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Review

Role of food processing in food and nutrition security

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ABSTRACT

Background: Food and nutrition security, a major global challenge, relies on the adequate supply of safe, affordable and nutritious fresh and processed foods to all people. The challenge of supplying healthy diets to 9 billion people in 2050 will in part be met through increase in food production. However, reducing food losses throughout the supply chain from production to consumption and sustainable enhancements in preservation, nutrient content, safety and shelf life of foods, enabled by food processing will also be essential.
Scope and approach: This review describes developments in primary food production systems and the role of food processing on population health and food and nutrition security. It emphasises the need to monitor the attitudes and values of consumers in order to better understand factors that may lead to negative perceptions about food processing.
Key findings and conclusions: For a resource constrained world, it is essential to have a balanced approach to both energy and nutrient content of foods. Environmental sustainability is critical and both the agrifood production and the food processing sectors will be challenged to use less resources to produce greater quantities of existing foods and develop innovative new foods that are nutritionally appropriate for the promotion of health and well-being, have long shelf lives and are conveniently transportable. Healthy diets which meet consumer expectations produced from resilient and sustainable agrifood systems need to be delivered in a changing world with diminishing natural resources. An integrated multi-sectoral approach across the whole food supply chain is required to address global food and nutrition insecurity.

1. Introduction

Food and nutrition security is a global challenge, and a prerequisite for a healthy and peaceful society. 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". Nutrition security "exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life" (FAO, IFAD, & WFP, 2015).

About 795 million people in the world were undernourished in 2014–16 (FAO et al., 2015) while more than 2 billion people were overweight or obese in 2013 (Ng et al., 2014). To be able to feed the world population that is expected to increase from 7.3 billion today to 9 billion in 2050, an increase in agricultural productivity by 30–40% is required by 2050 just to meet the dietary energy needs. The energy gap can be addressed by reducing demand, lessening the current level of food waste or increasing food production (Keating, Herrero, Carberry, Gardner, & Cole, 2014). While considering food demand in terms of calories to fulfil energy needs is one way to examine global food requirements, fundamental requirements of macronutrients and micronutrients for good health

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need to be met. It is essential to take into account the potential overconsumption of nutrients, changing demographic structure, consumer choice and cultural context of diets.

Over the past 50 years, feeding our rapidly growing global population was achieved through increases in agricultural productivity (DeFries et al., 2015). Although intensification of agricultural production while minimizing environmental degradation will still be critical, this alone may not be sufficient to meet the nutritional demands of the projected population expansion. Food processing is required to increase useful life of foods, optimize nutrient availability and food quality, and reduce losses and waste. Biodiversity, ecosystems and cultural heritage are a consideration when developing affordable sustainable diets for all people. Sustainable diets have low environmental impacts and contribute to healthy life of present and future generations (Johnston, Fanzo, & Cogill, 2014). Reducing the prevalence of food insecurity today and in future will require technological solutions through collaborative efforts across agriculture, food, nutrition and health that are acceptable to society. It is clear that many considerations need to be factored into a discussion of food and nutrition security, which also include effective distribution channels between where food is produced and required, the differing food regulations in various regions, the role of indigenous foods, religion and culture, urbanisation, biodiversity and climate change (Burlingame & Dernini, 2012; Muchenje & Mukumbo, 2015; Rolle, 2011). An integrated multi-sectorial systems approach to food supply chain efficiency and sustainable diets is needed (Lake et al., 2012; van Mil, Foegeding, Windhab, Perrot, & van der Linden, 2014; Wu, Ho, Nah, & Chau, 2014). The focus of this review is on the role of innovative and sustainable primary production systems and food processing in addressing challenges in food and nutrition security.

2. Primary production systems

Resilient production systems for sustainable diets have to be developed and managed whilst mitigating climate change, preserving biodiversity and the environment, while taking into account societal needs and expectations. The productivity of food systems should focus on innovation for improving nutritional needs, and providing aid to farmers to adopt innovations for sustainable intensification and novel food sources (Ingram *et al*., 2013). Consideration of multiple desirable endpoints requires consideration of synergies and trade-offs in the competing demands in production systems and sustainable diets so that food security is not compromised (Garnett, 2013).

2.1. Crop production systems

Biofortification of crops is one of the approaches that may be used for alleviating global nutrition insecurity (Arsenault, Hijmans, & Brown, 2015). Biofortification of crops that are part of the staple diet of local populations is an effective approach to improve the nutrient density and nutritional quality of the agricultural produce. The use of conventional plant breeding or transgenic methods may be used for introducing desirable nutrient traits into food crops. HarvestPlus, an interdisciplinary global alliance, has developed varieties of food crops with higher levels of micronutrients. Biofortified crops developed and released in the HarvestPlus program include cassava, maize and sweet potato high in vitamin A, high-iron beans and high-zinc wheat, millet and maize (www.harvestplus.org). These biofortified food staples which are denser in micronutrients provide a greater percentage of the recommended daily allowance and reduce malnutrition, especially in rural communities. The technical feasibility of providing micronutrient dense crops without affecting agronomic traits has been demonstrated and may be a cost effective method for reducing micronutrient deficiencies in vulnerable populations (Nestel, Bouis, Meenakshi, & Pfeiffer, 2006). The fortification of crops with the essential amino acids, lysine and methionine, has attracted attention because of the potentially limited supply of these amino acids, especially in developing countries where poor populations do not consume sufficient protein from animal sources. Advanced breeding methods have yielded higher protein maize. Transgenic approaches have been successful in increasing the level of lysine in Arabidopsis seeds, rice and soybean while increases in methionine have been obtained in Arabidopsis, alfalfa and potato leaves as well as in the storage proteins of canola, rice, soybean and rice. However more work is required to enable production of crops with increased levels of lysine and methionine with a normal phenotype (Galili & Amir, 2013).

Foods rich in dietary fibre and resistant starch have the potential to reduce the incidence of Type 2 diabetes and cardiovascular disease and improve metabolic and gut health and this led to interest in improving cereal grain carbohydrates for health outcomes (Lafiandra, Riccardi, & Shewry, 2014). Conventional plant breeding can produce barley grains with high levels of resistant starch and beta-glucan, and a low glycaemic index (Morell et al., 2003). A high beta-glucan, high amylose barley has been incorporated as an ingredient into a range of processed food products. A high resistant starch wheat has also been produced (Regina et al., 2015).

The benefits of long chain polyunsaturated omega-3 fatty acids (LC-PUFAs) for maintenance of good health, brain and eye development in early childhood and reducing the risk of cardiovascular diseases and inflammatory diseases are well recognised (FAO, 2010; Lorente-Cebrian et al., 2013). Gene technology has been used for the production of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in plants (Petrie et al., 2010). The ability to achieve a sustainable crop source of LC-PUFAs will reduce the reliance on fish and other marine sources.

2.2. Livestock production systems

Livestock is an important contributor to global diets. Meat and livestock are a good source of dietary protein. The consumption of meat and livestock products is increasing due to increasing population, especially in the developing world, with a demand for these foods, a growth in economic wealth and urbanisation. Strategies for improving the resilience of animal production systems need to be considered in the face of climate change, as higher temperatures affect the sustainability of livestock production and the quality and yield of animal products such as milk and eggs (Nardone, Ronchi, Lactera, Ranieri, & Bernabucci, 2010). For livestock production systems, there are challenges for achieving balance by resource minimization strategies which address the impact of land management on the ecosystem. A recent example is the use of tannin-rich ruminant feedstock to improve the production yield and quality of animal products in semi-arid areas (Mlambo & Mapiye, 2015). Improving the productivity and efficiency of livestock systems requires an understanding of the interactions between animal genetics and the environment and between the livestock, the plants and the soil within pastoral ecosystems (Greenwood & Bell, 2014; Herrero & Thornton, 2013).

Plant-based diets generally require less energy, land and water to produce compared to meat-based diets and from this perspective, lacto-ovo-vegetarian diets may be considered to be more sustainable than meat-based diets (Pimentel & Pimentel, 2003). However, livestock production provides the ability to generate food from environments unsuitable for other food production. Notably livestock efficiently converts low quality forage into energy dense meat and milk food products. Improving livestock productivity will assist in meeting the dietary needs for protein and the preferences of many consumers. Sustainable livestock production systems can provide efficient conversion of feeds on land unsuitable for other forms of agriculture, maintain biodiversity, and minimize carbon footprints whilst ensuring good animal welfare (Broom, Galindo, Murgueitio, & Fernandez, 2013). Ruminant livestock can form an important component of mixed livestock-cropping systems to broaden the commodity base, increase biodiversity and optimize nutrient cycling and biomass utilization.

The efficiency of the intensive livestock industry has shown remarkable gains in productivity. For example, in Australia the annual milk yield per cow has doubled from 2900 L to as high as 5900 L over the last 30 years, as a consequence of improvements in herd genetics, advances in pasture management and supplementary feeding regimes (http://www.dairyaustralia.com.au/Markets-and-statistics/Production-and-sales/Milk/Yield.aspx). Individual animal productivity continues to increase indicating that there are still substantial unrealised genetic gains. Current efforts to accelerate these gains are primarily focussed on the use of genetic markers to inform breeding decisions.

Genetics strategies have been used to improve the meat quality, the health of the animals, the resilience of the livestock to environmental challenges and to improve livestock production system efficiency. It is known that some traits for meat quality such as tenderness, intramuscular fat and omega-3 fatty acid content are moderately heritable and can be altered by breeding (Hopkins, Fogarty, & Mortimer, 2011). Better matching of elite genotypes to environmental and forage conditions either for improved productivity or health benefits and optimised forage assimilation is expected to provide further improvements. As an alternative to genetic strategies, feeding regimes are already being used to increase the level of unsaturated fatty acid composition in lamb meat (Howes, Bekhit, Burritt, & Campbell, 2015), beef (Mapiye et al., 2015) and omega-3 fatty acids in pork (Dugan et al., 2015).

While improving the nutrient profile of livestock and primary produce in a sustainable production system may be achievable, the effects of the altered agricultural produce on the quality, shelf-life implications and its processability into food products have to be considered to successfully bring the altered produce from the farm to the consumer. For example, there are challenges of making consistent and differentiated dairy products when processing milk with altered composition and structure arising from changed on-farm practices which need to be taken into account during dairy product processing (Augustin, Udabage, Juliano, & Clarke, 2013).

3. Food processing

Food processing is any deliberate change in a food that occurs before it is available. Typically inedible raw materials are processed into more useful, shelf-stable and palatable foods or potable beverages for human consumption (International Food Information Council Foundation, 2010). Since prehistoric times, food processing has been a key aspect of the food production chain that links agricultural production with the provision of food to people in the form and at the time it is required (Floros et al., 2010). Some of the common industrial processes used in food manufacturing include milling, cooling/freezing, smoking, heating, canning, fermentation, drying, extrusion cooking. Processing causes changes to the components of food and some of these changes can result in both detrimental as well as beneficial effects on the food quality, depending on the process used (Weaver et al., 2014). Although there has been many reports about the negative aspects of food processing which has focussed on issues such as the detrimental effects of heat treatment on food quality (e.g. formation of acrylamide, nutritional degradation, high sugar in formulated foods, introduction of *trans* fats into foods), it is essential to have a balanced view which includes the benefits of food processing (van Boekel et al., 2010). Some of the benefits of food processing include destruction of food-borne microbes and toxins, improved bioavailability of nutrients, extension of shelf life, improved sensory characteristics and functional properties (van Boekel et al., 2010).

Food processing also encompasses the use of additives which are used to increase quality (e.g. taste and appearance), extend shelf life and improve the safety of foods. The management of risks to food safety and stability constitutes an essential element of food security. Traditionally, brining and pickling were used. A range of chemical additives (e.g. sulfur dioxide for preservation of wine, nitrites in bacon), anti-microbials (e.g. benzoic acid) and antioxidants (e.g. tertiary butylhydroquinone for retarding oxidation of oils) has been employed over the years. However, there is now a trend towards the incorporation of natural preservatives and the phasing out of some synthetic chemical additives. There is increasing interest in the use of natural anti-microbials (e.g. bacteriocins, essential oils), preservatives (e.g. ascorbic acid, citric acid from fruits) and antioxidants (e.g. Maillard reaction products, polyphenols, rosemary extract) to improve food quality and shelf life (Kumar, Yadav, Ahmad, & Narsaiah, 2015; Vergis, Gokulakrishnan, Agarwal, & Kumar, 2015). In addition to the move to natural food additives, newer delivery systems (e.g. nanoencapsulation), smart additives and packages are also being developed as an alternative to direct incorporation of additives to food (Carocho, Barreiro, Morales, & Ferreira, 2014).

3.1. Traditional food processes

To a large extent, food processing has been used to preserve food, improve food safety and maintain quality. Over the last 100 years, traditional food preparation and preservation processes have been industrialised. The industrialization of food processing, with its economies of scale, has increased the availability of foods in both in local and export markets. For example, spray drying of milk was a means of preservation of milk but also enabled milk to be available in countries which did not have an adequate supply of local milk. The availability of milk powders spawned the growth of recombined dairy products such as recombined evaporated milk in Asia in the 1960's and 1970's (Sanderson, 1970). Recombined dairy products still serve many communities in Asia, the Middle East, Africa and South America.

Processing can occur at various points along the supply chain. It can be applied proximate to food harvest or capture (e.g. initial processing of agricultural commodities such as flour milling or fish canning) or further downstream when it is applied in the manufacture of formulated food products (e.g. bread, biscuit, noodles, yogurt). Table 1 provides selected examples of the impacts of common food processing operations and selected examples of processes for converting food materials into final products are summarised in Table 2. The evolution of food processing, particularly traditional food processing technologies, and how processed food has contributed to nutrition over history has been reviewed (Weaver et al., 2014; Welch & Mitchell, 2000).

3.2. Emerging food processes

While traditional food processing will continue to play a major role in providing food for people, it is expected that there will also be an increasing role for the application of novel and emerging food processing technology for improving the quality of food and processing efficiency. Novel and emerging technologies, particularly high pressure processing (HPP), pulsed electric field (PEF), cool

Table 1
Benefits and impacts of food processing operations.

Technique	Examples	Outcomes & benefits	Impact
Preservation	• Pasteurization of milk or juice • Fermenting dairy into cheese or yogurt • Pickling or canning produce • Salting meats	• Distributors can ship products over greater distances • Retailers can stock products longer • Consumers can keep foods longer	• A range of local and non-local foods remain available over a longer time frame
Processing for food safety (cleaning, sterilization)	• Washing, pasteurizing, cooking, salting, drying, refrigerating, freezing	• Food-borne pathogens and contaminants are removed or minimized, meaning that consumers are at a lower risk of foodborne illness	• A greater proportion of the population has access to safe food
Processing to change flavour, texture, aroma, color or form	• Milling grains • Mixing ingredients • Adding flavors and colors • Molding foods and ingredients into shapes	• Manufacturers may gain higher profits and a foothold in a competitive market • Consumers have access to a wider variety of products	• Adds value to food products
Processing to reduce preparation times and make food more portable	• Ready-to-serve meals • Fast foods • Convenience foods: Bottled drinks, meat jerky, cakes, cookies, breakfast cereal bars, frozen pizzas, baby food	• Manufacturers may gain higher sales by responding to consumer demand for convenience food • Consumers can eat virtually anywhere, at any time, with minimal effort	• Access to safe (and preferably nutritious) foods for time-poor consumers
Processing to restore and/or raise nutrient levels in food	• Fortifying milk with vitamin D, salt with iodine, and grains with B vitamins, iron and folic acid	• Manufacturers can use fortification as a selling point, potentially generating greater sales • Consumers are at lower risks for chronic nutrient deficiencies	• Adds value and nutrition density to food, can improve bioavailability and population health implemented as public health policies

Table 2
Examples of food products prepared with different processing methods.

Materials	Processes	Processed food products
Beef, lamb, pork, poultry & fish	• Slaughtering, cutting up, boning	• Frozen, refrigerated in bulk or retail packs
	• Comminuting, fermentation, extrusion, drying	• Small goods such as salami, bologna, sausages, jerky, cured dried meat/fish products, surimi
	• Cooking, pasteurization, sterilization, high pressure processing	• Ready to eat meal, meal components, luncheon or canned meat/fish products
Grains, cereal & legumes with may need dairy and other ingredients	• Grinding, sifting, milling	• Flour, milled rice, oat bran/grain
	• Rolling, steaming, puffing, drying, extrusion, frying	• Breakfast cereal, crispy snack foods, meat analogues
	• Cooking, steaming, sterilization, baking, fermentation, kneading	• Baked goods e.g. cake, bread, ready to eat grains e.g. precooked rice, beer, wine other healthy grain beverages
Dairy products	• Pasteurization, sterilization, separation, homogenization, high pressure processing, pulse electric field	• Liquid whole cream, skim and flavored cold pasteurize, pasteurized and UHT milks, cream
	• Fermentation, agitation, shearing and mixing	• Yoghurt, cheese, butter, whipped cream
	• Evaporation, sterilization, drying, separation	• Evaporated milk, condensed milk, milk powder, whey protein concentrate, whey, protein isolate
Fruits and vegetables	• Crushing, maceration, vacuum concentration, pasteurization, UHT, high pressure processing, pulse electric field	• Various concentrates, juices and juice mixes
	• Fermentation, picking, drying	• Kimchi, jams, dried and other form of pickled or preserved fruits and vegetables
	• Freezing, sterilization	• Frozen and canned fruits and vegetables products
	• Minimally processed	• Fresh produced

plasma, UV irradiation and ultrasound have been examined as treatments for improving the shelf life of foods and altering material properties (Knorr et al., 2011; Sanchez-Moreno, De Ancos, Plaza, Elez-Martinez, & Cano, 2009; Tao & Sun, 2015). The application of emerging, non-thermal techniques was shown to potentially reduce energy requirements for food processing and may contribute to improved energy efficiency in the food industry (Toepfl, Mathys, Heinz, & Knorr, 2006).

Of the emerging technologies, there has been most commercial application of HPP. In HPP, pressures in the range of 200–1000 MPa are used. HPP disrupts microbial cells but retains nutrients and flavour molecules, allowing shelf-life extension without the detrimental effects of high temperatures on food quality whilst retaining the fresh-like character of foods (Hendrickx & Knorr, 2002). HPP has been commercialized as a cold pasteurization process for a range of products including guacamole, processed meats, tomato salsas, oysters and yogurts (Knorr et al., 2011; Tokuşoğlu & Swanson, 2014). However, more investigation is still needed to understand how HPP can be used to modulate enzyme reactions and fermentation, and its effects on food-spoilage viruses and bacterial spores (Knorr et al., 2011). In PEF, short electric pulses are applied to food, causing permeabilization of microbes and the cells of plant and animal tissue. It may be used as an alternative to pasteurization (Knorr et al., 2011). In ultrasound processing, sound waves are transmitted through the food medium. Both low (20–100 kHz) and high (400 kHz and above) frequencies have been used in food processing. Low frequency ultrasound has been applied for disintegration and homogenization of foods, and to enhance extraction of components (Knorr et al., 2011; Vilkhu, Mawson, Simons, & Bates, 2008). Ultrasound may also be used to improve the efficiency of drying, filtration, brining, freezing and thawing processes (Tao & Sun, 2015). High frequency ultrasound, with the creation of standing waves, facilitates the separation of oils from emulsions such as milk (Juliano et al., 2011) and increases the yield of oil in the palm oil milling process (Juliano et al., 2013). HPP, PEF and ultrasound can also enhance extraction of anthocyanins from grape by-products with up to three, four and two fold increase in extraction respectively (Corrales, Toepfl, Butz, Knorr, & Tauscher, 2008).

3.3. Improving resource efficiency of food processing

Most operations in the food processing industry are energy-intensive and do not optimize the use of edible agricultural food sources. The sustainability of the current practice of industrial scale food processing is therefore sub-optimal. An example of There needs to be a re-evaluation about how food processing can be better applied to create food products more efficiently, involving lower resource use and accompanied by lower production of waste (van der Goot et al., 2016). Better integration along the whole food supply chain from the farm to the consumer, with attention to quality, sustainability, logistics, food products and processes is also required (Manzini & Accorsi, 2013).

3.3.1. Food processing to reduce food waste

The amount of food that is wasted along the global supply chain from farm to consumer is about 1.6 Gtonnes (or about one third of the total produced based on weight) and 1.3 Gtonnes of this waste is edible (Gustavsson, Cederberg, & Sonesson, 2011; FAO, 2011; FAO, 2013). In terms of kcal/person/day, this amounts to 24% of the produced food supply (614 kcal/person/day) that is lost within the food supply which could feed 1 billion people if the food wasted was halved (Kummu et al., 2012). Food may be lost from the supply because of safety and quality considerations, and under-utilization of edible by-products and side streams of food processing. Food losses and waste can occur on farm, between farm to retail, at retail level and after it has reached the consumer. The amounts of food losses and waste along the chain varies with the type of commodities and food products and between various countries. Food losses in developing countries are >40% at post-harvest and processing while in developed countries, >40% of the losses occur at retail and consumer levels (FAO, 2011).

Food processing may be used to reduce the amount of food lost by using preservation processes, such as freezing, drying, fermentation, canning, pasteurization and sterilization, and packaging technologies to increasing the shelf-life of products (Langelaan et al., 2013).

Waste in food processing has partly come about because of the food industry's evolution towards provision of refined single food components (e.g. protein), a food product or ingredient with a defined composition (e.g. whey protein concentrate) or a food product that meets standards for appearance (e.g. acceptable coloured and shaped fruits and vegetables). There are many potential uses for underutilized edible products (Fig. 1). For example, protein-based by-products of animal processing may be used for production of bioactive hydrolysates (Martinez-Alvarez, Chamorro, & Brenes, 2015). Wheat-bran, a by-product of wet milling of wheat is currently under utilized. It contains proteins, minerals, B complex vitamins, and dietary fibre. The protein component itself represents ~15.5 million tonnes of high quality wheat protein that is wasted annually. There is interest in extracting the protein for use an ingredient in food and for conversion into bioactive peptides (Balandrán-Qunitana, Mercado-Ruiz, & Mendoza-Wilson, 2015). By-products of fruit juice processing are another untapped resource. Components in apple pomace such as dietary fibre (pectin, hemicelluloses, cellulose and lignin) and phenolic compounds (flavonols, phenolic acids, dihydrochalcones and anthocyanins) may be extracted and put back into the food chain (Rabetafika, Bchir, Blecker, & Richel, 2014). In the case of the olive oil and palm oil industry, valuable phenolic compounds with antioxidant properties may be recovered from the oil mill wastewater (El-Abbassi, Kiai, & Hafidi, 2012; Rahmanian, Jafari, & Galanakis, 2014).

3.3.2. Resource efficient food processing

There are opportunities for reducing water and energy use in food processing and to develop zero discharge processes (van der Goot et al., 2016). An example is process intensification, which result in less water use (i.e. more concentrated processing) by using dry milling processes for separation of components in place of wet milling (van der Goot et al., 2016).

In the dairy industry, there has been interest in reducing the energy for milk powder production by increasing the total solids of the milk concentrate that is fed into the dryer. Removal of water by spray drying requires significantly more energy than the removal of water in an evaporator. Increasing the total solids concentration of milk that is fed into the dryer from 50 to 52% solids saves 6% energy and further increase to 60% solids reduces dryer energy requirements by 26% (Fox, Akkerman, Straatsma, & de Jong, 2010).

Recognition of the global challenge for more efficient use of resources is reflected in Goal 12 of the United Nations sustainable development goals. This goal is to ensure sustainable consumption and production patterns. The food sector uses 30% of the total global energy use and accounts for 22% of the total greenhouse gas emissions. The sector therefore has a responsibility to develop strategies to address this challenge (http://www.un.org/sustainabledevelopment/sustainable-consumption-production/).

4. Processed food: intake and effects on health

Processed foods are an important component of the food supply (Weaver et al., 2014). Few would argue that the increased bioavailability of macronutrients like starch from the processing of grains to flour and subsequent incorporation into breads, enhanced safety of meat achieved by refrigeration and cooking, improved safety of milk achieved through pasteurization and the year round availability of seasonal fruits and vegetables achieved through preservation, canning and freezing have not been beneficial to society and nutritional security. However, there are also processed foods that are high in salt, refined starch, sugar and fat which present unhealthy food options to the consumer.

Strategies to reduce sugar and salt in processed foods are expected to have significant impact in reducing non-communicable diseases (MacGregor & Hashem, 2014; Webster et al., 2014). Several countries in Europe, the Americas and the Western Pacific Region which have introduced salt reduction programs have reported reductions in salt levels in one or more food categories. The strategies involved working with industry, either voluntarily or mandatorily, and included food categories such as bread, breakfast cereal, soup, sauces (Webster et al., 2014). In Australia salt levels in bread were estimated to be reduced by 9%, in cereals by 25% and in processed meat by 8% during the period 2010 to 2013 (Trevena, Neal, Dunford, & Wu, 2014). To enhance the effectiveness of these strategies further coordination by government to include food reformulation, public education, food labelling, and robust monitoring and evaluation is advocated (Webster et al., 2015).

4.1. Intake of processed foods

Data from the National Health and Nutrition Examination Survey (2003–2008) on intake of food by Americans showed that minimally processed foods (e.g. washed and packaged fruit and vegetables) contributed about 14% of total dietary energy, and a higher percentage of dietary fibre, vitamin D, calcium, potassium and vitamin B12. Processed foods provided about 57% of total energy intake, and a higher percentage for sodium, added sugars, iron and folate. The other source of food was foods from restaurants and dining halls which provided about 29% of energy intake with a higher percentage for sodium and added sugars (Weaver et al.,

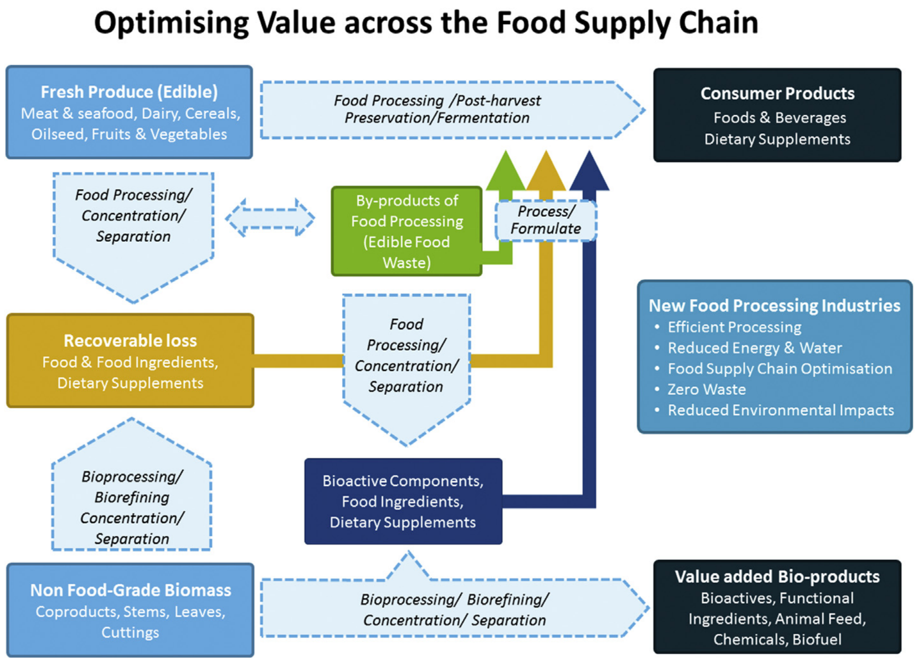

Fig. 1. Food processing — Possibilities for optimizing the food supply chain.

2014). Another recent analysis of the food supply of the United States determined that more than three-quarters of food energy in purchases by households in America came from moderately (15.9%) and highly processed (61.0%) foods and beverages in 2012 (Poti, Mendez, Ng, & Popkin, 2015). The conclusion is that highly processed food is a dominant, unshifting part of purchasing patterns in the United States, but such foods may have higher saturated fat, sugar and sodium contents than less processed foods. A relatively wide variation in nutrient content within food categories suggests better food choices are likely to be beneficial.

A food classification system developed in Brazil (Monteiro, 2009) groups food into unprocessed or minimally processed foods (group 1), processed culinary ingredients including oils, fats, pastas, starches and sugar (group 2) and ultra-processed food and drink products which are usually ready-to-eat or ready-to-heat (group 3). In Canada, the mean percentage of total energy intake from ultra-processed foods rose from 28.7% in 1938/39 to 61.7% in 2011 (Moubarac et al., 2013). This trend is spreading with the growing affluence of population groups, as observed by the increased rate of consumption of ultra-processed foods in low- and middle-income countries, compared to high-income countries (Moodie et al., 2013).

4.2. *Undesirable consequences of current highly processed formulated foods*

There is little doubt that processed foods and consumption of excess calories derived from this category, among other factors, have played a critical role in the rising levels of obesity in western society and increasingly, the developing world (Finucane et al., 2011) with its associated legacy of rising prevalence of non-communicable, chronic diseases such as cardiovascular disease (Anand & Yusuf, 2011), metabolic disease and diabetes (Danaei et al., 2011), as well as certain cancers (World Cancer Research Fund/American Institute for Cancer Research, 2007). It was estimated that halving the intake of ultra-processed food in the United Kingdom by replacing these with minimally processed and culinary ingredients would result in approximately 14,235 fewer coronary deaths and approximately 7820 fewer stroke deaths by 2030, comprising an almost 13% mortality reduction (Moreira et al., 2015). A trend towards a low-fat, high refined carbohydrate diet may have contributed to the current epidemic of obesity lipid abnormalities, type 2 diabetes, and metabolic syndrome (Weinberg, 2004). The International Agency for Research on Cancer, the cancer agency of the World Health Organization stated that there is a small risk of cancer with the consumption of processed meat (International Agency for Research on Cancer, 2015).

The partial hydrogenation process increases the degree of saturation of the fat and therefore the hardness of the fat and its oxidative stability, but the process introduces *trans* fatty acids which are harmful for health (Mensink & Katan, 1990). Partially hydrogenated fats were used for obtaining a desirable texture of margarine, baked goods and increasing the resistance of oils to oxidation during deep frying (Korver & Katan, 2006). On 16th June 2015, the FDA removed partially hydrogenated oils from the "generally recognised as safe" (GRAS) list and food manufacturers will have three years to comply with the legislation that restricts partially hydrogenated fats in human food.

4.3. *Desirable effects of food fortified or enriched during food processing*

The fortification and enrichment of foods during processing have beneficial effects on population health. Endemic brain damage, goitre and cretinism can be prevented by correcting for iodine deficiency and provided the rationale for the iodine fortification of salt with associated major impacts on the prevalence of these conditions (Hetzel, 2012). The introduction of commercially produced iodised salt during the middle of the last century substantially reduced iodine deficiency (Pearce, Andersson, & Zimmermann, 2013).

Low levels of folic acid in the diet of newly pregnant women causes neural tube defects and severe congenital malformations, affecting the brain and spinal cord in the developing foetus. Reducing the incidence of neural tube defects has been reported in countries following mandated fortification of food with folate, namely Chile, Argentina, Brazil, Canada, Costa Rica, Iran, Jordan, South Africa and the USA; with reductions as high as 58% in Costa Rica, 55% in Chile, 49% in Argentina and 49% in Canada (Castillo-Lancellotti, Tur, & Uauy, 2013).

The role of Vitamin D beyond bone health is increasingly being recognised (O'Mahony, Stepien, Gibney, Nugent, & Brennan, 2011). A range of vitamin D enhanced foods such as milk, yogurt, cheese, orange juice, soup and bread have been shown to effectively increase circulating vitamin D levels. Foods that made the greatest contribution to vitamin D intake varied between countries according to habitual dietary patterns (O'Mahony et al., 2011).

Long chain omega-3 polyunsaturated fatty acids (LC n-3 PUFAs) are essential for many biological functions, having wide ranging health benefits from brain development and function to heart health and immune function (FAO, 2011; Lorente-Cebrian et al., 2013). However, the capacity of humans to synthesise LC n-3 PUFA *de novo* is limited (Arterburn, Hall, & Oken, 2006) and their assimilation through the diet is therefore essential. Many people consume fish or other seafood infrequently, resulting in an inadequate intake of LC omega-3 PUFA which may result in sub-optimal health (Papanikolaou, Brooks, Reider, & Fulgoni, 2014). The fortification of foods with LC n-3 PUFA could contribute substantially to achieving recommended intakes of this essential fatty acid (Rahmawaty, Lyons-Wall, Charlton, Batterham, & Meyer, 2014).

The difficulties associated with the introduction of the LC n-3 PUFA and other sensitive nutrients without compromising food quality can be overcome by the design of appropriate encapsulation systems (Augustin & Sanguansri, 2015). For example, microencapsulation masks the fishy smell and taste of LC n-3 PUFA and protects them against oxidation without loss of bioavailability (Sanguansri et al., 2015). The ability to produce shelf-stable encapsulated fish oil ingredients enabled the incorporation of LC n-3 PUFA into a wide range of food products including infant and toddler formula, breads and baked goods.

5. Consumer understanding of food processing

The obvious customer for the food industry is the consumer and understanding their attitudes towards food processing is necessary, especially given that underlying attitudes are a major factor in purchase decisions. Without consumer acceptance, otherwise appropriate food processing strategies to address nutrition security risks may ultimately fail.

5.1. What do consumers want?

In regards to food processing, research on consumers in the United States suggests that people desire foods which are affordable, safe, convenient, fresh (minimal processing and packaging), natural and without preservatives, and without negative attributes (e.g. unhealthy; high fat, salt and/or sugar) (Zink, 1997). Consumers are also increasingly demanding products that not only cause no harm but which may also have protective effects such as reducing risk factors associated with disease (e.g. high cholesterol), and which promote healthy aging through enhanced psychological health and wellbeing (e.g. mood and cognition) (Zink, 1997). This quest for health can have a significant impact on food processors. For instance, today's marketplace has more perishable products and more innovative packaging than in previous decades, and consumer reservations regarding chemical preservation has impacted various preservation methods.

Observations from studies in the United States and the United Kingdom demonstrate that sustainable practices undertaken by food manufacturers can influence a customer's decision to purchase, giving positive feedback about the organization and cost savings arising from implementation of sustainable systems and processes (Bhaskaran, Polonsky, Cary, & Fernandez, 2006; Zink, 1997). Other desired attributes include a shorter distance from the point of primary production and the point of purchase, sustainability of production, and foods that are culturally aligned and provide a pleasurable food experience (Australian Institute of Health and Welfare, 2012).

5.2. Negative consumer perceptions about food processing

According to a survey of American consumers, there exists a variety of perceptions, both negative and positive, about certain aspects of the role of food processing (International Food Information Council Foundation, 2012). The reasons for negative perceptions about processed foods are many, and include mistrust of technology, low level of understanding of processing, advertising that has at times taken advantage of controversies relating to food processing, the increasing prevalence of obesity in many industrialised countries, the use of chemicals in food production or as additives, and concerns related to specific ingredients including salt and sugar (Floros et al., 2010). Further to these issues are the observations that many popular processed foods are of poor nutritional value and strongly held beliefs that multinational food companies specialising in processed food control the food intake of large numbers of people (Williams & Nestle, 2015). It is important that there be more research aimed at obtaining objective information about the effects of processing and to communicate this to the consumer in an unbiased way. Organizations which are seen as trusted advisors with no vested interested are best placed to deliver the objective messages to society.

5.3. Consumer food purchasing behaviour

Consumer acceptance of new food technologies and processing methods is critical for the commercial success of processed foods. Adequate economic returns to manufacturers are unlikely if food products do not appeal to the needs and desires of end users. Consumer food purchasing behaviour is particularly complex but a number of theories exist which attempt to describe these behaviours. Utility Theory, for example, regards purchasing behaviour as being largely rational (Levin, & Milgrom, 2004). It suggests that consumer choices are based on the expected outcomes of decisions, and that consumers are only concerned with self-interest. Alternate theories regard consumer behaviours as being driven by a wide range of internal factors including need recognition, evaluation of alternatives, the building of purchase intentions, the act of purchasing and subsequent consumption (Engel, Kollat, & Blackwell, 1968). Since the 1950's, it has been increasingly recognised that external factors also play a major role in consumer purchasing decisions. These factors include product marketing, social good and environmental concerns. In addition, whether or not consumers buy food is not only about availability of foods and whether they are healthy. It is influenced by how ingredients and foods can be substituted, and the manner in which they are transformed and marketed (Hawkes, Friel, Lobstein, & Lang, 2012). Both cognitive and emotional factors influence a consumer decision to purchase unhealthy foods and contribute to their less than optimal food and beverage choices (Sierra, Taute, & Turri, 2015).

Earned (news) media and social media do have a role to play in consumer perceptions and behaviour relating to food processing and technologies. Modern news cycles have a rapid churn rate and individual stories have a relatively short life span. Consumer conversations on social media such as Twitter, Facebook and YouTube can have a marked impact on the food choices and the brands that consumers purchase and thereby be an influencer of healthy

Table 3
Global megatrends, their translation into food megatrends and opportunities for a future food supply chain.

Global megatrends[a]	Food megatrends	Opportunities
More from less	More food from less resources	• Recovery and value addition • Extend shelf life through processing • Optimize supply chain logistics • Behavioural changes and changes in expectations by consumers
Planetary pushback	Foods for a healthy planet	• Genetically modified foods for improved nutrition and efficient production • Greater use of algae • Greener processes • Tissue engineering for meat and other products • Reduce food miles • Shaping consumer behaviour/acceptance • Food sharing • Better biodegradables supply
The silk highway	Foods for the Asian century	• Growing middle class • Assured food safety for ensured market access • Clean and with provenance (trusted food supplier) • Rapidly growing & aging population with rising chronic diseases (Foods for health) • Novel foods & ingredients with high nutritional value (Fermented dairy; novel protein sources, High protein for elderly, Foods for premium exports) • Novel food production and distribution systems for megacities
Forever young	Foods for beauty and health	• Foods for healthy aging - New market segments with different needs • Foods for health across life course • Foods & integrated programs for prevention of, and disease management • Food service for aging population • Pre and peri-pregnancy • Protein foods • Nutrient dense foods • Portion innovation • Weight loss, maintenance • Prevention/slowing of decline (e.g. cognition, physical performance • Shelf-stable healthy meals • Texture modification (e.g. 3D printing) • Pharma/functional foods • Foods/supplements for cosmetic improvement
Digital immersion	Digital food and the internet of food	• Nexus of sensors, data, processes, access, production, consumption • Use of big data and cloud computing to improve food supply • Mobile tests for provenance, content • Foods tagged and sensed, increasing use of innovative sensors (e.g. food safety) • More informed and connected consumers and ethical communication channels • Digital support for traditional and intensified production • Home indoor hydroponic food (digitally-enabled) • Online ordering of takeaways (e.g. drone delivery) • Conventional retail with click and collect stores
Porous boundaries	Producing food in a globally networked environment	• New horizontal networks (agile and flexible companies) • Networked leadership – greater sphere of influence • Global food supply, global R&D environment • Global health claim system • Networked environment • Communication and information (transparent, ethical, frequent) • Creativity and agile resolution of challenges • Agile and innovative R&D environment to support industry
Great expectations	Foods that meet our expectations	• Personalised better and faster services that meet consumer unique needs and delivered *en masse* • Billions impoverished still need basic food and water • Personalised foods, diets and lifestyle prescriptions based on preferences and health needs • Clean, natural foods • Provide the experience (e.g. Flavour bursts, Enhance the appearance, 3D printing in the home – digital gastronomy, Consistent chef-like meals produced at home) • Renewal of convenience, sustainability/eco-conscious, health, great food • Artisan, small-batch and direct-to-consumer (different delivery systems)

[a] Hajkowicz, 2015.

choices (Liu & Lopez, 2016). However, medium and long term marketing campaigns by food and beverage manufacturers also have a persuasive and pervasive influence on consumer attitudes and behaviour.

5.4. Addressing consumer concerns

Looking toward the future, it is important to consider the impact of new food technologies in the marketplace. Whilst sensory perceptions are major drivers of food choice, change in consumer sentiment towards a “fresh is best” viewpoint presents particular challenges for the food processing industry. Typically, novel food-related technologies, including processing, are met with significant concern (Cox, Evans, & Lease, 2011).

There needs to be clear demonstration of benefits and safety of the new technologies to consumers (Jaeger, Knorr, Szabóc, Hámori, & Bánáti, 2015). Even where new technologies are proven scientifically to produce food safe for human consumption, consumer hesitance is difficult to change (Aoki, Shen, & Saijo, 2010). For example, the impact of positive educational messages around food products differentially changes perceptions, with favourable outcomes (i.e. change from hesitance to acceptance) observed only in individuals who have sufficient trust in the relevant information authority (Loebnitz & Grunert, 2014).

6. Summary and future trends

The challenges to feed the world in 2050 cannot be met through improvements in food production alone. Reduction and recovery of food losses throughout the food chain from production to consumption and improvements in preservation, transportation, nutritional content, safety and shelf life of foods will be key strategies to combat food and nutrition demands of the future. A goal is to improve health of the consumer and to achieve healthier ageing for the population. It is essential to engage society in science to engender the trust of consumer in the food supply and important to ensure ethical food production and responsible consumption for a sustainable ecosystem (European Technology Platform, Strategic Research Agenda 2007–2020, http://etp.ciaa.eu). Global megatrends, which are due to shifts in geopolitical, environmental, economic, social or technology conditions that substantially change the way people live, will shape our world in the next 20 years. Seven global megatrends recently identified are (i) More from less, (ii) Planetary pushback, (iii) The silk highway, (iv) Forever young, (v) Digital immersion, (vi) Porous boundaries and (v) Great expectations (Hajkowicz, 2015). These megatrends will influence how we deal with food and nutrition security across the food supply chain (Table 3). It is expected that the digital revolution provides new opportunities in food processing automation, provenance and tracking providing a clear path to monitoring individual and population intakes as well as the ethical and safety aspects of food production. The agricultural sector will continue to increase productivity including through the introduction of novel and improved crops and livestock and the food processing industry will need to be agile to adapt to maximize the benefits for these new feedstocks. Growth in population, economic activity and market opportunities will be greatest in the Asian region, particularly, China and India. There is a need to address the food preferences of all populations, as well as aging demographics, when developing healthy food choices. A growing demand for foods with substantiated health benefits is anticipated. Against the background of climate change and diminishing resources reduction of the use of resources to produce existing and improved foods will be paramount.

In order to ensure future food and nutrition security, industry and consumers must be considered in tandem. The challenge for food industry involves the development of new processing technologies which ultimately associate with economic advantage. However, in the absence of tangible positive attributes as perceived by consumers, uptake of the products of new technologies and processes may be lower than expected. The lay-expert gap in risk perception, and the moral and ethical dimensions of how food is produced need to be considered for improved consumer acceptance of processed foods (Lusk, Roosen, & Bieberstein, 2014).

Healthy diets which meet consumer expectations produced from resilient and environmentally sustainable agrifood systems need to be delivered in a changing world with diminishing natural resources, changing demographics and increasing urbanisation in a digital age (Gormley, 2015; Wu et al., 2014). In the future, low-value food and underutilized edible biomass may be able to be processed back to their constituent macro- and micro-nutrients that can then be reconstructed into new foods, for example in the form of paints for 3D printing of foods (e.g. for second tier natural food lookalikes) (Kim, Golding, & Archer, 2012). Advances in knowledge regarding the characterisation and modification of the gut microbiome together with developments in food technologies can potentially enhance the *in vivo* delivery of bioactive ingredients with major impact on many aspects of health (Marchesi et al., 2015).

A multi-sectorial approach to improving food and nutrition security is required to address the complex societal challenge to feed the world responsibly and to minimize global food and nutrition insecurity in a changing world. Engagement and effective communication between all stakeholders along the food supply chain, including consumers and government, is essential for delivering innovative solutions for food and nutrition security. There needs to be a closer integration between social science and the sciences that underpin innovations in technology to understand and respond to consumer concerns, opposition to technological solutions and address issues that arise in the complex food supply chain (Hinrichs, 2014; Lowe, Phillipson, & Lee, 2008).

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References

Anand, S. S., & Yusuf, S. (2011). Stemming the global tsunami of cardiovascular disease. *Lancet, 377*(9765), 529–532.
Aoki, K., Shen, J., & Saijo, T. (2010). Consumer reaction to information on food additives: Evidence from an eating experiment and a field survey. *Journal of Economic Behavior & Organization, 73*, 433–438.
Arsenault, J. E., Hijmans, R. J., & Brown, K. H. (2015). Improving nutrition security through agriculture: An analytical framework based on national food balance sheets to estimate nutritional adequacy of food supplies. *Food Security, 7*, 693–707.
Arterburn, L. M., Hall, E. B., & Oken, H. (2006). Distribution, interconversion, and dose response of n-3 fatty acids in humans. *American Journal of Clinical Nutrition, 83*, 1467S–1476S.
Augustin, M. A., & Sanguansri, L. (2015). Challenges and solutions to incorporation of nutraceuticals in foods. *Annual Review of Food Science and Technology, 6*, 463–477.
Augustin, M. A., Udabage, P., Juliano, P., & Clarke, P. T. (2013). Towards a more sustainable diary industry: Integration across the farm-factory interface and the diary factory of the future. *International Dairy Journal, 31*, 2–11.
Australian Institute of Health and Welfare. (2012). *Risk factors contributing to chronic disease*. Canberra: AIHW. Cat No. PHE 157.
Balandrán-Qunitana, R. R., Mercado-Ruiz, J. N., & Mendoza-Wilson, A. M. (2015). Wheat bran proteins: A review of their uses and potential. *Food Reviews International, 31*(3), 279–293.
Bhaskaran, S., Polonsky, M., Cary, J., & Fernandez, S. (2006). Environmentally sustainable food production and marketing – Opportunity or hype? *British Food Journal, 108*, 677–690.
van Boekel, M., Fogliano, V., Pellegrini, N., Stanton, C., Scholz, G., Lalljie, S., et al. (2010). A review on the beneficial aspects of food processing. *Molecular Nutrition and Food Research, 54*, 1215–1247.
Broom, D. M., Galindo, F. A., & Murgueitio, E. (2013). Sustainable, efficient livestock production with high biodiversity and food welfare for animals. *Proceedings of the Royal Society B-Biological Sciences, 280*(1771). Article Number UNSP 21032025.
Burlingame, B., & Dernini, D. (2012). Sustainable diets and biodiversity: Directions and solutions for policy, research and action. In *Proceedings of the international scientific symposium on biodiversity and sustainable diets: United against hunger, 2010, Nov 3–5*. Rome: Food and Agriculture Organization.
Carocho, M., Barreiro, M. F., Morales, P., & Ferreira, I. C. F. R. (2014). Adding molecules to food, pros and cons: A review on synthetic and natural food additives. *Comprehensive Reviews in Food Science and Food Safety, 13*(4), 377–399.
Castillo-Lancellotti, C., Tur, J. A., & Uauy, R. (2013). Impact of folic acid fortification of flour on neural tube defects: A systematic review. *Public Health Nutrition, 16*, 901–911.
Corrales, M., Toepfl, S., Butz, P., Knorr, D., & Tauscher, B. (2008). Extraction of

anthocyanins from grape by-products assisted by ultrasonics high hydrostatic pressure or pulsed electric fields: A comparison. *Innovative Food Science and Emerging Technologies, 9*, 85–91.

Cox, D. N., Evans, G., & Lease, H. (2011). The influence of product attributes, consumer attitudes and characteristics on the acceptance of: (1) novel bread and milk, and dietary supplements and (2) fish and novel meats as dietary vehicles of long chain omega 3 fatty acids. *Food Quality and Preference, 22*, 205–212.

Danaei, G., Finucane, M. M., Lu, Y., Singh, G. M., Cowan, M. J., Paciorek, C. J., et al. (2011). National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: Systematic analysis of health examination surveys and epidemiological studies with 370 country-years and 2.7 million participants. *Lancet, 378*(9785), 31–40.

DeFries, R., Fanzo, J., Remans, R., Palm, C., Wood, S., & Anderman, T. L. (2015). Global nutrition: Metrics for land-scarce agriculture. *Science, 349*(6245). SI:238–240.

Dugan, M. E., Vahmani, P., Turner, T. D., Mapiye, C., Juárez, M., Prieto, N., et al. (2015). Pork as a source of omega-3 (n-3) fatty acids. *Journal of Clinical Medicine, 4*(12), 1999–2011.

El-Abbassi, A., Kiai, H., & Hafidi, A. (2012). Phenolic profile and antioxidant activities of olive mill wastewater. *Food Chemistry, 132*, 406–412.

Engel, J. F., Kollat, D. T., & Blackwell, R. D. (1968). *Consumer behavior* (1st ed.). New York: Holt, Rinehart and Winston.

FAO. (2010). *Fats and fatty acids in human nutrition: Report of an expert consultation No 91*. Rome: FAO.

FAO. (2011). *Global food losses and food waste – Extent, causes and prevention*. Rome: FAO.

FAO. (2013). *Food wastage footprint*. Rome: FAO.

FAO, IFAD, & WFP. (2015). *The state of food insecurity in the world 2015. Meeting the 2015 international hunger targets: Taking stock of uneven progress*. Rome: FAO.

Finucane, M. M., Stevens, G. A., Cowan, M. J., Danaei, G., Lin, J. K., Paciorek, C. J., et al. (2011). National, regional, and global trends in body-mass index since 1980: Systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet, 377*(9765), 557–567.

Floros, J. D., Newsome, R., Fisher, W., Barbosa-Canovas, G. V., Chen, H., Dunne, P., et al. (2010). Feeding the world today and tomorrow: The importance of food science and technology. An IFT review. *Comprehensive Reviews in Food Science and Food Safety, 9*, 572–599.

Fox, M., Akkerman, C., Straatsma, H., & de Jong, P. (2010). Energy reduction by high dry matter concentration and drying. *New Foods, 13*, 60–63.

Galili, G., & Amir, R. (2013). Fortifying plants with the essential amino acids lysine and methionine to improve nutritional quality. *Plant Biotechnology Journal, 11*, 211–222.

Garnett, T. (2013). Food sustainability: Problems, perspectives and solutions. *Proceedings of the Nutrition Society, 72*, 29–39.

van der Goot, A. J., Pelgrom, P. J. M., Berghout, J. A. M., Geerts, M. E. J., Jankowiak, L., Hardt, N. A., et al. (2016). Concepts for further sustainable production of foods. *Journal of Food Engineering, 168*, 42–51.

Gormley, R. (2015). Innovations in attractive and sustainable food for health: Outcomes from the EFFOoST annual meeting 2014, Uppsala, Sweden. *Trends in Food Science and Technology, 43*, 124–128.

Greenwood, P. L., & Bell, A. W. (2014). Consequences of nutrition during gestation, and the challenge to better understand and enhance livestock productivity and efficiency in pastoral systems. *Animal Production Science, 54*, 1109–1118.

Gustavsson, J., Cederberg, C., & Sonesson, U. (2011). *Global food losses and food waste – Study conducted for the international congress*. Rome: FAO.

Hajkowicz, S. (2015). *Global megatrends: Seven patterns of change shaping our future*. CSIRO Publishing.

Hawkes, C., Friel, S., Lobstein, T., & Lang, T. (2012). Linking agricultural policies with obesity and noncommunicable diseases: A new perspective for a globalising world. *Food Policy, 37*, 343–353.

Hendrickx, M., & Knorr, D. (2002). *Ultra high pressure treatment of foods*. New York: Kluwer Academic/Plenum Publication.

Herrero, M., & Thornton, P. K. (2013). Livestock and global change: Emerging issues for sustainable food systems. *Proceedings of the National Academy of Science, 110*(52), 20878–20781.

Hetzel, B. S. (2012). The development of a global program for the elimination of brain damage due to iodine deficiency. *Asia Pacific Journal of Clinical Nutrition, 21*, 164–170.

Hinrichs, C. C. (2014). Transitions to sustainability: A change in thinking about food systems change? *Agriculture and Human Values, 31*, 143–155.

Hopkins, D. L., Fogarty, M. N., & Mortimer, S. (2011). Genetic related effects on sheep meat quality. *Small Ruminant Research, 101*(1–3), 160–172.

Howes, N. L., Bekhit, A. E. D. A., Burritt, D. J., & Campbell, A. W. (2015). Opportunities and implications of pasture-based lamb fattening to enhance the long-chain fatty acid composition in meat. *Comprehensive Reviews in Food Science and Food Safety, 14*(1), 22–36.

Ingram, J. S., Wright, H. L., Foster, L., Aldred, T., Barling, D., Benton, T. G., et al. (2013). Priority research questions for the UK food system. *Food Security, 5*, 617–636.

International Agency for Research on Cancer, World Health Organization. (2015). *Q&A on the carcinogenicity for the consumption of red meat and processed meat*. http://www.iarc.fr/en/media-centre/iarcnews/pdf/Monographs-Q&A_Vol114.pdf.

International Food Information Council Foundation (IFICF). (2010). What is a processed food? you might be surprised! Understanding our food communications tool kit. In *Information handout for the international food information council foundation Sept 2010*. www.foodinsight.org.

International Food Information Council Foundation (IFICF). (2012). *Food and health survey: Consumer attitudes toward food safety, nutrition and health*. Washington CD: International Food Council Foundation, 2012.

Jaeger, H., Knorr, D., Szabóc, E., Hámori, J., & Bánáti, D. (2015). Impact of terminology on consumer acceptance of emerging technologies through the example of PEF technology. *Innovative Food Science and Emerging Technologies, 29*, 87–93.

Johnston, J. L., Fanzo, J. C., & Cogill, B. (2014). Understanding sustainable diets: A descriptive analysis of the determinants and processes that influence diets and their impacts on health, food security, and environmental sustainability. *Advances in Nutrition, 5*, 418–429.

Juliano, P., Kutter, A., Cheng, L. J., Swiergon, P., Mawson, R., & Augustin, M. A. (2011). Enhanced creaming of milk fat globules in milk emulsions by the application of ultrasound and detection by means of optical methods. *Ultrasonics Sonochemistry, 18*, 963–973.

Juliano, P., Swiergon, P., Lee, K. H., Gee, P. T., Clarke, P. T., & Augustin, M. A. (2013). Effects of pilot plant-scale ultrasound on palm oil separation and oil quality. *Journal of the American Oil Chemists Society, 90*, 1253–1260.

Keating, B. A., Herrero, M., Carberry, P. S., Gardner, J., & Cole, M. B. (2014). Food wedges: Framing the global food demand and supply challenge towards 2050. *Global Food Security, 3*, 125–132.

Kim, S., Golding, M., & Archer, R. H. (2012). The application of computer color matching techniques to the matching of target colors in a food substrate: A first step in the development of foods with customized appearance. *Journal of Food Science, 77*(6), S216–S222.

Knorr, D., Froehling, A., Jaeger, H., Reineke, K., Schlueter, O., & Schoessler, K. (2011). Emerging technologies in food processing. *The Annual Review of Food Science and Technology, 2*, 203–235.

Korver, O., & Katan, M. B. (2006). The elimination of *trans* fats from spreads: How science helped to turn an industry around. *Nutrition Reviews, 64*, 275–279.

Kumar, Y., Yadav, D. N., Ahmad, T., & Narsaiah, K. (2015). Recent trends in the use of natural antioxidants for meat and meat products. *Comprehensive Reviews in Food Science and Food Safety, 14*(6), 196–812.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P. F. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment, 438*, 477–489.

Lafiandra, D., Riccardi, G., & Shewry, P. R. (2014). Improving cereal grain carbohydrates for diet and health. *Journal of Cereal Science, 59*, 312–326.

Lake, I. R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A. B. A., Draper, A., et al. (2012). Climate change and food security: Health impacts in developed countries. *Environmental Health Perspectives, 120*, 1520–1526.

Langelaan, H. C., Pereira da Silva, F., Thoden van Velzen, U., Broeze, J., Matser, A. M., Vollebregt, M., et al. (2013). *Technology options for feeding 10 billion people. Options for sustainable food processing. State of the art report. Science and Technology Options Assessment*. Brussels: European Parliament. http://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/513533/IPOL-JOIN_ET(2013)513533_EN.pdf.

Levin, J., & Milgrom, P. (2015). *Introduction to choice theory stanford university*. September 2004 http://web.stanford.edu/~jdlevin/Econ%20202/Choice%20Theory.pdf Accessed 05.11.15..

Liu, Y. Z., & Lopez, R. A. (2016). .The impact of social media conversations on consumer brand choices. *Marketing Letters, 27*(1), 1–13.

Loebnitz, N., & Grunert, K. G. (2014). Evaluative conditioning of food technologies in China: Moderating effect of social trust. *Food Quality and Preference, 37*, 19–26.

Lorente-Cebrian, S., Costa, A. G. V., Navas-Carretero, S., Zabala, M., Martinez, J. A., & Moreno-Aliaga, M. J. (2013). Role of omega-3 fatty acids in obesity, metabolic syndrome, and cardiovascular diseases: A review of the evidence. *Journal of Physiology and Biochemistry, 69*, 633–651.

Lowe, P., Phillipson, J., & Lee, R. P. (2008). Socio-technical innovation for sustainable food chains: Roles for social science. *Trends in Food Science and Technology, 19*, 226–233.

Lusk, J. L., Roosen, J., & Bieberstein, A. (2014). Consumer acceptance of new food technologies: Causes and roots of controversies. *Annual Review of Resource Economics, 6*, 381–405.

MacGregor, G. A., & Hashem, K. M. (2014). Action on sugar – Lessons from UK salt reduction programme. *Lancet, 383*(9921), 929–930.

Manzini, R., & Accorsi, R. (2013). .The new conceptual framework for food supply chain assessment. *Journal of Food Engineering, 115*, 251–263.

Mapiye, C., Vahmani, P., Aalhus, J. L., Rolland, D. C., Baron, V. S., McAllister, T. A., et al. (2015). Fatty acid composition of beef steers as affected by diet and fat depot. *South African Journal of Animal Science, 45*(4), 386–394.

Marchesi, J. R., Adams, D. H., Fava, F., Hermes, G. D., Hirschfield, G. M., Hold, G., et al. (2015). The gut microbiota and host health: A new clinical frontier. *Gut* (doi: 10.1371/journal.pone.0134615).

Martinez-Alvarez, O., Chamorro, S., & Brenes, A. (2015). Protein hydrolysates from animal processing by-products as a source of bioactive molecules with interest in animal feeding: A review. *Food Research International, 73*, 204–212.

Mensink, R. P., & Katan, M. B. (1990). Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. *New England Journal of Medicine, 323*, 439–445.

van Mil, H. G. J., Foegeding, E. A., Windhab, E. J., Perrot, N., & van der Linden, E. (2014). A complex system approach to address world challenges in food and agriculture. *Trends in Food Science & Technology, 40*, 20–32.

Mlambo, V., & Mapiye, C. (2015). Towards household food and nutrition security in

semi-arid areas: What role for condensed tannin-rich ruminant feedstocks? *Food Research International, 76*, 953–961.
Monteiro, C. A. (2009). Nutrition and health. The issue is not food, nor nutrients, so much as processing. *Public Health Nutrition, 12*(5), 729–731.
Moodie, R., Stuckler, D., Monteiro, C., Sheron, N., Neal, B., Thamarangsi, T., et al. (2013). Profits and pandemics: Prevention of harmful effects of tobacco, alcohol, and ultra-processed food and drink industries. *Lancet, 381*(9867), 670–679.
Moreira, P. V. L., Baraldi, L. G., Moubarac, J. C., Monteiro, C. A., Newton, A., Capewell, S., et al. (2015). Comparing different policy scenarios to reduce the consumption of ultra-processed foods in UK: Impact on cardiovascular disease mortality using a modelling approach. *PLoS One*. doi:10.1371/journal.pone.0118353.
Morell, M. K., Kosar-Hashemi, B., Cmiel, M., Samuel, M. S., Chandler, P., Rahman, S., et al. (2003). Barley sex6 mutants lack starch synthase IIa activity and contain a starch with novel properties. *Plant Journal, 34*, 172–184.
Moubarac, J. C., Martins, A. P. B., Claro, R. M., Levy, R. B., Cannon, G., & Monteiro, C. A. (2013). Consumption of ultra-processed foods and likely impact on human health. Evidence from Canada. *Public Health Nutrition, 16*(12), 2240–2248.
Muchenje, V., & Mukumbo, F. E. (2015). Introduction to the special issue of food and nutrition security: Can science and good governance deliver dinner? *Food Research International, 76*, 879–881.
Nardone, A., Ronchi, B., Lactera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science, 130*(1–3), 57–69.
Nestel, P., Bouis, H. E., Meenakshi, J. V., & Pfeiffer, W. H. (2006). Biofortification of staple food crops. *Journal of Nutrition, 136*, 1064–1067.
Ng, M., Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., et al. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: A systematic analysis for the global burden of disease study 2013. *Lancet, 384*(9945), 766–781.
O'Mahony, L., Stepien, M., Gibney, M. J., Nugent, A. P., & Brennan, L. (2011). The potential role of vitamin D enhanced foods in improving vitamin D status. *Nutrients, 3*, 1023–1041.
Papanikolaou, Y., Brooks, J., Reider, C., & Fulgoni, V. L., III (2014). US adults are not meeting recommended levels for fish and omega-3 fatty acid intake: Results of an analysis using observational data from NHANES 2003–2008. *Nutrition Journal, 13*, 31.
Pearce, E. N., Andersson, M., & Zimmermann, M. B. (2013). Global iodine nutrition: Where do we stand in 2013? *Thyroid, 23*, 523–528.
Petri, J. R., Shrestha, P., Mansour, M. P., Nichols, P. D., Liu, Q., & Singh, S. P. (2010). Metabolic engineering of omega-3 long-chain polyunsaturated fatty acids in plants using an acyl-CoA Delta 6-desaturase with omega 3-preference from the marine microalga Micromonas pusilla. *Metabolic Engineering, 12*, 233–240.
Pimentel, D., & Pimentel, M. (2003). Sustainability of meat-based and plant-based diets and the environment. *American Journal of Clinical Nutrition, 78*(Suppl. 3), 660S–663S.
Poti, J. M., Mendez, M. A., Ng, S. W., & Popkin, B. M. (2015). Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *American Journal of Clinical Nutrition, 101*, 1251–1262.
Rabetafika, H. N., Bchir, B., Blecker, C., & Richel, A. (2014). Fractionation of apple by-products as source of new ingredients: Current situation and perspectives. *Trends in Food Science & Technology, 2014*(40), 99–114.
Rahmanian, N., Jafari, S. M., & Galanakis, C. M. (2014). .Recovery and removal of phenolic compounds from olive mill wastewater. *Journal of the American Oil Chemists Society, 91*, 1–18.
Rahmawaty, S., Lyons-Wall, P., Charlton, K., Batterham, M., & Meyer, B. J. (2014). Effect of replacing bread, egg, milk, and yogurt with equivalent omega-3 enriched foods on omega-3 LCPUFA intake of Australian children. *Nutrition, 30*, 1337–1343.
Regina, A., Berbezy, P., Kosar-Hashemi, B., Li, S., Cmiel, M., Larroque, O., et al. (2015). A genetic strategy generating wheat with very high amylose content. *Plant Biotechnology Journal*. doi: 10.1111/pbi.12345.
Rolle, R. S. (2011). Role of food processing and post-harvet management in improving food and nutrition security in cities. In *Food for the cities – Regional workshop, ensuring resilient food systems in Asian cities, 17–18 November 2011*. http://www.fao.org/fileadmin/templates/FCIT/workshops/Bangkok-2011/2-Rosa-Rolle-Rolefoodprocessingandpostharvestmanagement.pdf.
Sanchez-Moreno, C., De Ancos, B., Plaza, L., Elez-Martinez, P., & Cano, M. P. (2009). Nutritional approaches and health-related properties of plant foods processed by high pressure and pulsed electric fields. *Critical Reviews in Food Science and Nutrition, 49*(6), 552–576.
Sanderson, W. B. (1970). Reconstituted and recombined dairy products. *New Zealand Journal of Dairy Science Technology, 5*, 139–143.
Sanguansri, L., Augustin, M. A., Lockett, T. J., Abeywardena, M. Y., Royle, P. J., Mano, M. T., et al. (2015). Bioequivalence of n-3 fatty acids from microencapsulated fish oil formulations in human subjects. *British Journal of Nutrition, 113*, 822–831.
Sierra, J. J., Taute, H. A., & Turri, A. M. (2015). Determinants of intentions to purchase unhealthy food and beverage options: A dual-process theoretical perspective. *Journal of Food Product Marketing, 21*, 503–520.
Tao, Y., & Sun, D.-W. (2015). Enhancement of food processes by ultrasound: A review. *Critical Reviews in Food Science and Nutrition, 55*(4), 570–594.
Toepfl, S., Mathys, A., Heinz, V., & Knorr, D. (2006). Review: Potential of high hydrostatic pressure and pulsed electric fields for energy efficient and environmentally friendly food processing. *Food Reviews International, 22*(4), 403–423.
Tokuşoğlu, O., & Swanson, B. G. (2014). Introduction to improving food quality by novel food processing. In O. Tokuşoğlu, & B. G. Swanson (Eds.), *Improving food quality with novel food processing technologies* (pp. 3–7). London; UK: CRC Press Inc..
Trevena, H., Neal, B., Dunford, E., & Wu, J. H. Y. (2014). An evaluation of the effects of the Australian food and health dialogue targets on the sodium content of bread, breakfast cereals and processed meats. *Nutrients, 6*, 3802–3817.
Vergis, J., Gokulakrishnan, P., Agarwal, R. K., & Kumar, A. (2015). Essential oils as natural food antimicrobial agents: A review. *Critical Reviews in Food Science & Nutrition, 55*(10), 1320–1323.
Vilkhu, K., Mawson, R., Simons, L., & Bates, D. (2008). Applications and opportunities for ultrasound assisted extraction in the food industry – A review. *Innovative Food Science & Emerging Technologies, 9*, 161–169.
Weaver, C. M., Dwyer, J., Fulgoni, V. L., King, J. C., Leveille, G. A., MacDonald, R. S., et al. (2014). Processed foods: Contribution to nutrition. *American Journal of Clinical Nutrition, 99*, 1525–1542.
Webster, J., Treiu, K., Dunford, E., Nowson, C., Jolly, A.-A., Greenlands, R., et al. (2015). Salt reduction in Australia: From advocacy to action. *Cardiovascular Diagnosis and Therapy, 5*, 207–218.
Webster, J., Trieu, K., Dunford, E., & Hawkes, C. (2014). Target salt 2025: A global overview of national programs to encourage the food industry to reduce salt in foods. *Nutrients, 6*, 3274–3287.
Weinberg, S. L. (2004). The diet-heart hypothesis: A critique. *Journal of the American College of Cardiology, 43*, 731–733.
Welch, R. W., & Mitchell, P. C. (2000). Food processing: A century of change. *British Medical Bulletin, 56*(1), 1–17.
Williams, S. N., & Nestle, M. (2015). 'Big food': Taking a critical perspective on a global public health problem. *Critical Public Health, 25*, 245–247.
World Cancer Research Fund/American Institute for Cancer Research. (2007). *Food, nutrition, physical activity, and the prevention of cancer: A global perspective*. Washington DC: AICR.
Wu, S.-H., Ho, C.-T., Nah, S.-L., & Chau, C.-F. (2014). Global hunger: A challenge to agricultural, food, and nutritional sciences. *Critical Reviews in Food Science and Nutrition, 54*, 151–162.
Zink, D. L. (1997). The impact of consumer demands and trends on food processing. *Emerging Infectious Diseases, 3*, 467–469.