Food and Agriculture
Organization of the
United Nations

INTERNATIONAL YEAR OF
MILLETS
2023

UNLEASHING THE POTENTIAL OF MILLETS

International Year of Millets 2023
Background Paper

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White fonio
Digitaria exilis

Foreword

We are facing complex, interconnected challenges around the world. These include rising hunger and malnutrition, the depletion of natural resources, the worsening effects of the climate crisis, and ongoing conflicts. To reverse these negative trends, our global agrifood system must become more efficient, more inclusive, more resilient, and more sustainable. Tomorrow's agriculture must play a pivotal role in contributing to strong, local, and diversified agrifood systems – systems that are equipped to withstand shocks and disruptions by adopting sustainable crop production practices and approaches that prioritize farmers, address poverty and the needs of communities. At the same time, they must ensure the conservation of biodiversity, the sustainable use of natural resources, and confer resilience to changes in climates and markets. These agrifood systems must also support dryland zones where the majority of vulnerable populations reside.

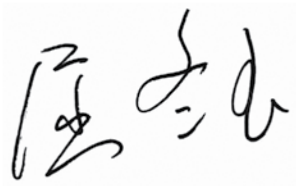
Amidst this need for transformation, millets present an opportunity. They are incredibly diverse, ancestral crops that can be cultivated in various adverse climates and arid regions, have the potential to strengthen food security, and can contribute to a healthy diet due to their high nutritional value. Millets encompass a diverse group of small-grained dryland cereals, including pearl, proso, foxtail, barnyard, little, kodo, browntop, finger and guinea millets, as well as black and white fonio, sorghum, teff and Job's tears, and many other diverse and local species. Millets are indigenous to many parts of the world, and form an intrinsic part of traditional culinary cultures, especially in India and sub-Saharan Africa. Although millets were among the first domesticated crops they are not widely known and their important role in food security and local cultures often goes unrecognized.

For this reason, the United Nations General Assembly at its 75th Session declared 2023 the International Year of Millets (IYM), based on the proposal by the Government of India. This International Year is a call to action, a moment to shed light on these neglected and underutilized crops, to amplify their many contributions and benefits, and to create innovative market opportunities for many countries to benefit farmers and consumers. The IYM is also contributing to the UN 2030 Agenda for Sustainable Development, particularly SDG 2 (Zero Hunger), SDG 3 (Good health and well-being), SDG 8 (Decent work and economic growth), SDG 12 (Responsible consumption and production), SDG 13 (Climate action) and SDG 15 (Life on land).

A key output of the IYM is this key background paper, which aims to raise awareness of the need to direct policy attention to the nutritional and health benefits of consuming millets and their social, environmental and economic contributions. My hope is that this paper will build your interest and create momentum generated through the IYM to support countries in improving the sustainable production and consumption of millets.

At the Food and Agriculture Organization of the United Nations (FAO), we recognize that millets are not just grain crops – they are an asset to our agrifood systems. Our Members have also identified millets as a Special Agricultural Product to be promoted under FAO's flagship initiative 'One Country One Priority Product'. As part of this initiative, FAO is supporting the efforts of countries in promoting teff and sorghum.

I encourage all of you to further engage in discussions aimed at developing more diversified, equitable and sustainable value chains for millets. Let's ensure that we advance our joint efforts through the Four Betters: better production, better nutrition, a better environment, and a better life, leaving no one behind.



QU Dongyu
FAO Director-General

Pearl millet
Pennisetum glaucum

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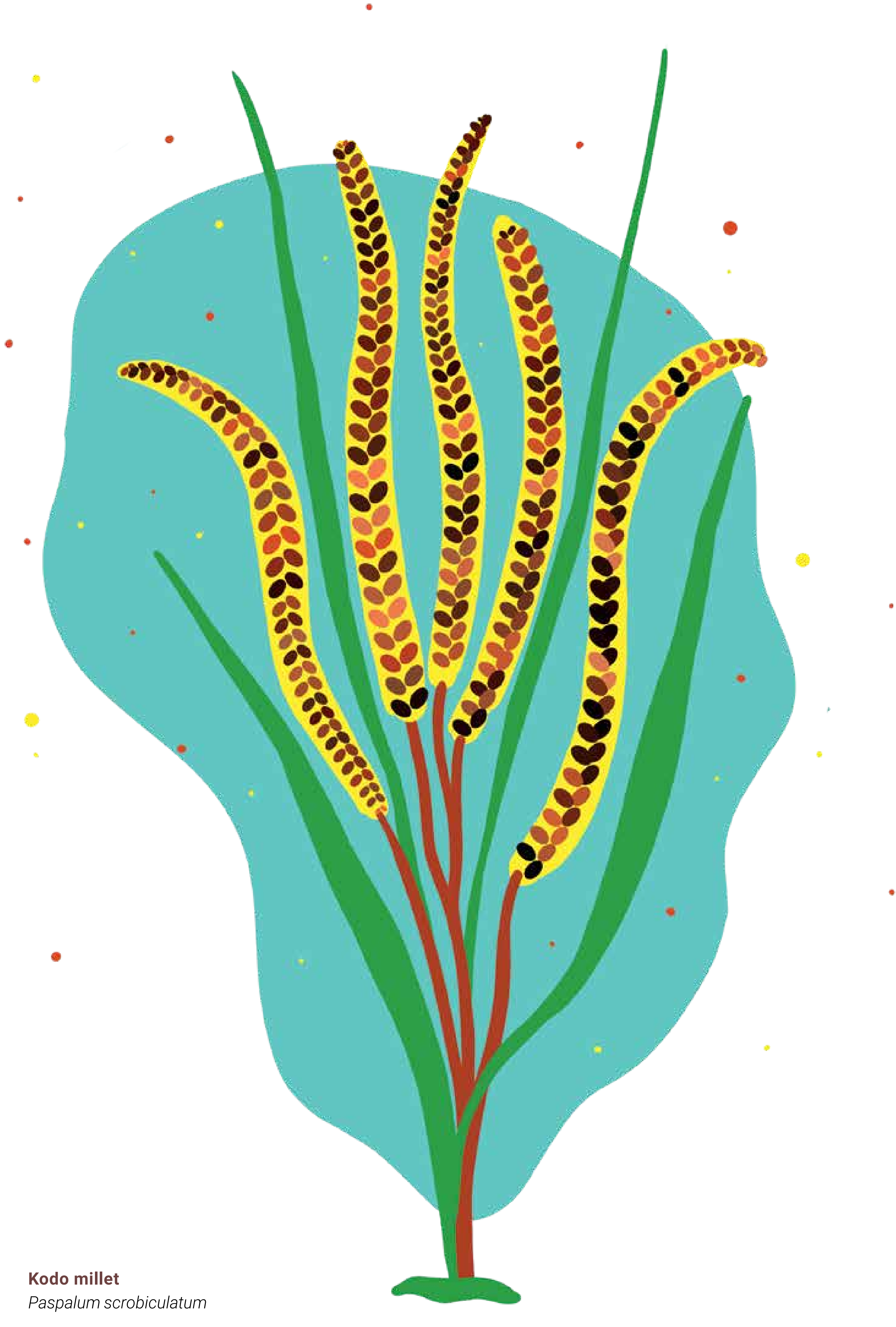
Acronyms

AARINENA	Association of Agricultural Research Institutions in the Near East and North Africa
BCE	Before Common Era
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-Ecological Zoning
GFAR	Global Forum on Agriculture Research and Innovation
GIAHS	Globally Important Agricultural Heritage Systems
IIASA	International Institute for Applied System Analysis
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IGC	International Grains Council
IYM	International Year of Millets
PGRFA	Plant genetic resources for food and agriculture
PBR	People's Biodiversity Registers
SDG	Sustainable Development Goals
UNESCO	United Nations Educational, Scientific and Cultural Organization



Kodo millet
Paspalum scrobiculatum

Executive summary

Some grains can grow in dry regions of the world. Others can help improve soil, be used to diversify healthy diets, or are cultivated to give farmers better opportunities. But if you are looking for grains that can do all these things and more, consider millets.

1

MILLETS ARE CLIMATE-RESILIENT CROPS

Millets can be grown in high temperatures and with little water, and are known to yield grain when other staple crops fail in extreme weather. This means millets can help stave off food insecurity as the climate becomes more erratic.

2

MILLETS PROVIDE AN OPPORTUNITY FOR DIVERSIFIED CROPPING SYSTEMS

Because of their short growing season and ability to grow in a variety of settings, millets can be grown in rotation with other grains as a cover crop. When used with legumes, they also improve soil health and result in higher productivity.

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3

MILLETS CAN CONTRIBUTE TO HEALTHY DIETS

As good sources of carbohydrates, dietary fibre, minerals, protein, antioxidants and vitamins, millets can contribute to healthy diets. They are also versatile ingredients in many cuisines around the world.

4

MILLETS HAVE UNTAPPED POTENTIAL AND CAN BE USED IN INNOVATIVE WAYS

Millets can help diversify food systems and give not only farmers but processors, entrepreneurs and consumers more opportunity for financial success while taking better care of the environment.

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5

MILLETS CAN HAVE FAR-REACHING IMPACTS FOR FARMERS AND INDIGENOUS PEOPLES

Millets grow in many different regions of the world and have been a staple crop for cultures over the course of human history; wisdom about the grains has evolved over centuries. Millets therefore present an opportunity for creative partnerships between researchers, farmers and Indigenous communities to further share knowledge about growing, processing, storing and marketing the grains to a wider audience.

There are, of course, challenges. Funding for research and development for millets is scarce, and some of the grains' genetic diversity has already been lost. Many cultures have switched their diets from millets to other, more easily obtained commodities, such as rice, wheat and maize. Yields for many species of millets are still quite low, and processing of the tiny grains can be difficult.

But several programmes, such as the Kodo-Kutki Model in India (described in detail on page 51) are exemplary in what can be achieved if proper attention is given to millets. In the model, the government provided training in best agricultural practices for the Indigenous women who grew the millets, while private wholesale buyers pledged to purchase the products. The women gained leadership and agricultural experience all while increasing their income. By all metrics – financially, environmentally and socially – the project was a success, and helped ensure local food security for many communities.

Additionally, millets are currently not a major commodity, traded in huge quantities by global entities, with patented seeds owned by corporations. Instead, millets have been grown and traded for millennia by farmers and Indigenous Peoples around the world and are considered ancient grains, connecting groups to the land and to each other. Increased attention, research and development into millets is therefore an opportunity to place family farmers, women and Indigenous communities at the centre of the conversation about the future of agriculture, acknowledging their knowledge systems that have evolved over generations.

There are a multitude of other ways in which the grains can be used to benefit humankind and the environment, many of which are elaborated upon in this document. It is our hope that the International Year of Millets will help inspire policymakers, farmers, consumers, processors and entrepreneurs to reconsider the role of the tiny giants in our midst.

Teff

Eragrostis tef

Chapter 1
Introduction

There are more than 30 000 plant species known to be available for human consumption, but less than 20 of them provide the majority of the world's food supply (Prescott-Allen and Prescott-Allen, 1990; Khoury *et al.*, 2023). Of those, three major cereals – rice, wheat and maize – account for most of the calories consumed by humans every day (Willett *et al.*, 2019).

Meanwhile, the global food system is facing a multitude of complex challenges: hunger, undernutrition and obesity; population growth; limited natural resources; and a changing climate. Solutions to these issues require more sustainable food production that empower small-scale family farmers and small and medium enterprises, the creation of resilient value chains and improved consumer access to affordable, diverse and healthy diets.

Millets, in their diversity, can contribute to these solutions as affordable sources of nutrients for healthy diets that can be cultivated in various adverse climates and arid regions with minimal external inputs.

"Millet" is a general term used for a wide range of cereals that produce small grains (seeds) from a naturally diverse set of grass species. They can be cultivated on marginal lands, in dry areas in temperate, subtropical and tropical regions. Species include pearl, foxtail, finger, proso, barnyard, little, kodo, browntop and guinea millets, black and white fonio, teff, Job's tears and sorghum, as well as many other diverse and local species.

Also known as "coarse", "small" or "minor" grains in different parts of the world, millets are some of the world's most ancient and versatile foods, and are part of a multitude of traditional and Indigenous culinary cultures. They can make excellent rotational cover crops, given their high resistance to dry conditions and short growing season. Yet, despite their clear potential, millets have been marginalized in recent decades, with few agronomists, economists or politicians giving them the attention they deserve. Family farmers have been disincentivized to continue the cultivation of these crops, and many traditional knowledge systems associated with them have been lost. The International Year of Millets aspires to change that.

"Millet" is a general term used for a wide range of cereals that produce small grains (seeds) from a naturally diverse set of grass species.

This paper includes a synopsis of the current status of millets around the world, and was created to inspire policymakers, farmers, civil society, opinion leaders, research and development agents, and the general public to reconsider the role of millets in diversified and healthy diets. **Chapter 2** looks at the history of the grains. **Chapter 3** asks "Why millets" and dives more deeply into the five reasons to celebrate them. **Chapter 4** discusses the challenges millets face and lays out the opportunities for millets locally, regionally and globally. **Chapter 5** looks at the nutritional aspects of millets and how they fit into a variety of diets, and **Chapter 6** provides policy recommendations for improving the millet value chain from seed to table.

THE INTERNATIONAL YEAR OF MILLETS AND THE UNITED NATIONS AGENDA FOR SUSTAINABLE DEVELOPMENT

The Seventy-fifth Session of the United Nations General Assembly in March 2021 declared 2023 the **International Year of Millets (IYM 2023)**, based on a proposal submitted by the Government of India and supported by 72 countries. The IYM 2023 is an opportunity to raise awareness of the potential benefits of millets, from nutrition and health to environmental sustainability and economic development. The Year will strengthen the interaction between science and policy, facilitate partnerships, mobilize stakeholders to produce and promote millets, and encourage the consumption of millets by the general public. The IYM 2023 aims to promote research and development into the sustainable and resilient production of millets, while highlighting millets' potential to provide new market opportunities for farmers and producers and innovative products for consumers.

INTERNATIONAL YEAR OF
MILLETS
2023

The International Year of Millets is an opportunity to identify, strengthen and promote the role of millets in Indigenous Peoples' food and knowledge systems, providing nutrition and ensuring food security.

Millets represent the strong connection of several Indigenous Peoples with their lands, territories and resources. The grains contribute to the diets of Indigenous nomads, pastoralists, hunter-gatherers and shifting cultivators, thus supporting the uniqueness and diversity of their food systems.

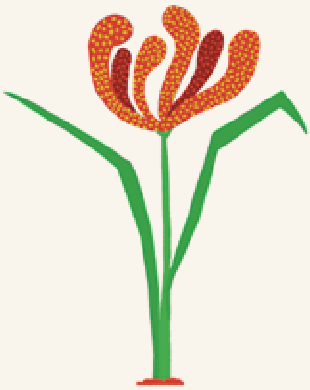
Millets ensure the broadening of the world's food base, necessary for the transformation of agrifood systems, where Indigenous Peoples play a key role. But millets also represent an opportunity to celebrate Indigenous knowledge and the potential for collaboration in biodiversity conservation with Indigenous Peoples and scientists.

The International Year of Millets features various national, regional and international celebrations around the world, including a webinar series to raise awareness of the various health and environmental benefits of millets. A Global Chefs Challenge launched on social media, featuring millet-based dishes created by chefs and hobby cooks, with selected recipes then compiled into a book. People submitted their best photos of millets in a contest, and the IYM website houses materials on millets, available worldwide.

The IYM 2023 contributes to the United Nations 2030 Agenda for Sustainable Development, particularly the goals of **Zero Hunger**, **Good Health and Well-being**, **Decent Work and Economic Growth**, **Responsible Consumption and Production**, **Climate Action** and **Life on Land**, among others.

Everyone has a role to play in the sustainability and resiliency of our food supply – from governments and private-sector companies to the general public, including farmers, traders, chefs, home cooks and young people. Together we can help unleash the potential of millets for human and planetary health and well-being.

The IYM 2023 highlights some of the most commonly grown millets, although there are a vast range of species grown today on farms around the world.



Finger millet

Eleusine coracana

Originally from Sudan, finger millet is mainly grown in eastern Africa (Uganda, Kenya and the United Republic of Tanzania) and southern Asia (India and Nepal). While India is the largest producer of finger millet today, it is also cultivated in Ethiopia, Rwanda, Malawi, Sudan, Zambia and Zimbabwe to a lesser extent. Finger millet is high in thiamin, copper, magnesium, phosphorus and selenium. It is also a source of iron.

NUTRIENT VALUES (per 100 g edible portion, raw)*

CALORIES: 336 kcal

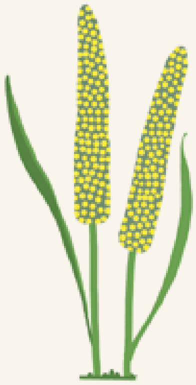
AVAILABLE CARBOHYDRATES: 67.3 g

PROTEIN: 6.7 g

FAT: 1.9 g[1]

DIETARY FIBRE: 11.2 g

Reference: 10 (id: A010)



Pearl millet

Pennisetum glaucum

Originating in West Africa, today pearl millet is distributed widely across the semi-arid tropics of Africa and Asia, and is primarily grown in sub-Saharan Africa. Pearl millet is high in copper, iron, magnesium, phosphorus, selenium and zinc. It is also a source of thiamin and vitamin B6.

NUTRIENT VALUES (per 100 g edible portion, raw)**

CALORIES: 366 kcal

AVAILABLE CARBOHYDRATES: 63 g

PROTEIN: 9.9 g (9.3 g–10.2 g)

FAT: 6.1 g (5.3 g–7.2 g)

DIETARY FIBRE: 9.5 g (8.8 g–11.5 g)

Reference: 9 (id: 01_032, 01_017); 10 (id: A003); 11 (id: 01025)

Foxtail millet

Setaria italica

Foxtail millet originated in northern China, before it spread to other parts of the world. Today, it is primarily grown in China, India, Afghanistan, Japan, the Democratic People's Republic of Korea, the Republic of Korea and Georgia. Foxtail millet is high in thiamin, pantothenic acid, copper, magnesium and phosphorus. It is a source of iron, niacin, Vitamin B6 and zinc.

NUTRIENT VALUES (per 100 g edible portion, raw)**

CALORIES: 356 kcal

AVAILABLE CARBOHYDRATES: 67.2 g

PROTEIN: 9.7 g (8.3 g–10.4 g)

FAT: 4.4 g

DIETARY FIBRE: 4.5 g (1.6 g–8.5 g)

Reference: 4 (id: 01-0006); 5 (id: 01-5-101); 8 (id: 01002)

Little millet

Panicum sumatrense

Evidence points towards the Indian peninsula as the origin of little millet. Today, it is mainly grown in India, Sri Lanka, Myanmar, Malaysia, Nepal and China. Little millet is high in copper, magnesium, selenium and is a source of thiamin, phosphorus and zinc.

NUTRIENT VALUES (per 100 g edible portion, raw)*

CALORIES: 353 kcal

AVAILABLE CARBOHYDRATES: 66.2 g

PROTEIN: 9.4 g

FAT: 3.9 g[1]

DIETARY FIBRE: 7.7 g

Reference: 10 (id: A016)

Teff

Eragrostis tef

Originally from Ethiopia, today teff is primarily grown in Ethiopia and Eritrea, where it is a major staple crop. It is also cultivated in the United States of America, South Africa, Australia, India and Kenya. Teff is high in thiamin, vitamin B6, copper, iron, magnesium, phosphorus, and is a source of riboflavin, niacin and pantothenic acid.

NUTRIENT VALUES (per 100 g edible portion, raw)*

CALORIES: 351 kcal

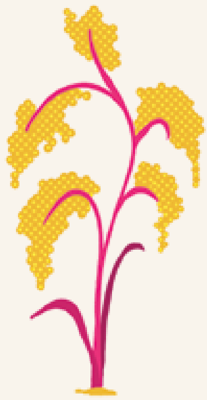
AVAILABLE CARBOHYDRATES: 66 g

PROTEIN: 12.4 g

FAT: 2.4 g

DIETARY FIBRE: 8.0 g

Reference: 6 (id: 169747)



Proso millet

Panicum miliaceum

The origins of proso millet go back to northern China. Today, it is mainly cultivated in China, India, Nepal, the Russian Federation, Ukraine, Belarus, the Near East, Türkiye, Romania and the United States of America. Proso millet is high in thiamin, copper, phosphorus, magnesium, zinc, and is a source of iron, selenium, riboflavin, niacin, pantothenic acid and vitamin B6.

NUTRIENT VALUES (per 100 g edible portion, raw)**

CALORIES: 350 kcal

AVAILABLE CARBOHYDRATES: 65.5 g

PROTEIN: 10.4 g (9.8 g–11.2 g)

FAT: 3.8 g (3.3 g–4.2 g)

DIETARY FIBRE: 6.2 g (1.6 g–8.5 g)

Reference: 4 (id: 01-0007); 5 (id: 01-9-002); 6 (id: 169702); 7; 8 (id: 01011)

* Mean values based on single data source.
** Mean values calculated based on several data sources.
1 Value presented refers to the INFOODS component definitions <FATCE> or <FAT-> and differs from the standardized component of <FAT>.

Sorghum

Sorghum bicolor

The origins of sorghum cultivation were found in the eastern Sudanese savannah. Today, Nigeria, the United States of America and Sudan are the largest producers of sorghum globally. Sorghum is high in copper, magnesium, phosphorus and selenium, and is a source of iron, zinc, thiamin, niacin, pantothenic acid and vitamin B6.

NUTRIENT VALUES (per 100 g edible portion, raw)**
CALORIES: 345 kcal
AVAILABLE CARBOHYDRATES: 63 g
PROTEIN: 10.1 g (8.6 g–11.5 g)
FAT: 3.4 g (1.7 g–4.7 g)
DIETARY FIBRE: 10.7 g (6.3 g–14 g)

Reference: 4 (id: 01-0027); 8 (id: 01140); 9 (id: 01_039, 01_040, 01_041); 10 (id: A005); 11 (id: 01037, 01039); 12 (id: F008474)

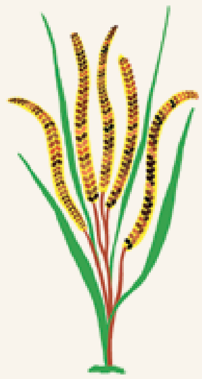
Black fonio

Digitaria iburua

Originally from West Africa, today, black fonio is mainly produced in Nigeria and Niger, and is also cultivated in Benin, Cameroon, Côte d'Ivoire and Togo.

NUTRIENT VALUES (per 100 g edible portion, raw)**
CALORIES: 354 kcal
AVAILABLE CARBOHYDRATES: 70.2 g
PROTEIN: 7.8 g[2] (7.4 g–8.2 g)
FAT: 3.8 g[1] (3.5 g–4.4 g)
DIETARY FIBRE: 3.8 g[3] (1.6 g–6.2 g)

Reference: 3



Kodo millet

Paspalum scrobiculatum

Kodo millet originated in India. Today, kodo millet is primarily grown in damp habitats across the tropics and subtropics of the world. Kodo millet is high in magnesium and selenium, and is a source of thiamin, riboflavin, copper and zinc.

NUTRIENT VALUES (per 100 g edible portion, raw)*
CALORIES: 336 kcal
AVAILABLE CARBOHYDRATES: 66.8 g
PROTEIN: 8.3 g
FAT: 2.6 g[1]
DIETARY FIBRE: 6.4 g

Reference: 10 (id: A010)

White fonio

Digitaria exilis

The origins of white fonio point to West Africa. Today, white fonio is primarily grown in Guinea, followed by Nigeria, Mali, Burkina Faso, Côte d'Ivoire, Niger, Benin, Senegal and Guinea-Bissau. White fonio is high in copper and is a source of folate, magnesium, phosphorus and zinc.

NUTRIENT VALUES (per 100 g edible portion, raw)*
CALORIES: 356 kcal
AVAILABLE CARBOHYDRATES: 76.9 g
PROTEIN: 7.1 g
FAT: 1.7 g
DIETARY FIBRE: 2.2 g

Reference: 4 (id: 01_050)

Japanese barnyard millet

Echinochloa esculenta

The origins of barnyard millet are found in tropical Asia. Barnyard millet is widely cultivated in Asia, particularly in India, China, Japan, the Democratic People's Republic of Korea and the Republic of Korea. Barnyard millet is high in pantothenic acid, phosphorous and zinc. It is a source of thiamin, copper and magnesium.

NUTRIENT VALUES (per 100 g edible portion, raw)*
CALORIES: 351 kcal
AVAILABLE CARBOHYDRATES: 69.4 g
PROTEIN: 8.8 g
FAT: 3.3 g
DIETARY FIBRE: 4.3 g

Reference: 8 (id: 01139)

Job's tears

Coix lacryma-jobi

Job's tears are native to the Indo-Myanmar region. They are used as food and herbal medicine in Asian countries such as China, Japan, the Philippines, Myanmar, Thailand, Sri Lanka and India. Job's tears are high in copper, magnesium, phosphorus and zinc. They are also a source of iron and thiamin.

NUTRIENT VALUES (per 100 g edible portion, raw)**
CALORIES: 357 kcal
AVAILABLE CARBOHYDRATES: 67.7 g
PROTEIN: 13.4 g (11.8 g–15.8 g)
FAT: 2.9 g[1] (1.3 g–4.7 g)
DIETARY FIBRE: 3.1 g (0.6 g–5.5 g)

Reference: 1 (id: A008), 2, 5 (id: 01-9-008), 8 (id: 01138)

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* Mean values based on single data source.
** Mean values calculated based on several data sources.
[1] Value presented refers to the INFOODS component definitions <FATCE> or <FAT-> and differs from the standardized component of <FAT>.
[2] Protein values are not standardized.
[3] Value presented refers to the INFOODS component definitions <FIB-> and differs from the standardized component of <FIBTG>

FIVE REASONS TO CELEBRATE MILLETS

A deeper dive into these points is also provided in **Chapter 3**.

1

MILLETS ARE CLIMATE-RESILIENT CROPS

Millets are a major energy source and staple for millions of people living in dry and arid regions of the world (Lancelotti *et al.*, 2019). They grow in marginal conditions in which the other major cereals fail to give substantial yields (Amadou, 2013), flourishing in areas of extreme heat and very little rainfall. As a result, they can be used as adaptive crops for ensuring food security and nutrition in regions of the world increasingly impacted by dramatic changes in weather.

2

MILLETS PROVIDE AN OPPORTUNITY FOR DIVERSIFIED CROPPING SYSTEMS

Along with legumes, millets are beneficial in rotational cropping, resulting in higher overall productivity, greater resource efficiency, water and soil conservation and improvement of soil health (Bhat *et al.*, 2018). A short growing season of 60–90 days and an ability to grow in both extreme heat and cooler climates allows millets to be used as a cover crop to prevent erosion and help guarantee yields for farmers, even in drought-stricken regions of the world.

3

MILLETS CAN CONTRIBUTE TO HEALTHY DIETS

Millets provide different nutrients, depending on the species, variety and growing conditions. In general, they are sources of carbohydrates, dietary fibre, minerals, protein, antioxidants and certain vitamins. Because they are consumed whole, they have a higher nutritional content, more dietary fibre and a lower glycaemic index compared to other commonly consumed refined grains and cereals. Millets are also gluten-free.

4

MILLETS HAVE UNTAPPED POTENTIAL AND CAN BE USED IN INNOVATIVE WAYS

Increasing production and developing value chains for millets can improve the diversity of the agri-food system while bringing income potential and innovation to rural communities around the world. Improving processing and storage practices can maximize the safe and effective use of millets, and provides opportunities for small and medium enterprises for post-harvest and processing services. New innovative food products based on millets are also receiving more interest by consumers and provide opportunities for entrepreneurs.

5

MILLETS CAN HAVE FAR-REACHING IMPACTS FOR FARMERS AND INDIGENOUS PEOPLES

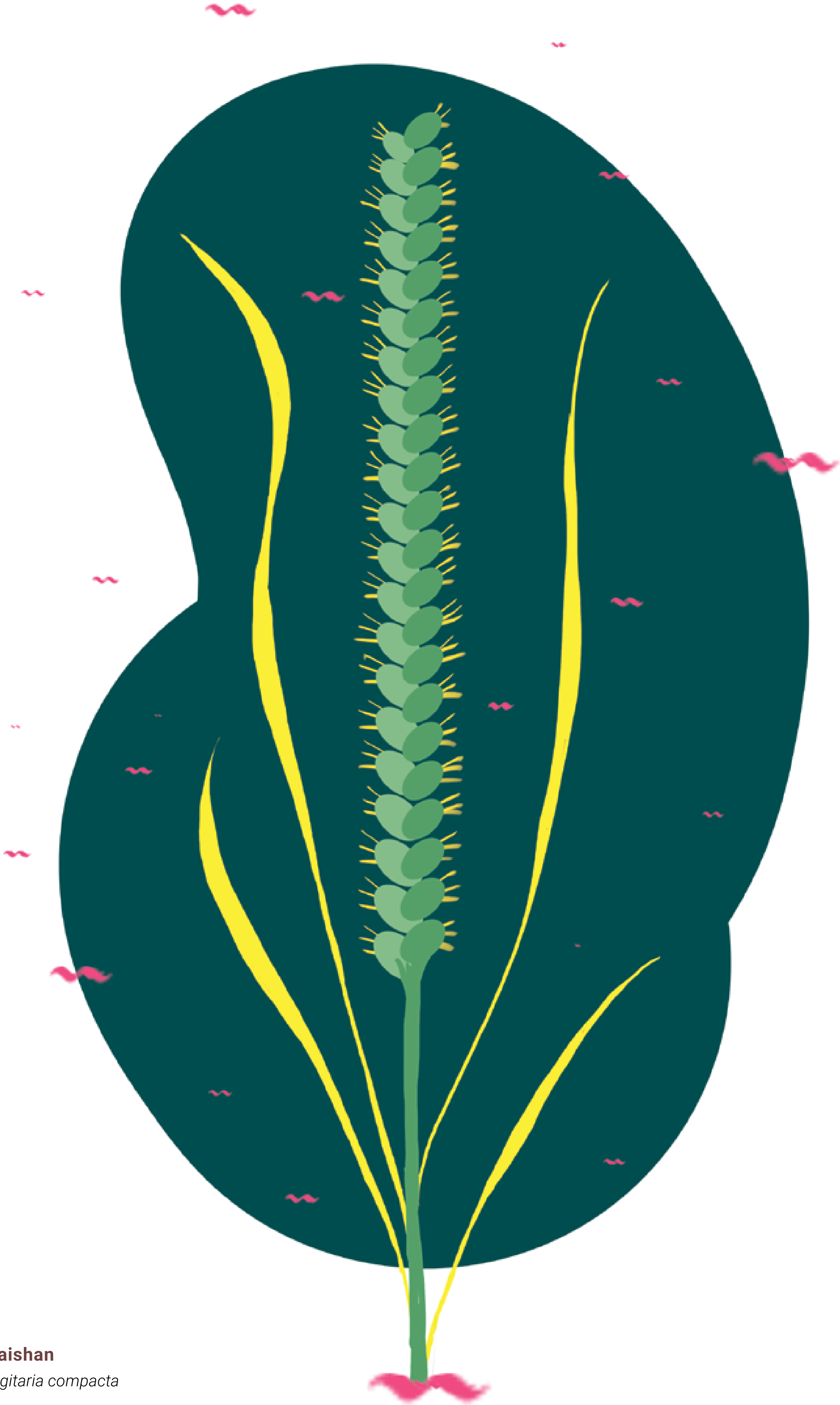
Millets are insurance against crop failure in severe weather conditions, and have a higher monetary return and cost–benefit ratio for the farmers who grow them (Maitra, 2020). There is also a proven connection between "forgotten foods" such as millets and the empowerment of smallholder farmers, especially women, and Indigenous communities. Stimulating the production of millets by family farmers and their inclusive participation in value chains has a direct impact in addressing poverty and food insecurity. Valorizing millets means acknowledging and celebrating the knowledge and experimentation capacity of farmers and the generations of wisdom amassed by those native to the land. This can result in the far-reaching effects of increased self-awareness, self-esteem and self-pride of the producers, galvanizing the agency of individuals and groups. Their position is transformed from recipients of technology to co-creators, co-researchers and co-innovators of knowledge alongside scientists.

BOX 1. Australian native millets

"The practice of growing Australian native millets was largely lost after colonization, when Aboriginal people were moved off their lands and local grains were replaced with wheat, barley and oats," explains Dianne Hall, a PhD researcher working in Narrabri, University of Sydney.

Hall and plant technician Kerrie Saunders are Gamilaraay, one of the largest Indigenous groups in Australia, as is the team's research assistant, Hannah Binge. "We are custodians of the native millet song line," says Hall, referring to the oral histories that trace the journeys of ancient spirits across the land and pass on valuable knowledge about the environment.

"Soon, people will understand that native millets are not just another food commodity," says Binge, "but rather a food and plant that connects people to the land and culture." (FAO 2023a).



Raishan

Digitaria compacta

Chapter 2
Where did millets originate?

Millets were among the first domesticated plants, and remain a traditional staple crop for millions as the grains can thrive in poor soils, resist crop diseases and pests, and are resilient in adverse climatic conditions.

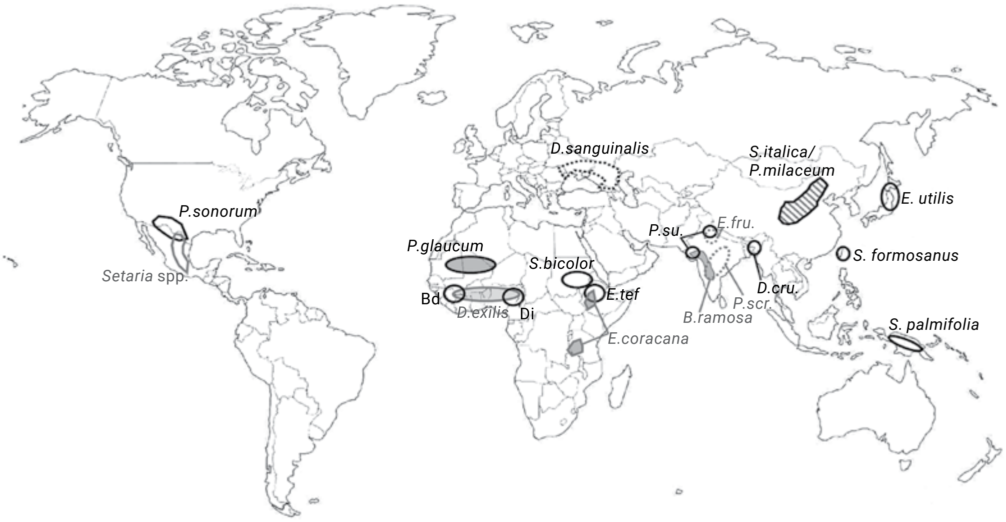
EARLY HISTORY OF MILLETS

One of the most impressive aspects of millets is their diversity. From the deserts of the Sahara to the highlands of Ukraine, millets can be grown in a multitude of environments. Historically, millets helped sustain communities throughout Asia and Africa, complementing and diversifying the diets of Indigenous Peoples, agricultural, pastoral and foraging groups (Lancelotti *et al.*, 2019).

Even in prehistoric times, millets were used in an array of ways, eaten as a staple cereal grain, ground into flour, mashed into porridge, and brewed into beverages in Asia, Africa and Europe. The grains may have been among the earliest cultivated crops, farmed before the advent of irrigation and used as food in early African and Asian cultures (Bhat *et al.*, 2018).

The oldest known millet grains were found along the Nile River in Africa, grown more than 8 000 years

FIGURE 1. The map of likely centres of origin for millets and minor cereals



Notes: Dotted lines less certain, some abbreviated: *Bd: Brachiaria deflexa, B. ramosa: Brachiaria ramosa, D. cru: Digitaria cruciata, D. exilis: Digitaria exilis, D. sanguinalis: Digitaria sanguinalis, Di: Digitaria iburua, E. coracana: Eleusine coracana, E. fru.: Echinochloa frumentacea, E. utilis: Eugeissona utilis, P. glaucum: Pennisetum glaucum, P. milaceum: Panicum miliaceum, P. scr: Paspalum scrobiculatum, P. sonorum: Panicum sonorum, P. su.: Panicum sumatrense, S. bicolor: Sorghum bicolor, S. formosanus: Spodiopogon formosanus, S. italica: Setaria italica, S. palmifolia: Setaria palmifolia, Setaria* spp.: *Setaria species.*

Source: Fuller, D., forthcoming

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BOX 2. **The role of millets in the development of societies**

It has been historically difficult to fully assess the role of millets in the development of societies because small millets are difficult to recover in archaeological sites as they are more apt to have been eaten by microorganisms and pests than larger ones. In addition, tiny seeds were almost impossible to see. Recently, new techniques, such as the use of flotation, allow for better understanding of millets' role in the development of human societies.

Millet recovery from the Indus Civilization site of Harappa exemplifies this issue. The site, occupied from 3300 to 1900 BCE in northern Pakistan, was believed to have been dominated by wheat and barley cultivation, and millets were rarely used. Yet more recently, researchers identified tens of thousands of small millets seeds, demonstrating that small millets cultivation was practiced at this site thousands of years earlier than had previously been thought (Weber and Fuller, 2007).

ago (Bhat *et al.*, 2018), and sorghum farming likely preceded the development of other staple crops like rice or wheat in India and West Africa (Weber and Fuller, 2007). Early millets have also been found in archaeological sites dating back to 6000 BCE in Mongolia; the dry and cold climate of Northern China allowed millets to thrive and by 5000 BCE, the people of the region relied on it as a staple food (Bhat *et al.*, 2018). People of the Korean Peninsula likewise used millets in 4000–3000 BCE, also predating the widespread use of rice as a staple crop in the region. In Europe, proso millet is believed to have been prevalent in Ukraine and in Neolithic sites in Georgia and Germany (Bhat *et al.*, 2018).

THE SPREAD OF MILLETS

Millets travelled with traders along the Silk Road to locations throughout Africa, Asia and Europe, and were increasingly used in rotation with other crops such as rice, creating multi-crop diversity, extending growing seasons and providing food security for ancient cultures (Bhat *et al.*, 2018). The earliest written record of millets in 2800 BCE lists it as one of the five sacred Chinese crops along with soybean, rice, wheat and barley (Bhat *et al.*, 2018). During the Middle Ages, millets became staple grains in Europe, grown more widely than wheat, and societies such as that of the Moors learned that millets sprouted easily and matured quickly, making them a viable rotational crop even in low-rain areas of the world like the Sahara Desert (Bhat *et al.*, 2018).

Yet the reliability of millets, even in the face of extreme conditions, was perhaps the main reason cultures around the world came to grow them. The Roman Empire used the hardy common and Italian millet species (foxtail millets) as insurance against famine (Bhat *et al.*, 2018). A Greek philosopher wrote "millet is the greatest preventive of famine, since it withstands every unfavourable weather, and can never fail, even though there be scarcity of every other grain" (Bhat *et al.*, 2018, p. 33). Northern Africa also exemplifies this sentiment; the region has relied on millets for centuries, even though the region includes some of the most challenging climatic environments on Earth.

Eventually, the ubiquity of breads and noodles comprised of other grains grew more common, and trade in wheat and rice surpassed that of millets. Subsequently, during colonial periods in many areas in the world, agriculture shifted to commercial plantation crops such as cotton, tea and other commodities that were traded throughout the empires (Bhat *et al.*, 2018). Although the grain continues to be of importance for many cultures, in current times, millet production and use has further waned as research and development for breeding, farm mechanization and processing has turned to other crops. In India, traditional foods such as millets have largely been replaced by grains that are generally consumed in a refined form and have higher energy but lower nutrient values (Eliazer Nelson *et al.*, 2019).

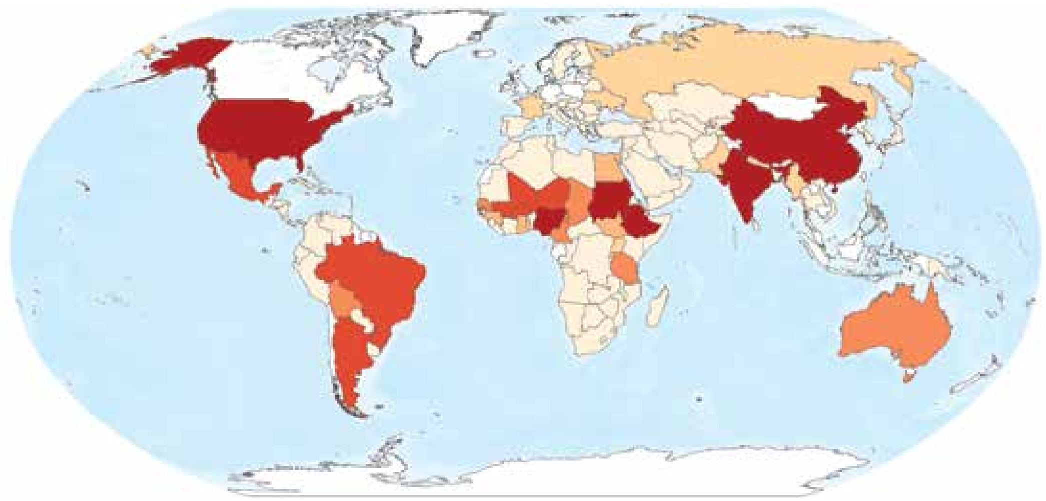
The surface area dedicated to millet cultivation today pales in comparison to its peak before the rise of global trade in wheat, maize and rice, and the advent of high-yielding grain varieties bred during the years of the Green Revolution beginning in the 1960s. Although millets were generally better adapted, more nutritious and native to many areas in Africa and Asia, new staples such as refined rice, maize and wheat changed the makeup of diets around the world (Fahey, 1998).

Millets' perceived ability to stave off hunger and famine also earned it a reputation as a staple for the poor, a crop of lesser quality and inferior taste. Nothing could be farther from the truth. They can be used in a range of recipes, from porridge to salads, stews to desserts and have a mild, nutty flavour and fluffy texture when cooked. And for consumers interested in choosing ingredients that are mindful of the environment, raised with little water or agrochemicals, millets, with all their diversity, are a good option.

Millets continue to be a staple food for millions of people worldwide. This continued cultivation of the grains despite the setbacks, speaks to the resiliency of farmers and Indigenous Peoples and the robust nature of knowledge systems surrounding the growing of millets. The existing variation in genetics, cultivation regimes and cultural cuisines in large part is due to the important role Indigenous Peoples have played in enhancing biodiversity and climate resilience and the continued importance of the relationships Indigenous Peoples have with the land and the food they grow.

There is great potential for many more farmers and processing companies around the world to include millets in their rotations or to improve the current growing, harvesting, storage, processing and marketing of the grain to improve the health and wellbeing of people and the planet.

FIGURE 2. Millet production in the world (tonnes)



No data available	250 000–500 000	1 000 000–2 000 000	5 000 000–18 020 000
0–250 000	500 000–1 000 000	2 000 000–5 000 000	

Sources: FAO. Crops and livestock products. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/QCL. Date of access: 7 July 2023.
United Nations Geospatial. 2020. Map geodata [shapefiles]. New York, USA, United Nations.

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Black fonio
Digitaria iburua

Chapter 3
Why millets?

Chapter 1 briefly listed five reasons to celebrate millets. In this chapter we dive more deeply into each point and examine how millets can be used as a mediation tool for a range of current issues.

MILLETS ARE CLIMATE-RESILIENT CROPS

Production of major cereal crops has grown more volatile in recent years as the weather has become increasingly erratic, agricultural lands erode and soils become depleted of nutrients. Those living with limited resources, particularly in drylands – the arid and semi-arid regions of the Earth[1] – are most at risk of food insecurity and poverty in a changing climate, as lands become increasingly unable to yield as much as they have previously (Padulosi *et al.*, 2015).

Models can provide a look into the suitability of growing millets and the potential the grains hold for farmers worldwide as the climate further changes. For example, Global Agro-Ecological Zoning data[2] shows that land suitable for pearl millet will increase by 2050 as the climate warms at higher latitudes and altitudes (FAO, 2023b). For foxtail millet, the effect of climate change is more variable, with more availability of suitable areas at higher latitudes and a decrease of acreage in the tropics.[3]

When compared to other cereals, millets can be more productive in high-temperature conditions and have a shorter growing season – the life cycle of millets is on average 8–12-weeks, while other major crops are in the 20–24-week range – making them a viable crop in challenging environmental situations.

Several agronomic traits allow millets to survive the stress of long-term drought and heat, such as millets' short stature, small leaf area, thickened cell walls and dense root systems (Babele *et al.*, 2022). Millets are well adapted to soil with low fertility and are resistant to drought, with some species recorded to grow with as little as 40 mm of water per year (Lancelotti *et al.*, 2019). Further, some research indicates millets such as pearl and finger millet can grow in soils with a salinity of 11–12 dS/m, four times the salinity in which rice is able to grow (Lancelotti *et al.*, 2019). And, as a plant with a C4 photosynthesis system, millets have enhanced photosynthetic rates in warm conditions and are able to use water and nitrogen efficiently, 1.5 to 4 times higher than C3 plants such as rice and wheat (Lancelotti *et al.*, 2019). Millets' C4 status also means improved carbon fixation in crops. Moreover, all these benefits are derived from millet crops within their short growing period of two to three months, while C3 crops take much longer to grow (Kaushik *et al.*, 2022).

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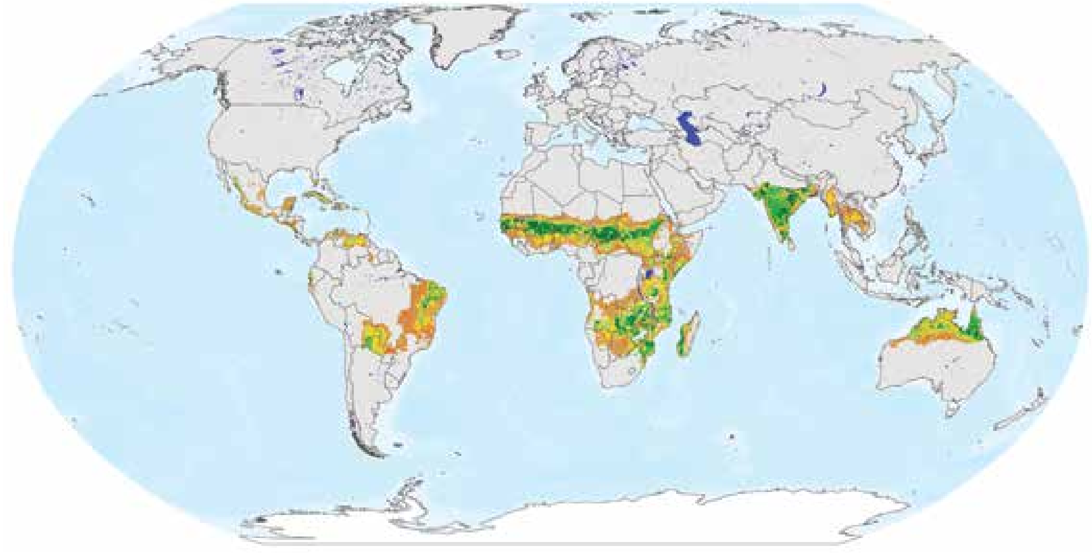
[1] Almost half of the world's agricultural lands lie in dryland areas that cover approximately 40 percent of the Earth's land area – and are home to more than 3 billion people. Yet drylands are among some of the planet's most vulnerable landscapes and have already experienced extensive degradation.

[2] The Global Agro-Ecological Zoning (GAEZ) methodology (Fischer *et al.*, 2021) is a successful approach to support sustainable agricultural development by providing information about current and future crop suitability, agricultural production risks and opportunities, irrigation water demand, and simulates crop development and adaptation options, while preserving environmental quality. The suitability of a crop to be cultivated on a given tract of land depends on specific crop requirements as compared to the prevailing agroclimatic and agroedaphic conditions at a location. GAEZ calculates potential yields according to assessed soil limitations and terrain constraints.

[3] GAEZ data shows that between 1981 and 2010, about 19 percent of rain-fed cropland and 16 percent of irrigated cropland globally was suitable for rain-fed pearl millet production. Foxtail millet was potentially suitable on 27 percent of the rain-fed cropland, and about 42 percent of land equipped with irrigation (FAO and IIASA, 2023).

FIGURE 3. GAEZ Map, Suitability index (0–100) by class for rain-fed pearl millets. Results are for baseline climate (1981–2010) and assumed advanced level of input and management.



Sources: FAO and IIASA. Global Agro Ecological Zones version 4 (GAEZ v4). Date of access: 7 July 2023. URL: https://gaez.fao.org/
United Nations Geospatial. 2020. Map geodata [shapefiles]. New York, USA, United Nations.

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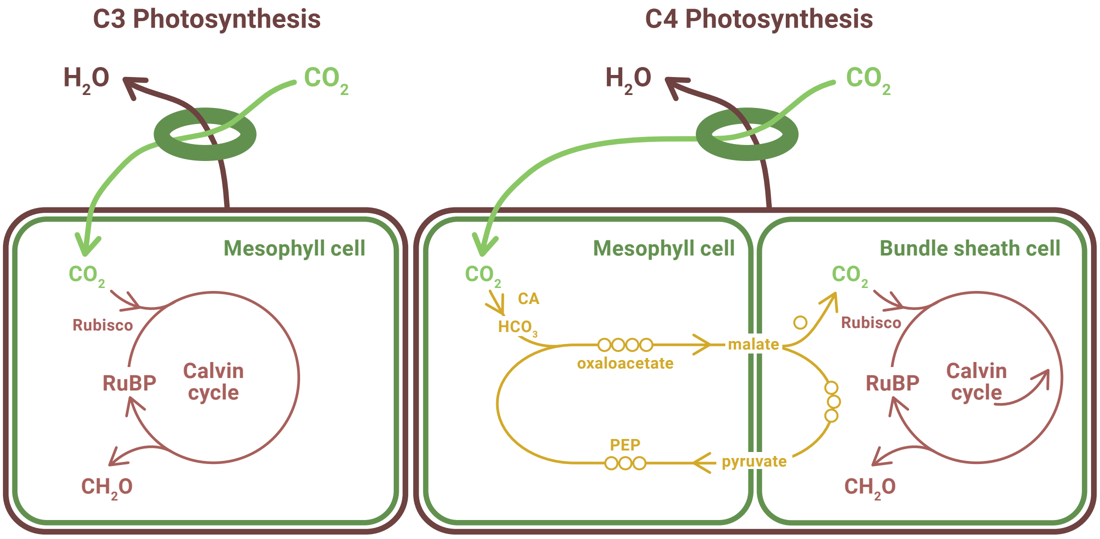
TABLE 1. Optimal ecological range for production of millets and other cereals

	MILLETS						CEREALS		
CROP NAME	FINGER MILLET	PROSO MILLET	PEARL MILLEET	FOXTAIL MILLET	SORGHUM	WHITE FONIO	WHEAT	MAIZE	RICE
Taxon	*Eleusine coracana*	*Panicum miliaceum*	*Pennisetum glaucum*	*Setaria italica*	*Sorghum bicolor*	*Digitaria exilis*	*Triticum aestivum*	*Zea mays*	*Oryza sativa*
Temperat. requir. – optimal min temp.	18	20	25	16	22	22	15	18	20
Temperat. requir. – optimal max temp.	30	32	35	26	35	27	23	33	30
Rainfall (annual) – optimal min	500	500	400	500	400	900	750	600	1 500
Rainfall (annual) – optimal max	1 100	750	900	700	600	1 600	900	1 200	2 000
Soil pH – optimal min	6	6	5	6	5.5	5.5	6	5	5.5
Soil pH – optimal max	7	6.5	6.5	6.8	7.5	6.5	7	7	7
Crop cycle – min	75	55	60	60	90	90	90	65	80
Crop cycle – max	180	280	120	120	300	130	250	365	180

Source: FAO. Crop Ecological Requirements Database (ECOCROP). Date of Access: 7 July 2023. URL: https://gaez.fao.org/pages/ecocrop

FIGURE 4. Diagram of the difference in C3 and C4 photosynthesis



The majority of plants use C3 photosynthesis, including rice, wheat and soybean. Millets use C4 photosynthesis, which is more efficient than C3 in high temperatures and can conserve water, as they concentrate carbon in another cell structure and can avoid photorespiration when processing carbon.

Source: Wang et al., 2012

Pearl millet, for example, is mainly cultivated on marginal lands with irregular rainfall and environmental stresses due to its natural capacity to survive and withstand stresses such as drought, salinity and heat. It is the most widely cultivated of all millets, and is one of the most drought-tolerant of all domesticated cereals. Foxtail millet ranks second in millet production in the world and continues to have an important place in global agriculture, providing food to millions of people dependent on poor or marginal soils in southern Europe and in temperate, subtropical and tropical Asia (FAO, 2023b). Sorghum also shows great potential in climate change models for being one of the most resilient millet species – more resilient, for example, than maize (Orr *et al.*, 2020).

MILLETS PROVIDE AN OPPORTUNITY FOR DIVERSIFIED CROPPING SYSTEMS

Rotating what is grown on the land can break pest and disease cycles, reduce weeds and help curb erosion. Rotations can be used to improve soil health, balance crop nutrients and increase biodiversity on the farm, all while helping farmers manage risk and take advantage of diverse and niche markets.

Millets can play a part in successful rotational cropping. Their short growing season means that they can be incorporated as rotational crops with other, more common grains such as maize or wheat, or with legumes such as soybeans, creating economic opportunity for farmers and keeping soil covered year-round. Use of millets in small- or large-scale farms can enhance land productivity, greater resource-use efficiency, and prevent loss of soil nutrients and soil erosion.

In high-income regions of the world such as Europe and North America, foxtail and pearl millet can be used as a cover crop to keep water and biomass in the soil (Parvin *et al.*, 2023) while browntop millet can be used to suppress nematode populations in tomato and pepper crops (Myers, 2018). Proso millet can be beneficial in a crop rotation as it enhances weed control, especially with winter wheat. And "summer smothering" with millet varieties helps to add organic

©CROP TRUST/PAUL NEATE

matter to fallowed fields while providing nutrient-rich pasture for livestock in the warm season (Reed and Duiker, 2021).

In Ethiopia, for instance, teff is a staple and the most important crop grown in the country in terms of cultivation area and production value. It contributes to crop diversification, and fights food shortages and dietary imbalance (Lee, 2018).

Grazing can also be incorporated into diversified cropping systems that include millets, as the stalks are good nutritional forage for animals, even after harvest. Rotational cropping with livestock is an important component of many millet production systems, and millet crop residues contribute significantly to fodder supplies (FAO, 1996).

Including millets in cropping systems during drought years might help ensure that a family has something to eat, sell and feed livestock at the end of the season, helping guarantee the family's food security for the year.

MILLETS CAN CONTRIBUTE TO HEALTHY DIETS

The make-up of a healthy diet varies, depend on the cultural context, local availability of food, climatic and ecological conditions, dietary customs, individual characteristics and personal preferences. Yet one key element of all diet is dietary diversity, the variety of foods from different food groups that make up what a person eats. Eating a larger variety of foods across and within food groups is associated with a decreased risk of insufficient micronutrients and related deficiencies. Consuming a healthy diet over the course of one's life helps to prevent against all forms of malnutrition and protects against diet-related non-communicable diseases such as diabetes, heart disease, stroke and cancer. Malnutrition is also linked with a decrease in adult productivity vital for the development of nations (FAO, IFAD, UNICEF, WFP and WHO, 2022).

Furthermore, millets, as whole grains, have a lower-glycaemic index compared to refined grains, making them an option in diets for those with high blood sugar or diabetes. Depending on the species, they can also be a cost-effective source of iron (Anitha *et al.*, 2021). Incorporating millets in our diets can provide us with affordable, tasty and nutritious alternatives to commonly consumed refined grains.

Millets can play an instrumental role in diversifying diets that currently rely on a few commodities. Indeed, basing most of our global caloric intake on just three crops – rice, wheat and maize – reduces the resilience of agrifood systems to shocks and stresses, with increased risks to human and planetary health. In Uganda, home production of millets can contribute to food security and provides necessary nutrients such as protein and minerals, especially when other staple food prices increase (Benson *et al.*, 2008).

As whole grains, millets provide dietary fibre. Dietary fibre can help regulate bowel function and lipids, and act as prebiotics supporting the growth of beneficial gut bacteria and the establishment of healthy human gut microbiota (Amadou, 2013). Selected probiotic bacteria isolated from flour and batter samples of sorghum and pearl millet could be used in the production of novel foods (Kunchala *et al.*, 2016).

Millets are also gluten-free, making them an option in diets for people suffering from coeliac disease or gluten intolerance.

Chapter 6 examines millets and how they are consumed around the world.

MILLETS CAN BE USED IN INNOVATIVE WAYS AND HAVE UNTAPPED POTENTIAL

Marketing opportunities exist because of the potential nutritional and environmental benefits of millets, creating alternatives for customers who are looking to purchase products better for the planet and for their health. By promoting millets and regaining market share for the grains, additional sources of revenue can be created for smallholders, boosting economic growth and bringing financial gains to rural communities. In this process, it is crucial to keep millets accessible to those who produce them.

There is also entrepreneurial potential in improving harvesting and processing (NAAS, 2022). Timely harvesting and threshing ensure good grain quality. Mechanized processes for dehusking of millets are often more efficient than manual dehusking, reducing work burden and losses from spillage and providing clean grains ready for market. Innovative agroprocessing, especially in the production of "natural" foods, could target both traditional and non-traditional markets such as young people, urban consumers, tourists, among others. This value addition could lead to market expansion, increasing demand and increasing prices for farmers.

Breeding adapted varieties could also target better yields, while increasing the nutritional value and processing potential of millets. There is also a growing need for diverse cover crop seed in places such as the United States of America and Europe, creating an opportunity for further testing, education and implementation of millets in sustainable larger-scale commercial cropping systems (Myers, 2018).

Additionally, improvement in the genetics, harvesting and processing of millets has a direct impact on women's livelihoods globally. Proven results from millet investments in the lives of women means that policy change and government support for millets is increasingly included in the public distribution system alongside major grains such as rice and wheat in places like India (World Bank & Han Ulaç Demirag, 2022).

See **Chapter 4** for a deeper look into the opportunities available for millets.

MILLETS CAN HAVE FAR-REACHING IMPACTS FOR FAMILY FARMERS AND INDIGENOUS PEOPLES

"Forgotten foods" include cultivated, semi-domesticated, wild species and traditional varieties that have been produced and consumed for millennia for their food, fibre, fodder, oil and medicinal properties, but whose roles have been undervalued and their importance neglected by researchers, policy-makers and markets (Hunter *et al.*, 2019). Millets are an example of such foods.

Because millets have been grown for centuries in traditional agricultural systems, there is an opportunity to place family farmers, women and Indigenous communities at the centre of conversations about the grains, ensuring the knowledge and expertise about millets is acknowledged, promoted and celebrated.

Public policies that stimulate the production of millets by family farmers should be part of comprehensive

strategies that integrate the three dimensions of sustainable development (economic growth, social inclusion and environmental protection).

The United Nations Decade of Family Farming (2019–2028) and its global action plan, enables and supports family farmers in attaining diversified, innovative and dynamic agricultural systems. This can increase the availability of nutritious, sustainably produced and culturally appropriate food, incentivizing healthy diets while promoting context-specific, diversified, resilient and sustainable food systems (FAO and IFAD 2019). Viable food systems that are built with family farmers can offer new economic opportunities and attractive employment.

Participatory research is a key element. Collaborative research, on-farm experimentation and innovation with farmers results in deep changes on personal and organizational levels, increasing self-awareness, self-esteem and pride in their work and wisdom.

This co-creation and sharing of knowledge can help overcome dynamics in today's technology transfer where scientists determine the issues to be addressed and the solutions to address them. Corporate entities have rarely involved those who grow food in the development of seeds or value chains. The Global Manifesto on Forgotten Foods – a collaboration by 27 national farmer organizations, 27 national research institutions and more than 100 public and private universities – requests instead "that smallholder farmers and their communities be recognized, respected and supported as … custodians of knowledge and good practice; as agents of change; and as partners in collective action" (AARINENA, 2021, p. 4). Sustainable development must include the valuing of foods such as millets and the recognizing of traditional knowledge.

Job's tears

Coix lacryma-jobi

Chapter 4
Challenges and opportunities

Millets face many challenges in regaining their prominence in healthy diets around the world. Yet they are ideal grains for a changing climate and consumer tastes. This chapter will explore some of the current roadblocks and opportunities for millets from seed to plate.

SEEDS

Challenges

As described previously, the area on which millets are grown has dwindled. Yet this shift away from growing millets is not just a problem of foods declining in popularity. This trend also threatens the genetic resources of many species of millets that could help improve the production of the grains.

As the grains are grown less frequently in the places where they evolved, the diversity of seeds available is declining. Reduced seed stock, in turn, makes research in the development of more agronomically desirable varieties increasingly difficult. Research into the improvement of crops often depends on the availability of seeds that are conserved in, and available from, the geographical zones and natural habitats in which they thrive (Bramel *et al.*, 2022). The genetic potential that millets hold can also reveal important indications as to how plants grow best in extreme environmental conditions, such as in high temperatures and with little water.

Unfortunately, conserving millet seeds has been considered a low priority by international donors and national governments. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) gene bank, for example, which conserves the world's largest and most diverse sorghum and millets germplasm collection (79 334 accessions) is not funded by global donors to a significant level, unlike other international gene banks.

Hence, the current global system for conserving and maintaining the germplasm to reflect the genetic diversity of millets is not highly secure or efficient, despite recommendations set by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2009). International standards for conserving seed are not followed in many locations, with more than three-quarters of the existing collections without seed duplications to ensure survival. This has created large gaps in the millet germplasm collections in many national gene banks, affecting their availability for further research and evaluation, and ultimately their use and adaptation (Bramel *et al.*, 2022).

The genetic potential that millets hold can also reveal important indications as to how plants grow best in extreme environmental conditions, such as in high temperatures and with little water.

Genetic research has also been limited within nations as the international distribution of seeds from conservation facilities is hampered by policy barriers, the high cost of distribution and administrative complexity. The limited amount of research conducted on millets, compared to other grains and crops, also poses risks not only to the continued conservation of seed, but also to the continued diversity of crops found in farmers' fields (Bramel *et al.*, 2022).

Opportunities

The variety of desirable traits from the genetic pool of millets presents an exciting opportunity to feed the world with more nutritious, resilient and productive crops. Within the seeds of these grains lies a large capacity for enhanced genomic-assisted breeding, targeted research into stress tolerance and the exploration of new traits that can help with optimized crop production.

For instance, many traits unique to millets and their role in stress tolerance have been identified, as in the case of the germplasm collections of pearl millet, finger millet, foxtail millet and proso millet, which can inform breeding programmes in the development of varieties with higher yields under diverse cultivation conditions (Babele *et al.*, 2022) Thus, varieties, or accessions, with well-understood genetic functions have been documented and preserved in gene banks. These accessions indicate a plethora of untapped sources of resistance to common biotic and abiotic stresses, enhanced growth and water-use efficiency, as well as nutritional traits. Finger millet, for example, is a rich source of calcium, while pearl millet is the richest source of protein and iron in cereals.

TABLE 2. Global status of millet germplasm

CROP	NO. OF COLLECTIONS	NO. OF ACCESSIONS GLOBALLY	NO. OF ACCESSIONS AT ICRISAT
Sorghum	135	259 595	42 880
Pearl millet	57	73 578	24 663
Finger millet	49	43 862	7 513
Foxtail millet	46	46 368	1 542
Proso millet	52	29 865	849
Barnyard millet	34	8 920	749
Kodo millet	13	4 398	665
Little millet	12	3 734	473
Teff	21	8 305	–
Fonio	13	1 170	–
Grand total		**479 795**	**79 334**

Source: ITPGRFA

BOX 3. Documentation of the plant genetic resources for food and agriculture

The documentation of the plant genetic resources for food and agriculture (PGRFA) is the foundation for enhancing the use of trait-specific germplasm with agronomically desirable traits in breeding programmes. The accurate characterization and evaluation of these plant genetic resources for food and agriculture is essential for their effective conservation and use. Through the production of descriptor lists in collaboration with national agricultural research programmes, CGIAR centres, crop networks and research institutes, the ITPGRFA encourages the characterization, research and development of different plant genetic resources collections, including millets, by establishing guidelines that are uniform and unambiguous to describe and share relevant information on the germplasm for future use.

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Some accessions also include specific DNA markers that are linked to traits and candidate genes that could be used to further improve crops to adapt to the multifaceted challenges of climate change and population growth. Because most millets have been stored regionally, these genetic resources are available for local as well as international use, in which research and development projects can directly obtain and utilize specific germplasm.

The International Treaty on Plant Genetic Resources for Food and Agriculture facilitates the exchange of sorghum and pearl millet for research, training and breeding by creating a global gene pool from national and international gene banks. These materials are transferred for free, so that researchers, plant breeders and farmers have access to them. The further inclusion and distribution of other millets through the Treaty could positively impact research and the broader use of these resources in food and agriculture.

ON-FARM

Challenges

Much of the success attributed to the "Green Revolution crops" (rice, wheat and maize) that replaced millets in many diets around the world was directly related to high rates of investment in crop research, infrastructure, market development and the corresponding support in government policies (Pingali, 2012). Today, government-sponsored farm subsidies and insurance for major commodity crops in many countries encourage the large-scale production of those crops, whereas such risk-management tools for millets rarely exist. In the United States of America, for example, those growing maize, rice and wheat qualify for government subsidized insurance, while only proso millet is insured, and only if it is grown for bird or livestock feed, not for human consumption (USDA, 2016).

Even simple techniques to improve millet yields are no longer common knowledge. Indigenous knowledge in places where millets were traditionally grown was often lost as different crops took centre stage (Bramel, 2022). Additionally, one of the main challenges to the cultivation of millets remains the drudgery-prone activities needed to harvest and process it – tasks often assigned to women – although improvements in seeds and mechanization could alleviate much of the hardship of the work.

As a result of this lack of knowledge and support, many farmers – from small-scale subsistence farms to large commercial operations – are not willing to grow millets, even if sowing the grains makes environmental and nutritional sense. Farmers instead choose to grow different crops: production of millets has plateaued from approximately 25 million tonnes in the 1960s to just under 30 million tonnes in 2021 (FAOSTAT, 2023). During the same period, production of maize almost tripled (Orr *et al.*, 2020). The perception that millets cannot compete with other cereal crops for on-farm land use has further weakened the business case for increased research and development (Orr *et al.*, 2020).

Opportunities

Millets, however, have been a staple in Indigenous cultures for centuries and, in many cases, the wisdom of their cultivation has been passed down for generations without corporate interference, seed conservation or patents. Farmers, both women and men, and Indigenous Peoples can use "peasant seeds" for planting traditional, non-modified seeds, adapted over centuries to the local climate. Grown this way, millets produce seeds that farmers can replant, share and trade (FAO, 2023c). Many commercial crop seeds, on the other hand, are patented and are illegal to share, requiring farmers to buy new seeds each year.


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On-farm conservation of millet landraces should, therefore, be at the centre of research into millets. In some countries, farmers have benefited from collaborative and participatory plant breeding programmes that, with the support of governments, have contributed to the development of local and small-scale seed production.

There is a great opportunity for co-creation and participatory research in millets among farmers – especially women and Indigenous communities – and scientists to achieve comprehensive seed conservation and selection for use on farms, and to improve millet production and marketing. Support by local seed banks, research and extension systems can increase sustainable millet production, while also ensuring the availability of a wider collection of local cultivars for future use.

Growing millets also presents opportunities for farmers to have better food security and nutrition. Millets help people in marginal environments secure food in dire conditions, helping to address hunger and malnutrition. Because of millets' ability to use less water and fertilizer, growing them also requires fewer inputs, making millets a cheaper crop to cultivate than other popular staples. Farmers are more likely guaranteed a successful crop, which reduces the financial risks of growing millets. And, as a rare crop able to tolerate challenging terrain, millets can allow farmers with land that is considered otherwise unfarmable to farm nutritious crops.

Last, millets can help farmers improve livelihoods. In Mali, for example, the grains had positive economic returns, with annual income of millet farmers increasing fivefold in comparison to other crops. In addition, both farmers and the government saved money in the programme, due to the reduced need for fertilizers and the accompanying subsidies offered for fertilizer on maize and cotton crops (Miklyaev, 2017). With an appropriate value chain available, selling millets can bring income to small-scale farmers and small and medium enterprises for post-harvest and processing services if enabling environments are provided.

Likewise, large-scale farms can also include millets in rotation to improve their cropping systems, thereby creating soils with more organic matter and less erosion. This too means increased profits in the long term, and more sustainable agricultural practices on-farm.

PROCESSING AND STORAGE

Challenges

The challenges millets face post-harvest impacts farmers and entrepreneurs of every size, from the small-scale subsistence farmer to the large-scale industrial processing facility. Additionally, the way millets are processed can dramatically impact their nutritional value. Traditional, hand milling methods retain more nutrients but are slow and cannot be done at scale; mechanical milling creates a more easily used flour with an improved shelf life but can result in less nutrients.

The large number of species of millets also means many different types of processing are needed. And there are a range of possible techniques available for processing millets, such as blanching, dry heating, acid treating or popping, among many others, but each technique takes time and money to explore, and has to consider the retention of nutritional value and consumer preferences. The small size of many millets can result in excessive waste in processing. Dehulling many species, for instance, means a large percentage of the grain is lost and can lower the nutritional qualities of the end product. Further, because the grains are processed and stored at both household and industrial levels, new techniques must be applicable for small-, medium- and large-scale entrepreneurs (Obilana, 2003). The lack of processing units in or near villages has been a major disincentive for small-scale farmers cultivating millets. Creating only large-scale, industrial processing will result in smaller farms remaining outside of the global food network, unable to benefit from investments.

One common challenge of family farmers – particularly for women and young farmers – is the missed opportunity to add value to their products and the lack of participation in inclusive value chains. Investment into processing, packaging and storage for family farmers who are mostly small-scale producers will help them to add value to millets, creating employment and contributing to local, social and economic development of the community for generations to come.

Specific constraints for women and young family farmers in accessing markets should be addressed. Investing in young family farmers and in their access to market infrastructure is key to providing successful and viable livelihoods for all future generations. Basic processing, and improved facilities for storage, processing, conditioning and packaging should be integral parts of agriculture policies for family farmers and for the empowerment of women in different contexts. Several niche markets of particular interest to millet entrepreneurs have been limited by current production capabilities. For many potential commercial uses of millets, such as pasta, flour mixes and cereals, the current demand for millet-based foods outstrips the supply of such products (Amadou, 2013).

Some millets also have a short shelf-life. Millet products produced without chemicals for the "preservative free" or "natural" market must therefore be sold quickly, before the product expires. Inventory control – and the labour to conduct product checks – is imperative. But such control is costly, especially if the products do not sell rapidly (Shah *et al.*, 2023).

Finally, there are alarmingly high losses in post-harvest stages of processing and storage of millets. The average loss for sorghum in four different areas in Ethiopia during the drying, threshing and storage stages, for example, was almost one-third of the entire crop harvested (FAO, 2017). Because of a lack of policy or research focus to train farmers on proper techniques and to design and implement better storage, households continually face food insecurity and unacceptable levels of waste.

Opportunities

One of the simplest ways to improve the processing of millets is to select for varieties that require less arduous and time-consuming work. The cultivation of a species of millet in East Africa with a "snapping trait", for instance, allows the stalk of the plant to snap when bent. This can be harvested by hand without a knife, reducing the work burden on women farmers (CGIAR, 2022).

There are also an increasing number of mechanized processing solutions being developed that can help farms process grains more easily while keeping the nutritional value of millets. Mini-mills, for example, can be used for a greater variety of millets and can be available at local or household levels (Obilana, 2003). Locating state-of-the-art equipment near farms – much as is done with rice (Kaushik, 2022) – can also improve the quality of harvested millet by removing stones from the grain. These facilities can also work to ease the labour of the millions of women involved in growing, harvesting and processing in the millet supply chain.

Specific techniques for processing show potential for retaining millet nutrients while meeting consumer desires for easy-to-use products. Popped and flaked millet products are gaining popularity, and ready-to-eat products with desirable properties and crisp textures are becoming more available and affordable. The growth in demand for sorghum- and millet-based convenience foods and beverage products in India is evidenced by the introduction of a number of innovative new products marketed to address chronic diseases (Alavi *et al.*, 2018). Fermenting millets – a process used since ancient times – can today be done in larger batches, making products rich in various macro- and micronutrients, which have significantly higher protein digestibility and can improve bowel function.

Flour processors in Africa have reported increasing demand for prepackaged flour and expect the market to continue to grow, especially for finger millet flour. Pearl millet can also make commercially viable flour – on its own or blended with wheat flour – if issues of rancidity can be addressed. Studies indicate there is potential for developing shelf-stable millet-based products when processing includes the use of anti-oxidants and thermal processing or better packaging.

Additionally, there are many opportunities for the development of better storage for millets, a critical late-stage step of the whole production system. Storage allows farmers to keep food for the future, for both family needs and to wait for a time when the market for goods is high.

While some millet species – and other major cereals – are difficult to store, others have excellent storage properties and can be kept for up to four to five years in simple storage facilities such as traditional granaries. For these millets, one low-tech solution to extend shelf-life is to improve underground storage in sealed drums. Storing millets in hermetically sealed bags can also easily remedy storage issues if they are available at low cost.

BOX 4. Women in the millet value chain

Gender relations shape all levels of the millet value chain: directly through unequal division of labour, decision-making and access to resources, and indirectly through uneven distribution of information and a lack of investment.

The role of men and women in the production of millets varies. In finger millet cultivation, for instance, the most drudgery-prone activities include threshing, winnowing and harvesting – 80 to 95 percent of the work – is most often performed by women. Post-harvest processing is also often traditionally carried out without machinery by women on open floors, reducing the quality and increasing the risk of contamination of the millets. This affects the sale price of the millets and exposes the women to respiratory issues (Jeeva *et al.*, 2019).

Yet the millet supply chain is also an opportunity for women to improve their own circumstances, leading to significant increases in their income and participation in decision-making, giving them better access to resources.

One example is in Ghana where men typically only participate in the most profitable endeavours that are well supported with capital and resources. Agricultural commodities like millets are traditionally produced and traded by women, with profits going to the head of the household (traditionally a man). In the past, this has reduced women's motivation to participate and to improve the quality of their work, which has affected the final product. Today, many formal markets (supermarkets) give women the opportunity to improve their role and agency through their participation in farm-based organizations that sell millets to grocers and enable access to markets for women producers.

Another millet project in Odisha, India, impacted one of the most marginalized and poorest segments of society: Dalit women. These women traditionally face different forms of discrimination, segregation, violence and inequality, and do not have the same access to education and economic opportunities as other castes in India. Yet in the dry and infertile fields Dalits inhabit in the region, self-help women's groups worked to improve millet yields and to change the traditional women's roles of post-harvest workers and seed collectors, to those who process *ragi* (finger millet), and run cafes where millet-based dishes are sold. Today 2 700 women across 50 communities harvest more than 3 million kilograms of grain, six times more than before establishing the Eco-Employment Programme (UNDP, 2022).

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MARKETING AND CONSUMER AWARENESS

Challenges

Despite population gains, there has been little overall change in the consumption of millets over the past twenty years or so as dietary preferences, incomes and lifestyles have changed and people have migrated to cities (IGC, 2023). Consumers are unaware of millets and their potential nutritional, environmental and economic contributions (Shah *et al.*, 2023). In Africa, a main constraint on millet-flour demand was the lack of consumer awareness of the potential contribution of the grains to healthy diets and nutrition (Orr *et al.*, 2023).

In part, this lack of awareness stems from the fact that there are many different species of millets and a multitude of languages spoken across the globe. Consumers are confused as to what millets are, the species included in the term, and how they are to be prepared. For instance, the word for millets in Japanese translates to "minor grains", while the Spanish term, *mijo*, is used to refer to a narrower set of species. As a result, it is a challenge for entrepreneurs to determine how best to market millet products and what terms to use on product packaging.

Similarly, consumer focus on wheat, maize and rice, has left many younger generations unfamiliar with millets, and reliant on more heavily processed, easier to cook, foods (Orr *et al.*, 2020). In other areas of the world, millets were never traditionally eaten, making their appearance on plates an unfamiliar and rare occurrence.

In addition, busy consumers are now used to purchasing food products that are convenient to buy, cook and eat. Not only are millets less available in the supermarket in most places in the world, some species also take longer to cook than more highly processed grains. Other millets need special attention, requiring skills like pounding or fermenting. While millet flours are used as an alternative to wheat, specific knowledge is necessary for baking. All of this means that home cooks not familiar with millets often need to take the time to find recipes and experiment in order to become accustomed to the product.

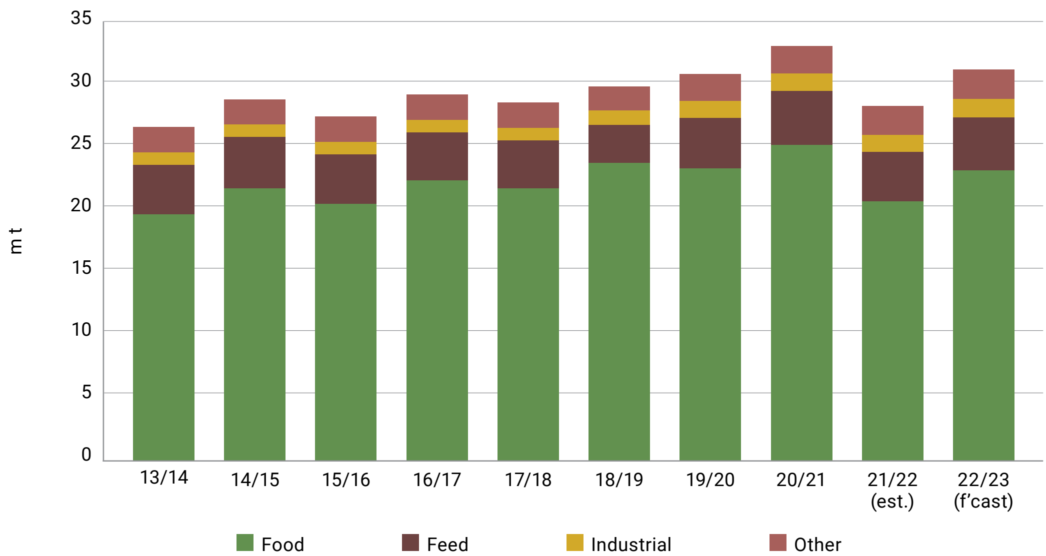
Opportunities

There are several global trends that could greatly impact the trajectory of the consumption of millets in the future.

Opportunities for millets in global and local markets

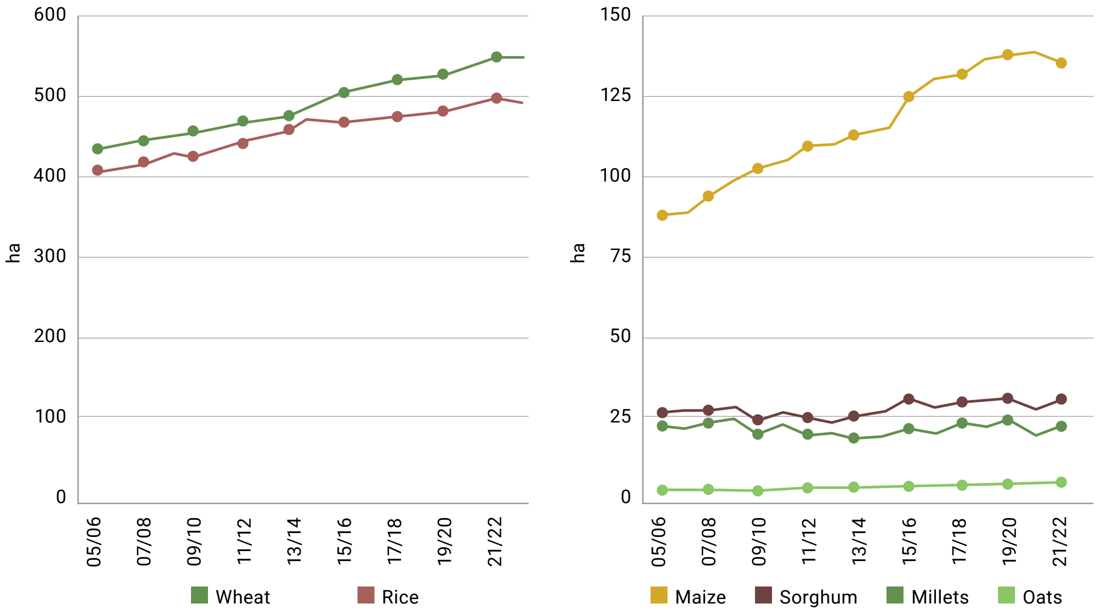
Currently the annual global consumption of millets averages around 30 million tonnes, with sub-Saharan Africa and South Asia accounting for more than 85 percent of use. This is far below maize, rice and wheat, and is a fraction of what is eaten daily around the world, as is seen in **Figure 6**. This leaves room for market-share growth for millets in global human consumption patterns.

FIGURE 5. World consumption of millets



Source: IGC, 2023

FIGURE 6. Comparison of world food consumption of cereals



Source: IGC, 2023

Millets are predominantly used for human consumption, consumed most often as porridge, flat breads or steamed. They are also used in a range of savoury and confectionary dishes, and are an important energy source in rural parts of East Asia (IGC, 2023). As consumers learn more about the potential health and environmental contribution of millets, there is great potential for further growth.

In some regions, millets are only known as animal feed, and their contribution to human diets and resilience require further education. This would require significant investment in consumer education, and may be an opportunity for the private sector to reach new markets.

Innovative ways to incorporate millets into cuisines and dishes that originally do not contain millets can also be explored. Through the Global Chefs Challenge implemented through the IYM, recipes are shared including traditional and new ways of using millets. Local and national governments have also created successful programmes to highlight millets. One example is an initiative in the district of Raigarh, Chhattisgarh, India. Here a "Millet Café" was created, involving a local women's self-help group. The cafe was established in May 2022 to encourage the inclusion of millets in the daily diet of local people, but it also promoted self-employment and entrepreneurship among women and encouraged farmers to increase their productivity of millets. The cafe serves millets in both local and new dishes, bringing culturally relevant and innovative recipes to the community.

Millets are part of a return to territorial diets

Consumer preferences are closely connected with place-based identity and cultural heritage.

Many people desire to bring back foods eaten by their ancestors, returning to traditional or indigenous recipes and diets linked to specific territories. One example of this is in Africa, where production of the traditional crop fonio almost quadrupled from 1990 to 2020 (FAOSTAT, 2023). While many fonio growers are subsistence farmers and grow the grains mainly for their own consumption, there is also a growing demand for millet flour in Africa as incomes increase and consumers desire to return to a more local diets and traditional dishes (Orr *et al.*, 2020).

BOX 5. Millets in India

Millets are also growing in popularity again in India, owing in part to a renewed attraction to traditional medicine in the country (Ayurveda) where millets are considered an integral part of healthy eating. Under the aegis of the International Year of Millets 2023, India has rebranded millets in the national and global market as "Shree Anna" meaning "the mother of grains".

The country has also created a "Millet Missions" programme in 11 states (Assam, Chhattisgarh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu and Uttarakhand) to facilitate the production, processing, value addition, marketing and consumption of millets. Small-scale and tribal farmers are supported through training in improved agronomic practices and capacity building, and by facilitating market linkages.

Ogi, a fermented porridge in Nigeria and Ghana, is the most extensively consumed breakfast food in the region, and couscous – made in Northern Africa for generations out of pearl millet – has become a popular dish globally. Yet new preparation methods are needed to deal with the time constraints of modern lives. Entrepreneurial African chefs now celebrate millets by integrating them into modern recipes and making them available in products like fonio chips and pilaf.

Regional culinary pride and a return to "decolonized diets" has also made small grains like millets appealing to consumers. Eating "ancient grains" in many parts of the world is a popular way to limit intake of refined foods and to add whole grains to diets. Millets fit all of these categories, and are often cheaper than other competing whole grains such as quinoa.

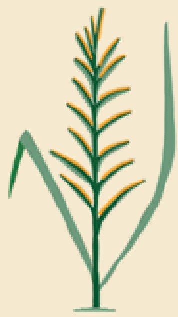
And, because most millets are grown by small-scale farmers and Indigenous Peoples, the grains are also attractive to consumers looking to purchase foods directly sourced from groups who benefit from the sale.

BOX 6. Odisha Millet Mission

In 2018, the Odisha Millet Mission went to Ms Jyoti Dang's village to talk about millets. There she learned that millets can be grown on marginal lands, organically, with less inputs, and can have significant positive health outcomes.

Dang began a conversation with community members to share crop on their fallow lands, and was able to secure 0.4 hectares (1 acre) of land to start millet cultivation. The Odisha Millet Mission provided several recommendations as well as training to Dang. Dang increased the land under cultivation from 0.4 to 0.5 hectares from 2018 to 2020, and her production grew from 530 kg to 680 kg.

The Millets Mission programme also included the grains in the Odisha public distribution system and in Child Development Services, creating a market for what is produced. Millet dishes are included in nutritious midday meals offered in districts and states across India.



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Millets support biodiversity and sustainable land restoration

In comparison to cereals like wheat and rice, millets require significantly less water to cultivate, and are often naturally more pest-resistant, requiring fewer chemical fertilizers and pesticides (Babele *et al.*, 2022). Proso and pearl millets, for example, require a sixth of the water rice needs to grow (Lancelotti *et al.*, 2019). In addition, the variety of diverse grains can also be marketed and eaten as a substitute to imported wheat-, rice- and maize-based products in places where it grows locally, brought to market with less transportation.

This is especially relevant for family farmers and Indigenous Peoples, who are the custodians of biodiversity and manage around 70 to 80 percent of farmland worldwide, as is recognized in the United Nations Decade of Family Farmers.

Entrepreneurs interested in making "environmentally friendly" products available to consumers can market the environmental benefits of the grains on packaging and in advertising. This will also help to better inform the public about the sustainable impacts of millets.

Millets can contribute to healthy diets

Millets can be processed in unique ways, which can add value to the raw material and maintain or improve the nutritional value of the final products. Dedicated awareness-raising campaigns could target young people and urban dwellers to educate consumers about the nutritional potential of millet-based meals for healthy and diversified diets.

Healthcare providers recommend whole grains, including millets, to individuals suffering from diabetes or high blood pressure, and to those looking for alternative diets for weight reduction (Shah *et al.*, 2023). Another potential market for millets is in the creation of gluten-free products.

Chapter 5 will discuss at length the nutritional aspects of millets.

GLOBAL CHEFS CHALLENGE

Millet tortillas with mushroom stuffing

by Chef Spicy Moustache

Millet tortillas

Ingredients:

- ◯ 250 g millet
- ◯ water for soaking
- ◯ handful spinach
- ◯ parsley
- ◯ salt
- ◯ black pepper
- ◯ garlic powder
- ◯ olive oil

Preparation:

1. Soak the millet overnight.
2. Use a blender to combine all ingredients.
3. If too thick, add 2 tbsp of water at a time.
4. In a pan, heat one tsp of olive oil to prevent the tortilla from sticking.
5. Pour around 3–4 tbsp of the mix into the pan to make a small tortilla.
6. Use a spoon to spread the batter into a tortilla shape, as the batter is thick and does not spread evenly.

Mushroom stuffing

Ingredients:

- ◯ 500 g mushrooms of your choice
- ◯ 1 medium onion
- ◯ olive oil
- ◯ 2 garlic cloves, minced
- ◯ salt
- ◯ black pepper
- ◯ parsley

Preparation:

1. Stir fry the onion with the garlic and olive oil until golden and soft.
2. Add the mushrooms and spices and cook for about 5 minutes on medium heat.
3. Keep stirring so nothing sticks to the pan or burns.

Pink béchamel sauce

Ingredients:

- ◯ 3 tbsp vegan butter
- ◯ 3 tbsp flour
- ◯ 2 cups soybean milk
- ◯ ½ tsp ground black pepper
- ◯ ¾ tsp nutmeg
- ◯ for colour, 1 small beetroot or purple potato, already baked or boiled

Preparation:

1. In a pan on low heat, melt the butter with some of the milk, add the flour and stir until combined with no lumps.
2. Slowly pour the rest of the milk into the pan, add the spices and boil until thickened.
3. Use a blender and mix the béchamel with the beetroot or potato until it has a creamy texture.
4. Store in the refrigerator for up to 5 days.

GLOBAL PRODUCTION AND TRADE

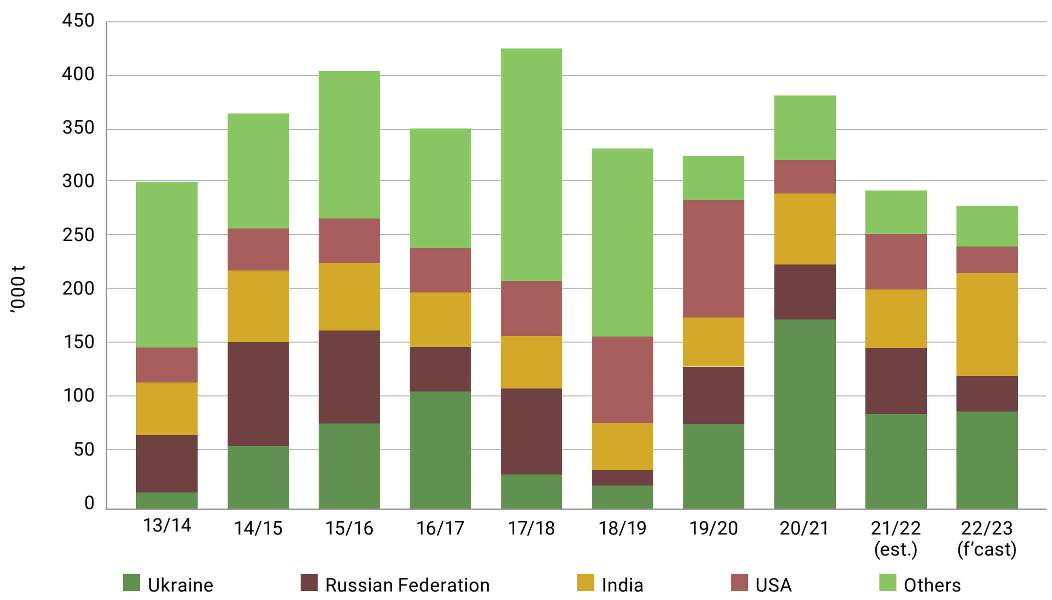
Four countries make up the bulk of the global exports of millets: Ukraine, the Russian Federation, India and the United States of America. Together, trade from these nations make up 70 percent of total recorded shipments worldwide. Ukraine – normally the world's largest supplier – mostly exports millets to the European Union, along with smaller sales to countries in Asia and Africa. The Russian Federation exports to Türkiye, while India typically sells to countries in Asia and Africa. Exports of millets from the United States of America vary considerably and have dropped sharply from their peak in 2019–2020 (IGC, 2023).

The European Union has emerged as the world's largest importer. Other major importers include Indonesia, Türkiye, the United Arab Emirates, Saudi Arabia and Canada.

It is estimated that only 1 percent of total millet production is traded on the international market – a number that is significantly lower than other staple grains such as wheat (24%), maize (15%), barley (20%), oats (10%), rice (8%) and rye (4%) (IGC, 2023). Most millets are sold in local markets, close to where they are grown, indicating an important local-market system that contributes to livelihoods. Local trade is an important opportunity for farmers and small and medium enterprises providing processing services to gain access to markets. Through low-cost government support via public procurement, micro-loans and educational programmes such as farmer field schools, governments can contribute to increase the demand for millets, which can improve the livelihoods of small-scale farmers and small and medium enterprises. The Government of India, for example, announced procurement of millet flour for troops from 2024 onwards.

Equally as important, on the supply side, there is significant room to increase yields in millets without expanding the area of production and causing further environmental degradation. With appropriate investment in the millet supply chain, farmers could produce more product for a global market without increasing production area. One such example is the continued ability of farmers to save local seed, breed them as they wish and to buy and sell them in an open and competitive market. Trade in seed must remain uncontrolled by large corporate interests, unlike other staple grains that are today patented and heavily controlled.

FIGURE 7. World exports of millets (July/June)



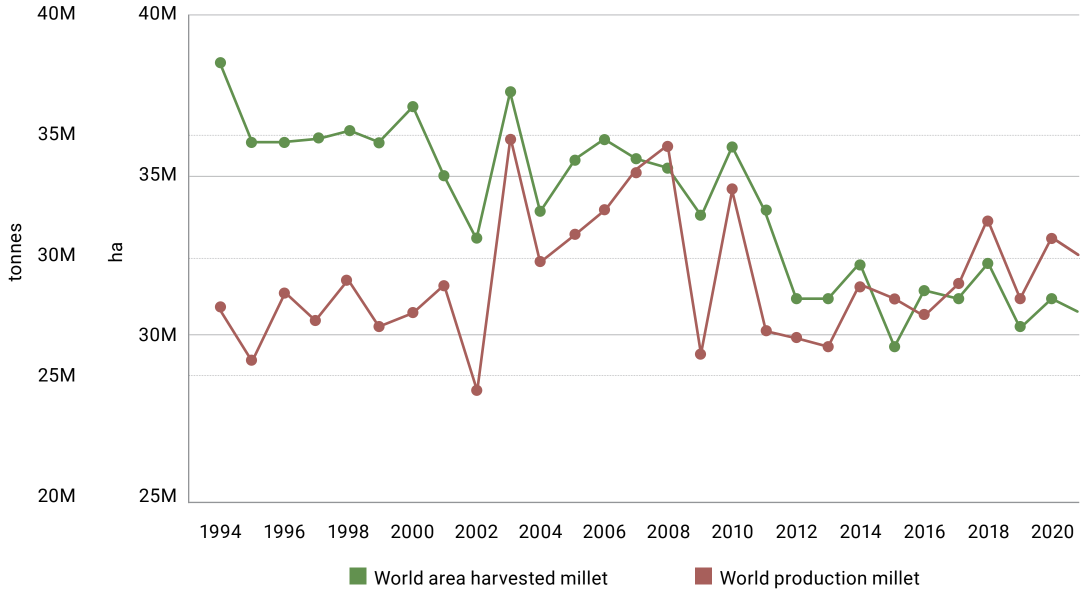
Source: IGC, 2023

Figure 8 shows the improvement in the production of millets while at the same time the harvested area shrank; millet yields have increased slightly over the past ten years. There is an opportunity for accompanying trade in millets to best utilize the higher yields.

FAOSTAT data include small-grained cereals with a large number of different millet species, *inter alia*: barnyard, finger, proso, kodo, pearl and foxtail millet, and teff. Sorghum (**Figure 9**) and fonio are listed separately in FAOSTAT, but are included in the celebration of IYM 2023.

FIGURE 8. World production and harvested area of millet, 1994–2021

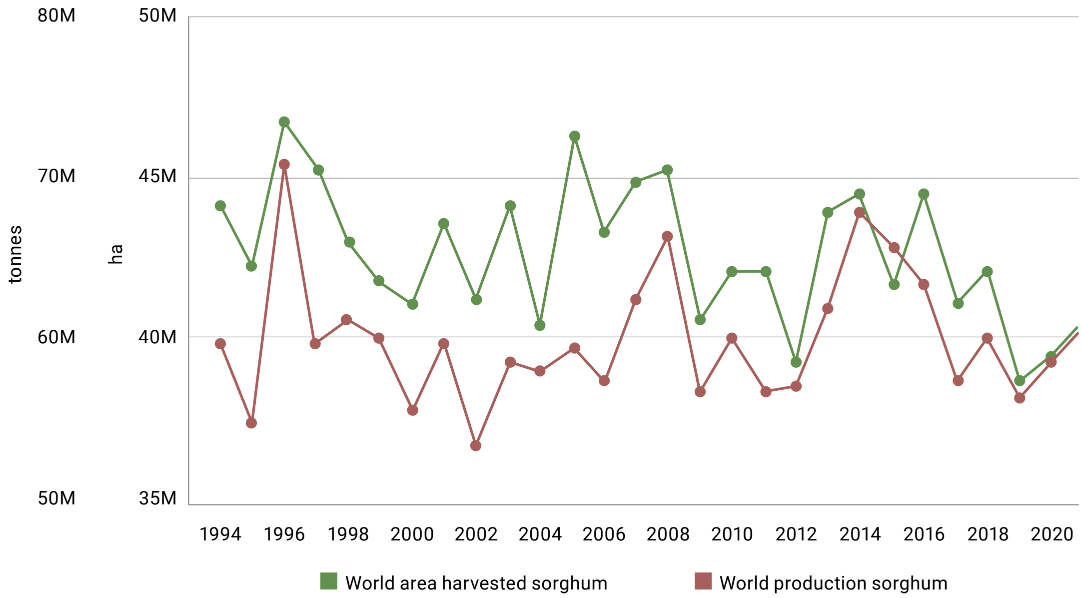
Production/yield quantities of millet in world + (total)



Source: FAOSTAT

FIGURE 9. World production and harvested area of sorghum, 1994–2021

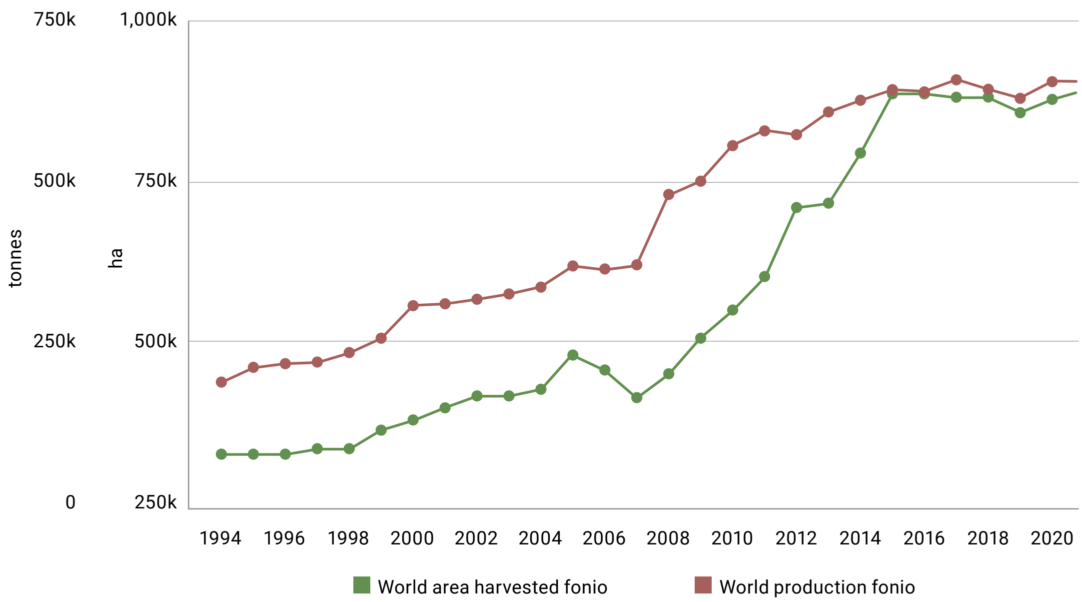
Production/yield quantities of sorghum in world + (total)



Source: FAOSTAT

In the case of fonio (**Figure 10**) in West Africa, production and the area harvested have steadily increased over the past several decades in response to the increase in demand.

FIGURE 10. World production and harvested area of fonio, 1994–2021
Production/yield quantities of fonio in world + (total)



Source: FAOSTAT

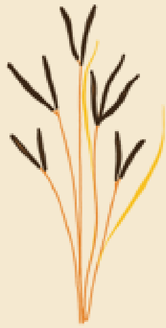
BOX 7. **"Millets have brought us joy and saved my family!" – Patrick Mutepeya, Zimbabwe**

When he started his own farm more than three decades ago, Patrick Mutepeya did not think twice about growing maize. Raised in rural Zimbabwe, where maize, although not native, had been king and the harvests of the 1980s plentiful, it was the obvious choice to make.

He witnessed the great drought of 1992, which decimated yields, left millions of farmers in need of aid, and turned Zimbabwe – previously a "breadbasket" of Africa – into a net importer of food for decades to come.

Mutepeya recovered and kept growing maize. But good harvests were few and far between after that, he says – about once every five years.

Then, in 2017, after learning about various climate-resilient farming methods, Mutepeya finally made the transition to growing pearl millet. Like many in his area, he was sceptical about the grain at first. But the local farmer field school he attended allowed him to experiment on test plots, and the consistent results ultimately convinced him. He never regretted his choice.



"Millets have brought us joy and saved my family," he says sincerely. And that is not just because the grain is drought tolerant; it is also cheaper to produce, he says.

"The native seed varieties are more accessible and available from the local seedbank," he explains. "[It] has greatly contributed to reduced production costs" (FAO, 2023d).

©PATRICK MUTEPEYA

Guinea millet
Urochloa deflexa

Chapter 5
Millets for diversified and healthy diets

The potential of millets to contribute to healthy diets are wide ranging. They can be used to create tasty and healthy recipes, and their consumption can contribute to a diversified and healthy diet. This chapter will examine more specific information about the nutritional aspects of millets, and review some of the ways in which millets are featured in cuisines across the world.

MILLETS, AS WHOLE GRAINS, HAVE A HIGHER NUTRITIONAL CONTENT COMPARED TO REFINED CEREALS

Whole grains are important sources of energy and carbohydrates, and their contribution to nutrient intakes is significantly higher compared to more refined grains.

Some millet species like proso, pearl and little millet are sources of protein; Job's tears have a comparable level of protein to cereals and grains known for their protein content, such as oats, amaranth or buckwheat. When eaten with other foods such as legumes, the proteins in grains are better absorbed. Millets can be good sources of minerals and vitamins.

TABLE 3. The comparative proximate nutritional values of several millets, maize, rice and wheat

Proximate composition per 100 g edible portion on fresh weight basis (raw, uncooked grain) including range values shown in brackets.									
COMMON NAME	**BOTANICAL NAME**	**ENERGY** (kcal)[4]	**WATER** (g)	**PROTEIN** (g)[5]	**FAT** (g)	**DIETARY FIBRE** (g)	**AVAILABLE CARBO-HYDRATES** (g)[6]	**ASH** (g)	**REFERENCES**
Kodo millet	*Paspalum scrobiculatum*	336	14.2	8.3	2.6*	6.4	66.8	1.7	10 (id: A017)
Little millet	*Panicum sumatrense*	353	11.4	9.4	3.9*	7.7	66.2	1.3	10 (id: A016)
Finger millet	*Eleusine coracana*	336	10.9	6.7	1.9*	11.2	67.3	2.0	10 (id: A010)
Proso millet	*Panicum miliaceum*	350	11.3 (8.7–13.8)	10.4 (9.8–11.2)	3.8 (3.3–4.2)	6.2 (1.6–8.5)	65.6	2.9 (0.7–4.3)	4 (id: 01-0007); 5 (id: 01-9-002); 6 (id: 169702); 7; 8 (id: 01011)
Foxtail millet	*Setaria italica*	356	12.2 (11.6–13.3)	9.7 (8.3–10.4)	4.4	4.5 (1.6–8.5)	67.2	2.0 (1.2–3.3)	4 (id: 01-0006); 5 (id: 01-5-101); 8 (id: 01002)
Pearl millet	*Pennisetum glaucum*	366	9.3 (7.8–11)	9.9 (9.3–10.2)	6.1 (5.3–7.2)	9.5 (8.8–11.5)	63.0	2.2 (1.4–2.7)	9 (id: 01_032, 01_017); 10 (id: A003); 11 (id: 01025)
Sorghum	*Sorghum bicolor*	345	11.1 (9–12.2)	10.1 (8.6–11.5)	3.4 (1.7–4.7)	10.7 (6.3–14)	63.0	1.7 (1.3–2)	4 (id: 01-0027); 8 (id: 01140); 9 (id: 01_039, 01_040, 01_041); 10 (id: A005); 11 (id: 01037, 01039); 12 (id: F008474)
Japanese barnyard millet	*Echinochloa esculenta*	351	12.9	8.8	3.3	4.3	69.4	1.3	8 (id: 01139)
Teff	*Eragrostis tef*	351	8.8	12.4	2.4	8	66.0	2.4	6 (id: 169747)
Job's tears	*Coix lacryma-jobi*	357	11.4 (10.2–13)	13.4 (11.8–15.8)	2.9* (1.3–4.7)	3.1 (0.6–5.5)	67.7	1.6 (0.2–3.5)	1 (id: A008); 2; 5
Black fonio	*Digitaria iburua*	354	10.6 (10.3–11)	7.8‡ (7.4–8.2)	3.8* (3.5–4.4)	3.8# (1.6–6.2)	70.2	3.9 (3.3–4.7)	3
White fonio	*Digitaria exilis*	356	10.9	7.1	1.7	2.2	76.9	1.2	4 (id: 01_050)
Maize, yellow	*Zea mays mays*	363	10.4	9.4	4.7	7.3	67.0	1.2	6 (id: 170288)
Common wheat	*Triticum aestivum*	340	9.6	11.3	1.7	12.2	63.7	1.5	6 (id: 169719)
Rice, white, long grain	*Oryza sativa*	352	11.6	7.1	0.7	1.3	78.7	0.64	6 (id: 169756)

* Values presented refer to the INFOODS component definitions <FATCE> or <FAT-> and differ from the standardized component of <FAT>.

‡ Protein values are not standardized (i.e. lack of information on the nitrogen-to-protein conversion factor applied).

Value presented refers to the INFOODS component definition <FIB-> and differs from the standardized component of <FIBTG>.

[4] Energy (kcal/100 g) calculated using energy conversion factors (https://www.fao.org/3/y5022e/y5022e04.htm) as follows: carbohydrates, 4 kcal/g; protein, 4 kcal/g; fat, 9 kcal/g; dietary fibre, 2 kcal/g.

[5] Protein calculated from total nitrogen using nitrogen-to-protein conversion factor 5.83 for all species (except for sorghum factor 6.25 was applied). (https://www.fao.org/3/i3089e/i3089e.pdf). Conversion factors for maize (6.25), wheat (6.25) and rice (5.70) as suggested by data source.

[6] Available carbohydrates (g/100 g) calculated by difference as follows: 100 - (water + ash + fat + protein + fibre).

TABLE 4. Vitamin values[1] per 100 g edible portion on fresh weight basis (raw, uncooked grain) including range values shown in brackets

COMMON NAME	BOTANICAL NAME	THIAMINE (mg)	RIBOFLAVIN (mg)	NIACIN (mg)	PANTOTHENIC ACID (mg)	VITAMIN B6 (mg)	FOLATE (µg)
Kodo millet	*Paspalum scrobiculatum*	0.29#	0.2#	1.2	0.63	0.07	39[2]
Little millet	*Panicum sumatrense*	0.26#	0.05	1.3	0.6	0.04	36[2]
Finger millet	*Eleusine coracana*	0.37*	0.17	1.3	0.29	0.05	35[2]
Proso millet	*Panicum miliaceum*	0.41* (0.34–0.45)	0.21# (0.09–0.29)	3.2# (1.2–4.7)	0.85#	0.29# (0.2–0.38)	49 (13–85)
Foxtail millet	*Setaria italica*	0.49* (0.33–0.59)	0.09 (0.07–0.11)	2.5# (1.5–3.2)	1.83*	0.28# (0.18–0.38)	57
Pearl millet	*Pennisetum glaucum*	0.28# (0.25–0.29)	0.19 (0.17–0.2)	1.6 (0.9–2)	0.5	0.27#	36[2]
Sorghum	*Sorghum bicolor*	0.30# (0.21–0.4)	0.13 (0.03–0.28)	3.6# (2.1–6)	0.85# (0.27–1.42)	0.24# (0.1–0.31)	46 (20–64)
Japanese barnyard millet	*Echinochloa esculenta*	0.25#	0.02	0.4	1.5*	0.17	14
Teff	*Eragrostis tef*	0.39*	0.27#	3.4#	0.94#	0.48*	
Job's tears	*Coix lacryma-jobi*	0.22#	0.1 (0.05–0.15)	1.3 (0.5–2)	0.16	0.07	16
Black fonio[4]	*Digitaria iburua*						
White fonio	*Digitaria exilis*	0.16	0.18			0.16[3]	62#
Maize, yellow	*Zea mays mays*	0.39*	0.2#	3.6#	0.424	0.62*	19
Common wheat	*Triticum aestivum*	0.39*	0.11	4.4#	0.954#	0.37#	38
Rice, white, long-grain	*Oryza sativa*	0.07	0.05	1.60	1.01#	0.16	8

[1] Nutrient values are marked accordingly in Table 3: (#) source of; (*) high in based on the contribution made to nutrient requirements. The highest nutrient requirement for men or women was used from the following sources: FAO/WHO (2004) *Vitamin and mineral requirements in human nutrition: Report of a joint FAO/WHO expert consultation, 2nd ed.*; the World Health Organization; or the Institute of Medicine (2006) *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press. The colour coding considers only the mean value, recognizing that some species may be higher or lower in nutrient content as indicated by their range.

[2] Values presented refer to the INFOODS component definition <FOLSUM> and differ from the standardized component of <FOL>.

[3] Value presented refers to the INFOODS component definition <VITB6C> and differs from the standardized component of <VITB6A>.

[4] No micronutrient data available.

Notes: mg = milligrams; µg = micrograms.

Bibliographic reference sources for each species are identical to the list provided for proximate composition (Table 3).

Millets are whole grains that contribute to the intake of critical vitamins and minerals such as B vitamins, iron and magnesium, depending on the variety consumed. **Table 4** shows the vitamin values of whole grain millets when compared to commonly consumed refined staple grains. Values highlighted in darker red signify a high nutritional value based on millets' contribution to daily requirements.

Diversifying the daily diet of individuals to include millets has the potential to positively impact public health. In Myanmar, where 80 percent of energy intake comes from rice, millets are currently grown for export and for animal feed. Integrating millets into the diets of children could have a positive impact on stunting, wasting and low weight that result from a lack of nutrients, particularly of protein and micronutrients (Anitha *et al.*, 2019).

TABLE 5. Mineral values[1] per 100 g edible portion on fresh weight basis (raw, uncooked grain) including range values shown in brackets

COMMON NAME	BOTANICAL NAME	CALCIUM (mg)	COPPER (mg)	IRON (mg)	MAGNESIUM (mg)	PHOSPHORUS (mg)	POTASSIUM (mg)	SODIUM (mg)	ZINC (mg)
Kodo millet	*Paspalum scrobiculatum*	15	0.26[#]	2.3	122[*]	101	94	3.4	1.7[#]
Little millet	*Panicum sumatrense*	16	0.34[*]	1.3	91[*]	130[#]	105	4.8	1.8[#]
Finger millet	*Eleusine coracana*	364[*]	0.67[*]	4.6[#]	146[*]	210[*]	443	4.8	2.5[*]
Proso millet	*Panicum miliaceum*	33 (8–99)	0.62[*] (0.38–0.75)	3.4[#] (2.1–5)	115[*] (84–146)	234[*] (160–285)	185 (148–200)	5.4 (2–9.6)	2.2[*] (1.7-–2.7)
Foxtail millet	*Setaria italica*	29 (14–41)	0.81[*] (0.49–1.4)	4.2[#] (2.8–5.1)	99[*] (81–110)	266[*] (229–290)	278 (250–300)	4.1 (1–7)	2.0[#] (1.5–2.5)
Pearl millet	*Pennisetum glaucum*	26 (23–32)	0.48[*] (0.45–0.54)	9.3[*] (6.3–15.2)	101[*] (84–124)	373[*] (289–427)	329 (291–365)	6.7 (4–12)	3.2[*] (2.6-–4.1)
Sorghum	*Sorghum bicolor*	20 (10–28)	0.35[*] (0.18–0.46)	5.1[#] (2.3–9.5)	161[*] (101–290)	315[*] (222–430)	356 (233–590)	5.6 (1–9)	1.9[#] (1.4–2.7)
Japanese barnyard millet	*Echinochloa esculenta*	7	0.15[#]	1.6	58[#]	280[*]	240	6	2.2[*]
Teff	*Eragrostis tef*	180	0.81[*]	7.6[*]	184[*]	429[*]	427	12	3.6[*]
Job's tears	*Coix lacryma-jobi*	46 (6–146)	0.44[*] (0.23–0.8)	5.5[#] (0.4–13.6)	133[*] (88– 158)	301[*] (217–385)	215 (85–296)	12.2 (1–42)	2.5[*] (0.4–3.6)
Black fonio[2]	*Digitaria iburua*								
White fonio	*Digitaria exilis*	24	0.94[*]	2.1	41[#]	113[#]	178	5	1.7[#]
Maize, yellow	*Zea mays mays*	7	0.314	2.7[#]	127[*]	210[*]	287	35	2.2[*]
Common wheat	*Triticum aestivum*	32	0.36[*]	4.6[#]	93[*]	355[*]	432	2	3.3[*]
Rice, white, long-grain	*Oryza sativa*	28	0.22[#]	0.8	25	115[#]	115	5	1.1[#]

[1] Nutrient values are marked accordingly in Table 3: (#) source of; (*) **high in** in based on the contribution made to nutrient requirements. The highest nutrient requirement for men or women was used from the following sources: FAO/WHO (2004) *Vitamin and mineral requirements in human nutrition: Report of a joint FAO/WHO expert consultation, 2nd ed.*; the World Health Organization; or the Institute of Medicine (2006) *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press. The colour coding considers only the mean value, recognizing that some species may be higher or lower in nutrient content as indicated by their range.

[2] No data available.

Notes: mg = milligrams; µg = micrograms.

Bibliographic reference sources for each species are identical to the list provided for proximate composition (Table 3).

Table 5 shows the wide variety of minerals available in millet species. Values highlighted in darker red signify a high nutritional value based on millets' contribution to daily requirements.

Iron is one of the important minerals found in millets, contained in different amounts depending on the species and variety of millet. Iron-deficiency anaemia is a public health concern globally, with 42 percent of pregnant women and 47 percent of preschool-aged children suffering from the condition worldwide. In India, it has been proposed that diversifying diets to include millet varieties that contain iron could help address iron-deficiency anaemia (FAO, 2003). Nutritional status outcomes such as stunting, wasting and anaemia are complex, and their eradication requires improvements in healthy diets to occur in tandem with advances in health, poverty reduction and many other areas.

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Adequate intake of calcium is necessary for bone health. Finger millet is high in calcium (364 mg per 100 g), one of the few known cereals with such a high calcium content, while teff is also a source of calcium (180 mg per 100 g) (see **Table 5**). Finger millet is high in other minerals such as zinc and magnesium (Anitha, 2019) (see **Table 5**).

WHOLE GRAIN MILLETS HAVE A LOWER GLYCAEMIC INDEX THAN MANY REFINED GRAINS

The glycaemic index is a number from zero to 100 that indicates how quickly a food makes blood sugar levels rise in the body. While the glycaemic index of a product is only indicative, as we normally do not consume individual foods alone and it is the amount and combination of foods consumed in a meal that affects blood sugar levels, healthy meals with a lower glycaemic index and glycaemic load might help people with diabetes better control their blood sugar. Some millets – especially teff, barnyard millet and fonio – have lower glycaemic values than many refined grains, representing good options for diets of people with diabetes (Anitha, 2021).

WHOLE GRAIN MILLETS CAN BE A GOOD SOURCE OF DIETARY FIBRE

As whole grains, each species of millet provides different amounts and types of dietary fibre. Dietary fibre has a role in regulating bowel function, blood sugar and lipids, satiation and in improving the human microbiome, as known beneficial microbes flourish with a fibre-rich diet (Gill *et al.*, 2021; Bazzano *et al.*, 2003; McRae 2017).

A high-fibre diet benefits individuals by normalizing bowel movements and maintaining bowel health, helping control blood-sugar levels and lowering cholesterol levels. Dietary fibre lowers blood cholesterol levels. Slow-moving fibre ferments in the large intestine (including the colon) thereby reducing the risk of colon cancer and bowel disease. In addition, this generates the creation of short-chain fatty acids, which inhibit the retention of cholesterol in the liver (Kedar *et al.*, 2019).

Kodo millet and sorghum, in their whole-grain form, are high in fibre. The bran of millets is also a rich source of dietary fibre and can contribute to healthy diets for the reduction of blood glucose level as well as insulin response. They also reduce the risk of bowel disorders (Dayakar *et al.*, 2017).

MILLETS ARE GLUTEN-FREE

The number of people affected by coeliac disease (around 1 percent (Lebwohl *et al.*, 2018)) and gluten intolerance worldwide is small when compared to the general population. In addition, the diagnosis of non-coeliac gluten sensitivity remains elusive because of poor knowledge of the condition and the lack of reliable biomarkers.

Although the experience remains challenging to diagnose, what is known is that millets are gluten free, and therefore are a viable option for those suffering from coeliac disease or gluten intolerance.

MILLETS CAN BE PROCESSED TO MAINTAIN BENEFICIAL CHARACTERISTICS

Not all processing is equal when it comes to impact on the nutritional content of millets. Local and traditional knowledge integrated with nutritional information based on modern science can help communities choose appropriate processing techniques to maintain or enhance nutritional value, maximize nutrient bio-availability, improve palatability and enhance the shelf life of millets, all while growing culturally relevant foods with less water and agrochemicals.

Like other grains, millets require basic processing such as threshing, cleaning, grading and sorting (separation to remove materials such as stones and chaff remaining after harvest, and the leftover grain from previous crops, etc.), which can be achieved through appropriate mechanization activities. After the initial cleaning of the grains, millets need to be further processed to remove the inedible portions, undergo pretreatments to extend their shelf life and, in some cases, undergo specific processing operations to reduce antinutritional factors and enhance nutritional value and cooking quality before they can be further processed and are ready to eat.

Not all processing is equal when it comes to impact on the nutritional content of millets.

Ancient techniques such as dehulling, soaking, drying, germination and malting, roasting, milling and fermentation can reduce antinutrients in millets leading to enhancement in bio-availability of micronutrients, reducing cooking time and thus making millets more nutritious and fit for consumption. Further modern or secondary processing methods such as puffing, popping, baking, retorting (microwaveable formats) and extrusion cooking are a used to develop value-added millet-based processed ready-to-eat and ready-to-cook food products. However, these processes can result in the destruction of nutrients if the processing conditions and product formulation are not optimized.

When highly processed, millets lose many of their unique and important health-benefitting properties. Similarly, whole grain wheat can be nutrient rich, but taking off the bran and refining wheat leaves white bread with little nutritional value. Likewise, some kinds of millet-refinement operations are better for enhancing the nutritional profile by retaining minerals, fibre and other nutrients and improving other health-benefitting desirable characteristics such as antioxidants more than other types of refinement (Gowda *et al.*, 2022).

For example, finger millet contains antinutrients that constrains calcium bio-availability. The major antinutrients in finger millet are phytate, oxalate and tannins, among others (Antony *et al.*, 1999; Makokha *et al.*, 2002; Ramachandra *et al.*, 1977). Thus, appropriate processing methods, that reduce the antinutrients without the loss of calcium, need to be applied during processing of finger millet. Bio-availability of calcium from finger millet is found to improve through sprouting and malting and fermentation as these processes result in reduction of the antinutrients. Though decortication of finger

GLOBAL CHEFS CHALLENGE

Stuffed bottle gourd (*lauki*) with barnyard millet

by Chef Anahita Dhondy Bhandari

Ingredients:

- ◯ 6 bottle gourds (*lauki*)
- ◯ 2 tbsp boiled barnyard millet (*samak* rice)
- ◯ 1 green chilli, finely chopped
- ◯ 1 tsp ginger
- ◯ rock salt (*sendha namak*) to taste
- ◯ 1 tsp cumin powder
- ◯ 1 tsp red chilli powder
- ◯ ghee for brushing
- ◯ 2 tbsp paneer

Preparation:

1. Cut the head of the bottle gourds and steam both the head and the whole gourd for about 7–8 minutes.
2. Once boiled, scoop out the inside of the bottle gourd, put the gourd flesh in a bowl and add boiled barnyard millet, ginger, coriander, rock salt, cumin and red chilli powder, mix well.
3. Fill the steamed bottle gourd with this filling and top it with some grated paneer, cover with its head and brush with a little ghee.
4. Put it in the oven for about 15 minutes and enjoy.

millet is found to improve calcium bio-availability, the process also results in a loss of calcium (Krishnan *et al.*, 2012). Thus, processes such as boiling and micro-waving of finger millet, which have been reported to have minimal effect in improving calcium bio-availability from finger millet (Amalraj and Puis 2015), need to be combined with other methods that reduce antinutrients.

Given the IYM 2023, the time is right for existing millet-processing technologies to be further evaluated and gaps identified in order to make them more efficient.

In general, when germinated or fermented, the dietary fibre, mineral and vitamin content of most millets is enhanced. Simple processing techniques – ones used for generations in Indige-nous cultures – such as soaking, germination and malting reduce antinutrients, leading to improved bio-availability of minerals and digestibility of starch and protein. Conversely, dehulling, milling and extru-sion of millets can result in loss of fractions rich in proteins, dietary fibre and micronutrients (Gowda *et al.*, 2022). Recovering the various nutrient-rich fractions or by-products, e.g. micronutrient-rich bran, starch and protein-rich fractions, resulting from various millet processing operations, and exploring innovative ways of using them in formu-lating different millet-based food products, needs to be further explored to fully tap into the nutritional and health potential of millets.

Further, millet puffs, for example, do not hold the same nutritional value as a fermented millet grain, and hence further research on combining various food-processing technologies to promote the development and commercialization of innovative and nutritious millet-based food products is paramount. Therefore, there is still a need for research to discover ways to utilize millets for modern products – making them easier to cook and eat – without compromising their nutritional value or contribution to health, as well as for research to focus on appropriate service solutions. While it is indispensable to implement suitable incentives for producers and value-chain actors, it is quite important to focus on consumer awareness as well, providing accurate information so that consumers can understand claims made about different types of millets. This can enable them to make good decisions regarding their food choices and to practice healthy diets.

Given the IYM 2023, the time is right for existing millet-processing technologies to be further evaluated and gaps identified in order to make them more efficient. In addition, novel technologies (Datta *et al.*, 2022) such as air-jet milling, use of microbial strains in germination and fermentation, biochemical, nanotechnology, ultrasound and gamma irradiation also need to be leveraged in order to ensure both scientific and commercial benefit to the community, especially to millet farming communities as well as to consumers.

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Browntop millet
Urochloa ramosa

Chapter 6
Millets for now and for the future

As discussed in Chapter 4, there are many opportunities for research and development to promote millets and support farmers and entrepreneurs in growing and processing the grains more widely.

RESEARCH AND DEVELOPMENT NEEDS

And yet millets play a unique role in the lives of the farmers who grow them; they are for the most part grown by small-scale farmers, often in challenging locations and with increasingly erratic weather. This means that research and development – and the policies created to promote further understanding and use of the grains – must keep farmers, including women and young people, and the Indigenous Peoples who have cultivated millets for generations, at the centre of the conversation.

For example, government and international donor support of genetic conservation of seeds should adhere to standards outlined in the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2001), in which clear protocols and goals are already established. Yet any kind of data collection must also respect and protect the Indigenous and farmer knowledge – including those from women – that already exists. The Government of India created the People's Biodiversity Registers (PBRs) in which local communities and individuals can create a database of resources. This information is then a legally binding document that provides evidence of prior knowledge in case of patent claims on biological resources (Notaro *et al.*, 2017).

In addition, increased investment in basic research, genetic improvements, and in farm and processing machinery suited to millets needs attention so as to reduce drudgery and minimize post-harvest losses. Governments can also increase demand for millets through educational initiatives and can help create markets for purchasing the grains for institutional programmes. Countries have also been successful in establishing programmes that pay farmers for growing millets (and other selected crops). The food collected is then redistributed to impoverished populations lacking food security (Notaro *et al.*, 2017).

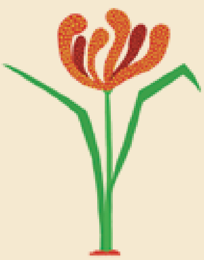
Increased investment in basic research, genetic improvements, and in farm and processing machinery suited to millets needs attention so as to reduce drudgery and minimize post-harvest losses.

There are also various ways for governments and the private sector to invest in local and territorial markets and small-scale farming through micro-loans, subsidized crop insurance products and by giving networks of farmer collectives a seat at the decision-making table to advocate for themselves.

Increased global trade can have both positive and negative effects on farmers. International trade can help countries balance needs for diet diversity and create global markets for local goods. But it can also mean the exportation of products necessary for local food security and the exploitation of inexpensive land and labour for the benefit of international corporations and consumers.

Trade does not automatically result in improved access to food, particularly for the most vulnerable populations – including small-scale farmers and Indigenous Peoples – in developing countries. Many farmers grow millets for their own consumption and food security, and it must be a priority to ensure that farmers remain at the heart of millet production in the future.

BOX 8. Millets and Globally Important Agricultural Heritage Systems (GIAHS)



Globally Important Agricultural Heritage Systems (GIAHS) are agroecosystems inhabited by communities that live in an intricate relationship with their territory. These evolving sites are resilient systems characterized by remarkable agrobiodiversity, traditional knowledge, invaluable cultures and landscapes, sustainably managed by farmers, herders, fishers and forest people in ways that contribute to their livelihoods and food security. Currently, four sites out of 74 systems around the world include millets.

UNESCO-designated sites, such as Biosphere Reserves, Natural World Heritage Sites and Global Geoparks, along with GIAHS could function as places to strengthen the conservation of wild millet germplasm for scientific research, awareness and development of millet species, subspecies and varieties. UNESCO has supported scientific research into the use of millet species (such as *Panicum turgidum* and *Pennisetum divisum*) under marginal soil-water conditions in dry desert countries, and under high-salinity conditions.

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BOX 9. Kodo-Kutki Model

The Kodo-Kutki Model of the project “Linking agrobiodiversity value chains, climate adaptation and nutrition: Empowering the poor to manage risk” provides a successful example. The International Fund for Agricultural Development (IFAD) project focused on two common millets – kodo and *kutki* (little millet) – grown for centuries by the local people of Madhya Pradesh state in India for household consumption. Indigenous women farmers in the project grew traditional millet crops for a commercial market, while protecting the local environment and sharing in the inherent risks of changing farming practices. Over 1 500 women were involved, organized into village groups, with 40 village groups making up a federation of kodo-kutki producers, giving them power in numbers. The state government played a role in training farmers in best agricultural practices and in setting up local centres with hulling equipment and storage space where the millets were aggregated for sale. The federation provided training and high-quality seed to the farmers and good management, while the private sector involved wholesale buyers and banks offering micro-loans.

The local centres for processing and storage meant little crop loss for farmers post-harvest. Because they had a market and were earning money, each participant contributed to the cost of the equipment, making the endeavour financially sustainable. Increased government support of millets through educational programmes meant higher demand for the products and a larger market. By all metrics – financially, environmentally and socially – the project was a success, and helped ensure local food security for the communities.

FIGURE 11. Project results

SOURCE	2014	2019–2020	SDG
Household net return (Indian rupees)	1 800	9 200	1 No poverty
Self-consumption of millets (% of production)	0	17–20	2 Zero hunger; 3 Good health and well-being
Number of farmers growing kodo-kutki millets	1 500	14 300	8 Decent work and economic growth; 5 Gender equality
Area covered by climate-resilient crop (hectares)	303	6 020	13 Climate action

Source: World Bank and Han Ulaç Demirag, 2022

This project is an example of how government policy, working with Indigenous groups, women producers and entrepreneurs, and the private sector, can create market opportunities that are good for local communities by increasing their resilience and diversifying diets. Without tapping into global markets to export their goods, the communities accessed markets, thrived and were in control of their own products from seed to plate.

POLICY SUPPORT NEEDS AND RECOMMENDATIONS

There are clearly many benefits and opportunities for farmers, civil society, opinion leaders, research and development agents, and the general public to reconsider the role of millets in diversified and nutritious diets. Policymakers too are responsible for improving the accessibility and sustainability of our food system. FAO has set out the following policy recommendations in support of the millet sector.

- **The need for genetic conservation of multiple varieties** via gene banks and partnerships with farmers and Indigenous communities preserving materials and traditions.
- **The development of a seed-conservation system**, safeguarding access to the collection by all farmers and Indigenous Peoples.
- **The need for complete and up-to-date analytical food-composition data** on all millet species so that their nutritional content and potential can be fully understood.
- **The creation of incentives for farmers** to diversify production systems including through subsidies for cover cropping, grants for neglected and underutilized crops and crop insurance.
- **Support for initiatives** targeting small-scale farmers for improvements in cultivation, harvesting and storage of millets using gender-sensitive technologies.

- **Small business development grants** for millet entrepreneurs, including improving available processing services.
- **Promotion of millet consumption** as part of healthy diets through public procurement and food education, involving private-sector engagement.
- **Public–private partnerships** to develop more diversified value chains that include millets.
- **Public and private investment** in supporting research and development needs as described above.
- **The creation and maintenance of databases, community organizations and networks** of Indigenous Peoples, researchers, governments, universities, farmers, women's organizations, chefs and the general public interested in millet conservation, cultivation, processing and education.
- **Enabling environment for millet-sector development** by keeping farmers, Indigenous peoples and small and medium businesses at the centre of millet production and processing services.

Barnyard millet
Echinochloa colona

Chapter 7
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DISCLAIMERS AND POINTS TO BE CONSIDERED WHEN INTERPRETING THE RESULTS

- The nutrient values refer to 100 g edible portion on fresh weight basis of raw, uncooked grains.
- Nutrient contents can vary due to factors such as soil, climate, food genetics, agricultural production systems, storage, food processing techniques, food preparation, and others.
- Best practices and international standards were used to compile the nutrient profiles, but ambiguities in identifying foods (i.e. whole grains vs. processed grains) may impact nutrient levels, especially fibre content.
- Data harmonization was carried out for most components, but due to missing information in data sources some values have been marked to indicate they are not directly comparable with others.

VALUES WERE CALCULATED USING THE FOLLOWING EQUATIONS

- Energy (kcal/100 g) was calculated using FAO energy conversion factors: carbohydrates, 4 kcal/g; protein, 4 kcal/g; fat, 9 kcal/g; dietary fibre, 2 kcal/g.
- Available carbohydrates (g/100 g) were calculated by difference as follows: 100 - (water + ash + fat + protein + fibre).
- Protein was calculated from total nitrogen using nitrogen-to-protein conversion factor 5.83 for all species (except for sorghum factor 6.25 was applied), according to FAO/INFOODS Guidelines.

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