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Millets and Millet Technology

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Foreword

World is facing agrarian as well as nutritional challenges. Globally, more than 800 million people are undernourished while >2 billion people have one or more chronic macro- and micronutrient deficiencies (MNDs) notably the minerals calcium (Ca), iodine (I), iron (Fe), selenium (Se), zinc (Zn), and vitamins (e.g., vitamin A). Food-based solutions for dealing with micronutrient deficiencies, although extremely challenging, are potentially sustainable, affordable, effective, and feasible approaches for addressing macro- and micronutrient malnutrition. The whole grains of millets are rich in protein, minerals, and excellent source of other biologically important molecules. Millets rank sixth in the world cereal grain production. In Africa and Asia, these underutilized grains play a major role in the food security of millions of people. They can strongly resist the conditions of drought and even can grow in rain fed region. India is known to be the leading producer of both large and small millets. Considering their climate resilience, role in nutritional and health security, the Government of India has declared the year 2018 as "National year of Millets" and year 2023 as "International Year of Millets" by United Nations. These nutri-cereals harbor vitamins, minerals, essential fatty acids, phyto-chemicals, and antioxidants can help to eradicate the plethora of nutritional deficiency diseases. Millets cultivation can keep dry lands productive and ensure future food and nutritional security.

Millets are orphan crops with tremendous potential but underexplored source of nutraceutical properties as compared to other regularly consumed cereals. Regular consumption of millets can reduce the chance of various live-threatening diseases such as diabetes, obesity, cardiovascular diseases, osteoporosis, and even age-associated diseases. It is not common in our diets so the chance of incorporating it into various types of food products holds a vast scope to study and research for scientific rationalization of its health healing properties and moreover millets can also probably transform food products into magical food products, i.e., super foods using various agri-processing and other modern technologies integrating the fundamental knowledge of genomics, bioinformatics, biotechnology, and nanotechnology. Promotion of millets production and value addition contribute significantly to meet many of the Sustainable Development Goals (SDGs). As significant scientific advances in regulatory, technological, and policy changes, mainstreaming of millets for human welfare will be needed. This book *Millet and Millet Technology* will be proven useful for developing thoughts and solutions that will not be achieved unless enough resources are made available for research and implementation.

In order to aid to nutritional security, development of the novel, value-added food, and healthcare products are the need of time. Therefore, using traditional and modern or advance techniques to process millets for value addition or convenient food products can be a great idea to introduce it for better consumption. Due to its reasonably high grain mineral contents and nutritionally good quality, millets can be used for formulating diets for pregnant and lactating women as well as for growing children. Bioactive substances in foods can represent "extra-nutritional" constituents naturally present in small quantities in the food matrix, produced upon either in vivo or industrial enzymatic digestion, the latter being a result of food-processing activities.

It gives me great honor and pleasure to write this Foreword to the latest book of Dr. Anil Kumar and his editorial team known to me for many years as they are part of our own Central Agricultural University and Indian Council of Agricultural Research where I earlier served as Deputy Director General (Education). This, third book of Dr. Kumar's group from Springer Nature, indicates his keen interest in providing with his tradition of thoroughly reading and conceptualization of thought-provoking topics written by different authors of this book. This book having 21 chapters is a milestone and will evoke a great interest to researchers and students of the various academic institutions, scientists, processors, and consumers.

Rani Lakshmi Bai Central Agricultural University Arvind Kumar
Jhansi, Uttar Pradesh, India

Preface

Globalization and industrialization of agriculture although benefitted with adequate food supplies, its negative side effects have also been realized particularly with respect to loss of agro-biodiversity and sustenance of minor crops. Narrowing of diversity in crop species contributing to the world's food supplies has been considered a potential threat to global food security. Only 12 crops provide 75% of the world's food supplies and three major crops, rice, wheat, and maize, provide 50% of global dietary requirements. While these crops are the primary suppliers of carbohydrates, they lack essential amino acids and minerals for a balanced nutrition. This lack of nutritional quality in human diet affects millions of people worldwide leading to hidden hunger, which results from insufficient vitamins and micronutrients, e.g., zinc (Zn), magnesium (Mg), and iron (Fe) intake. For instance, nearly half of the world's micronutrient deficient population live in developing countries. This is mainly because of overdependence on starchy food such as rice, wheat, and maize. Supplementation of major cereals with alternative crops possessing better nutritive value and nutraceutical properties would be an effective strategy for dietary diversification and reduction of hidden hunger.

Sustainable crop alternatives are needed to meet the world hunger and to increase the income of farmers. Role of millets cannot be ignored for achieving sustainable means for nutritional security. Millets are the crops with high potential as source of underexplored nutraceutical properties and have the potential to act as alternative food-grain in most parts of the world. The gluten-free nature of protein, low glycemic index, high concentration of micronutrients, bioactive flavonoids, and small peptides makes them promising crops for the future agricultural systems to combat hidden hunger. Additionally, the C4 photosynthetic pathway and the ability to withstand environmental stress and low input marginal agriculture make them golden crops of future. Millets are not only the staple food but also serve as an important source of high-quality fodder for livestock in semi-arid regions of the world. In order to promote millets for nutritional and health security due to their richness in nutritionally and biologically important ingredients, it is mandatory to bring them in mainstream of cultivation and value addition. The role of millets in formulating the modern foods like multigrain and gluten-free cereal products is well known. Besides agro-processing, various modern sciences like biotechnology and nanotechnology can also be used to convert agricultural produce into the form which is most acceptable by consumers. Usually, with the help of such technologies, essential nutrients can be added to farm produce or agricultural commodities can be produced in their organic state. Also, the agricultural produce can be modified so as to increase bioavailability of some essential nutrients. As a result of this transformation, the nutritional quality of food is increased and farmers can earn more from their agriculture by selling their produce at higher price to consumers. On the other hand, consumers are ready to pay more price for value-added products as they want to get high-quality nutritious and healthy products to avoid nutrition-related deficiencies or lifestyle-related diseases. Due to increased awareness regarding the health-promoting profile of millets, preference towards their consumption has been observed. Because the consumers have become more health conscious, they are willing to pay more price to buy quality products. Thus, the book *Millet and Millet Technology* is an attempt to put forward various technological approaches by which millets can be proposed as nutraceutical crops from its status of orphan crops. Such opportunities can create employment opportunities for weaker sections of society especially women and rural youths who can establish small industries for the development and marketing of value-added products.

In recent years, there has been a revived interest in cultivation of millets for their use as potential nutritional substitute in food formulations, pharmaceutical use, animal feed and for commercial starch production. Calling them as "climate resilient crops" and "powerhouse of nutrients" the Government of India has declared eight millet crops as nutri-cereals and the year 2018 as "National Year of Millets." Owing to their tremendous agricultural potential, the Food and Agriculture Organization (FAO) declared 2023 as the "International Year of Millets." Keeping in view the global scenario, this book is an attempt to bring together the historical perspective, present status, and future outlook of millets. This book is an attempt to increase awareness among the masses about diversifying and adapting our cropping systems to future consumer needs (qualitative food security) and a changing environment. Our suggestions in the form of this book are widely transferable to many minor crops of immense nutraceutical potential, which have been neglected in the last decades.

The edited book, *Millet and Millet Technology*, comprising 21 chapters will cover the current research and development in the field of millet nutrition, food processing, and novel processing technologies; value-added products, human health, omics approach for grain quality improvement and nutraceutical traits, quality management, and millets-based entrepreneurship development. Chapter 1 of the book is basically an introduction to millets to readers. It gives a cursory impression of the way millets have been adopted and utilized by different societies in the course of history. It further highlights the nutritional and medicinal importance of millets for a healthy lifestyle. Finally, it provides a brief overview of policies to design and execute millet-based climate resilient agricultural technologies. Chapter 2 is devoted to the global production scenario of minor millets and their economic importance. It provides an overview of major production constraints associated with millets and suggested future prospects that can accelerate millet production and productivity.

Minor millets have always been an integral part of tribal agriculture. They are the heritage grains adapted to ecological niches of tribal agriculture where crop substitution is very tough. Therefore, understanding the ethno-botany, traditional knowledge, and its protection in natural habitat is essential for ensuring future food and nutritional security. All these aspects are narrated in Chap. 3. Asia and Africa are the home of the world's largest malnourished population. It has been observed that proportion of malnutrition among the vulnerable section of the society is quite high in these countries. For instance, proportion of children with stunted growth and anemic pregnant women is quite high in these countries compared to the rest of the world. Millets being the native of Asia and Africa have the potential to solve the malnutrition problem of the world. Therefore, Chaps. 4 and 5 are an attempt to understand the unparallel macro- and micronutrient profile, flavonoids, and nutraceutical potential of minor millets for their effective utilization in combating hidden hunger and malnutrition. Millets are nutritionally similar or superior to some major cereal grains. The additional benefits of the millets like gluten-free proteins, high fiber content, low glycemic index, and richness in bioactive compounds made them a suitable healthy food. Similarly, millet starch has very high medicinal and commercial value. The slow digestion of millet starch results in low glycemic load on human belly; therefore, it is an ideal food for people suffering from diabetes and obesity. Chapter 6 covering this aspect is an attempt to compile the latest advances in understanding the structural and functional properties of millet starch. It has been estimated that 97% of the millets are consumed where they are produced. India is one of the largest producers and consumers of millets in the world. They are heavily consumed in the form of various traditional dishes from the southern states to North West and North Eastern Himalayan region. Chapter 7 has covered the consumption pattern of millets in the country.

Millet grains are the source of high-quality protein and nutritive substitute for cereal protein. Millet seed protein is especially preferred as a substitute of wheat in diets of patients with celiac disease due to its gluten-free properties. Therefore, Chap. 8 is the holistic compilation of biologically and nutritionally important proteins and bioactive peptides of millets. While the most widely known health benefit of millets is that the grains are effectively gluten-free, there are several reports of the presence of a variety of bioactive compound with potential nutraceutical properties in their grains. A detailed account of such compounds is dealt with in Chap. 9.

Chapter 10 explores the genomics approaches such as large-scale genotyping and next-generation sequencing for millets improvement and searching genes governing traits of economic importance. Processing is the most important technology for value addition of millets. Therefore, Chaps. 11–14 cover the various aspects associated with millet processing and value addition technology. In Africa, alcoholic and nonalcoholic beverages made from malted and sprouted finger millet, pearl millet, and sorghum are widely consumed. For instance, Nigeria is the largest producer of sorghum beer. Chapter 15 of the book provides a detailed account of millet-based traditional food beverages. Diabetes mellitus is a metabolic disorder characterized by hyperglycemia owing to insufficient or inefficient insulin secretion. Globally, half a billion people are living with diabetes, and in India it is increasing at an alarming rate. The nutraceutical potency of millets aids in lowering the glycemic index (GI) of food containing millets. Therefore, Chap. 16 of the book is specifically devoted to the various millet-based value-added food products for diabetics, their chemical composition, and glycemic index. Chapter 17 provides the current knowledge and emerging insights of genomics, transcriptomics, proteomics, and metabolomics for improving the grain quality like micronutrient accumulation, protein quality, and bioactive compounds.

The processing aspects and development of complete value chain of millets have a huge scope for entrepreneurship development of rural livelihoods promotion. All these developments and strategies are narrated in Chap. 18. In the last decades, several incidents have occurred in the agro-food sectors, such as an incidence of food-borne diseases and production of higher risk food products. Owing to their unparallel nutraceutical potential, millet grains are being used in the development of various food products. Therefore, quality management systems occur for millets from many legal forums, such quality management system utilizing multidisciplinary approach for millets is elaborated in Chap. 19. The last two chapters (Chaps. 20 and 21) of the book deal with the concept of value chain models, demand creation measures, generic incubation, and different business and incubation opportunities possible in the development of value chain on millets.

The chapters of the book have been authored by various experts keeping in view syllabi of different research institutions, researchers, students as well as requirement of the industry. This book will serve as an instructional material for researchers in food science, microbiology, process engineering, biochemistry, biotechnology, and reference material for those working in industry and R & D labs. Efforts have been made to avoid overlapping in contents; however, some overlapping in isolated spots is unavoidable.

We express our sincere thanks to all the contributors of the 21 chapters. We sincerely appreciate their continuous cooperation starting from first submission of drafts to revision of the chapters as suggested by editors. We also thank our family members for bearing us throughout the process of editing of this book.

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Anil Kumar is Director, Education, Rani Lakshmi Bai Central Agricultural University, Jhansi (UP). He has 30 years of research, teaching and administrative experience in various capacities. He had worked as Professor & Head, (2006–2018), Associate Professor (2003–2006) and Assistant Professor (1993–1999) Dept. of Molecular Biology & Genetic Engineering, G.B. Pant University of Agriculture & Technology, Pantnagar. The research interests focus on Plant Molecular & Cell Biology, Functional Genomics, Immunodiagnostic applications in Agriculture, Host-Pathogen Interaction and solving problems of agricultural importance employing the *OMICS* tools and techniques of molecular biology and immunology. He has to his credit more than 250 research papers, reviews, and also several chapters contributed to books, popular articles, 16 Books/Bulletins/Manuals. He has been recipient of several prestigious awards and honors of national importance and also a highly cited scientist who contributed for augmenting biotechnology education in the country.

Manoj Kumar Tripathi is currently working as Principal Scientist at ICAR-Central Institute of Agricultural Engineering, Bhopal, India. He has 17 years of research, teaching and administrative experience. His major areas of professional interest include medicinal compounds, functional Food, nutraceutical, probiotic fermented food, food safety and food quality. He has published more than 80 research papers and 85 abstracts in International and National journal of repute, more than 40 book chapters, 30 popular articles. He has authored/edited 12 books and 5 technical bulletins. He has been recipient of several prestigious awards and honours. He is also working as an editor-In-chief, editor and member of editorial board of more than 10 reputed National and International journals.

Dinesh Joshi is currently working as Senior Scientist at ICAR-Vivekananda Institute of Hill Agriculture, Almora, Uttarakhand, India. He worked on large scale molecular characterization of millets (sorghum) and established unique molecular identification profiles of important sorghum landraces. Currently, his area of specialization includes breeding and genomics of small millets and pseudo-cereals and attained recognition as excellent millets' plant breeder. He has to his credit 30 referred research papers and 15 book chapters.

Vishnu Kumar is currently working as Associate Professor (Genetics & Plant Breeding) at Rani Lakshmi Bai Central Agricultural University, Jhansi. His area of specialization is genetic enhancement of coarse cereals and millets for grain physical and quality traits coupled with grain yield improvement and biotic stress resistance. He has published 70 research papers in referred journals.

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Millets for Life: A Brief Introduction

1

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Abstract

Millets or nutri-cereals are high-energy foods; that were domesticated and cultivated as early as 10,000 years ago. The millets cultivation is taken up usually in degraded and marginal lands that receive very less rainfall and are poor in soil nutrient content. Seven important millets cultivated globally are finger millet, pearl millet, foxtail millet, barnyard millet, proso millet, kodo millet, and little millet. Overdependence on cereals after the green revolution and the present-day sedentary lifestyle of people has proliferated health-related disorders like obesity, diabetes, coronary diseases, gastrointestinal disorders and risk of colon, breast, and oesophageal cancer. The only way to fight back is through the introduction of nutritionally rich millets in our daily diets. Millets are unique for their richness in dietary fibers, antioxidants, minerals, phytochemicals, polyphenols, and proteins; that act as elixir to fight against health-related disorders. Recent global phenomenon of climate change has lead to a decrease in the yield of major staple cereals and has paved path for introduction of millets into agriculture production system to formulate climate resilient cropping systems because millets are C4 plants with very superior photosynthetic efficiency, short duration, higher dry matter production capacity, and a high degree of tolerance to heat and drought. Keeping the

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above advantages of millets, the efforts have hastened to collect, conserve, and utilize germplasm of millets in breeding programs. Of late, several private and government agencies have ventured into value addition of millets to manufacture food and non-food products. But, the governments have a key role in formulating policies to promote cultivation and consumption of millets.

Keywords

Millets · C4 plants · Health related disorders · Climate resilient cropping system · Food and non-food products · Government policies · Climate resilience · Chronic disorders

1.1 Introduction

Millets also called small millets are cultivated for their small kernels which are the products of small grassy plants belonging to the Poaceae family. The other name minor millets may indicate them to be minor crops yet are important for their nutritional values, medicinal benefits, feed for animals, and saviors during food crisis (Joshi and Agnihotri 1984; Yenagi et al. 2010). The word "millet" has originated from the French word "Mile" meaning thousand which implies a handful of millets contain thousands of grains. Millets are often grown in semi-arid conditions with very less rainfall and marginal or degraded lands with very low nutrient contents. The crops support the livelihood of people in areas where famine is a regular phenomenon and the millets yield a more dependable harvest compared to other crops in low rainfall areas (Tadele 2016). Millets are C4 plants with very superior photosynthetic efficiency, short duration, higher dry matter production capacity, and a high degree of tolerance to heat and drought. They also easily adapt to degraded saline, acidic and aluminum toxic soils (Yadav and Rai 2013). These extraordinary characters of millets make them suitable crops to tackle the hurdles of climate change and formulate millet-based climate resilient technologies.

The modern sedentary lifestyle associated with several health issues has urged people to seek for healthy and nutritious diets. Small millets satiate these requirements of modern society by being a healthy food choice because millets are a storehouse of nutrient and, in particular, finger millet grains contain remarkably high calcium content (>350 mg/100 g); foxtail millet, barnyard millet, and proso millet are prosperous in protein (>10%); little millet and foxtail millet are well-off in fat (>4.0%); foxtail millet, barnyard millet, and little millet are superior in crude fiber (6.7–13.6%), barnyard millet and little millet contain high amount of iron (9.3–18.6 mg/100 g) in comparison to other major cereals like rice, wheat, barley, maize, and sorghum (Dwivedi et al. 2012; Kam et al. 2016). The increase in demands of millets in both national and international markets have triggered the interests of researchers to collect, conserve, and utilize the germplasm available globally for their important traits in crop improvement, development of genomic resources, and value addition. Recently several private organizations have ventured into value addition and marketing chain of millets that has boosted millet cultivation and consumption. In this process, the government has a role to play by formulating suitable policies in order to motivate cultivation, marketing, and consumption of millets to achieve food and nutritional security.

There are no less than 14 species of millets belonging to 10 genera, that include pearl millet (*Pennisetum glaucum* L.), foxtail millet (*Setaria italica* L. subsp. *italica*), Finger millet (*Eleusine coracana* L.), barnyard millet (*Echinocloa esculenta* A. and *Echinocloa colona* L.), proso millet (*Panicum miliaceum* L. subsp. *miliaceum*), kodo millet (*Paspalum scrobiculatum* L.), and little millet (*Panicum sumatrense* Roth.) that are cultivated widely throughout the world. However, the study of literature on millets is very cumbersome because of different common names and vernacular names given to the same species of millets and they are usually studied as minor cereals. In this section, we will be listing seven important millets cultivated in the world, their centers of origin, common names or vernacular names, along with area and production in India and the world (Table 1.1).

Pearl millet (*Pennisetum glaucum* L.): Bajra or Pearl millet is estimated to be originated as early as 5000 years in Africa (Andrews and Kumar 1992) and was introduced to the Indian subcontinent around 3000 years ago. The crop is well adapted to adverse environmental conditions with rainfall less than 250 mm and temperature of 30 °C and above and mainly grown by subsistence farmers throughout Africa, Asia, and Australia. Recently the crop is gaining importance as a commercial crop in Australia and accounts for almost half of the world's area under millets (National Research Council 1996).

Foxtail millet (*Setaria italica* L. subsp. *italica*): The probable center of origin of Foxtail millet or Italian millet is China; however, the crop is known to be domesticated during Neolithic culture. It is among one of the ancient cereals cultivated in Europe and Asia, with China contributing more than 45% of world production (Jiaju and Yuzhi 1994). The crop is well adapted to cooler climates and matures in less than 70–120 days.

Proso millet (*Panicum miliaceum* L. subsp. *miliaceum*): Broom millet or Proso millet has probably originated in Manchurian region of China (House 1995) and presently cultivated in northwest China, southern and central parts of India, Australia, the USA, and Europe. It is the third most important millet crop cultivated after pearl millet and foxtail millet and it is well adapted to temperate climatic conditions up to altitudes of 3500 m and various soil types (Baltensperger 2002).

Finger millet (*Eleusine coracana* L.): The ear heads of the crop resemble finger of human hand thus giving it the name. The probable origin of Ragi or Finger millet is highlands of Ethiopia and Uganda (National Research Council 1996). Asia and Africa are major centers of production and India is the leading producer in the world. The crop is adapted to tropical climates with an intermediate altitude (500–2400 m) and low to moderate rainfall (500–1000 mm). The crop can thrive under dry and hot conditions up to 35 °C in well-drained soils. The grains of finger millet can be stored for up to 50 years thus serving as a good reserve against famine (National Research Council 1996).

Table 1.1 Important millets cultivated in India and the world, along with their area and production (2016–2017)

Common name	Scientific name	Vernacular names	Area in world (million ha)	Production in world (million tons)	Center of origin	Major countries	Area in India (million ha)	Production in India (million tons)	Major states	Uses
Pearl millet	*Pennisetum glaucum* L.	Bajra, Bulrush millet, cattail millet, Babala,	27.16	23.09	Africa Sahelian zone (western Sudan to Senegal)	India, Western and Central Africa, Eastern and Southern Africa	7.12	10.28	Rajasthan, Uttar Pradesh, Gujarat, and Madhya Pradesh	Grown for food grain and fodder
Finger millet	*Eleusine coracana* L.	Ragi, Wimbi	2.11	3.42	Highlands of Uganda and Ethiopia	India, Nepal, Sri Lanka, Rwanda, Ethiopia, Uganda, Malawi, Burundi	1.14	1.82	Karnataka, Uttarakhand, Tamilnadu, Maharashtra	Grown for food grain and beer making
Barnyard millet	*Echinocloa esculenta* A.	Japanese barnyard millet	0.15	0.15	Japan	India, Japan, China, Malaysia	0.14	0.146	Madhya Pradesh, Chhattisgarh, Uttarakhand, Maharashtra, and Karnataka	Grown for human food and animal fodder
Shama millet	*Echinocloa colona* L.	Sawa millet, Awnless barnyard grass, Jungle rice Corn panic grass, Jungle			India	India				

		ricegrass, Deccan grass								
Kodo millet	*Paspalum scrobiculatum* L.	Creeping paspalum, Indian paspalum, Water couch, Ditch millet	0.20	0.084	India	India	0.19	0.082		Grown for human food and animal fodder
Proso millet	*Panicum miliaceum* L. subsp. *miliaceum*	Broom millet, Panic millet, Common millet, Hog millet	0.94	1.45	Manchuria	The USA, Russia, India, Iran, Ukraine, South Korea, Poland, Belarus, Kazakhstan, France	0.003	0.002		Grown for human food and animal fodder
Foxtail millet	*Setaria italica* L. subsp. *italica*	Italian millet, Foxtail bristle millet	1.06	2.29	China	China, Myanmar, India, Eastern Europe	0.072	0.052		Grown for human food and animal fodder
Little millet	*Panicum sumatrense*	Blue panic, heen	0.25	0.12	Eastern Ghats of India	India	0.25	0.12	Karnataka, Tamilnadu,	Grown for food

(continued)

Table 1.1 (continued)

Common name	Scientific name	Vernacular names	Area in world (million ha)	Production in world (million tons)	Center of origin	Major countries	Area in India (million ha)	Production in India (million tons)	Major states	Uses
		meneri, Sajje							Kerala, Andra Pradesh	grain and fodder

Source: Directorate of Economics & Statistics, DAC&FW *4th Advance Estimates; IIMR estimates based on FAO/DES-GOI data, Taylor and Emmambux 2008

Barnyard Millet or Sawa millet (*Echinocloa esculenta* A. and *Echinocloa colona* L.): The Barnyard millet or Japanese millet has originated in Japan province, whereas sawa millet was domesticated in the Indian subcontinent (House 1995). Both millets belong to the same genus and their morphology is similar. The crops prefer warm climatic conditions but can be cultivated in cold temperatures too. The cultivation of barnyard millet is mainly taken up in Japan, China, Korea, and India and the crop is known for its good storability.

Kodo Millet (*Paspalum scrobiculatum* L.): or Ditch millet is known to be domesticated 3000 years ago and is indigenous to India (House 1995). Kodo millet is majorly produced in India and the production accounts for 90% of total world production (Hedge and Chandra 2005). Although kodo millet is well adapted to tropical and sub-tropical climatic conditions, the crop takes 120–180 days to mature and the grain yields are very low (250–1000 kg/ha).

Little millet (*Panicum sumatrense* Roth.): Eastern Ghats of India are known to be the place of domestication of Little millet as early as 2000 years ago and the crop is majorly cultivated in peninsular Indian states like Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala. The crop is adapted to both dry and humid conditions and can be cultivated in drought-prone areas as well as water-logged conditions, as the crop matures early and withstands adverse conditions. The genetic diversity of this crop is very little because of its restricted cultivation in India, Sri Lanka, Nepal, and Myanmar, with India accounting for more than 98% of the area and production of little millet.

1.2 History of Millets in India and World

Millets are among the oldest crops domesticated and cultivated in the world for human food and animal fodder and their cultivation dates back to 8700–10,300 years ago (Lu et al. 2009a, b). Various millet species were initially domesticated in different parts of the world like South Asia, East Asia, East Africa, and West Africa. However, they spread well beyond their initial area of domestication. Whereas, the earliest record of millets domestication and cultivation is of Foxtail millet and Proso millet from China around 3000–2000 BC and Indian valley of Kashmir is regarded as a place of integrated networks, where major trade of millets took place between Asia, Europe, and Africa (Oelke et al. 1990). The history regarding the origin of millets, their domestication, and cultivation is very vast and difficult to summarize in a small section, so important dates in the history are briefly covered in the current section.

1.2.1 History in India

The cultivation of millets in India is as old as human civilization. The record of cultivation of foxtail millet during Harappan civilization, Pearl millet in the Neolithic period in South India (2000–1200 BC), kodo millet and finger millet during early

Iron age (1200–1000 BC), little millet, native small millet (*Setaria* spp.), and browntop millet during the later Harappan period (2500–2000 BC), Browntop millet and bristly foxtail millet (*Setaria verticillata*) during Neolithic-Chalcolithic period are some of the recorded proofs of Indian history. There are also specific records like

Harappan civilization: the foxtail millet spread from China and its cultivation started during Harappan civilization in India. Around 2500–2200 BC (Harappan levels) the cultivation of foxtail millet started in Shikarpur (Kutch) and around 1900–1400 BC (late Harappan levels) the cultivation began in Punjab.

Yajurveda or Indian Bronze age (1500 BC): The mention of millets foxtail millet (priyangava), proso millet (aanava), and Barnyard millet (shyaamaka) in Indian Sanskrit text Yajurveda's verses, indicated that millet cultivation and consumption was very common in India (Roy 2009).

Ancient Indian texts: There is a mention of millet cultivation in ancient Indian texts like Sushruta Samhita (600–500 BC)—classification of cereals into millets, Charaka Samhita (100–200 AD)—Sorghum, Vishnu Purana (450 AD)—classification of cereals and millets, Abhijnana Shakuntalam (400–500 AD)—foxtail millet and Ramadhanya Charithre (1600 AD)—finger millet.

1.2.2 History of the World

Cultivation of millets in China and Africa cover the major history of world millet cultivation, wherein foxtail millet cultivation started in China during 3000–2000 BC and was later spread to other regions of the world (Lu et al. 2009a, b; Lawler 2009).

The Pearl millet was cultivated as early as 2500 BC in the Sahel region of West Africa and moreover the cultivation of finger millet in highlands of East Africa dates back to 1800 BC (Engels et al. 1991), wherein vast majority of the people were dependent on the cultivation of millets for their livelihood. But, Palaeoethnobotanists could not find any evidence of millets in their surveys in ancient Egyptian tombs (Krishnaswamy 1938).

There are several literatures showing the recent introduction of millets to European countries, i.e., between 1850 and 1950 AD. But, the cultivation of millets in European countries dates back to the Late Bronze age (3000 BC), wherein in the region of Macedonia and northern Greece the millets were growing in wild and their seeds were stored by the farmers and used as food (Nesbitt and Summers 1988). Megasthenes (350–290 BC) the Greek historian revealed about millet cultivation after the summer solstice, along with sorghum and wheat.

1.3 Nutritional Values of Millets

In the last few decades, the incidence of obesity and diabetes has increased exponentially due to excessive consumption of processed junk foods. To combat them there is rise in demand for foods containing high amounts of complex carbohydrates, dietary fibers, and beneficial phytochemicals (Shobana et al. 2007). Although, the research is in progress to biofortify the wholegrain cereals like wheat and rice, with phenolic acids that impart antimutagenic, antiglycemic, and antioxidative properties, the high content of gluten in these cereals is an obstacle to develop healthy foods or nutraceuticals (Friedman 1997; Jones and Engleson 2010; Chandrasekara and Shahidi 2010). Keeping these drawbacks of wholegrain cereals and the growing public awareness of health care and nutrition, there is an immediate need to identify novel sources of nutraceuticals, natural foods, and nutritional materials with desirable functional characters.

Millets are a good substitute for the major cereals and an elixir to overcome health problems like obesity and diabetes. They are distinctive among cereals because of their richness in dietary fibers, antioxidants, phytochemicals, proteins, and polyphenols (Devi et al. 2011; Muthamilarasan et al. 2016). Table 1.2 represents the nutritional value of minor millets and their comparison with major non-millet cereals, along with mineral content, amino acid composition, and vitamin concentration. From Table 1.2, we can conclude that millets are a very rich source of nutrients and are significantly nutritionally richer than widely cultivated and consumed cereals like rice, wheat, maize, and sorghum (Obilana and Manyasa 2002). Millets are a rich source of calcium (10–348 mg/100 g), iron (2.2–17.7 mg/100 g), zinc (32.7–60.6 mg/100 g), and phosphorus (200–339 mg/100 g), vitamins such as thiamine (0.15–0.60 mg/100 g), niacin (0.09–1.11 mg/100 g), and riboflavin (0.28–1.65 mg/100 g), that makes them a perfect energy food (Kumar et al. 2018). The millets are non-glutinous, so easy to digest. The carbohydrate concentration in most millets ranges from 60% to 70% and having a major portion as non-starchy polysaccharides adding to many health benefits of millets (Shivran 2016). The lower carbohydrate content and non-glutinous property make them most suitable diets for diabetic patients. In particular, finger millet is the richest source of calcium (344 mg/100 g), magnesium (137 mg/100 g), potassium (408 mg/100 g), sodium (11 mg/100 g), and phenolic compounds (0.3–3%). The barnyard millet and foxtail millet have the highest mineral nutrient concentration even among millets, while barnyard millet contains six times higher mineral content than rice. The millets are also rich in fats and millet oil is a good source of oleic acid, linoleic acid, palmitic acid, and tocopherols that are known to play a major role in the immune system and defense mechanism in the human body (Liang et al. 2010; Amadou et al. 2011). Moreover, the millets are a rich source of most essential amino acids like methionine, cysteine, and lysine thus providing special dietary benefits to vegetarians dependent on plant foods to complete their dietary requirements (FAO 2012). However, the millets do contain phytates (0.48%), polyphenols, tannins (0.61%), trypsin inhibitory factors, and dietary fiber, which were earlier considered as "anti-nutrient elements" due to their metal chelating and enzyme inhibition activities (Thompson 1993) but the recent studies have termed them as nutraceutical compounds with antioxidant, metal chelating, and metal reducing power (Chandrasekara and Shahidi 2010).

Apart from grains, the seed coat of millets is an edible component that is rich in phytochemicals, such as polyphenols (0.2–3.0%) and dietary fiber (Hadimani and Malleshi 1993; Ramachandra et al. 1977). It is now recognized that polyphenols,

Table 1.2 Nutritional values of minor millets in comparison with major cereals (composition per 100 g edible portion)

Nutrients	Pearl millet	Finger millet	Foxtail millet	Proso millet	Little millet	Barnyard millet	Kodo millet	Rice (white milled, Raw)	Wheat	Sorghum	Maize	Oats
Energy (kcal)	361	336	331	341	329	300	353	345	346	329		
Protein (g)	11.6	7.7	12.3	12.5	7.7	6.2	8.3	6.8	11.8	10.6	12.1	17.1
Fat (g)	5	1.5	4.3	1.1	4.7	2.2	1.4	0.5	1.5	3.5	4.6	6.4
Ash (g)	2.2	2.7	3.3	1.9	1.5	4.4	2.6	0.6	1.5	1.6	1.8	3.2
Crude fiber (g)	2.3	3.6	8.0	7.2	7.6	9.8	9.0	0.2	1.2	2.0	2.3	11.3
Carbohydrate (g)	67.5	72.6	60.9	70.4	67.0	65.5	65.9	78.2	71.2	72.1	62.3	52.8
Phenols (mg/100 g)	51.4	102	106	–	–	–	368	2.51	20.5	43.1	2.91	1.2
Minerals (g)	2.3	2.7	3.3	1.9	1.5	4.3	2.6	0.6	1.5	1.6		
Minerals and trace elements (mg/100 g dry matter)												
Phosphorous (mg)	296	283	290	206	251	340	215	160	298	222	290	380
Magnesium (mg)	137	137	81	153	133	82	166	64	138	165	140	130
Calcium (mg)	42	350	31	14	12	21	31	10	30	13	30	11
Iron (mg)	8	3.9	2.8	0.8	13.9	9.2	3.6	0.7	3.5	3.36	3.1	6.2
Zinc (mg)	3.1	2.3	2.4	1.4	3.5	2.6	1.5	1.3	2.7	1.7	2.0	3.7
Copper (mg)	1.06	0.47	1.60	5.80	1.6	1.30	5.80	–	–	–	–	–
Manganese (mg)	1.15	5.94	0.6	0.6	1.03	1.33	2.9	0.51	2.29	0.78	0.50	0.45
Molybdenum (mg)	0.069	0.102	0.7	–	–	–	–	0.05	0.051	0.039	–	–
Chromium (mg)	0.023	0.028	0.070	0.040	0.240	0.140	0.080	–	–	–	–	–

Sodium (mg)	10.9	11	4.6	8.2	–	–	–	–	17.1	2	3.0	2.0
Potassium (mg)	307	408	250	113	–	–	–	–	284	363	370	470
Amino acid composition (mg per gram protein)												
Isoleucine	256	275	475	405	416	288	188	181	148	173	154	164
Leucine	598	594	1044	762	679	725	419	345	269	523	480	287
Lysine	214	181	138	189	114	106	188	166	130	89	126	166
Methionine	154	194	175	160	142	133	94	103	56	54	85	62
Cysteine	148	163	–	–	–	175	–	101	101	70	97	136
Phenyl alanine	301	325	419	307	297	362	375	222	179	218	199	192
Tyrosine	203	–	–	–	–	150	213	199	125	175	166	160
Threonine	122	191	263	61	49	35	63	144	125	133	148	137
Tryptophan	122	191	61	49	35	63	38	55	43	99	16	39
Valine	345	413	431	407	379	388	238	269	199	221	211	227
Vitamins												
Thiamine (mg)	0.33	0.42	0.59	0.2	0.41	0.30	0.33	0.41	0.45	0.33	0.38	0.77
Riboflavin (mg)	0.25	0.19	0.11	0.18	0.28	0.09	0.10	0.06	0.17	0.096	0.14	0.14
Niacin (mg)	2.3	1.1	3.2	2.3	–	–	0.70	1.9	5.5	3.7	2.80	0.97
Total folic acid (ug)	45.5	18.3	15	–	–	–	–	8	36.6	20	–	–
Vitamin E (mg)	–	22	–	–	–	–	–	–	–	0.5	–	–

Source: Shivran (2016), Kaur et al. (2019), Gopalan et al. (2004), USDA National Nutrient Database for Standard Reference, Release 28 (2016), Muthamilarasan et al. (2016)

phytates, and tannins add to antioxidant activity of millet foods, which is an imperative factor in human health, aging, and metabolic diseases (Bravo 1998). Considering the nutritional richness of millets, they have to be an essential constituent of human diet in order to augment people's diet diversity and maintaining good nutrition.

1.4 Medicinal Values or Health Benefits of Millets

As seen in the previous section, the millets are known for their superior nutritional values along with several health benefits, which are attributed to their richness in polyphenols, dietary fibers, non-glutinous as well as non-starchy carbohydrate content making them superior over major wholegrain cereals (Muthamilarasan et al. 2016). Millets are also documented for their beneficial health effects like antioxidant activity, anti-diabetic, anti-tumorigenic, atherosclerogenic effects, and antimicrobial properties (Yang et al. 2012). Cardiovascular diseases, risk of type II diabetes, gastrointestinal cancers, and a range of other disorders can be kept at bay by regular consumption of whole grain millets and their products (McKeown 2002). Based on several epidemiological studies, consumption of millets improves the digestive system, detoxifies the body, lowers the risk of cancer, increases energy levels, increases immunity in respiratory health, and improves neural and muscular systems. Millet consumption also protects against several degenerative diseases such as Parkinson's disease and metabolic syndrome (Manach et al. 2005; Chandrasekara and Shahidi 2012). Usually, millets are consumed along with seed coat that is rich in minerals, dietary fiber, vitamins and phenolics, which offer better health benefits to humans than other wholegrain cereals (Antony et al. 1996). Some major health benefits of individual millets in our daily diet are furnished in Table 1.3.

1.4.1 Millets Are Cure for Coronary Diseases

The millet grains are the powerhouse of nutrition that help in improving heart health and effectively trim down the coronary blockage. They are enriched with magnesium, potassium, and plant lignins, which effectively reduce blood pressure by acting as a vasodilator and decrease heart attacks and other cardiovascular risks. The high fiber content of millets lowers the cholesterol level thus eliminating LDL (Low Density Lipoprotein) from the system and increases the positive effects of HDL (High Density Lipoprotein) in the body (Kumari and Thayumanavan 1997; Park et al. 2008; Lee et al. 2010).

1.4.2 Millets Can Manage Sugar Level to Tackle Diabetes

Diabetes mellitus is a chronic metabolic disorder characterized by hyperglycemia with alterations in carbohydrate, protein, and lipid metabolism. It is a common