Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 27 (2) :245 - 257 (June - 2025)
https://doi.org/10.54386/jam.v27i2.2892
https://journal.agrimetassociation.org/index.php/jam

Review Article

Millets as a dual-purpose crop for sustainable nutritional and energy security: A comprehensive review

DEMISIE EJIGU[1], RAJI PUSHPALATHA[1], SRUTHY S[1], VINOD PADIL[1], BYJU GANGADHARAN[2], THENDIYATH ROSHNI[3], SAJITHKUMAR KJ[1], GHANSHYAM UPADHYAY[1]

[1]Amrita School for Sustainable Futures, Amrita Vishwa Vidyapeetham, Kollam, Kerala, India
[2]ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India
[3]National Institute of Technology, Patna, India
Corresponding author's email: rajip@am.amrita.edu

ABSTRACT

Millets are multipurpose crops that can grow in diverse climatic conditions and have high nutritional value. However, the nutritional importance and various climatic adaptability of millets are not well recognized. The current review emphasizes the response of millet to climate variability, the significance of value-added products, and the role of millet agro residues. This review paper is a summary of a total of 106 published articles from different database sources. The results revealed that millets are a high source of protein, fat, minerals, and dietary fiber and rich in micronutrients which are used to overcome malnutrition and non-communicable diseases. Foxtail millet uses 257 g of water to produce 1 g of dry biomass as compared to maize (470g) and wheat (510g) indicating its climate resilience. The study also indicates a potential possibility of utilization of millet biomass in the production of bioenergy which in turn promotes the sustainability of renewable energy. Hence, developing schemes such as distributing seeds, fertilizer, pesticides, subsidized credit facilities, and promoting various value-added products are the main options to promote millet for further cultivation and consumption.

***Keywords**: Millets; Nutritional content; Health benefits; Climate resilience; Value added products*

Millets come under the Poaceae family and are considered future food crops that can grow in various agro-climatic conditions (FAO, 2021). The drought tolerance and comparable nutritional composition of millets make their broader acceptability in changing climatic conditions (Sharma *et al.,* 2023; Swain *et al.,* 2023). Millets are easily adaptable and can be intercropped with other cropping systems by considering the varieties of short crop durations (Sharmili *et al.,* 2021). Millets represent a diverse and nutritionally rich group of crops and have superior nutritional profiles of protein, fat, fiber, and essential minerals (Wilson and Vanburen, 2021). The low gluten content and favorable glycaemic index position make millet a healthy choice for combating lifestyle-related ailments such as diabetes and obesity (Tripathi *et al.,* 2023). Even though millets have a greater nutritional potential and are more resilient to extreme climate events they are underutilized compared to rice, wheat, and maize (Prajapati *et al.,* 2023). As millets gain importance and demand globally, this review so far analyses different varieties of millets' nutritional content, health benefits, and climate resilience compared to other cereals under changing climatic conditions. Also, this review addresses the possibility of millets in extracting bioenergy, value-added products, and the prospects for sustainable practices to improve livelihoods and ensure food security based on the existing literature.

MATERIAL AND METHODS

A total of 106 published articles were downloaded from various databases such as Science Direct, Scopus, and Google Scholar. The articles were collected between the years 2010 and 2024 using specific keywords such as "millets," "millets nutritional content and health benefit," "millets climate resilience" and "value-added products". All the references used in this study were collected from twelve countries (India, China, USA, Italy, UK, Canada, Ethiopia, Niger, Senegal, Australia and Indonesia). Among the 106 studies, 17 are review papers focusing on the importance and scope

***Article info - DOI**: https://doi.org/10.54386/jam.v27i2.2892*
Received: 15 January 2025; Accepted:11 March 2025; Published online : 1 June, 2025

of millets in the context of climate variation.

RESULT AND DISCUSSION

Millet production across the globe

The analysis of the past 11 years of world production of millets indicates an increasing trend as per the Food and Agriculture Organization Statistical Database (FAOSTAT, 2023), with a decadal increase in the production of 4.2 tons (Fig. 1). According to (FAOSTAT, 2023), India is the primary of output of millet, with a production of 13.21 million tons, followed by Niger (3.4), China (2.7), Nigeria (2), and Mali (1.8). A total of 76 countries are cultivating millet globally (Fig. 2).

The area of production, the percentage contribution to global production, and the cropping season of the top producers are presented in Table 1 (USDA, 2023). In most countries, the season starts in May, and harvesting starts in September. However, the millets can be cultivated throughout the year, regardless of season (Junior *et al.,* 2023).

The area under millet cultivation, as presented in Table 1, indicates a considerable possibility of increasing the production within this available cultivated area by integrating advanced techniques and sustainable farming practices.

Types of millets and Agro-ecology

Nowadays millets are cultivated worldwide such as sorghum (*Sorghum bicolor L.*), pearl millet (*Pennisetum glaucum L.*), finger millet (*Eleusine corocana L.*), foxtail millet (*Setaria italica L.*), proso millet (*Panicum miliaceum L.*), barnyard millet (*Echinochloa frumentacea L.*), kodo millet (*Paspalum scorbiculatum L.*), little millet (*Panicum sumatrense L.*), browntop millet (*Brachiaria ramosa*), teff (*Eragrostis tef*) and fonio (*Digitaria exilis*) (Meena *et al.,* 2021). Sorghum can tolerate agricultural drought by extracting water from deeper soil layers due to the deep root system. It is suitable in dryland conditions as it can withstand higher temperatures at any stage of its growth than other cereal crops (Kumar *et al.,* 2018; Meena *et al.,* 2021). Pearl millet is a climate-smart grain crop and is adaptable to drought and heat stresses. The rainfall requirement for pearl millet is 300 to 350 mm but it is grown in areas receiving less than 300 mm and can use water efficiently compared to sorghum and maize (Ullah *et al.,* 2017). However, unlike sorghum, it can't resist drought, but in such conditions, it can shorten its life cycle and come to maturity earlier. Finger millet is much more popular, can tolerate salinity, and can grow in areas with less than 400 mm of rainfall (Sharma *et al.,* 2023). Foxtail millet is a drought-tolerant crop and is grown in drylands under conditions with higher CO_2 abatement opportunities and stands out with its rapid ripening mechanism and efficient photosynthesis, and it can achieve a good yield within a short duration by withstanding low soil fertility (Maitra, 2019; Nadeem *et al.,* 2020). Proso millet is one of the underutilized millets and has been selected as a climate-resilient crop. It is also a short-duration crop with low moisture requirements, and it thrives in various soil types and climates (Bhat *et al.,* 2019; Wimalasiri *et al.,* 2023).

Barnyard is one of the minor millets and is cultivated widely in China, Japan, India, Pakistan, Nepal, and Africa (Renganathan *et al.,* 2020; Sood *et al.,* 2020). This drought-tolerant crop excels in marginal lands, matures rapidly, offers high nutritional content, and can possess various health benefits (Bhatt *et al.,* 2022; Sood *et al.,* 2015). Kodo millet is the coarsest cereal globally, exhibiting remarkable drought resistance among minor millets (Ranjan *et al.,* 2023). Known for yielding well within a short growth period (70–90 days), it adapts to drought, high temperatures, and poor soil conditions (Goutam *et al.,* 2023). A short-duration little millet also withstands drought and waterlogging (Dey *et al.,* 2022). With grains resembling rice, its elevated fiber content positions it as a nutritious rice substitute, abundant in vitamin B and essential minerals (calcium, iron, zinc, and potassium) (Sushmita *et al.,* 2020). Among these, foxtail millet is getting wider attention due to its resilience to insects and salinity. Also, it is a short-duration crop compared to other varieties (Sharma *et al.,* 2023). Fig. 3 below shows images of different millets.

Nutrition and health benefits of millets

The temporal shift in the total number of undernourished people in millions is illustrated in Fig. 4, which shows an increasing trend from 2018 to 2022 (FAOSTAT, 2023). Undernourishment leads to various diseases, so exploiting locally available, easily adaptable crops like millet is important to overcome malnutrition and ensure nutritional security (Louhar *et al.,* 2021).

The highest protein content (12.61g per 1000g), the highest fat content (4.28), and total mineral (4.77) are recorded in the proso, pearl, and little millet, respectively (Table 2). The undernourishment can be bridged by promoting millet as they have the same or superior nutritional profile as rice and wheat (Kumar *et al.,* 2018). Proso has the uppermost protein content among millets, and lipid content is similar to rice and wheat, with values ranging from 1.43 to 6 g/100 g. On average, millets have a carbohydrate (56.88 to 72.97 g/100 g), and dietary fiber (78.5%) higher than rice and wheat. Little and kodo millets have higher fiber content, which makes millet suitable for diabetic patients (Kumar *et al.,* 2018; Yadav *et al.,* 2023). The micronutrient content in millets (1.7 to 4.3 g/100 g) is more advanced than that of rice by 0.6% and wheat by 1.5%. The calcium content of finger millet is 350 mg/100 g, which is higher than that of major cereal crops, and hence, this can control osteoporosis (Singh and Sarita, 2016). Due to their high iron content, pearl, barnyard, and foxtail millet are good for children and pregnant women. Foxtail is also rich in zinc (Chandel *et al.,* 2014, Kumar *et al.,* 2018). These specialties make these millets in maintaining the immunity of the body.

Millet is used for controlling different non-communicable diseases (diabetes, cardiovascular diseases, cancer, inflammation and wound, coeliac disease, ocular diseases, and disorders) and also keeps our body from fattiness/obesity, anti-microbial activity, and aging (Fig. 5). It's worth noting that the phytochemicals present in various millet grains have become increasingly significant due to their potential health benefits, particularly for individuals with type II diabetes mellitus (TDM) (Ren *et al.,* 2016). Millets are packed with essential nutrients like phosphorous, potassium, iron, and magnesium, with a glycemic index of 54 to 68 (Dayakar *et al.,* 2017; Sathiya and Chithra, 2019). The glycemic index (GI) measures

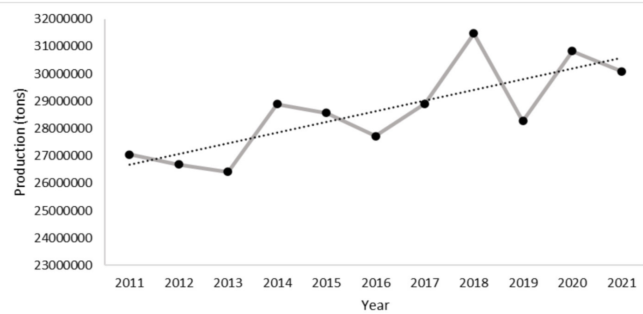

Fig. 1: The trend in the world production of millets (tons) from 2011 to 2021 (FAOSTAT, 2022)

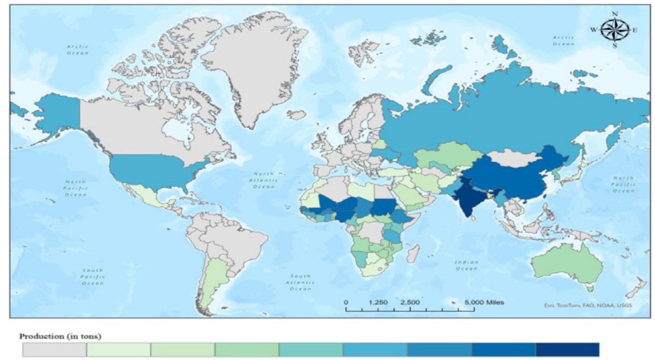

Fig. 2: World production of millets: Data source: (FAOSTAT, 2023)

Table 1: The global percentage contribution and seasons of millet cultivation (USDA)

World rank	Country	World production (%)	Area harvested (1000 ha)	Cropping Season
1	India	40	9,500	May-October
2	Niger	11	7,000	March-December
3	China	9	900	March-October
4	Nigeria	7	2,000	March-December
5	Mali	6	2,100	March-December
6	Sudan	5	2,500	March-December
7	Ethiopia	4	450	March-December
8	Burkina Faso	3	1,200	March-December
9	Senegal	3	1,000	March-December
10	Chad	2	1,180	March-December

Table 2: The nutrient profile of millets

Nutrients	Foxtail	Little	Barnyard	Kodo	Proso	Pearl	Finger
Protein (g/100g)	11.02	9.44	10.45	9.07	12.61	11.86	7.41
Fat	4.01	3.72	3.50	3.22	3.08	4.28	1.71
Total minerals	3.38	4.77	4.23	3.16	2.85	2.25	2.70
Mineral elements (mg/100g)							
Fe	2.64	1.43	5.07	1.17	0.92	6.85	4.82
Zn	2.43	3.61	2.13	1.62	1.38	2.82	2.45
Ca	34.19	17.17	22.31	14.58	13.41	24.93	350.33
Mn	0.44	0.32	1.10	0.47	1.25	1.60	3.86
Cu	0.20	0.38	0.34	0.27	0.47	0.54	0.69

Source: (Goudar *et al.,* 2023)

how quickly carbohydrate-containing foods raise blood glucose levels (Viguiliouk *et al.,* 2018). Their significant dietary fiber, protein, and mineral content contribute to stabilizing blood sugar levels and promoting overall health (WHO, 2018). The presence of antioxidants, including beta-glucans, flavonoids, anthocyanidins, tannins, lignans, and policosanols are instrumental in lowering LDL cholesterol effectively. Incorporating millet flour into the diet or having millet for breakfast can play a substantial role in weight loss, particularly in reducing the Body Mass Index (BMI) of obese individuals (Abdali *et al.,* 2015). The phytochemicals found in millets showcase antiproliferative effects, reducing the formation of cancer cells in the colon, breast, and liver, all while ensuring the well-being of normal cells without causing any damage and sorghum modifies the effect of fluoride that causes dental fluorosis (Janakiram *et al.,* 2011). In addition to its nutritional importance the existence of silver and silicon in a foxtail millet is used to prepare anti-microbial action such as ciprofloxacin and ampicillin antibiotics (Darshitha *et al.,* 2022).

Millets for climate-resilient agriculture

Millets have a remarkable ability to withstand diverse ecological conditions which can be attributed to their adaptability, demonstrated by reduced water requirements and diminished dependence on synthetic fertilizers (Serba *et al.,* 2020; Tadele, 2016). Millets are a type of C_4 plant and possess high photosynthetic rates in warmer temperatures superior to C_3 plants due to the capacity of high water and nitrogen use efficiency (W& NUE) (Zhang *et al.,* 2021). For instance, foxtail millet demonstrates significantly superior WUE, to harvest 1 g of dry biomass needs only 257 g of water in compared to maize and wheat, which demand 470 and 510 g, respectively (Challa *et al.,* 2023). In addition, millets show a flexible biomass distribution and decreased hydraulic conductivity

[a]Finger millet; [b]Foxtail millet; [c]Pearl Millet; [d]Little millet; [e]Proso Millet; [f]Kodo Millet

Fig. 3: Types of millets: Source: (https://americangardener.net/types-of-millet/)

Table 3: Climate resilience of millets

Millets	Influences					
	Drought tolerance	Salt tolerance	Water logging	Heat tolerance	Water requirement (mm)	Crop period (months)
Sorghum	Yes	Yes	Yes	-	450-650	3-4
Teff	Yes	-	Yes	-	300	2-5
Finger	Yes	Yes	-	-	350	3-6
Pros	Yes	-	-	-	200-300	2-3
Pearl	Yes	-	-	Yes	250-350	2-3
Fonio	Yes	-	-	-	250-350	2-3
Foxtail	Yes	-	-	-	300	2-4
Japanese	Yes	-	-	-	310	2-3
Kodo	Yes	-	-	-	800	4-6
Little	Yes	Yes	-	-	150	2-5
Browntop	Yes	-	-	Yes	440	2-3

Source: https://www.icrisat.org/public/crops/pearl-millet/varieties-developed

per leaf area unit during high temperatures and shortage of water, these distinctive attributes position millets as promising crops for the future, prompting research endeavors to explore their climate-resilient traits (Amelework *et al.,* 2015; Krupa *et al.,* 2017). Similarly, millet responds to biotic stresses, such as elevated levels of antioxidants, and scavenging enzymes (catalase and superoxide), and produces osmolytes and stress-related proteins (Ajithkumar *et al.,* 2014; Meng *et al.,* 2024). Zhang *et al.* (2012) conducted phylogenetic and evolutionary analyses on carbonic anhydrase homologs across all five grass genomes, emphasizing the high expression of the genome sequence of foxtail millet (Ft_CA1) in the mesophyll. Furthermore, millets swiftly establish deep and fibrous root systems, enhancing water accessibility and ensuring resilience to environmental fluctuations (Ashoka *et al.,* 2023). In summary, a combination of high specific leaf area, net assimilation rate, and root-to-shoot ratio contributes to an overall enhancement in the relative growth rate of millets (Lenka *et al.,* 2020).

All the listed millet varieties in Table 3 have drought tolerance; In addition, sorghum, finger millet, and little millet have the resilience to salt. Only sorghum and teff can withstand waterlogging. Heat tolerance is observed with pearl millet and brown top millet. Among different varieties, little millet requires a very low amount of water (150 mm), and kodo millet requires the highest amount of water (800 mm) for the cropping season. The overall crop growth period is from 3 to 4 months, which is beneficial to farmers by supporting them with more crop seasons irrespective of the climatic conditions, ensuring food availability. The extensive and deep-reaching root system of millets, extending up to 2 meters, emphasizes their resilience, adaptability, and drought resistance (Ashoka *et al.,* 2023). These characteristics position millets as robust crops capable of thriving in diverse climatic conditions, presenting them as valuable contributors to addressing the challenges associated with global climate change.

Table 4: Cereal crops' heat requirement

Types of crops	Base temperature	Heat requirement (GDD), ^{O}C-days
Millet (pearl millet)	12^{O}C	1, 900-2,300
Wheat	4-5^{O}C	1,800-2, 200
Rice	10^{O}C	2, 000-3500
Maize	10^{O}C	1, 000-2800

Source: FAO (2010); GDD-Growing Degree Day

Heat unit requirement of millets related to other cereal crops

A crop heat unit requirement refers to the total accumulated amount of heat, typically measured in "degree days" (DD), needed for a plant to reach maturity (McMaster *et al.,* 1997). This is used to assess the suitability of a region for the production of a particular crop, estimating the growth stages of crops. Different crops have varying heat unit requirements depending on their variety and the climate conditions in which they are grown. The heat requirement of millet differs from other cereal crops like wheat, rice, and maize as summarized in Table 4.

Millet is considered a thermophilic crop, requiring higher temperatures for optimal growth but has a lower overall growing degree day (GDD) requirement compared to wheat, maize, and rice, making it suitable for regions with shorter growing seasons, unpredictable rainfall, arid and semi-arid conditions or tropical and subtropical regions. According to the study by Bhuva and Detroja (2018) pearl millet required approximately 1,200-1,500 ^{O}C days from sowing to maturity and the finding highlights the adaptability of pearl millet to high-temperature environments compared to other cereals. Pradhan *et al.* (2018) reported the GDD requirement for maturity in case of little millet is 1794–1848-degree days, and it is the highest (3057–3164-degree days) for finger millet.

Carbon footprint of millets

FAO (2019) noted that, within the global agri-food systems, 7.2 billion tonnes of greenhouse gas (GHG) emissions were produced within the farm gate, constituting a significant portion of the total emissions amounting to 16.5 billion tonnes. Millets, among significant cereals like wheat and rice, offer a means of mitigating the impacts of climate change due to their lower carbon footprint (Shah *et al.,* 2024). Fig. 6 illustrates the carbon emission equivalent (CEE) and the global warming potential (GWP) of millet, wheat, and rice. This indicates the suitability of millet as a climate-smart crop in reducing greenhouse gas emissions compared to the major food grain crops (rice and wheat).

Processing and value-added products of millets

Naturally, millets contain a higher concentration of anti-nutritional (polyphenols, tannins, phytates, trypsin inhibitors, and oxalates) as compared to wheat and rice. Anti-nutritional factors can interfere with nutrient absorption, resulting in decreased nutrient bioavailability and utilization (Dayakar *et al.,* 2017; Bora *et al.,* 2019). Consuming raw foods that contain antinutrients and chemicals is harmful to humans. This can cause bloating, nutrient deficiency, and malnutrition. Therefore, to improve the nutritional and sensory properties, it is better to process the millet before consumption by removing the anti-nutritional factors and inedible portions (Dayakar *et al.,* 2017). There are primary and secondary processing methods in millet. Primary processing (cleaning, washing, soaking, germination, drying, dehulling, roasting, polishing, milling, and refining) and secondary/modern processing methods (fermenting, parboiling, cooking, puffing, propping, malting, baking, flaking, and extrusion (Pradeep and Sreeram, 2015; Rathore *et al.,* 2019). The processing of millet-based value-added food products improves digestibility and nutrient bioavailability but, may result in a significant nutrient loss or degradation during each processing step (Birania *et al..* 2020; Nazni and Devi, 2016) and the processes cause physicochemical changes that alter food's nutrition, function, and physical characteristics (Gowda *et al.,* 2020). Also as described by Yousaf *et al.,* (2021) processing is used to make grains edible, extend shelf life, and improve texture, flavor, taste, palatability, nutritional quality, and digestibility. Paschapur *et al.,* (2021) provided a detailed list of value-added products that can be extracted from millets in the Indian context. This includes puffs, extruded snacks, extruded flakes, instant idli mix, upma mix, laddu mix, semolina, millet flour, millets vermicelli, cookies, bread, cake, pizza base, sorghum bran peda (sweet), energy bars, bran fryums, pasta, and biscuits. Later, Paschapur *et al.,* (2021) and Deshpande and Nishad, (2021) provided a list of technologies available to add nutritional value to millets in India, such as milling, puffing, baking, flaking, and extrusion. The major value-added millet products are composite flour, baked products, fermented products, extruded products, dairy products, malting and weaning foods, pasta, and noodles, and puffed and flaked millets (Jindal and Nikhanj, 2023). Table 5 illustrates the nutritional profiles of value-added millet products.

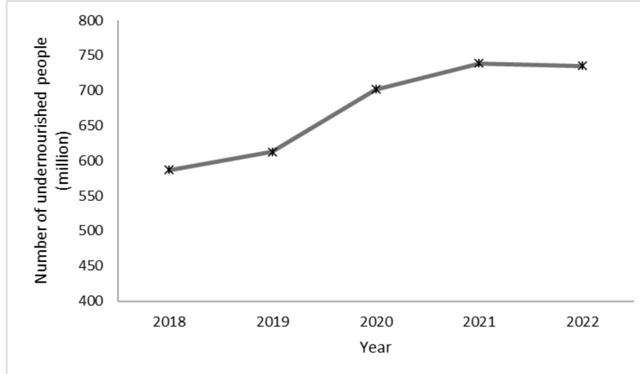

Fig. 4: Temporal shift in the total number of undernourished people in millions

Role of millet grain processing on the nutrient contents

The processing methods can have both positive and negative effects on the nutrient and antinutrient content. According to the results of different studies, processing has more positive effects on traditional and modern health foods (Bora *et al.,* 2019; Gowda *et al.,* 2022). Roasting proso millet can increase its protein content by 9.5% (Nazni and Devi, 2016) and the process of puffing or popping kodo millet can increase its protein from 7.92% to

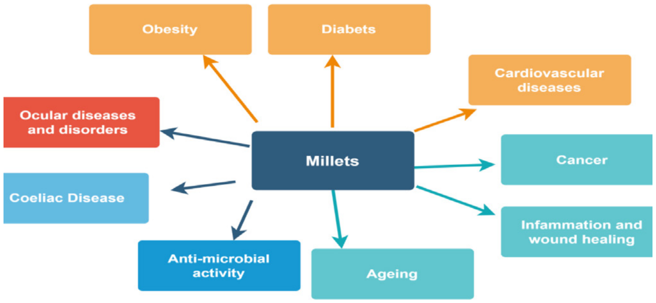

Fig. 5: Overview of health benefits of millet, sources (Anagha, 2023; Sabu and Kumar, 2020, Venkateswarlu *et al.,* 2023).

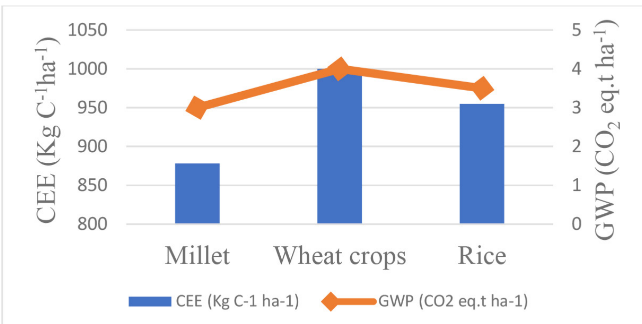

Fig. 6: Carbon foot printing of crops; Source: (Shah *et al.,* 2024)

8.12%, and germination also shows a substantial rise in the protein content of pearl millet (11.4% to 16.3%) (Iyabo *et al.,* 2018) and the carbohydrate of foxtail millet increased by 1.29% after 72 hours of germination (Chu *et al.,* 2019). Dehulling significantly increases the carbohydrate content by around 16% but parboiling significantly reduces the total starch of pearl and proso millet by 5-10% (Bora *et al.,* 2019). Dehulling millet grains beyond 30% leads to a substantial loss of dietary fiber (Yousaf *et al*., 2021) and the study found that fermenting foxtail millet bran increases the ratio of soluble dietary fiber to insoluble fiber by 10.9% and 16.8%, respectively (Chu *et al.,* 2019). Similarly, malting pearl millet for 24 hours boosts the fiber content from 0.77% to 0.87% but puffing and popping decline in crude fiber by 1.71% (Chauhan and Sarita, 2018). The mineral content of kodo millet increased from 232.82 to 251.73 mg/100 g after 36 hours of germination at 38.75 ^{o}C (Sharma *et al.,* 2017). Fermentation improves Ca by 20%, Fe by 27%, and P and Zn by 26%, bleaching pearl millet increases Fe from 2.19 to 3.29 mg/100 g (Pushparaj and Urooj, 2017; Rani *et al.,* 2018), and also roasting pearl millet increases its iron content by 274%. (Obadina *et al.,* 2016) but during the milling/sieving process of finger millet, the amount of Fe, Zn, and Ca is reduced to 3.29 mg, 1.98 mg, and 294.8 mg, respectively (Oghbaei and Prakash, 2016).

The vitamin content of millet is highly affected by decortication and a 67% decrease in vitamin E by decortication is recorded (Kundgol *et al.,* 2013), also during the milling and sieving of flour thiamine decreased from 0.552 to 0.342 mg per 100 g, and riboflavin decreased from 0.243 to 0.196 mg per 100 g (Oghbaei and Prakash, 2016) but germination increases vitamin C content from 0.04 to 0.06 mg per 100 g (Oghbaei and Prakash, 2016). The fat content of germinated foxtail millet is 3.6%, while non-germinated millet has 4.4% fat content (Sharma *et al.,* 2015), soaking with high pressure reduces the fat content by 27.98%, and malting for 24 hours

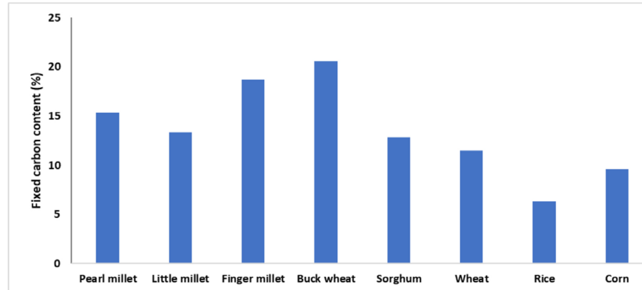

Fig. 7: Amount of fixed carbon in millet and other cereals. Data Source (Tagade *et al.,* 2021)

also results in a reduction in fat by 6.34 to 5.55% in pearl millet (Sharma *et al*., 2018). Roasting increases fat content, the amount of fat content in the roasted grain is (3.2g) greater than the raw (2.9 g per 100g) but the fat content in pressure-cooked, germinated, and boiled grains is less than the raw ones (Nazni and Devi, 2016). Fermentation of crude fat reduces fat value from 2.25 to 1.70% (Kaur *et al.,* 2019) but fermentation of pearl millet increases the content of crude fat from 1.83% to 3.71% (Yousaf *et al*., 2021). Other studies reported that roasting reduced crude fat by 0.71%, puffing and popping decreased fat content by 0.06% and 1.3-0.63 g/ 100 g, respectively (Yousaf *et al*., 2021; Saleh *et al.,* 2013). The general summary of millet nutrient content response to different processing methods is described in Table 6 below.

Non-food application of millet waste as bioenergy

Biomass resources, readily available locally and capable of being transformed into secondary energy carriers, offer a sustainable avenue for renewable energy production (Wang and Yang, 2016). Unlike traditional fossil fuels, biomass actively engages in the carbon cycle by absorbing carbon dioxide through photosynthesis during combustion, resulting in minimal CO_2 emissions (Ringsmuth *et al.,* 2016). The utilization of biomass in the production of bioenergy promotes the sustainability of renewable energy (Singh *et al.,* 2022). A significant share of biomass for bioenergy production originates from agricultural residues (Singh *et al.,* 2020). According to FAO (2020), India leads globally in cropland area with 170 million hectares and a robust agricultural sector, India generates considerable agricultural crop residues (Venkatramanan *et al.,* 2021). India produces 1043.24 million tonnes of crop residue annually, of that, 356.7 million tonnes can be used directly for power production (Chauhan *et al.,* 2022). Jowar, Bajra, and Ragi are the most produced millets, and their waste is being explored for use in polymer applications such as potential absorbents, polymer fillers, bioplastics, lightweight building materials, and packaging alternatives. It contributes to agro-waste and substitutes for depleted petroleum resources such as natural gas, coal, and minerals (Handayani *et al.,* 2019). The sorghum straws were used to extract xylose, which is then converted to xylitol. It was also used to create furfural. The ideal conditions for using acid hydrolysis to make furfural from xylose were 300 minutes at 134°C and 6% H_3PO_4, this resulted in approximately 13.7g L^{-1} of furfural (Sun *et al.,* 2013).

Millet produces residues (cobs, husks, stalks, and straws) and to address the challenge of excess residues, farmers often resort

Table 5: Nutritional profile of value-added products of millets

Food Products	Protein (%)	Fat (%)	Dietary fiber (g)	Energy (kcal)	Carbohydrates (g)
Sorghum puffs	11.9	3.02	13.88		
Extruded snacks	12.9	1.7	12.88		
Extruded flakes	13.9	1.4	14.88		
Instant upma mix	13.4	1.8	1.5	374	78.7
Instant dosa mix	12.4	1.9	-	364	71.7
Instant pongal mix	13.2	2.1	1.54	348	69.4
Sorghum muesli	17.1	2.1	1.7	342.4	75.4
Millets flour	6.1	2.2	1.5		
Bajra vermicelli	8.39	1.38	1.88		
Korra vermicelli	7.65	1.24	1.32		
Millet bread	7.4	12.3	0.8		
Millets cake	9.4	25.3	1.8		
Millets pizza base	6.4	21.3	4.8		
Sorghum bran peda	9.4	18.1	17.8		
Zinc rich jowar vermicelli	11.4	0.51	0.52	348.4	75.2
Zinc-enriched jowar pasta	11.4	0.51	0.52	350.4	76.2
Zinc-enriched jowar biscuits	12.4	6.3	2.2	485	76.3
Iron-rich jowar vermicelli	11.4	0.51	0.52	328.4	85.2
Iron-rich jowar pasta	11.4	0.51	0.52	332.4	86.5

Data Source (Deshpande and Nishad, 2021)

to the prevalent practice of burning, presenting environmental issues. The pyrolysis process is a cost-effective approach to converting millet residues into high-energy-density biofuel, making it a sustainable closed-loop method for waste management and energy recovery (Van de Velden *et al.,* 2010; Vikraman *et al.,* 2021). This is acknowledged as an eco-friendly technique and addresses challenges associated with residue disposal (Tagade *et al.,* 2021). Pyrolysis is a process that converts organic materials into gas, liquid, and solid products. This unique process offers great flexibility (Sharma *et al*., 2023; Tagade and Sawarkar, 2023). Most millet residues such as sorghum straw and stalk, usually contain less ash content, typically below 10%. This means that these residues are less likely to cause fouling and slagging during pyrolysis. Also, there will be a substantial decrease in ash production during the process, which can result in a higher energy yield from agro-residues. Additionally, the ash content in millet residues proposes that the fuels generated from these agricultural remnants will have better ignition efficiency.

The concentration of fixed carbon in biomass is a critical factor in determining its heating value, contributing significantly to the heat generated during combustion (Mishra and Mohanty, 2018). As depicted in Fig.7, biomass with higher proportions of fixed carbon tends to yield more biochar in the pyrolysis process (Ganesh, 2016). After careful analysis, it is evident that several millet residues have significantly elevated levels of fixed carbon (Tagade *et al.,* 2021). The substantial carbon content in residues highlights their potential for substantial biochar production through pyrolysis (Ding *et al.,* 2023; Tagade *et al.,* 2021). Additionally, these millet residues surpass the fixed carbon content in cereal: wheat straw (11.47%) (Sahoo *et al.,* 2021), rice husk (2.82%) (Singh *et al.,* 2020), rice straw (6.3%) (Gautam *et al.,* 2020), corn cob (9.6%) (Biswas *et al.,* 2017), and corn stalk (7.6%) (Zhai *et al.,* 2022). Among millets: pearl millet straw, sorghum straw, and stalk are particularly promising for bio-oil production, with sorghum stalk exhibiting a higher heating value (Tagade and Sawarkar, 2023). Polymer composites based on Sorghum waste into various value-added composites/products are sorghum fiber (HDPE and PLA), sorghum stalk as filler in HDPE, sorghum bran/recycled LDPE, sorghum straw (PVOH) and particle board from sorghum stalk (Mohite *et al.,* 2022).

Addressing challenges in millet production

The decadal production change in the top millet producers is presented in Fig. 8. The production of millet is showing an increasing trend in all the top producers except China, with a range of -6 to -8 million tons (mt) decreasing trend. In India and Niger, the productivity of millet is increased up to 4 mt within a decade. However, emphasis should be given to addressing the current challenges by the farming communities in accepting millet as a food security crop. Das and Rakshit (2016) reported that extreme weather events due to the changing climatic conditions and the conversion of millet-growing regions to other crops and cash crops contribute to reducing global millet production areas.

Promoting and developing schemes and policies is one of the options to promote millet cultivation. Swain *et al.* (2023) reported that government policies are required to promote the production and consumption of millet at the macro level, such as minimum support price, distribution of seed, fertilizer, pesticide, and subsidized credit facilities. Including millets in the government distribution system at national and international levels is another way to promote the consumption of millets. They also recommend

Table 6: Effect of processing on the nutrient contents of millets

Nutrients	Processing methods						
	Dehulling	Milling	Malting	Fermenting	Roasting	Cooking	Propping
Proteins	D	D	I	I	I	I	I
Carbohydrate	I	NA	NA	I	NA	D	D
Fiber	D	D	I	I	D	I	D
Mineral	D	D	I	I	I	NA	ID
Vitamins	D	D	I	I	NA	NA	NA
Fat	ID	D	D	ID	ID	D	D

I-Increase; D-Decrease; ID-Increase/Decrease; NA-Not available

Sources (Gowda *et al.,* 2022; Konapur *et al.,* 2014; Rani *et al.,* 2018; Sharma *et al.,* 2018).

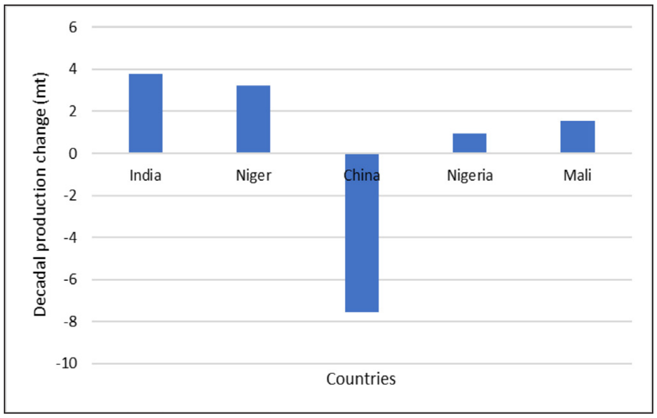

Fig. 8: The decadal change in millet production; Source (FAOSTAT, 2023)

Note: Decadal change indicates the ten-year trend analysis of millet productivity up to 2023.

region-specific farming practices for attaining better crop yield for millets. As a primary producer of millets, some of the schemes available in India to promote millet cultivation include the National Food Security Mission (NFSM), Rashtriya Krishi Vikas Yojana (RKVY), National Mission for Sustainable Agriculture (NMSA), Paramparagat Krishi Vikas Yojana (PKVY), and Integrated Farming System (IFS). UNESCO Intangible Cultural Heritage of Humanity, Millets in Food Assistance Programs, Climate-Resilient Agriculture Initiatives, Nutrition and Public Health Programs, the Global Alliance for Improved Nutrition (GAIN), and International Trade and Market Access are some of the international initiatives to promote millets for food and nutritional security. The reachability of such schemes to the farmer's level is still lacking, and there needs to be more focus so that the stakeholders will get such information and can improve their farming system with millet.

CONCLUSION

Although the production of millet is showing increasing trends, and the nutritional value of millet is high, there is a challenge in cultivating millet as food security. Therefore, incorporating millet-based foods in state, federal, and international feeding programs can alleviate nutrient deficiencies in poor countries. Additionally, educating people on the benefits of consuming these grains can lead to a healthier and disease-free life. Improvements to these high-value, nutrient-dense grains will benefit people's immunity, fitness, socio-economic status, and overall well-being. Also, further policy intervention is needed to promote and develop schemes such as the distribution of seeds, fertilizer, pesticides, subsidized credit facilities, and creating awareness of the value and nutritional food security of millet for further cultivation and consumption in the community.

ABBREVIATION AND NOMENCLATURE

USDA	United State Developmental Agency
CO_2	Carbon dioxide
LDL	Low-density lipoprotein
C_4	Corbon four plants
WUE	Water use efficiency
CEE	Cation emission equivalent
GWP	Global warming potential
FAO	Food and Agricultural Organization
H_3PO_4	Phosphoric acid

ACKNOWLEDGEMENT

The authors would like to thank the E4Life program at Amrita School for Sustainable Futures, Amrita Vishwa Vidyapeetham, for complete assistance in carrying out this work. We acknowledge Ms. Surya Harilal to prepare a map (Fig. 2) based on the shared data. We also thank all the peer reviewers and other relevant bodies who reviewed this manuscript.

Funding: The study was funded by the E4LIFE fellowship program at Amrita Vishwa Vidyapeetham.

Declaration of interest: The authors declare that they do not have any competing interests.

Author contributions: **D. Ejigu**: Preparation of the manuscript; **R. Pushpalatha**: Supervision and editing; **Sruthy S**: Reviewing and editing; **V. Padil**: Reviewing and editing; **B. Gangadharan**: Reviewing and editing; **R, Thendiyath**: Reviewing and editing; **Sajithkumar KJ**: Reviewing and editing; **G. Upadhyay**: Data collection and visualization

Disclaimer: The contents, opinions and views expressed in the

research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Abdali, D., Samson, S. E. and Grover, A. K. (2015). How effective are antioxidant supplements in obesity and diabetes? *Med. Princ. Pract.,* 24(3): 201-215. https://doi.org/10.1159/000375305

Ajithkumar, I. P. and Panneerselvam, R. (2014). ROS Scavenging System, Osmotic Maintenance, Pigment and Growth Status of Panicum sumatrense Roth. Under Drought Stress. *Cell. Biochem. Biophys.*, 68(3): 587-595. https://doi.org/10.1007/s12013-013-9746-x

Anagha, K.K. (2023). Millets: Nutritionl importance, health benefits, and bioavailability: A review. *Energy*, 12(8): 223-227. www.thepharmajournal.com

Amelework, B., Hussien, S., Pangirayi, T. and Mark, L. (2015). Physiological mechanisms of drought tolerance in sorghum, genetic basis and breeding methods: A review. *Afr. J. Agric. Res.,* 10(31): 3029-3040. https://doi.org/10.5897/ajar2015.9595

Ashoka P., Raut, D., Sudeepthi, B., Gawande, K. N., Reddy, Gurrala. S. V., Padhan, S. R. and Panigrahi, C. K. (2023). Millet's Role as a Climate Resilient Staple for Future Food Security: A Review. *Int. J. Environ. Clim. Change*, 13(11): 4542-4552. https://doi.org/10.9734/ijecc/2023/v13i113634

Bhatt, D., Rasane, P., Singh, J., Kaur, S., Fairos, M., Kaur, J., Gunjal, M., Mahato, D. K., Mehta, C. M., Avinashe, H. and Sharma, N. (2022). Nutritional advantages of barnyard millet and opportunities for its processing as value-added foods. *J. Food Sci. Technol.,* 60 (11): 2748-2760). Springer. https://doi.org/10.1007/s13197-022-05602-

Bhat, S., Nandini, C., Srinathareddy, S., Jayarame, G. and K., P. (2019). Proso millet (Panicum miliaceum L.)-a climate resilient crop for food and nutritional security: A Review. *Environ. Conserv. J.,* 20(3): 113-124. https://doi.org/10.36953/ECJ.2019.20315

Bhuva, H.M., and Detroja, A.C. (2018). Thermal requirement of pearl millet varieties in Saurashtra region. *J. Agrometeorol.,* 20 (4): 329-331 https://doi.org/10.54386/jam.v20i4.577

Birania, S., Rohilla, P., Kumar, R. and Kumar, N. (2020). Post harvest processing of millets: A review on value added products. *Int. J. Chem. Study,* 8 (1): 1824-1829. https://doi.org/10.22271/chemi.2020.v8.ilaa.8528

Biswas, B., Pandey, N., Bisht, Y., Singh, R., Kumar, J. and Bhaskar, T. (2017). Pyrolysis of agricultural biomass residues: Comparative study of corn cob, wheat straw, rice straw, and rice husk. *Bioresour. Technol.,* 237: 57-63. https://doi.org/10.1016/j.biortech.2017.02.046

Bora, P., Ragaee, S. and Marcone, M. (2019). Characterization of several types of millet as functional food ingredients. *Int. J. Food Sci. Nutr.,* 70: 714-724. https://doi.org/10.1080/09637486.2019.1570086

Challa, M. and Aparna, K. (2023). Development of Value -Added Millet Beverage with Foxtail Millet (PKS-22) and Bajar (PBH-1625). Thesis.

Chandel, G., Meena, R. K., Dubey, M. and Kumar, M. (2014). Nutritional properties of minor millets: neglected cereals with potentials to combat malnutrition. *Curr. Sci.,* 107(7), 1109-1111. http://faostat.fao.org/site/339/default.aspx

Chauhan, E. S. and Sarita. (2018). Effects of processing (germination and popping) on the nutritional and anti-nutritional properties of finger millet (Eleusine coracana). *Curr. Res. Nutr. Food. Sci.,* 6(2):566-572. http://dx.doi.org/10.12944/CRNFSJ.6.2.30

Chauhan, A., Upadhyay, S., Saini, G. and Senthilkumar, N. (2022). Agricultural Crop Residue Based Biomass in India: Potential Assessment, Methodology and Key Issues. *Sustain. Energy Technol.,* 53. https://doi.org/10.1016/j.seta.2022.102552

Chu, J., Zhao, H., Liu, Z., Lu, F., Bie, X. and Zhang, C. (2019). Improved physicochemical and functional properties of dietary fiber from millet bran fermented by Bacillus Natto. *Food Chem*., 294(1): 79-86. https://doi.org/10.1016/j.foodchem.2019.05.035

Darshitha, P.P., Ravi. A., Lasya. P., Menon, M., Sivasubramanian, G., Sreekanth, K.M. and Sreedhar, K.M. (2022). Foxtail millet husk as an innovative biomass in the preparation of silica-silver composite with antimicrobial and free radicle scavenging activities. *Materials Today: Proceedings*, 66: 1830-1836.

Das, I.K. and Rakshit, S. (2016). Millets, Their Importance, and Production Constraints. In I.K. Das & P.G. Padmaja (Eds.), *Biotic Stress Resist. Millets*, 3-19. https://doi.org/10.1016/B978-0-12-804549-7.00001-9

Dayakar Rao, B., Kandlakunta, B. and Golla, S. D. (2017). Nutritional and Health Benefits of Millets. ICAR_ Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad, 112. www.millets.res.in

Deshpande, S. D. and Nishad, P. K. (2021). Technology for Millet Value-Added Products. *In Millets Millet Technol*., 293–303. https://doi.org/10.1007/978-981-16-0676-2_14

Dey, S., Saxena, A., Kumar, Y., Maity, T. and Tarafdar, A. (2022). Understanding the Antinutritional Factors and Bioactive Compounds of Kodo Millet (Paspalum scrobiculatum) and Little Millet (Panicum sumatrense). *J. Food Qual.,* https://doi.org/10.1155/2022/1578448

Ding, S., Lan, Z. and Fang, S. (2023). Pyrolysis temperature determines the amendment effects of poplar residue-derived biochars on reducing CO_2 emission. *GCB Bioenergy*, 15(8): 1030-1045. https://doi.org/10.1111/gcbb.13080

FAO (2010). Millets and Sorghum in Crop Adaptation Strategies for Drylands. Retrieved from Food and Agriculture Organization. https://www.fao.org/3/i1638e/i1638e03.pdf

FAO (2019). The share of agri-food systems in total greenhouse gas emissions Global, regional and country trends. FAOSTAT analytical brief 31.

FAO (2020). World Food Agriculture Statistical Year Book 2020. http://www.fao.org/3/cb1329en/CB1329EN.pdf

FAO (2021). World Food and Agriculture – Statistical Yearbook 2021. FAO. https://doi.org/10.4060/cb4477en

FAOSTAT (2022). World Food and Agriculture – Statistical Yearbook 2022. https://doi.org/10.4060/cc2211en

FAOSTAT. (2023). World Food and Agriculture – Statistical Yearbook 2023. In World Food and Agriculture – Statistical Yearbook 2023. FAO. https://doi.org/10.4060/cc8166en

Gautam, N. and Chaurasia, A. (2020). Study on kinetics and bio-oil production from rice husk, rice straw, bamboo, sugarcane bagasse, and neem bark in a fixed-bed pyrolysis process. *Energy,* 190. https://doi.org/10.1016/j.energy.2019.116434

Ganesh, I. (2016). Electrochemical conversion of carbon dioxide into renewable fuel chemicals - The role of nanomaterials and the commercialization. *Renew. Sustain. Energy Rev.,* 59: 1269-1297. https://doi.org/10.1016/j.rser.2016.01.026

Gowda, N.N., Taji, F., Subramanya, S. and Ranganna, B. (2020). Development a table top centrifugal dehuller for small millets. *AMA Agric. Mech. Asia Africa Latin Am*, 51, 72-78.

Gowda, N.A., Kaliramesh. S., Vara Prasad, P.V., Bhatt. Y. and Netravati, B.P. (2022). Modern Processing of Indian Millets: A Perspective on Changes in Nutritional Properties. *Foods*, 11: 499. https//doi.org/10.3390/foods11040499

Goudar, G., Manne, M., Sathisha, G. J., Sharma, P., Mokalla, T. R., Kumar, S. B. and Ziouzenkova, O. (2023). Phenolic, nutritional and molecular interaction study among different millet varieties. *Food Chem Adv.,* 2: https://doi.org/10.1016/j.focha.2022.100150

Goutam, P. K., Giri, A., Sharma, M., and Panigrahi, C. K. (2023). Scientific cultivation practices of Kodo millet. *Handbook of Millets,* 365-284. ISBN - 978-81-967770-4-3

Handayani, S., Hussuil, Y. A., Handayani, A.S., Ismojo and Chalid, M. (2019). Application of waste sorghum stem (sorghum bicolour) as a raw material for microfibre cellulose. *IOP Conf. Series: MSEJ*, 509012015. https://doi.org/10.1088/1756-899X/509/1/012015

Iyabo, O.O., Ibiyinka, O. and Abimbola Deola, O. (2018). Comparative study of nutritional, functional and anti-nutritional properties of white sorghum bicolor (Sorghum) and pennisetum glaucum (Pearl Millet). *Int. J. Eng. Technol. Man. Res.,* 5 (3): 151-158.

Janakiram, C., Thankappan, K.R. and Sundaram, K.R. (2011). Sorghum Consumption Modifies the Effect of Fluoride on Dental Fluorosis in India. *JECH*, 65: A364. Doi: https://doi.org/10.1136/jech.2011.142976m.45

Jindal, P. and Nikhanj, P. (2023). A review on processing technologies for value-added millet products. *J. Food Process Eng.,* https://doi.org/10.1111/jfpe.14419.

Junior, V. N., Carcedo, A. J. P., Min, D., Diatta, A. A., Araya, A., Prasad, P. V. V., Diallo, A. and Ciampitti, I. (2023). Management adaptations for water-limited pearl millet systems in Senegal. *Agric. Water Manag.,* 278: 1-12. https://doi.org/10.1016/j.agwat.2023.108173

Kaur, P., Purewal, S.S., Sandhu, K.S., Kaur, M. and Salar, R.K. (2019). Millets: A cereal grain with potent antioxidants and health benefits. *J. Food. Meas. Charact,* 13: 793-806.

Konapur, A., Gavaravarapur, S.R.M., Gupta, S. and Nair, K.M. (2014). Millets in meeting nutrition security: Issues and way forward for Inda. *India J. Nutr. Diet.,* 51: 306-321.

Kundgol, N.G., Kasturiba, B., Math, K.K., Kamatar, M.Y., Usha, M. (2013). Impact of Decortication on Chemical Composition, Antioxidant Content and Antioxidant Activity of Little Millet Landraces. *IJERT*, 2(10): 1705-1720.

Krupa, K.N., Dalawai, N., Shashidhar, H.E., Harinikumar, K.M., Manojkumar, H.B., Bharani, S. and Turaidar, V. (2017). Mechanisms of Drought Tolerance in Sorghum: A Review. *Int. J. Pure Appl. Biosci.,* 5(4): 221-237. https://doi.org/10.18782/2320-7051.2845

Kumar, A., Tomer, V., Kaur, A., Kumar, V. and Gupta, K. (2018). Millets: A solution to agrarian and nutritional challenges. *Agric Food Secur.,* 7 (1). BioMed Central Ltd. https://doi.org/10.1186/s40066-018-0183-3

Lenka, B., Kulkarni, G. U., Moharana, A., Singh, A. P., Pradhan, G. S. and Muduli, L. (2020). Millets: Promising Crops for Climate-Smart Agriculture. *Int. J. Curr. Microbiol. App Sci.,* 9(11): 656-668. https://doi.org/10.20546/ijcmas.2020.911.081

Louhar, G., Bana, R. S., Kumar, V. and Kumar, H. (2021). Nutrient management technologies of millets for higher productivity and nutritional security. *Indian J. Agric. Sci.,* 90(12): https://doi.org/10.56093/ijas.v90i12.110267

Maitra, S. (2019). Potential of Intercropping System in Sustaining Crop Productivity. *IJAEB*, 12(1). https://doi.org/10.30954/0974-1712.03.2019.7

Meng, R., Li, Z.-P., Kang, X.-T., Zhang, Y.-J., Wang, Y.-R., Ma, Y.-C., Wu, Y.-F., Dong, S.-Q., Li, X.-R., Gao, L., Chu, X.-Q., Yang, G.-H. and Yuan, X.-Y. (2024). Overexpression of foxtail millet (Setaria italica) amino acid permease 9

(SiAAP9) inhibits the growth in transgenic Arabidopsis. *J. Res. Sq.,* 1-28. https://doi.org/10.21203/rs.3.rs-3907371/v1

Meena, R. P., Joshi, D., Bisht, J. K. and Kant, L. (2021). Global Scenario of Millets Cultivation. *In* Millets and Millet Technology, 33-50. https://doi.org/10.1007/978-981-16-0676-2_2

McMaster, G. S. and Wilhelm, W. W. (1997). Growing degree-days: one equation, two interpretations. *Agric. For. Meteorol.,* 87(4): 291-300. https://doi.org/10.1016/S0168-1923(97)00027-0

Mishra, R. K., and Mohanty, K. (2018). Pyrolysis kinetics and thermal behavior of waste sawdust biomass using thermogravimetric analysis. *Bioresour. Technol*., 251: 63-74. https://doi.org/10.1016/j.biortech.2017.12.029

Mohite, A.S., Jagtap, A.R., Avhad, M.S. and More, A.P. (2022). Recycling of major agriculture crop residues and its application in polymer industry: *Energy nexus*, 7: https://doi.org/10.1016/j.nexus.2022.100134

Nadeem, F., Ahmad, Z., Ul Hassan, M., Wang, R., Diao, X. and Li, X. (2020). Adaptation of Foxtail Millet (Setaria italica L.) to Abiotic Stresses: A Special Perspective of Responses to Nitrogen and Phosphate Limitations. *Front Plant Sci.*, 11. Frontiers Media S.A. https://doi.org/10.3389/fpls.2020.00187

Nazni, S., and Devi, S. (2016). Effect of processing on the characteristics changes in barnyard and foxtail millet. *J. Food Process. Technol*., 7(3): 1-8. http://dx.doi.org/10.4172/2157-7110.1000566

Obadina, A., Ishola, I., Adekoya, O., Soares, A., de Carvalho, C.W. and Barboza, H. (2016). Nutritional and physico-chemical properties of flour from native and raosted whole grain pearl millet (Pennisetum [L.] R.Br.). *J. Cereal Sci.,* 70: 247-252. http://dx.doi.org/10.1016/j.jcs.2016.06.005

Oghbaei, M. and Prakash, J. (2016). Effect of primary processing of cereals and legumes on its nutritional quality: A Comprhensive Review. *Cogent Food. Agric*., 2: http://dx.doi.org/10.1080/23311932.2015.1136015

Paschapur, A. U., Joshi, D., Mishra, K. K., Kant, L., Kumar, V. and Kumar, A. (2021). Millets for Life: A Brief Introduction. *In* Millets and Millet Technology, 1–32. https://doi.org/10.1007/978-981-16-0676-2_1

Pradeep, P.M. and Sreeram, Y.N. (2015). Impact of processing on the phenolic profiles of small millets: Evaluation of their antioxidant and enzyme inhibitory properties associated with hyperglycemia. *Food Chem.,* 169: 455-463. http://dx.doi.org/10.1016/j.foodchem.2014.08.010

Pradhan, A., Nag, S. K. and Mukherjee, S. C. (2018). Thermal requirement of small millets in Chhattisgarh plateau under rainfed. *J. Agrometeorol.,* 20(3): 244-245. https://doi.org/10.54386/jam.v20i3.554

Prajapati, S. K., Kumar, B., Chandra, P., Azad, S., Kumar, D. and Chandra, R. (2023). Small Millets: A Nutritional Powerhouse for Food Security and Health. http://www.rdagriculture.in

Pushparaj, FS. and Urooj, A. (2017). Impact of household processing methods on the nutritional characteristics of pearl millet (Pennisetum typhoideum): A Review. *Moj Food Process. Technol,* 4(1): 28-32. 00082.

Ranjan, R., Singh, S., Dhua, S., Mishra, P., Chauhan, A. K. and Gupta, A. K. (2023). Kodo Millet (Paspalum scrobiculatum): Bioactive Profile, Health Benefits and Techno- Functionality. In Nutri-Cereals: Nutraceutical and Techno-Functional Potential, 193-211). CRC Press. https://doi.org/10.1201/9781003251279-8

Rathore, T., Singh, R., Kambel, D.B., Upadhyay, A. and Thangalakshmi, S. (2019). Review on finger millet: Processing and value addition. *Pharma Innov. J.,* 8(4): 283-291.

Renganathan, V. G., Vanniarajan, C., Karthikeyan, A. and Ramalingam, J. (2020). Barnyard Millet for Food and Nutritional Security: Current Status and Future Research Direction. In Frontiers in Genetics, 11. Frontiers Media S.A. https://doi.org/10.3389/fgene.2020.00500

Rani, S., Singh, R., Sehrawat, R., Kaur, B.P. and Upadhyay, A. (2018). Pearl millet processing: A Review. *Nutr. Food. Sci.,* 48 (1): 30-44. https://doi.org/10.1108/NFS-04-2017-007

Sabu, K.M., and Kumar, T.K.M. (2020). Predictive analytics in Agriculture: Forecasting prices of Arecanuts in Kerala. *Procedia Comput. Sci.*, 171: 699-708. https://doi.org/10.1016/j.procs.2020.04.076

Sahoo, K., Kumar, A. and Chakraborty, J. P. (2021). A comparative study on valuable products: bio-oil, biochar, and non-condensable gases from pyrolysis of agricultural residues. *JMCWM*, 23(1): 186-204. https://doi.org/10.1007/s10163-020-01114-2

Saleh, A. S. M., Zhang, Q., Chen, J. and Shen, Q. (2013). Millet Grains: Nutritional quality, processing and potential health benefits. *Compr. Rev. Food Sci. Foods Saf*, 12: 281-295. https://doi.org/10.1111/1541-4337.12012

Ren, X., Chen, J., Molla, M. M., Wang, C., Diao, X., and Shen, Q. (2016). In vitro starch digestibility and in vivo glycemic response of foxtail millet and its products. *Food Funct.,* 7(1): 372-379. https://doi.org/10.1039/c5fo01074h

Ringsmuth, A. K., Landsberg, M. J. and Hankamer, B. (2016). Can photosynthesis enable a global transition from fossil fuels to solar fuels, to mitigate climate change and fuel-supply limitations? *Renew. Sustain. Energy Rev*., 62: 134-163). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.04.016

Sathiya, V. and Chithra, R. (2019). Nutritive Value, Glycemic Index and Glycemic Load of Selected Dosa Varieties. *I.JHSR*, 9(3): 215–219. ISSN: 2249-9571

Serba, D. D., Yadav, R. S., Varshney, R. K., Gupta, S. K., Mahalingam, G., Srivastava, R. K., Gupta, R., Perumal, R. and Tesso, T. T. (2020). Genomic designing of pearl millet: A resilient crop for arid and semi-arid environments. *In* Genomic Designing of Climate-Smart Cereal Crops, 221–286. Springer International Publishing. https://doi.org/10.1007/978-3-319-93381-8_6

Sharma, S., Saxena, D.C. and Riar, C.S. (2015). Antioxidant activity, total phenolics, flavonoids, and antinutritional characteristics of germinated foxtail millet (Setaria italica). *Cogent Food Agric.,*1. http://dx.doI.org/10.1080/23311932.2015.1081728

Sharma, S., Saxena, D.C., Riar, C.S. (2017). Using combined optimization, GC-MS and analytical technique to analyze the germination effect on phenolics, dietary fibers, minerals and gaba contents of kodo millet (Paspalum scrobiculatum). *Food Chem.,* 233, 20-28. https://doi.org/10.1016/j.foodchem.2017.04.099

Sharma, N., Goyal, S.K., Alam, T., Fatma, S., Chaorungrit, A.,Niranjan, K.(2018). Effect of high pressure soaking on water absorption, gelatinization, and biochemical properties of germinated and non-germinated foxtail millet grains. *J. Cereal Sci.,* 83: 162-170. https://doi.org/10.1016/j.jcs.2018.08.013

Sharma, N., Sahu, J. K., Bansal, V., Esua, O. J., Rana, S., Bhardwaj, A., Punia Bangar, S., and Adedeji, A. A. (2023). Trends in millet and pseudomillet proteins - Characterization, processing, and food applications. *In Food Res Int., 164*: Elsevier Ltd. https://doi.org/10.1016/j.foodres.2022.112310

Sharmili, K., Yasodha, M., Rajesh, P., Rajendran, K., Thankappan, S. and Minithra, R. (2021). Millet and pulse-based intercropping system for agricultural sustainability - A review. *Crop Res.,* 56(6): 369-378. https://doi.org/10.31830/2454-1761.2021.059

Shah, P., Mehta, N. and Shah, S. (2024). Exploring the factors that drive millet consumption: Insights from regular and occasional consumers. *J. Retail. Consum. Serv.,* 76. https://doi.org/10.1016/j.jretconser.2023.103598

Singh, E. and Sarita. (2016). Potential functional implications of finger millet (Eleusine coracana) in nutritional benefits, processing, health and diseases: A review. *Int. J. Home Sci.,* 2(1): 151-155. www.homesciencejournal.com

Singh, A., Kumar, M. and Shamim, Md. (2020). Importance of minor millets (Nutri Cereals) for nutrition purposes in the present scenario. *Int. J. Chem. Stud.,* 8(1): 3109-3113. https://doi.org/10.22271/chemi.2020.v8.i1au.9226

Singh, A. D., Gajera, B. and Sarma, A. K. (2022). Appraising the availability of biomass residues in India and their bioenergy potential. *J. Waste Manag,* 152: 38-47. https://doi.org/10.1016/j.wasman.08.001

Sood, S., Khulbe, R. K., Gupta, A. K., Agrawal, P. K., Upadhyaya, H. D. and Bhatt, J. C. (2015). Barnyard millet - A potential food and feed crop of future. *Plant Breed.*, 134 (2): 135-147. https://doi.org/10.1111/pbr.12243

Sood, S., Joshi, D. C. and Pattanayak, A. (2020). Breeding Advancements in Barnyard Millet. In Accelerated Plant Breeding: *Cereal Crops,* 1: 391-409. https://doi.org/10.1007/978-3-030-41866-3_15

Sun, S.L., Wen, J.L., Ma, M.G. and Sun, R.C. (2013). Successive alkali extraction and structural characterization of hemicelluloses from sweet sorghum stem. *Carbohydr. Polym*, 92: 2224-2231. http://dx.doi.org/10,1016/j.carbpol,2012,11.098

Sushmita, V. P., Lakshmi, J. and Lakshmi APGC, K. (2020). Nutrient Composition of Little Millet Varieties. *The Andhra Agric. J.*, 67 (1). https://aaj.net.in/wp-content/uploads/2023/08/67-1-014.pdf

Swain, P. S., Mohanty, B. B. and Pradhan, A. K. (2023). Untangling the factors influencing finger millet production: Evidence from the Indian states. *Int. J. Soil Sci.,* 73(248): 359-372. https://doi.org/10.1111/issj.12423

Tadele, Z. (2016). Drought Adaptation in Millets. In Abiotic and Biotic Stress in Plants - Recent Advances and Future Perspectives, *Tech*: 640-662. https://doi.org/10.5772/61929

Tagade, A., Kirti, N. and Sawarkar, A. N. (2021). Pyrolysis of agricultural crop residues: An overview of researches by Indian scientific community. *Bioresour. Technol. Rep.,* 15. https://doi.org/10.1016/j.biteb.2021.100761

Tagade, A. and Sawarkar, A. N. (2023). Valorization of millet agro-residues for bioenergy production through pyrolysis: Recent inroads, technological bottlenecks, possible remedies, and future directions. *In Bioresour. Technol.,* 384. Elsevier Ltd. https://doi.org/10.1016/j.biortech.2023.129335

Tripathi, G., Jitendrakumar, P. H., Borah, A., Nath, D., Das, H., Bansal, S., Singh, N. and Singh, B. V. (2023). A Review on Nutritional and Health Benefits of Millets. *Int. J. Plant Soil Sci.,* 35(19), 1736-1743. https://doi.org/10.9734/ijpss/2023/v35i193722

Ullah, A., Ahmad, A., Khaliq, T. and Akhtar, J. (2017). Recognizing production options for pearl millet in Pakistan under changing climate scenarios. *In J. Integr. Agric.,* 16 (4), 762-773. https://doi.org/10.1016/S2095-3119(16)61450-8

USDA (2023). Report of Top-Producing Millets by the Countries. https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=0459100

Van de Velden, M., Baeyens, J., Brems, A., Janssens, B. and Dewil, R. (2010). Fundamentals, kinetics and endothermicity of the biomass pyrolysis reaction. *J. Renew. Energy,* 35(1), 232–242. https://doi.org/10.1016/j.renene.2009.04.019

Venkateswarlu, R., M, M. V, Jacob, J., V, R. C. and Kumar, M.

(2023). Health benefits of millets. *Indian Farming*, 73(01), 91-93.

Venkatramanan, V., Shah, S., Prasad, S., Singh, A. and Prasad, R. (2021). Assessment of Bioenergy Generation Potential of Agricultural Crop Residues in India. *CE & S.,* 1(4), 1335-1348. https://doi.org/10.1007/s43615-021-00072-7

Viguiliouk, E., Nishi, S. K., Wolever, T. M. S. and Sievenpiper, J. L. (2018). Point: Glycemic index'an important but oft-misunderstood marker of carbohydrate quality. *CFW*, 63(4), 158-164. https://doi.org/10.1094/CFW-63-4-0158

Vikraman, V.K., Kumar, D. P., Boopathi, G. and Subramanian, P. (2021). Kenetic and thermodynamic study of finger millet straw pyrolysis through thermogravimetric analysis. *Bioresour. Technol.,* 342, 2-11. https://doi.org/10.1016/j.biortech.2021.125992

Wang, J. and Yang, Y. (2016). Energy, exergy, and environmental analysis of a hybrid combined cooling heating and power system utilizing biomass and solar energy. *Energy Convers, Manag.,* 124, 566-577. https://doi.org/10.1016/j.enconman.2016.07.059

WHO. (2018). A healthy diet is sustainably produced. WHO/NMH/NHD/18.12 https://iris.who.int/bitstream/handle/10665/278948/WHO-NMH-NHD-18.12-eng.pdf?sequence=1

Wimalasiri, E. M., Ashfold, M. J., Jahanshiri, E., Walker, S., Azam-Ali, S. N. and Karunaratne, A. S. (2023). Agro-climatic sensitivity analysis for sustainable crop diversification; the case of Proso millet (*Panicum miliaceum* L.). *PLoS ONE*, 18(3). https://doi.org/10.1371/journal.pone.0283298

Wilson, M. L. and VanBuren, R. (2022). Leveraging millets for developing climate resilient agriculture. *In Curr.Opin. Biotechnol.,* 75. Elsevier Ltd. https://doi.org/10.1016/j.copbio.2022.102683

Yadav, A., Niresh, A., Kumar, S., Chaitali, S. and Satvika, C. (2023). The Pharma Innovation Journal 2023; 12(3): 3026-3035 Studies on development of technology for preparation of millet based extruded snack. *The Pharm. Innov. J.,* 12(3), 3026-3035. www.thepharmajournal.com

Yousaf, L., Hou, D., Liaqat, H. and Shen, Q. (2021). Millet: A review of its nutritional and functional changes during processing. *Food Res. Int.,* 142, 1-13. https://doi.org/10.1016/j.foodres.2021.110197

Zhang, G., Wang, J., Zhang, G., Liu, X., Quan, Z., Cheng, S. (2012). Genome sequence of foxtail millet (Setaria italica) provides insights into grass evolution and biofuel potential. *Nat. Biotechnol.,* 30(6), 549-554. https://doi.org/10.1038/nbt.2195

Zhang, D., Ali, L., Shu, K.L., Ping, L., Zong, Y., Zhiqian, G. and Hao, X. (2021). Increased carbon uptake under elevated CO_2 concentration enhances water-use efficiency of C4 broomcorn millet under drought. *Agric. Water Manag.,* 245, 1-10. https://doi.org/10.1016/j.agwat.2020.106631

Zhai, Y., Zhu, Y., Cui, S., Tao, Y., Kai, X. and Yang, T. (2022). Study on the co-pyrolysis of oil shale and corn stalk: Pyrolysis characteristics, kinetic and gaseous product analysis. *J. Anal. Appl. Pyrolysis*, 163. https://doi.org/10.1016/j.jaap.2022.105456