat consumption. 2. Non-significant but negative association between poultry intake in the highest quartile (median intake: 37.18 g/day) and cognitive impairment. 3. Organ meat consumption in the highest quartile found to be protective against cognitive impairment. 4. Fresh red meat and preserved/processed meat in the highest quartile respectively associated with a 15% increased likelihood of cognitive impairment.	16 948 participants	Singapore	Prospective cohort study	Jiang *et al.*, 2020

Notes: BW = birth weight. GWG = gestational weight gain. LA = linoleic acid. ALA = α-linoleic acid. AA = arachidonic acid. DHA = docosahexaenoic acid. FVF = full vegetable fat milk. SF = standard fat milk. PVF = partially vegetable fat milk. N/A = not available.

Table C7. Examples of micronutrient related recommendations from food-based dietary guidelines

Country	Document title and web link	Recommendation
Afghanistan	National food-based dietary guidelines for Afghans – a manual	Animal source foods are a good source of iron, zinc, calcium, B vitamins and protein.
Australia	The Australian guide to healthy eating	During pregnancy, three to four servings a day of animal source foods are recommended to provide additional iron and zinc.
Kenya	National guidelines for healthy diets and physical activity	Meat is a more complete source of micronutrients than plants for vitamin A, iron, zinc and vitamins B1, B2, B12.
Lesotho	Lesotho Food and Nutrition Policy	The high prevalence of anaemia among under-five children in Lesotho is related to low intake of iron-rich foods (like meat, fish, dried beans and green leafy vegetables) combined with lower intakes of dietary enhancers of iron absorption (like Vitamin C) and higher intakes of iron absorption inhibitors (like cereal bran and grain in general).
New Zealand	Eating and activity guidelines for New Zealand adults	Red meat is an excellent source of key nutrients like iron (in an easily absorbed form) as well as zinc. Low iron levels are a problem for some New Zealanders, particularly young women.
Nigeria	Food-based dietary guidelines for Nigeria – a guide to healthy eating	Foods such as liver, milk, butter and local cheese (wara) have good amounts of vitamin A.
Sierra Leone	Food-based dietary guidelines for healthy eating	Meat, bushmeat and poultry are particularly rich sources of haem-based iron.

Table C8. Examples of sustainability related recommendations from Food-based Dietary Guidelines

Country	Document title and web link	Recommendation
Canada	Canada's food guide	There is evidence supporting a lesser environmental impact of patterns of eating higher in plant-based foods and lower in animal-based foods. Potential benefits include helping to conserve soil, water and air
Canada	Healthy eating and the environment	An eating pattern that is higher in plant-based foods and lower in animal-based foods can decrease the negative impact of food on the environment
Denmark	The official dietary guidelines – good for health and climate	To reduce the effect on the environment, eat a more plant-based diet and less meat.
Italy	Dietary guidelines for healthy eating – revision 2018	Select poultry or legumes over red meat to reduce environmental impact.
Netherlands	Food based dietary guidelines for the Netherlands	To limit environmental impact, reduce consumption of meat to a maximum of 500 grams per week; consume 2–3 portions of dairy products per day, more is not necessary and eat fish (only) once a week.
Norway	National action plan for better diet (2017–2021)	It is pointed out in the Public Health Report that a plant-based diet as well as increased intake of fish and less meat will help to reach both health policy and climate policy goals.
South Africa	Food-based dietary guidelines for South Africa	The delicate balance between adequate, over- and underconsumption of animal sources of food remains a very complicated aspect of ensuring healthy and nutritionally adequate, yet environmentally sustainable, diets.
Sweden	Find your way to eat greener, not too much and be active!	Limit consumption of dairy, as cattle used to produce these products have an environmental impact.
Uruguay	Dietary guidelines for the Uruguayan population: for a healthy, shared and enjoyable diet	Combining foods of plant origin with foods of animal origin contributes to a balanced diet. It also contributes to the promotion of a more sustainable food system.

Table C9. Examples of life-cycle phase related recommendations from food-based dietary guidelines

Country	Document title and web link	Recommendation
Afghanistan	National food-based dietary guidelines for Afghans – a manual	Pregnant women should take extra servings of meat, fish, eggs or dairy products every day.
Finland	Finnish nutrition recommendations 2014	Infants above 6 months of age should be fed high protein milk products and a moderate amount of poultry and some red meat.
Iceland	Manual for the kindergarten kitchen	Limit consumption of processed meats for infants and young children.
Lesotho	Lesotho Food and Nutrition Policy	The high prevalence of anaemia among under-five children in Lesotho is related to low intake of iron-rich foods (like meat, fish, dried beans, and green leafy vegetables) combined with lower intakes of dietary enhancers of iron absorption (like vitamin C) and higher intakes of iron absorption inhibitors (like cereal bran and grain in general).
Nigeria	Food-based dietary guidelines for Nigeria – a guide to healthy eating	Pregnant mothers should eat more iron-rich foods such as snails.
Sierra Leone	Food-based dietary guidelines for healthy eating	Animal source food should be allocated to family members with special needs, such as young children aged six months to five years old and pregnant and lactating women.
Türkiye	Dietary guidelines for Turkey	Young children should consume eggs daily.

Table C10. Number of policy documents available in common databases and analysed, by year

Year	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
2000	1	-	-	-	-	1
2001	1	-	-	-	-	1
2002	2	-	-	-	-	2
2003	2	-	-	-	-	2
2004	2	-	-	-	-	2
2005	1	-	-	-	-	1
2006	5	-	-	-	-	5
2007	4	-	-	-	-	4
2008	6	-	-	-	-	6
2009	5	-	-	-	-	5
2010	8	-	-	-	-	8
2011	3	-	-	-	-	3
2012	16	-	-	-	-	16
2013	16	-	-	-	-	16
2014	13	-	-	-	-	13
2015	12	2	0	2	0	16
2016	11	10	11	3	3	38
2017	5	39	2	1	3	50
2018	7	3	5	2	7	24
2019	4	16	3	2	3	28
2020	4	1	2	1	0	8
2021	1	0	0	0	0	1

Notes: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html). The most recent FBDG from each country was analysed. - = not in the scope of this analysis.

Table C11. **Number of quantitative and qualitative recommendations in policy documents available in common databases and analysed**

Recommendations	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Qualitative	543	130	12	12	16	713
Quantitative	327	34	3	1	0	365

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C12. **Number of policy documents extracted from common databases and analysed, by region**

Region	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Africa	7	16	5	5	12	45
Asia and the Pacific	18	13	3	2	3	39
Europe	34	16	0	1	0	51
Latin America and the Caribbean	29	9	2	1	1	42
Near East	9	2	1	0	0	12
North America	2	1	0	0	0	3

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C13. **Number of recommendations in policy documents available in common databases and analysed, by food group**

Food group	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Animal source food	162	63	17	7	8	261
Eggs	191	13	0	0	0	204
Meat from wild animals	6	0	0	1	1	8
Insects	6	1	0	0	0	7
Meat	366	46	1	5	2	420
Milk and dairy products	281	44	4	1	1	331
Offal	53	2	0	0	0	55
Poultry	133	7	2	1	0	143
Red meat	48	10	0	0	0	58
White meat	5	2	0	0	0	7

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.htm).

Table C14. Number of recommendations in policy documents available in common databases and analysed, by category

Category	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Animal welfare	1	0	0	0	0	1
Micronutrients	695	10	15	13	16	749
Non-communicable diseases	145	154	8	0	0	307
Sustainability	9	3	0	0	0	12

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C15. Number of recommendations in policy documents available in common databases and analysed, by life-cycle phase

Life-cycle phase	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Infants, 0-3 years	76	3	4	0	0	83
Children, 4-9 years	94	21	6	0	3	124
Adolescents, 10–18 years	64	5	0	1	0	70
Women of reproductive age, 15-49 years	23	3	0	1	0	27
Women, pregnant	23	0	4	0	1	28
Women, lactating	11	0	0	0	0	11
Older adults, women and men, above 65 years	30	1	0	0	0	31
Older women, above 65 years	2	0	0	0	0	2
Older men, above 65 years	2	0	0	0	0	2
No differentiation by life-cycle phase	607	143	10	11	12	783

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

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Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes An evidence and policy overview on the state of knowledge and gaps

Corrigendum

23 June 2033

The following corrections were made to the PDF of the report after it went to print.

Page	Location	Text in printed PDF	Text in corrected PDF/ Notes
xi	left column 3rd bullet point	Fabrice DeClerck (Alliance Bioversity International – International Center for Tropical Agriculture, Italy	~~Fabrice DeClerck (Alliance Bioversity International – International Center for Tropical Agriculture, Italy~~
xi	left column 10th bullet point	Walter Willett (Harvard Medical School, United States of America)	~~Walter Willett (Harvard Medical School, United States of America)~~

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Diverse foods derived from livestock production systems, including grazing and pastoralist systems, and from the hunting of wild animals and wildlife farming, provide high-quality proteins, important fatty acids and various vitamins and minerals – contributing to healthy diets for improved nutrition and health. Preferences and socio-economic and cultural factors, which vary across agrifood systems and population subgroups, can shape demand for, and consumption of, terrestrial animal source food.

Livestock species – mammals, birds and insects – are adapted to a wide range of environments, including areas that are unsuitable for crop production. Globally, more than a billion people depend on livestock value chains for their livelihoods. Small-scale livestock farmers and pastoralists make up a large proportion of livestock producers. Well-integrated livestock production increases the resilience of small-scale farming systems and thus enables poor farmers, in particular, to better cope with disruptions. Livestock also provide other important ecosystem services in landscape management, provide energy and help to improve soil fertility. Rangeland or grassland ecosystems occupy some 40 percent of the world's terrestrial area. Livestock keepers raise grazing animals to transform grassland vegetation into food.

Challenges related to high resource utilization and pollution, food–feed competition, greenhouse-gas emissions, antimicrobial resistance and animal welfare as well as zoonotic and food-borne diseases, accessibility and affordability need to be solved if agrifood systems are to become more sustainable.

FAO's Committee on Agriculture requested a comprehensive, science- and evidence-based global assessment of the contribution of livestock to food security, sustainable food systems, nutrition and healthy diets, considering environmental, economic and social sustainability.

The assessment consists of four component documents. This first component document provides a holistic analysis of the contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes over the course of people's lives.

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