2019

Beyond Bird Feed: Proso Millet for Human Health and Environment

Saurav Das
University of Nebraska-Lincoln, saurav12das@gmail.com

Rituraj Khound
University of Nebraska-Lincoln, rkhound2@unl.edu

Meenakshi Santra
Colorado State University, meenakshisan@yahoo.com

Dipak K. Santra
University of Nebraska-Lincoln, dsantra2@unl.edu

Das, Saurav; Khound, Rituraj; Santra, Meenakshi; and Santra, Dipak K., "Beyond Bird Feed: Proso Millet for Human Health and Environment" (2019). *Agronomy & Horticulture -- Faculty Publications*. 1235.
https://digitalcommons.unl.edu/agronomyfacpub/1235

agriculture

MDPI

Review

Beyond Bird Feed: Proso Millet for Human Health and Environment

Saurav Das [1], Rituraj Khound [1], Meenakshi Santra [2] and Dipak K. Santra [1,*]

[1] Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Scottsbluff, NE 69361, USA; sdas4@unl.edu (S.D.); rkhound2@unl.edu (R.K.)

[2] Department of Soil and Crops Sciences, Colorado State University, Fort Collins, CO 80523, USA; meenakshisan@yahoo.com

* Correspondence: dsantra2@unl.edu

Received: 1 February 2019; Accepted: 20 March 2019; Published: 24 March 2019

Abstract: Domesticated in 8000–10,000 BP in northern China, proso millet (*Panicum miliaceum* L.) is the best adaptive rotational crop for semiarid central High Plains of the USA, where average annual precipitation is 356–407 mm. Proso millet has multiple benefits when consumed as human food. Proso millet is rich in minerals, dietary fiber, polyphenols, vitamins and proteins. It is gluten-free and therefore, ideal for the gluten intolerant people. Proso millet contains high lecithin which supports the neural health system. It is rich in vitamins (niacin, B-complex vitamins, folic acid), minerals (P, Ca, Zn, Fe) and essential amino acids (methionine and cysteine). It has a low glycemic index and reduces the risk of type-2 diabetes. Unfortunately, in the USA, it is mostly considered as bird feed, whereas it is mainly used as human food in many other countries. Besides human health benefits, proso millet has an impeccable environmental benefit. Proso millet possesses many unique characteristics (e.g., drought tolerance, short-growing season) which makes it a promising rotational crop for winter wheat-based dryland farming systems. Proso millet provides the most economical production system when used in a two years wheat/summer fallow cropping system in semiarid High Plains of the USA. It helps in controlling winter annual grass weeds, managing disease and insect pressure and preserving deep soil moisture for wheat. Proso millet can also be used as a rotational crop with corn or sorghum owing to its tolerance for atrazine, the primary herbicide used in corn and sorghum production systems. Proso millet certainly is a climate-smart, gluten-free, ancient, and small grain cereal, which is healthy to humans and the environment. The main challenge is to expand the proso millet market beyond bird feed into the human food industry. To overcome the challenge, unique proso millet varieties for human food and ready-to-use multiple food products must be developed. This requires successful collaboration among experts from diverse disciplines such as breeders, geneticists, food chemists and food industry partners.

Keywords: proso millet; food; gluten; human; dryland; USA

1. Introduction

Millets are annual small-seeded cereal crops grown all over the world for food, feed, forage and fuel. There are about 20 different species of millets. Commonly cultivated species include proso millet (*Panicum miliaceum* L.), pearl millet (*Pennisetum glaucum* (L.)R.Br.), finger millet (*Eleusine coracana* Gaertn.), kodo millet (*Paspalum scrobiculatum* L.), foxtail millet (*Setaria italic* (L.) P. Beauvois), little millet (*Panicum sumatrense* Roth ex Roem. & Schult.) and barnyard millet (*Echinochloa esculenta* (A.Braun) H.Scholz) [1]. Though they belong to the *Poaceae* family, a significant morphogenetic diversity exists at species, genus and subfamily levels. They differ at their genome size, ploidy levels and breeding systems [2]. Millet is the world's sixth most important cereal grain supporting as a major source of energy and protein for millions of people in India, Africa, and China, and especially for the people living in arid and semiarid regions [3]. Millets are cultivated globally with major contributions from India, Nigeria, Niger, China, Mali and Burkina Faso [4]. Asia (48%) and Africa (48%) dominate the production of millet compared to Europe (3%) and America (1%) (Figure 1) [4]. Short duration and wide adaptability under different environmental conditions make millet one of the most suitable crop for sustainable agriculture and future food security [1]. Millets can give significantly higher yields on marginal lands with low fertility and low input agricultural systems compared to many other crops. Millet can serve as a savior for the world's rapidly increasing population with the potential to avert food shortage and famine.

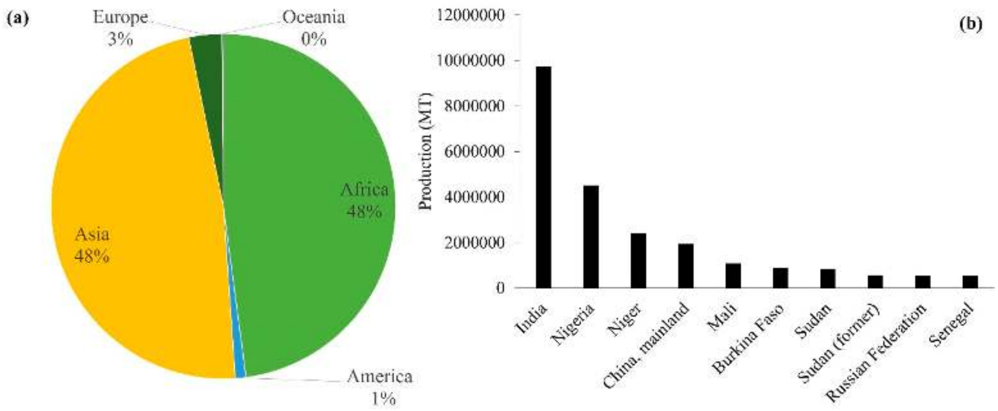

Figure 1. (**a**) Global millet production. (**b**) The world's top 10 millet producers. India, African countries and China dominate the production scale. (*Production units are in Metric Tons (MT)). (Data: FAOSTAT, 2016, accessed from http://www.fao.org/faostat/en/#data/QC/visualize).

Proso millet (PM) is popularly known as Broomcorn millet (China), Common millet (USA), Barri (India), Broomtail millet, Kashfi Millet, Red Millet, and White Millet, Brown Millet, Chinese Millet, Kibi, Mijo (Spain), Panic Millet (France), Gijang (Korea) (Figure 2) [5,6]. PM was domesticated in 8000–10,000 BP in northern China. PM is distributed around the world for its wide adaptability in different climatic zones [1,7]. It is widely cultivated in India, China, Nepal, Africa, Russia, Ukraine, Belarus, Middle East, Turkey and Romania. It was introduced in North America in 1875 by the German-Russian immigrants, who planted along the eastern Atlantic coast [1,8]. It is one of the best-suited crops for the rainfed agricultural system where annual rainfall is $\leq$100 mm [8,9]. The shallow root system (90–120 cm) and short growing season crop (60–90 days) make it an ideal dryland crop [10,11]. In the USA, it is grown as a dryland crop on an average of 204,366 ha land [12]. Its production in the Central Great Plains (CGP) is mainly concentrated in the states of Nebraska, Colorado and South Dakota [8]. Proso millet is an important rotational crop used in CGP following sunflower (*Helianthus annuus* L.) and corn (*Zea mays* L.) because of the short growing season and high-water use efficiency [9,11]. The short growing season allows farmers to harvest the millet prior to sowing the winter crops. This is an important feature as winter wheat serves as the base crop for most of the dryland cropping system.

PM is an under-utilized crop although one-third of protein and energy in developing countries are derived from it. The major market share for PM is contributed by birdseed industries. Irrespective of several health benefits, including gluten-free, low glycemic index, high protein, and fibers, PM is still struggling to enter human food markets. Recent increases in gluten-free trends and escalation in health consciousness among people have created renewed interests in ancient grains. The human food market for PM has found its way to different breakfast cereals, bakery products, fermented products and brewing. Promotional marketing, research for the development of new varieties, and awareness among farmers and consumers are necessary to revive the lost ancient trend where PM was common in cuisines of different communities.

Figure 2. Proso millet (*Panicum miliaceum* L.).

There are few review papers on millets for human health and environmental sustainability. However, there is no such review article specifically on PM. Therefore, the purpose of this paper was to provide comprehensive information on PM for environmental benefits and human health, its socioeconomic importance, and PM-based food around the world.

2. Methodology

The following methods were used to for this paper. We undertook a literature search for relevant studies (peer-reviewed journals, and news articles) especially addressing the purpose mentioned above. Primary keywords used in search were proso millet, drought, climate, health benefits, ancient grain and water use efficiency. As an inclusion criterion, we tried to incorporate the most recent studies and a few old relevant reports for which no recent reports were available.

Due to a lack of published information on PM-based food around the world, we thought that the best way to gather information is through personal communication with PM scientists in countries growing millets from ancient times. We hypothesized that the countries growing millets for this long should have this cereal as an important ingredient of their food culture. Thereafter, we identified proso millet research groups working on health benefit aspects and developing different food recipes. Then, based on our past attendance of the International Broomcorn Millet Symposium (1st in 2012: China; 2nd in 2015: Korea, 3rd in 2018: USA), we communicated (via emails) with the scientists in USSR, Japan, Korea, and Europe (Germany, Switzerland, Italy) and India.

3. Proso Millet for Climate-Change

Increasing population always corresponds to increased demand for food. At present, on average 50% of the total calorie intake of the world is supported by cereals [13]. Wheat, rice, and maize are the key cereal crops which dominate global production. However, an increase in the production areas of these high water requiring crops has also increased water requirements for agricultural systems. According to Sharma (2016), an increase in total acreage by 1% in the production of rice, sugarcane and cotton have decreased the distance of groundwater water level and groundwater table by 0.009%, which is equivalent to the loss of 7191 L of groundwater/ha [14,15]. PM is highly adapted to dryland cropping systems with high water use efficiency and short growing seasons. They can grow in marginal lands and can give a significant amount of yield compared to major cereal crops.

3.1. Drought

Development of climate resilient and high yielding varieties to feed the future generations is always a concern for the scientific community. Among different climatic stresses, drought is a constant environmental pressure to one-third of the agricultural land in the world. Nearly 1.3 billion people or 40% of the world population are affected by drought [16]. Limited water availability of semiarid lands always demands a plant variety with high water use efficiency as well as adaptability to high temperature. McDonald [17] provided a climate model which projected an increase of arid environment in the 21st century in the south western United States with far reaching impact. Drought can severely affect yield in rain-fed or dryland agricultural systems. Drylands can be classified into four major types, viz. hyper-arid deserts, arid, semiarid and dry sub-humid [18]. PM are greatly cultivated in the semiarid region of the world where low and erratic rainfall is common with periodic drought. PM can produce significant yield with water requirements as low as 20–50 cm (entire growing season: planting to harvest), which is several folds lower than wheat (30–100 cm) and rice (100–300 cm) (Table 1) [15]. As in every crop, most of the water use occurs during active vegetative growth to seed filling stage. A study by Habiyaremye, showed significant yield under water-stressed non-irrigated conditions but there was no significant correlation between the varieties and yield in irrigated vs. non-irrigated land. This suggests the same variety which has a higher yield at irrigation may not be high yielding at non-irrigation. According to their studies, varieties like "GR658" and "Minsum" were very successful in non-irrigated plots while "GR665" and "Earlybird" were successful in irrigated plots [10].

Millet uses a three-way system to adopt drought stress, viz. drought escape, drought avoidance and drought tolerance [19,20]. In drought escape, the plant reaches maturity before the onset of drought. Drought escape-associated characteristics of plants are rapid growth, early flowering, high leaf nitrogen level, and high photosynthetic capacity [21]. Early maturing and short season of the PM helps them to escape the drought before it occurs. In drought avoidance, plants maintain an optimal water balance inside the tissue under low moisture by reducing the stomatal conductance, thus reducing transpiration. As a C4 plant, millets can reduce their photorespiration rate by controlling the stomatal conductance [22]. Drought tolerance is referred to as plants' ability to produce significant yield by withstanding low water potential. Associated traits are like increased osmoprotectants (like betaines and amino acids) and osmotic adjustments (reducing osmotic potential by accumulating organic and inorganic substances) [19,21].

Table 1. Optimal environmental conditions for the major cereal crops and millet.

Crop	Scientific Name	Optimum Soil Type	Altitude Range (m)	Temp. (°C)	pH	Soil Salinity (dS/m)	Rainfall Required (cm)	Maturity Time (days)
Rice	*Oryza sativa* L.	HSL	≥2500	21–37	6.5–8.5	<3.0	100–300	100–160
Wheat	*Triticum aestivum* L.	LC or HL	≥2500	1.3–35	6.0–7.0	6.0	30–100	90–125
Sorghum	*Sorghum bicolor* (L.) *Moench*	C or L	≥3000	7–30	5.0–8.0	4.0–6.0	40–100	90–120
Pearl millet	*Pennisetum glaucum*	LC or SL	≥2700	30–34	6.0–7.0	11.0–12.0	20–60	60–70
Finger millet	*Eleusine coracana*	L	≥2300	26–29	4.5–7.5	11.0–12.0	50–60	90–120
Proso millet	*Panicum miliaceum*	SL, A	1200–3500	20–30	5.5–6.5	1.5–9.5	20–50	60–90
Foxtail millet	*Setaria italica* (L.) P. Beauvois	SL	≥2000	5–35	5.5–7.0	6.0	30–70	75–90
Barnyard millet	*Echinochloa*, *E. frumentacea* (Indian barnyard millet) and *E. esculenta* (Japanese barnyard millet),	HSL	≥2000	15–33	4.6–7.4	3–5	–	45–70
Kodo millet	*Paspalum scrobiculatum*	F/M Land	≥1500	25–27	–	–	80–120	100–140
Little millet	*Panicum sumatrense*	–	≥2100	–	–	–	–	80–85
Corn	*Zea mays*	SL	≤2200	25–33	5.5–7.0	1.7–4.0	50–65	60–100
Sunflower	*Helianthus annuus*	SL	–	21–26	6.0–7.5	–	50–100	80–120

– = no report; H—Heavy, S—Sandy, L—Loam, A—Acidic, F—Fertile, M—Marginal. (Source: [15,23]).

Optimum crop productivity with low agricultural input is essential to ensure the security of global food supply and protect the diminishing freshwater resources. Irrigation requirements to mitigate productivity loss associated with drought makes the agricultural industry one of the largest consumers of water [24]. Around 2 billion people in the future will not have access to water, which will impact food production, socio-economic development and human health [25]. To address the challenge in future, we would require an integrated approach combining modern irrigation practices and the crops with high water use efficiency (WUE) [26,27]. WUE is defined as the ratio of biomass produced to the rate of transpiration. Increased water utilization can be seen in the plant while adapting to severe soil water deficits. Therefore, developing a crop with high WUE is a focus of many drought-resistant crop studies. However, the question lies in a simultaneous increase in productivity along with the water use efficiency, which is the desired trait in crop production. Drought is a permanent constraint limiting crop production in many developing and developed countries. Developing countries often suffer more due to lack of precision agriculture and lack of advanced irrigation practices [28]. Thus, it has always been a challenge for plant breeders to develop and select genotypes endowed with WUE that exhibit high yield in drought stress conditions. Most of the crops require additional irrigation, while PM can get 90% of the total seasonal water requirement from the precipitation during the growing season and stored water in topsoil [29]. Low water availability has a lesser effect on PM yield compared to other crops, and its yield increases with additional water at a rate of 132 kg/ha/cm. Yield response to water use of PM was 32.57 kg/ha/mm, which is higher than the other C4 crops, like corn 25.7 kg/ha/mm and grain sorghum 30.2 kg/ha/mm [11]. This indicated that PM has higher water-use efficiency than other C4 crops corn and sorghum. Similarly, Shantz and Piemeisel, also reported PM as one of the most water-use efficient crop out of the 52 crops they compared. A total of 100 mm/ha of water is adequate to initiate seed formation in PM, which is much lower than that for wheat (127 mm/ha), sunflower (177 mm/ha) and corn (228 mm/ha) [30]. A study by McDonald et al., in Colorado reported that a total of 330–355 mm/ha annual water is what is needed for PM [9,30,31]. The critical stage for water requirement in PM is before and after anthesis. Water stress during flower induction and inflorescence can delay flowering [32–34]. However, a recent study by Habiyaremye et al., reported water stress did not affect flowering of PM [9].

The shallow root system of PM makes it an efficient crop at removing water from the topsoil and converting it to dry matter. It also allows PM to adapt and grow without using much subsoil water and mostly relies on early summer rains. Due to this, the soil moisture level at planting can be used to predict grain yield as it responds more considerably to soil water at the time of planting when compared to crops such as corn, sunflower and sorghum [10,11,29].

3.2. Marginal and Degraded Soil

Drought-prone areas always have a major problem of low fertility and degraded soils, which leads to huge economic losses. However, PM can be successfully grown in poor land with lower water holding capacity and low fertility. PM can be successfully cultivated in acidic soil with a pH of 5.5–6.5, which is not possible in the case of wheat or rice, which need pH 6.0–7.0 and 6.5–8.5, respectively. PM can also be cultivated in high altitude soils ranging from 1200 to 3500 m above sea level (Table 1). Salinity is one of the major causes of land degradation in semiarid and arid regions. In Europe, about 3.8 million ha of agricultural lands are affected by soil salinity. Rice and wheat are very sensitive to saline soil. Rice is resistant $\leq$3.8 dS/m, while wheat is resistant up to $\leq$6.0. However, millets are very well adapted to salinity and can resist up to 11–12 dS/m (Table 1). PM was found to be resistant up to 1.5–9.5 dS/m [23].

3.3. High Temperature

The Intergovernmental Panel for Climate Change (IPCC) has predicted a rise of 2 °C in the Earth's temperature. This increase can greatly affect the productivity of major crops like wheat, maize and rice, especially in tropical regions like West Africa, South East Asia, Central and Northern South

America [35]. As a warm season crop, millets are highly adapted to high temperature and very much sensitive to frost. The optimal temperature for growth is 20–30 °C. In addition, the rise in temperature above 30 °C stops the vegetative growth and flowering of PM, and its primary stems are maintained at a shorter height to better resist the drought [10].

3.4. Rotational Crop

PM is usually planted in late May or early June and harvested in late August or early September. It can be used in rotation with the small grain and row crops. A five-year study by Baltensperger et al., in west-central South Dakota comparing the winter wheat-fallow and winter wheat-PM rotation showed 71% yield advantage over the fallow cropping system [29]. Besides the economic advantage, planting of PM in the summer fallow improves the control of volunteer wheat and winter annual grass weeds, reduces insect and disease pressure along with maintaining adequate soil moistures for the deep-rooted crops [29,36,37]. Extensive root systems of sunflower or corn often depletes soil water at 183 cm or deeper which restricts planting of a second deep-rooted crop immediately afterwards. The winter wheat/sunflower/PM/fallow rotation was successful in many areas of the great plains in restoring the subsoil water [29]. In a study by Nielsen and Vigil they found PM planted in very wet soil followed by a dry growing season surprisingly only extracted 257 mm water out of an entire 0–180 cm of water [38]. PM can also be used with a rotation of corn or sorghum because of its ability to tolerate atrazine, an herbicide input in the corn and sorghum production systems. Planting of PM followed by two winter crops or by a winter crop and fallow period reduces 90% of the annual summer weed seedbanks [1]. An introduction of alternative crops in cropping systems of low rainfall areas can provide better weed management compared to summer fallow. Rasmussen et al. (1998) also found that the cropping system with summer fallows loses organic matter due to high biological oxidation and absence of any organic carbon input in the fallow year [39]. Thus, growing crops such as PM in a summer fallow system conserves the organic matter and helps farmers to meet soil conservation requirements. Along with this, as an added benefit, PM can be an extra cash crop in wheat-PM-fallow rotation and can compensate for wheat crop loss due to environmental calamities like freezing, wind erosion, drought or hail [40]. A comparative study of conventional tillage, reduced tillage and no-tillage production systems indicated that wheat-corn-PM and wheat-PM rotation produces double the grain compared to wheat-fallow rotation [41]. It was also observed that continuous cropping systems with wheat-corn-PM and wheat-PM rotations with no-tillage increases the soil concentration of glomalin which is important to improve soil aggregation [42]. Residue of PM can also improve snow capture providing much-needed soil moisture for crops in semiarid plains [29].

4. Proso Millet as Human Food and Health Benefits

Nutritional quality is the key element that determines the dietary importance of a grain and its importance towards human health. PM is known for several health benefits. It has high nutritive value and is comparable to major cereal grains (Table 2). PM is a good source of minerals like calcium, phosphorus, potassium, sodium, magnesium, manganese, iron, magnesium and zinc (Table 3). PM has all the essential amino acids viz. methionine, phenylalanine, tryptophan, valine etc. [43] (Table 4). The limiting amino acid in PM is lysine, which is only 189 mg/g (Table 4). The essential amino acid index was found to be higher (51%) in PM compared to wheat [44]. Major nutritional component protein, carbohydrate, and energy values are comparable to popular cereals like rice, wheat and barley (Table 2). PM has 11% (which may range from 11.0% to 14.0%) of protein per 100 g of grains, compared to that of wheat (14.4%) and rice (7.5%) (Table 2) [45]. Moreover, PM has a low glycemic index (GI) compared to rice, wheat, and barley, which makes it an ideal food for people with type-2-diabetes mellitus and cardiovascular disease (CVD). Products prepared with 100% PM showed GI (%/g) of 50–65 compared to 70–80 of refined corn and wheat-based products [46].

Table 2. Nutritional composition of millets and other cereals (per 100 g).

Cereals	Protein (%)	Fat (%)	Crude Fiber (%)	Ash (%)	Starch (%)	Total Dietary Fiber (%)	Total Phenol (mg/100g)
Wheat	14.4	2.3	2.9	1.9	64.0	12.1	20.5
Rice	7.5	2.4	10.2	4.7	77.2	3.7	2.51
Maize	12.1	4.6	2.3	1.8	62.3	12.8	2.91
Sorghum	11.0	3.2	2.7	1.8	73.8	11.8	43.1
Barley	11.5	2.2	5.6	2.9	58.5	15.4	16.4
Oats	17.1	6.4	11.3	3.2	52.8	12.5	1.2
Rye	13.4	1.8	2.1	2.0	68.3	16.1	13.2
Finger millet	7.3	1.3	3.6	3.0	59.0	19.1	102
Pearl millet	14.5	5.1	2.0	2.0	60.5	7.0	51.4
Proso millet	11.0	3.5	9.0	3.6	56.1	8.5	13.3
Foxtail millet	11.7	3.9	7.0	3.0	59.1	19.1	106.0
Kodo millet	8.3	1.4	9.0	3.6	72.0	37.8	368.0

Source: [45].

Table 3. Mineral composition of the millets and other cereals.

Cereals	Ca (%)	P (%)	K (%)	Na (%)	Mg (%)	Fe (%)	Mn (%)	Zn (%)	Thiamin (mg/100 g)	Riboflavin (mg/100 g)	Nicotinic Acid (mg/100 g)
Wheat	0.04	0.35	0.36	0.04	0.14	40.10	40.00	30.90	0.57	0.12	7.40
Rice	0.02	0.12	0.10	0.00	0.03	19.00	12.00	10.00	0.07	0.03	1.60
Maize	0.03	0.29	0.37	0.03	0.14	30.00	5.00	20.00	0.38	0.14	2.80
Sorghum	0.04	0.35	0.38	0.05	0.19	50.00	16.30	15.40	0.46	0.15	4.84
Barley	0.04	0.56	0.50	0.02	0.14	36.70	18.90	23.60	0.44	0.15	7.20
Oats	0.11	0.38	0.47	0.02	0.13	62.00	45.00	37.00	0.77	0.14	0.97
Rye	0.05	0.36	0.47	0.01	0.11	38.00	58.40	32.20	0.69	0.26	1.52
Finger millet	0.33	0.24	0.43	0.02	0.11	46.00	7.50	15.00	0.48	0.12	0.30
Pearl millet	0.01	0.35	0.44	0.01	0.13	74.90	18.00	29.50	0.38	0.22	2.70
Proso millet	0.01	0.15	0.21	0.01	0.12	33.10	18.10	18.10	0.63	0.22	1.32
Foxtail millet	0.01	0.31	0.27	0.01	0.13	32.60	21.90	21.90	0.48	0.12	3.70
Kodo millet	0.01	0.32	0.17	0.01	0.13	7.00	–	–	0.32	0.05	0.70

Source: [45].

Sedentary lifestyle and food habits are the primary cause of diabetes, obesity and cardiovascular diseases. Therefore, dietary modification is an important preventive and protective measure against all metabolic disorders. PM protein (PMP) has an important role in cholesterol metabolism as they can increase concentration of the high-density lipoprotein (HDL) cholesterol level, especially the isomer HDL2, and adiponectin without affecting the concentration of low-density lipoprotein (LDL) cholesterol. Adiponectin is important in accelerating insulin sensitivity and promotes lipid metabolism [47]. Clinical studies showed that lean people have more adiponectin compared to obese people [48]. Research by Park et al. (2008) clearly indicates upregulation in the expression of adiponectin in PMP diet modules [49]. Elevated levels of HDL in bloodstream also can help in maintaining blood LDL level and can protect endothelium or inner walls of blood vessels from any damage. Damage to inner walls of blood vessels is considered as the first step in the process of atherosclerosis, which is the reason for heart attack or stroke [50]. Thus, feeding of PMP can actively reduce blood glucose and insulin levels under high-fat diet conditions by elevating levels of HDL and adiponectin. PMP also downregulate tumor necrosis factor alpha (TNFα) and increase insulin sensitivity as both are negatively correlated [49]. Dietary improvement and avoidance of gluten is the only nutritional therapy available for a person suffering from celiac disease. As in this disease, people are allergic to gluten (a protein found in the wheat, rye, barley, oats etc.). On average 1% of the European and US population is suffering from celiac disease [51].

Nutrient composition of PM has been evaluated by many authors, [43,45]. PM has high mineral content that includes calcium, iron, potassium, magnesium, phosphorous, zinc, dietary fiber, polyphenols and protein (Table 3). PM contains a high amount of lecithin which plays an important role in the neural health system by repairing and regenerating myelin fiber and intensifying brain cell metabolism. PM also contains a significantly high amount of vitamin B-complex, folic acid and niacin [52,53]. The mineral content of PM is much higher in comparison to major cereal grains. High content of fiber, and antioxidants in PM is also valuable in prevention of CVD and cancer. A study by Zhang et al. (2014) showed antiproliferative properties of PM against MDA (originally isolated as part of the MD Anderson series of breast cancer cells; hence MDA) human breast cancer and HepG2 human liver cancer cells [54]. PM in regular diets can lower cholesterol, TNFα, phytate, and increase HDL and adiponectin. An increase in HDL and adiponectin can reduce the risks of many hormone-dependent cancers, CVD and breast cancer [1,49,55]. PM can be used as a prebiotic. Non-digestible carbohydrates in PM helps in the growth of desirable microflora in the intestine. It can prevent constipation and is, therefore, quite effective as preventive food against colon cancer [56].

Table 4. Essential amino acid composition (mg/100 g) of different millet.

Grain	Isoleucine	Leucine	Lysine	Methionine	Cystine	Phenylalanine	Tyrosine	Threonine	Tryptophan	Valine
Sorghum	245	832	126	87	94	306	167	189	63	313
Pearl millet	256	598	214	154	148	301	203	241	122	345
Finger millet	275	594	181	194	163	325	-	263	191	413
Foxtail millet	475	1044	138	175	-	419	-	194	61	431
Proso millet	405	762	189	160	-	307	-	147	49	407
Little millet	416	679	114	142	-	297	-	212	35	379
Barnyard millet	288	725	106	133	175	362	150	231	63	388
Kodo millet	188	419	188	94	-	375	213	194	38	238

Source: [57].

5. Proso Millet vs. Quinoa

In the last few years, the market share of ancient grains has increased rapidly. Nutritional benefits of ancient grains have created a rapid hype in the health food market [58]. PM and quinoa are two popular grains which resemble each other in many characteristics including seed shape, color and nutritional profile. Though their similarities, PM, which is long known for the health benefits, could not generate much hype in consumers despite being lower priced (US $4.4/kg) compared to quinoa (US $15.4/kg). In the last decade, the export of quinoa has exponentially increased in developed countries including the USA and UK. The exponential increase has also created distressing ecosystem and imbalance in regional markets. It indicates a big gap between the available information on nutritional profile of PM to consumers and stakeholders. The lesser known and underutilized PM have similar nutritional qualities to substitute quinoa in a more sustainable way. We tried to provide a comparative study between PM and quinoa to provide a better understanding of the differences.

Quinoa and PM are gluten-free with a low glycemic index, rich in protein, vitamins and minerals (Table 5). Protein content is higher in quinoa than in PM. While both quinoa and PM are rich in all the essential amino acids, lysine is low in PM. Both quinoa and PM are rich also in dietary fiber and antioxidants. Therefore, the nutritional composition of quinoa and PM is essentially similar except for protein content.

Quinoa seed can be white, red, black and purple, while PM seeds can be white, red, yellow, or black. Quinoa seeds are oval or disk-shaped while PM seeds are mostly circular. Both PM and quinoa seeds have mild flavors.

Price Hike and Ecosystem

A wave of superfoods in developed countries like the US and UK has led to the relatively unknown commodity quinoa to become an upper-class staple in the last decade. Import of quinoa to the US has witnessed a tenfold increase from 0.24 million kg per year in 2004 to 3.37 million kg in 2017. Price has also quadrupled in these years [59]. Rise in price has raised several questions and concerns regarding welfare of individual and households where quinoa is traditionally produced and consumed (Peru, Bolivia, Colombia, and Ecuador). One study by Blythman (2013), which was published in the Guardian claimed the following: *"There is an unpalatable truth to face for those of us with a bag of quinoa in the larder. The appetite of countries such as ours for this grain has pushed up prices to such an extent that poorer people in Peru and Bolivia, for whom it was once a nourishing staple food, can no longer afford to eat* *it. Imported junk food is cheaper. In Lima, quinoa now costs more than chicken. Outside the cities, and fueled by overseas demand, the pressure is on to turn land that once produced a portfolio of diverse crops into quinoa monoculture*" [60]. In terms of ecological consequence, the growth in the consumption of quinoa in non-indigenous regions has led to intensive farming of the crop, which expanded quinoa farming into ecologically brittle ecosystems [61].

Table 5. Nutritional difference between proso millet and quinoa.

Nutrient	Unit	Proso Millet (Per 100 g)	Quinoa (Per 100 g)
Water	g	8.67	13.28
Energy	kcal	378	368
Energy	kJ	1582	1539
Protein	g	11.02	14.12
Total lipid (fat)	g	4.22	6.07
Ash	g	3.25	2.38
Carbohydrate	g	72.85	64.16
Fiber, total dietary	g	8.50	7.00
Calcium, Ca	mg	8	47
Iron, Fe	mg	3.01	4.57
Magnesium, Mg	mg	114	197
Phosphorus, P	mg	285	457
Potassium, K	mg	195	563
Sodium, Na	mg	5	5
Zinc, Zn	mg	1.68	3.10
Copper, Cu	mg	0.75	0.59
Manganese, Mn	mg	1.63	2.03
Selenium, Se	µg	2.70	8.50
Thiamin	mg	0.42	0.36
Riboflavin	mg	0.29	0.32
Niacin	mg	4.72	1.52
Pantothenic acid	mg	0.85	0.77
Vitamin B-6	mg	0.38	0.49
Folate, total	µg	85	184
Tryptophan	g	0.12	0.17
Threonine	g	0.35	0.42
Isoleucine	g	0.47	0.51
Leucine	g	1.40	0.84
Lysine	g	0.21	0.77
Methionine	g	0.22	0.31
Cystine	g	0.21	0.20
Phenylalanine	g	0.58	0.59
Tyrosine	g	0.34	0.27
Valine	g	0.58	0.59
Arginine	g	0.38	1.09
Histidine	g	0.24	0.41
Alanine	g	0.99	0.59
Aspartic acid	g	0.73	1.13
Glutamic acid	g	2.40	1.87
Glycine	g	0.29	0.70
Proline	g	0.88	0.78
Serine	g	0.65	0.57

Source: [62,63].

In comparison, locally grown PM in the High Plains of the USA can potentially substitute quinoa in a more beneficial way. Increase in consumption of PM can improve economy of farmers in the High Plains and producers and can compensate economic loss of importation. The cost of PM (US $4.4/kg) is also several folds lower than that of quinoa (US $15.4/kg), which makes PM a common man's food rather affluent people. A balance between regional food and imported food will be beneficial for maintaining a sustainable ecosystem both in exporting and importing countries. Equilibrium in demand and export/import ratio will also reduce price spikes which has quadrupled in last few years.

6. Proso Millet Based Foods and Beverages across the World

Traditional use of PMs in cuisines of Russia, Germany and China dates back to 8000–10,000 BP. Russians used it in preparation of a sweet dish by mixing with milk and sugar, or sometimes consumed as savory mixed with meat and vegetables. Chinese people used to consume it without milk and sugar, frequently mixed with different vegetables like beans, potato or squash. In Germany, people also used to take it as a sweet dish added with apples and honey [64].

Potential health benefits of PM grain have attracted several food industries in Europe and North America. Mild flavor with light color and gluten-free properties is ideal for making bread for people suffering from celiac disease [1,64]. Many industries produce bread, pasta, flour and couscous-like products with PM alone or in combination with other grains. The gluten-free food market in the US is growing, which is evident from the increase of the 0.9 billion dollars market in 2006 to 10.5 billion dollars in 2015 and is expected to be 23.9 billion dollars by 2020 (Figure 3) [65]. Research on product quality and nutritional value of the food produced from PM and comparison with popular grains showed positive results [15,43]. A recent study by McSweeney (2017) compared four different food products, viz. muffin, couscous, extruded snacks and porridge, made from refined PM and refined corn for their in vitro starch digestibility, nutritional composition and expected glycemic index (eGI). Interestingly, they found that the products made from refined PM with the maximum concentration had significantly ($p < 0.05$) less eGI compared to corn and corn proso mixed products and were gluten-free [46,66]. However, the absence of gluten often makes it hard for the bread industry to make a proper dough. However, this can be addressed by the addition of hydrocolloids like xanthum gum, guar gum [67].

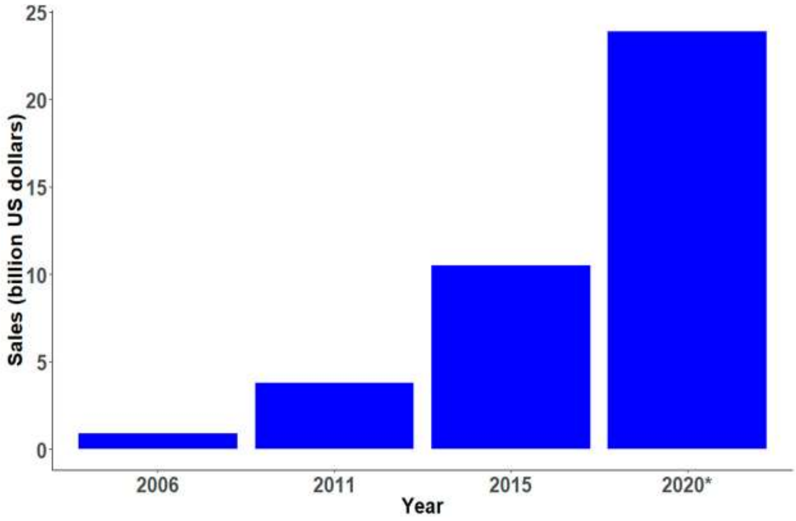

Figure 3. Gluten-free food market in the US from 2006 to 2020. (Source: Statista, 2018; * indicates projected value).

PM-based food products can be categorized into porridges, steamed cooked products, bakery products, beverages (PM Tea) and fermented products.

6.1. Porridge and Steamed Food

Porridge is one of the most popular dishes made from PM. Though porridge recipes across different countries and communities is similar, lack of proper documentation is still a major hindrance in popularization. For information on porridge across the world, we had personal communications via e-mails with appropriate scientists in a few important countries where PM is common. According to Dr. Galina Suvorova, head of the department of genetics and biotechnology from the All-Russia Research Institute of Legumes and Groat Crops, PM is one of the popular foods in her country, which is sold as groats (dehulled seed) (Russian name of millet groat is "psheno" (пшено)) (Figure 4a). Groats are usually boiled with water or milk to prepare the porridge. In Russia, the preparation is known as "Kasha" (Figure 4b,c). In Korea, the porridges are prepared by boiling millet in water and adding honey and eggs (Information from Dr. Hijin Kim and Cheol Ho Park, Kangwon National University, Korea) (Figure 4d). Rice-based meals and noodles are major steamed foods used in Japan and Korea. Steamed noodles (Jinju noodles), and rice meal (Ogokbap, Gohan) are famous in Japan and Korea (Figure 5a,b). Migliaccio, another regional dish from Italy, is prepared in the winter months with hog blood, millet flour, chocolate and milk. Polenta, a historic dish of Italy which is now prepared with corn flour, was prepared with millet in the 16th century. Panissa (the term originating from Panicum), a risotto-like dish, was originally made with millet and was popular in the Piedmont area of Italy (Information from Dr. Silvano Ciani, Lead Corporate Research & Innovation—Basic Research, Trieste, Italy).

Figure 4. (**a**) Dehulled millet from Russia (groat) (Picture credit: Dr. Suvorova). (**b**,**c**) Proso millet milk porridge with pumpkin (Picture: Dr. Galina Suvorova); (**d**) porridge from Korea cooked with water, egg and honey. (Picture credit: Dr. Hijin Kim and Dr. Cheol Ho Park).

6.2. Bakery Products

Bakery products hold the maximum uses of millet among all these categories. Shadang and Jagnathan (2014) used different proportions of PM, finger millet, foxtail millet, pearl millet with added wheat flour to prepare cookies, cakes and biscuits. Sensory evaluation suggested acceptable taste and flavor among products [68]. Several food technologists tried different combinations of millets including proso, pearl, barnyard, foxtail and sorghum to find out an acceptable ratio of mixing, followed by their nutritive evaluation [69,70]. Multigrain bread is the most popular among the bakery products. A study by Kamaraddi and Shanthakumar (2003) tried different concentrations of millet mixture to test dough characteristics. They concluded that wheat flour can be substituted to 10%–20% with millet flour for dough preparation. PM can be used to substitute 15% wheat flour used for bread making in comparison to the 10% substitution index of finger, foxtail and little millet [71]. Balloi et al. (2014), found out that 50% flour composition can be replaced with the millet composition [72]. Bakery products produced with combination of PM flour showed lower glycemic index compared to refined flour (Table 6). Anju and Sarita (2010) tried preparation of biscuits out of foxtail millet, barnyard millet and refined wheat flour in combination with hydrogenated fat, eggs, curd and baking powder. Sensory evaluation of the product also revealed overall acceptability and a low glycemic index compared to wheat flour biscuits [73].

Figure 5. (**a**) A bowl of Jinju Noodles. (**b**) A platter of Ogokbap. (**c**) Millet Dosa—An Indian pancake made from fermented millet batter. (**d**) Noti—a Korean pancake made from waxy broomcorn millet flour. (Picture Credit; Dr. Hijin Kim and Dr. Cheol Ho Park for (**a**,**b**,**d**); Meenakshi Santra for (**c**)).

Table 6. Glycemic index of the proso milled based products [66].

Percentage of Millet	100%	75%	25%	0%
Biscuit	56.0	64.4	71.0	78.5
Extruded Snacks	64.7	71.7	74.5	83.8
Porridge	53.1	65.1	78.1	86.3
Couscous	50.2	58.9	66.1	79.43

6.3. Fermented Products and Beverages

Two common fermented products are dosa (Figure 5c) and noti (Figure 5d). Dosa is an Indian pancake and is made from fermented batter using 2:1 millet and black grams. Noti is a Korean pancake and is prepared with broomcorn millet in many regions (personal communication with Dr. Hijin Kim and Dr. Cheol Ho Park).

Different countries have their own traditional millet-based fermented alcoholic drinks. Gluten-free beverages are growing fast in European and American beverage production industries. In the US, especially brewing companies from the Great Plains, have started producing beers using PM as a base ingredient. Companies like Colorado Malting Co. (Alamos, CO), New Planet Beer, Eddyline Restaurant and Brewing Co., and Pagosa Brewing have already started preparing malts and beer from PM (personal communication with the breweries). In the state of Nebraska, Modern Monks Brewery in Lincoln has brewed beer using PM [64]. PM is an important malting material for its high amylase activity. Malt from PM was used in substitution of barley in the European countries during World War II [74]. Traditional brewing of beer from millet has been descending in many tribes for ages. The people of Nepal or eastern Himalayan parts of India (Darjeeling and Sikkim) use millet as a base ingredient for fermented alcoholic beverages like Tongba (Figure 6a,b) Rakshi and Marcha [64,75]. Romanian and Bulgarians used to make fermented drink Boza out of millet. Likewise, people of the Orchid Island in Taiwan produce traditional fermented beer from millets [64]. Fermented millet beverage Jiu was mentioned in ancient Chinese text (1200–1000 BC) [74]. Sur is another millet-based fermented drink of Himachal Pradesh, India. It is mainly prepared with a mixture of roasted barley, local herbs (“Dhaeli”), and millets. Alcohol content of the drink may vary from 5% to 10% [76]. Madua is one of the most popular millet-based drinks of Arunachal Pradesh, India. Millets are roasted and softened by boiling, mixed with starter culture and left for 4–7 days for fermentation. Other millet-based drinks of the state are Themsing, Rakshi, Mingri, and Lohpani [77]. Oshikundu is a traditional fermented beverage of Namibia which is sour-sweet in taste. Koozh, a fermented beverage from Tamil Nadu, India, is generally made with millet flour and rice [15]. Suutei Tsai (Figure 6c,d) is a famous Mongolian tea prepared with milk, salt, green tea and millet [78].

Figure 6. (**a**,**b**) Tongba—a fermented beer produced from millet in Sikkim (an eastern Himalayan and northeastern state of India) (Picture: Saurav Das). (**c**,**d**) Suutei Tsai—A Mongolian Tea made from millet (Picture credit: Global Table Adventure: http://globaltableadventure.com/recipe/mongolian-millet-green-milk-tea-suutei-tsai/).

7. Bioethanol

Bioethanol production is another potential sector for PM. Starch content of PM is similar to corn, which is used as common feed stock in the US for distiller's dried grains with solubles (DDGS) and the fuel ethanol industry. In a study conducted at the University of Nebraska-Lincoln in 2012, fermentation efficiencies of PM was found to range from 84% to 91%, which is comparable to the 97% of highly fermentable corn hybrid [79]. Waxy proso millet (82.4%) lines were more efficient compared to non-waxy varities (75.5%) [64,79].

The DDGS is an important co-product of ethanol production. High DDGS were recovered from PM compared with highly fermentable corn-based fermentation. PM-derived DDGS also had higher protein content (26.6%–33.4%) than the DDGS from corn (17.2%–23.4%) [79]. This suggests that PM-derived DDGS can be used as livestock feed similar to corn-based DDGS. Use of PM instead of corn or blending PM with corn for ethanol production can improve the local economy and can compensate for the occasional shortage of corn as common raw materials.

8. Socio-Economic Aspect of Millet

PM is one of the ancient millets in many countries in the world mainly in semiarid and drought-prone areas. PM is mainly consumed as food in those cultures from ancient times and it had a pivotal role in the early development of multi-crop agricultural systems and settling of the farming societies [80]. PM and other millets were replaced by higher yielding crops like wheat, corn, soybean in agricultural system of those countries during 20th century. As a result, the significance of PM and other millets in rural socio-economy was greatly reduced in the last century agrarian system. However, PM, like many other millets, are getting renewed attention in millennial agriculture owing to the awareness of millets as climate smart crops and their human health benefits.

Professor Martin Jones, a renowned archaeobotanist and archaeogeneticist at the University of Cambridge, has conducted extensive research on ancient farming practices in Europe and China [81]. He identified foxtail and PM as two key Asian millet species in the prehistoric crop records in Europe, suggesting their widespread presence in ancient farming systems. Professor Jones also reported that an ancient multi-crop farming system, which included millets, is still practiced in Aohan and Mongolia. The Aohan Dryland Farming System has been recognized as a 'Globally Important Heritage Systems' site by FAO. The millet from Aohan has witnessed a recent surge in sales as a high-quality product in the local Chinese market [81]. Similarly, PM is getting significant attention in several European countries like Poland, Slovenia, Switzerland and Germany [82,83]. Significant research is being conducted in the areas of use of PM in specialized organic breakfast cereals, organic poultry feed and gluten-free food. Thus, PM will be playing important role in the rural socio-economy of those countries.

PM is also getting similar renewed attention in the USA. On March 11, 2017, a millet commission named "High Plains Millet Association (HPMA)" was formed in the High Plains of the USA. The mission of the HPMA is to "provide sustainability to the millet industry through research, production, and marketing" [84]. The comparable nutritional profile with wheat along with gluten-free characteristics can itself give millet an expanded market in the gluten-free food sector. Only a small fraction of the PM grown in the USA goes to the domestic food market, while the majority goes into the birdseed market. HPMA has encouraged farmers to opt for other market aspects of PM including a gluten-free human food market, and livestock food markets like dog, hamsters, swine, sheep and cattle. An expanded PM market will only be able to generate more revenues for research and development. The current funding prospects in PM are less, which is another limiting factor in PM research and development. Recent proposals from HPMA also suggested that the Agricultural Marketing Act should be amended to include PM as an agricultural commodity so that the PM producers and handlers can vote for the referendum to approve different marketing orders and assess the funding for education, research and promotional programs [84–87].

In India, the notion of the importance of millets started changing with the realization of the immense agronomic, environmental and nutritional benefits these crops offer [88]. The National Food Security Act of 2013 has particularly given the highest priority to millets among coarse grains. The M.S Swaminathan Foundation has requested an amended policy to investigate small millets and their potential role for climate-smart agriculture [88]. The report by Padulosi et al. (2015) also showed the importance of minor millets including PM in economic and nutritional sustainability of rural India. The majority of the Indian population is economically unable to afford an expensive balanced diet [89]. Thus, promoting use of underutilized millet is a powerful way contributing nutritional security along with economic growth of rural Indian populations. In southern India, the government of Tamil Nadu has started including millet in school meals with different recipes along with rice and wheat to boost its wide acceptance and cultivation. Scientists in International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) had also started working on HarvestPlus programs to improve the nutritional content of millet to support daily intake of iron and zinc, which are vital for the mental and physical developments of children [90].

9. Future Prospect and Perspectives

PM is one of the miracle grains with several environmental and health benefits. They can be used to control annual grass weed, insect pressure, and disease incidence in wheat [9]. They are economically important rotational crops for the semiarid regions. They conserve the soil water level and can produce significant yield at marginal lands. PM can play an important role in global food security under changing climate [1]. Water shortage is a major threat for agriculture in future and urges a shift in farming practices. Inclusion of PM in cropping systems could play an important role in water shortage mitigation [38]. Activities associated with an ever-increasing population has also degraded the inherent soil quality. Almost 66% of the topsoil has been lost in the last decade and every year 0.001 t/ha of flat land with grass or forest cover, 1–5 t/ha of mountain regions with vegetation are eroded [25]. PM also could play an important role in addressing this issue.

Adoption of a PM-based diet can potentially prevent deterioration of human health resulting from a sedentary lifestyle. PM can lower the risk of cardiovascular disease, and type 2 diabetes and can help in maintaining obesity levels [49,50]. Although a number of research articles emphasizing potential health benefits have been published, industrial application of PM is still facing major competition. There is still a broad gap in studies delineating the nutritional composition of different millets, their agroecosystem, health benefits and applications in food industry. Studies defining different processing methods and different food applications are necessary to promote its wide applications in different market sectors. Production and market gaps will only be overcome by educating people about prospects of millets including both nutritional and environmental values. Additional market research and promotion of this alternative crop for a healthy diet and lifestyle is necessary for wide acceptance and consumption.

Author Contributions: All the authors contributed equally.

Funding: This research received no external funding.

Acknowledgments: The authors would like to acknowledge all the researchers and stakeholders in the field of millet research for their contributions to this field. The authors would like to acknowledge especially Hijin Kim and Cheol Ho Park, Kangwon National University, Korea for their contribution in preparing the list of Korean and Japanese millet foods and their recipes. The authors are also grateful to Galina Suvorova, Head of the department of genetics and biotechnology from All-Russia Research Institute of Legumes and Groat Crops, for the information on Russian millet dishes and the pictures and recipes.

Conflicts of Interest: The authors have no conflict of interests.

References

1. Habiyaremye, C.; Matanguihan, J.B.; D'Alpoim Guedes, J.; Ganjyal, G.M.; Whiteman, M.R.; Kidwell, K.K.; Murphy, K.M. Proso Millet (*Panicum miliaceum* L.) and Its Potential for Cultivation in the Pacific Northwest, U.S.: A Review. *Front. Plant Sci.* **2017**, *7*. [CrossRef] [PubMed]

2. Dwivedi, S.; Upadhyaya, H.; Senthilvel, S.; Hash, C.; Fukunaga, K.; Diao, X.; Santra, D.; Baltensperger, D.; Prasad, M. Millets: Genetic and Genomic Resources. In *Plant Breeding Reviews*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2011; pp. 247–375.
3. Amadoubr, I.; Le, M.; Le, G.-W. Millets: Nutritional composition, some health benefits and processing—A Review. *Emir. J. Food Agric.* **2013**, *25*, 501–508. [CrossRef]
4. FAOSTAT. Data on millet producing countries. 2016. Available online: http://www.fao.org/faostat/en/#data/QC/visualize (accessed on 22 December 2018).
5. U.S. National Plant Germplasm System Taxonomy: *Panicum miliaceum* L. Available online: https://npgsweb.ars-grin.gov/gringlobal/taxonomydetail.aspx?id=317710 (accessed on 11 December 2018).
6. Sheahan, C.M. *Plant Guide for Proso Millet (Panicum miliaceum)*; USDA-Natural Resources Conservation Service: Cape May Plant Materials Center, Cape May, NJ, USA, 2014.
7. Lu, H.; Zhang, J.; Liu, K.; Wu, N.; Li, Y.; Zhou, K.; Ye, M.; Zhang, T.; Zhang, H.; Yang, X.; et al. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 7367–7372. [CrossRef] [PubMed]
8. Santra, D.K. Proso Millet Varieties for Western Nebraska. NebGuide, University of Nebraska-Lincoln, G2219. 2013. Available online: http://extensionpublications.unl.edu/assets/pdf/g2219.pdf (accessed on 22 December 2018).
9. Lyon, D.J.; Burgener, P.A.; DeBoer, K.L.; Hein, G.L.; Hergert, G.W.; Holmon, T.L.; Nelson, L.A. Proso Millet in the Great Plains. University of Nebraska-Lincoln, Extension Article EC137. 2008. Available online: http://extensionpublications.unl.edu/assets/pdf/ec137.pdf (accessed on 22 December 2018).
10. Habiyaremye, C.; Barth, V.; Highet, K.; Coffey, T.; Murphy, K.; Habiyaremye, C.; Barth, V.; Highet, K.; Coffey, T.; Murphy, K.M. Phenotypic Responses of Twenty Diverse Proso Millet (*Panicum miliaceum* L.) Accessions to Irrigation. *Sustainability* **2017**, *9*, 389. [CrossRef]
11. Nielsen, D.C.; Vigil, M.F. Water use and environmental parameters influence proso millet yield. *Field Crops Res.* **2017**, *212*, 34–44. [CrossRef]
12. USDA-NASS Crop Production 2015 Summary. USDA, 2016. Available online: https://www.usda.gov/nass/PUBS/TODAYRPT/cropan16.pdf (accessed on 22 December 2018).
13. Awika, J.M. Major Cereal Grains Production and Use around the World. In *Advances in Cereal Science: Implications to Food Processing and Health Promotion*; American Chemical Society: Washington, WA, USA, 2011; pp. 1–13.
14. Sharma, C.P. *Overdraft in India's Water Banks: Studying the Effect of Production of Water Intensive Crops on Groundwater Depletion*; Georgetown University: Washington, DC, USA, 2016.
15. Kumar, A.; Tomer, V.; Kaur, A.; Kumar, V.; Gupta, K. Millets: A solution to agrarian and nutritional challenges. *Agric. Food Secur.* **2018**, *7*, 31. [CrossRef]
16. FAO. Drought and Agriculture. Available online: http://www.fao.org/land-water/water/drought/droughtandag/en/ (accessed on 11 December 2018).
17. MacDonald, G.M. Water, climate change, and sustainability in the southwest. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 21256–21262. [CrossRef]
18. Tadele, Z. Drought Adaptation in Millets. In *Abiotic and Biotic Stress in Plants—Recent Advances and Future Perspectives*; InTech: London, UK, 2016.
19. Blum, A. Drought resistance, water-use efficiency, and yield potential—Are they compatible, dissonant, or mutually exclusive? *Aust. J. Agric. Res.* **2005**, *56*, 1159. [CrossRef]
20. Monneveux, P.; Jing, R.; Misra, S.C. Phenotyping for drought adaptation in wheat using physiological traits. *Front. Physiol.* **2012**, *3*, 429. [CrossRef] [PubMed]
21. Fang, Y.; Xiong, L. General mechanisms of drought response and their application in drought resistance improvement in plants. *Cell. Mol. Life Sci.* **2015**, *72*, 673–689. [CrossRef] [PubMed]
22. Vivitha, P.; Vijayalakshmi, D. Minor millets as model system to study C 4 photosynthesis—A review. *Agric. Rev.* **2015**, *36*, 296–304. [CrossRef]
23. Kafi, M.; Zamani, G.; Ghoraishi, S.G. Relative salt tolerance of south Khorasan millets. *Desert* **2009**, *14*, 63–70.
24. Hamdy, A.; Ragab, R.; Scarascia-Mugnozza, E. Coping with water scarcity: Water saving and increasing water productivity. *Irrig. Drain.* **2003**, *52*, 3–20. [CrossRef]
25. Saxena, R.; Vanga, S.; Wang, J.; Orsat, V.; Raghavan, V.; Saxena, R.; Vanga, S.K.; Wang, J.; Orsat, V.; Raghavan, V. Millets for Food Security in the Context of Climate Change: A Review. *Sustainability* **2018**, *10*, 2228. [CrossRef]

26. Gregory, P.J.; George, T.S. Feeding nine billion: The challenge to sustainable crop production. *J. Exp. Bot.* **2011**, *62*, 5233–5239. [CrossRef] [PubMed]
27. Davies, W.J.; Bennett, M.J. Achieving more crop per drop. *Nat. Plants* **2015**, *1*, 15118. [CrossRef] [PubMed]
28. Ceccarelli, S.; Grando, S. Drought as a challenge for the plant breeder. *Plant Growth Regul.* **1996**, *20*, 149–155. [CrossRef]
29. Baltensperger, D.; Lyon, D.; Anderson, R.; Holman, T.; Stymiest, C.; Shanahan, J.; Nelson, L.; Deboer, K.; Hein, G.; Krall, J. *Producing and Marketing Proso Millet in the High Plains*; University of Nebraska-Lincoln Extension: Lincoln, MI, USA, 1995.
30. Shantz, H.; Piemeisel, L.N. The water requirement of Plants at Akron, Colorado. *J. Agric. Res.* **1927**, *34*, 1093–1190.
31. McDonal, S.; Hofsteen, L.; Downey, L. *Crop Profile for Proso Millet in Colorado*; Colorado State University: Fort Collins, CO, USA, 2003; Available online: https://bit.ly/2tFOWNL (accessed on 22 December 2018).
32. Seghatoleslami, M.J.; Kafi, M.; Majidi, E. Effect of drought stress at different growth stages on yield and water use efficiency of five proso millet (*Panicum miliaceum* L.) Genotypes. *Pak. J. Bot.* **2008**, *40*, 1427–1432.
33. Matsuura, A.; Tsuji, W.; An, P.; Inanaga, S.; Murata, K. Effect of Pre- and Post-heading Water Deficit on Growth and Grain Yield of Four Millets. *Plant Prod. Sci.* **2012**, *15*, 323–331. [CrossRef]
34. Emendack, Y. Mid-Season water stress on yield and water use of millet (*Panicum miliaceum*) and sorghum (*Sorghum bicolour* L. *Moench*). *Aust. J. Crop Sci.* **2011**, *5*, 1486–1492.
35. Roberts, D. This Graphic Explains Why 2 Degrees of Global Warming Will Be Way Worse Than 1.5. Available online: https://www.vox.com/energy-and-environment/2018/1/19/16908402/global-warming-2-degrees-climate-change (accessed on 13 December 2018).
36. Shanahan, J.F.; Anderson, R.L.; Greb, B.W. Productivity and Water Use of Proso Millet Grown under Three Crop Rotations in the Central Great Plains. *Agron. J.* **1988**, *80*, 487–492. [CrossRef]
37. Felter, D.G.; Lyon, D.J.; Nielsen, D.C. Evaluating Crops for a Flexible Summer Fallow Cropping System. *Agron. J.* **2006**, *98*, 1510–1517. [CrossRef]
38. Nielsen, D.C.; Vigil, M.F. Soil Water Extraction for Several Dryland Crops. *Agron. J.* **2018**, *110*, 1–9. [CrossRef]
39. Rasmussen, P.E.; Albrecht, S.L.; Smiley, R.W. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. *Soil Tillage Res.* **1998**, *47*, 197–205. [CrossRef]
40. Baltensperger, D.D. Foxtail and Proso Millet. In *Progress in New Crops*; Janick, J., Ed.; ASHS Press: Alexandria, VA, USA, 1996; pp. 182–190.
41. Anderson, R.L.; Bowman, R.A.; Nielsen, D.C.; Vigil, M.F.; Aiken, R.M.; Benjamin, J.G. Alternative Crop Rotations for the Central Great Plains. *J. Prod. Agric.* **1999**, *12*, 95. [CrossRef]
42. Wright, S.F.; Anderson, R.L. Aggregate stability and glomalin in alternative crop rotations for the central Great Plains. *Biol. Fertil. Soils* **2000**, *31*, 249–253. [CrossRef]
43. Saleh, A.S.M.; Zhang, Q.; Chen, J.; Shen, Q. Millet Grains: Nutritional Quality, Processing, and Potential Health Benefits. *Compr. Rev. Food Sci. Food Saf.* **2013**, *12*, 281–295. [CrossRef]
44. Kalinova, J.; Moudry, J. Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties. *Plant Foods Hum. Nutr.* **2006**, *61*, 45–49. [CrossRef]
45. Devi, P.B.; Vijayabharathi, R.; Sathyabama, S.; Malleshi, N.G.; Priyadarisini, V.B. Health benefits of finger millet (*Eleusine coracana* L.) polyphenols and dietary fiber: A review. *J. Food Sci. Technol.* **2014**, *51*, 1021–1040. [CrossRef]
46. Mcsweeney, M. *Proso Millet as an Ingredient in Foods Common to North Americans*; University of Guelph: Guelph, ON, Canada, 2014.
47. Turer, A.T.; Scherer, P.E. Adiponectin: Mechanistic insights and clinical implications. *Diabetologia* **2012**, *55*, 2319–2326. [CrossRef] [PubMed]
48. Nigro, E.; Scudiero, O.; Monaco, M.L.; Palmieri, A.; Mazzarella, G.; Costagliola, C.; Bianco, A.; Daniele, A. New Insight into Adiponectin Role in Obesity and Obesity-Related Diseases. *BioMed Res. Int.* **2014**, 1–14. [CrossRef] [PubMed]
49. Park, K.O.; Ito, Y.; Nagasawa, T.; Choi, M.-R.; Nishizawa, N. Effects of Dietary Korean Proso-Millet Protein on Plasma Adiponectin, HDL Cholesterol, Insulin Levels, and Gene Expression in Obese Type 2 Diabetic Mice. *Biosci. Biotechnol. Biochem.* **2008**, *72*, 2918–2925. [CrossRef]

50. Rosenson, R.S.; Brewer, H.B.; Barter, P.J.; Björkegren, J.L.M.; Chapman, M.J.; Gaudet, D.; Kim, D.S.; Niesor, E.; Rye, K.-A.; Sacks, F.M.; et al. HDL and atherosclerotic cardiovascular disease: Genetic insights into complex biology. *Nat. Rev. Cardiol.* **2017**, *15*, 9–19. [CrossRef] [PubMed]
51. Fasano, A. European and North American populations should be screened for celiac disease. *Gut* **2003**, *52*, 168–169. [CrossRef] [PubMed]
52. Hulse, J.H.; Laing, E.M.; Pearson, O.E. *Sorghum and the Millets: Their Composition and Nutritive Value*; Academic Press: Cambridge, MA, USA, 1980.
53. Ragaee, S.; Abdel-Aal, E.S.M.; Noaman, M. Antioxidant activity and nutrient composition of selected cereals for food use. *Food Chem.* **2006**, *98*, 32–38. [CrossRef]
54. Zhang, L.; Liu, R.; Niu, W. Phytochemical and antiproliferative activity of proso millet. *PLoS ONE* **2014**, *9*, e104058. [CrossRef] [PubMed]
55. Coulibaly, A.; Kouakou, B.; Chen, J. Phytic Acid in Cereal Grains: Structure, Healthy or Harmful Ways to Reduce Phytic Acid in Cereal Grains and Their Effects on Nutritional Quality. *Am. J. Plant Nutr. Fertil. Technol.* **2011**, *1*, 1–22. [CrossRef]
56. Bhide, G. Millets for the Healthy Gut. Available online: http://www.difodin.com/blog/post/10-millets-for-the-healthy-gut-.html (accessed on 27 January 2019).
57. FAO. Sorghum and Millets in Human Nutrition. Available online: http://www.fao.org/docrep/t0818e/T0818E0d.htm (accessed on 11 December 2018).
58. Conis, E. Ancient Grains: The Best Thing Since Sliced Bread? Available online: http://articles.latimes.com/2011/feb/19/health/la-he-ancient-grains-20110220 (accessed on 27 January 2019).
59. Comtrade, U. Quinoa Imports of the United States from 2013 to 2017 (in Million Kilograms). Available online: https://www.statista.com/statistics/486411/us-quinoa-imports/ (accessed on 27 January 2019).
60. Blythman, J. Can Vegans Stomach the Unpalatable Truth about Quinoa? Available online: https://www.theguardian.com/commentisfree/2013/jan/16/vegans-stomach-unpalatable-truth-quinoa (accessed on 13 December 2018).
61. Small, E. Quinoa—Is the United Nations' featured crop of 2013 bad for biodiversity? *Biodiversity* **2013**, *14*, 169–179. [CrossRef]
62. USDA Food Composition Databases Show Foods—Millet. Available online: https://ndb.nal.usda.gov/ndb/foods/show/6500?fg=&man=&lfacet=&count=&max=&sort=&qlookup=&offset=&format=Full&new=&measureby= (accessed on 13 December 2018).
63. USDA Food Composition Databases Show Foods—Quinoa. Available online: https://ndb.nal.usda.gov/ndb/foods/show/20035?n1=%7BQv%3D1%7D&fgcd=&man=&lfacet=&count=&max=25&sort=default&qlookup=quinoa&offset=&format=Full&new=&measureby=&Qv=1&ds=&qt=&qp=&qa=&qn=&q=&ing= (accessed on 13 December 2018).
64. Santra, D.K.; Rose, D.J. *Alternative Uses of Proso Millet*; University of Nebraska-Lincoln Extension: Lincoln, CA, USA, 2013; pp. 3–6.
65. Grocer, P. Gluten-Free and Free-from Food Retail Sales in the United States from 2006 to 2020 (in Billion U.S. Dollars). Available online: https://www.statista.com/statistics/261099/us-gluten-free-and-free-from-retail-sales/ (accessed on 30 November 2018).
66. McSweeney, M.B.; Ferenc, A.; Smolkova, K.; Lazier, A.; Tucker, A.; Seetharaman, K.; Wright, A.; Duizer, L.M.; Ramdath, D.D. Glycaemic response of proso millet-based (*Panicum miliaceum*) products. *Int. J. Food Sci. Nutr.* **2017**, *68*, 873–880. [CrossRef] [PubMed]
67. Motta Romero, H.; Santra, D.; Rose, D.; Zhang, Y. Dough rheological properties and texture of gluten-free pasta based on proso millet flour. *J. Cereal Sci.* **2017**, *74*, 238–243. [CrossRef]
68. Shadang, C.; Jaganathan, D. Development and standardisation of formulated baked products using millets. *Int. J. Res. Appl.* **2014**, *2*, 75–78.
69. Rai, S.; Kaur, A.; Singh, B. Quality characteristics of gluten free cookies prepared from different flour combinations. *J. Food Sci. Technol.* **2014**, *51*, 785–789. [CrossRef] [PubMed]
70. Surekha, N.; Naik, R.S.; Mythri, S.; Devi, R. Barnyard millet (*Echinochloa frumentacea* Link) Cookies: Development, value addition, consumer acceptability. *IOSR J. Enivron. Sci. Toxicol. Food Technol.* **2013**, *7*, 1–10.

71. Kamaraddi, V.; Shanthakumar, G. Effect of incorporation of small millet flour to wheat flour on chemical, rheological and bread characteristics. In *Proceedings of the Recent Trends in Millet Processing and Utilization*; CCS Hisar Agricultural University: Hisar, India, 2003; pp. 74–81.
72. Ballolli, U.; Malagi, U.; Yenagi, N.; Orsat, V.; Gariepy, Y. Development and quality evaluation of foxtail millet [*Setaria italica* (L.)] incorporated breads. *Karnataka J. Agric. Sci.* **2014**, *27*, 52–55.
73. Anju, T.; Sarita, S. Suitability of Foxtail Millet and Barnyard Millet forDevelopment of Low GI Biscuits Suitability of Foxtail Millet (*Setaria italica*) and Barnyard Millet (*Echinochloa frumentacea*) for Development of Low Glycemic Index Biscuits. *Malays. J. Nutr.* **2010**, *16*, 361–368. [PubMed]
74. Kalinová, J. Nutritionally Important Components of Proso Millet (*Panicum miliaceum* L.). *Food* **2007**, *1*, 91–100.
75. Tamang, J.P. *Ethnic Fermented Foods and Alcoholic Beverages of Asia*; Tamang, J.P., Ed.; Springer: Berlin/Heidelberg, Germany, 2016.
76. Joshi, V.K.; Kumar, K.; Thakur, N.S. Technology of Preparation and Consumption Pattern of Traditional Alcoholic Beverage 'Sur' of Himachal Pradesh. *Int. J. Food Fermented Technol.* **2015**, *5*, 75–82. [CrossRef]
77. Shrivastava, K.; Greeshma, A.G.; Srivastava, B. Biotechnology in action—A process technology of alcoholic beverages is practices by different tribes of Arunachal Pradesh, North East India. *Indian J. Tradit. Knowl.* **2012**, *11*, 81–89.
78. Sasha Martin Mongolian Millet & Green Milk Tea Suutei Tsai. Available online: http://globaltableadventure.com/recipe/mongolian-millet-green-milk-tea-suutei-tsai/ (accessed on 12 December 2018).
79. Rose, D.J.; Santra, D.K. Proso millet (*Panicum miliaceum* L.) fermentation for fuel ethanol production. *Ind. Crops Prod.* **2013**, *43*, 602–605. [CrossRef]
80. NPR Millet: How A Trendy Ancient Grain Turned Nomads into Farmers. Available online: https://www.npr.org/sections/thesalt/2015/12/23/460559052/millet-how-a-trendy-ancient-grain-turned-nomads-into-farmers (accessed on 12 December 2018).
81. Jones, M. Archaeology Shows There's More to Millet Than Birdseed. Available online: https://www.cam.ac.uk/research/features/archaeology-shows-theres-more-to-millet-than-birdseed (accessed on 27 February 2019).
82. Hiltbrunner, J. Organic Millet—An interesting Niche in Switzerland. In Proceedings of the 3rd International Millet Symposium, Fort Collins, CO, USA, 8–12 August 2018; Santra, D.K., Johnson, J.J., Eds.; p. 19.
83. Kaute, V.W. Past, Present and Future of Proso Millet in Germany and Austria. In Proceedings of the 3rd International Millet Symposium, Fort Collins, CO, USA, 8–12 August 2018; Santra, D.K., Johnson, J.J., Eds.; p. 23.
84. HPMA High Plains Millet Association. Available online: https://sites.google.com/view/hpma/home (accessed on 12 December 2018).
85. Journal-Advocate Survey Shows Millet Growers Favor Checkoff. Available online: http://www.journal-advocate.com/sterling-local_news/ci_32010026/survey-shows-millet-growers-favor-checkoff (accessed on 12 December 2018).
86. Journal-Advocate Millet Group Pushes for Yes Vote. Available online: http://www.journal-advocate.com/sterling-local_news/ci_32060169/millet-group-pushes-yes-vote (accessed on 12 December 2018).
87. Fort Morgan Times Millet Growers Consider State Market Order. Available online: http://www.fortmorgantimes.com/fort-morgan-local-news/ci_31518021/millet-growers-consider-state-market-order (accessed on 12 December 2018).
88. India Waterportal Towards Enhancing India's Food Security: Millet Must Be Accorded Highest Priority in Terms of Denominating It as the Major Crop. Available online: http://www.indiawaterportal.org/news/towards-enhancing-indias-food-security-millet-must-be-accorded-highest-priority-terms (accessed on 12 December 2018).
89. Padulosi, S.; Mal, B.; King, O.; Gotor, E.; Padulosi, S.; Mal, B.; King, O.I.; Gotor, E. Minor Millets as a Central Element for Sustainably Enhanced Incomes, Empowerment, and Nutrition in Rural India. *Sustainability* **2015**, *7*, 8904–8933. [CrossRef]
90. Tata-Cornell Institute Will India's New Food Bill Have an Impact on Under-Nourished Women and Children. Available online: https://tci.cornell.edu/blog/will-indias-new-food-bill-have-an-impact-on/ (accessed on 12 December 2018).