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Millets: Past, present and future

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Abstract

The research article examines the historical development of millets focusing on their fundamental role as food crops throughout different global regions. The cultivation of millets stretches over thousands of years when researchers discovered these crops during Chinese and Indian ancient periods. Millets have expanded globally from their origin across Africa to Europe and the Americas while farmers have modified them to flourish within local climates alongside traditional recipes. The piece examines current obstacles to millet cultivation and consumption patterns alongside strategies for preserving this fundamental crop in today's agricultural environment. It explores challenges such as crop competition and changing eating habits alongside climate change impacts. Large-grained wheat along with corn and rice receive proper recognition regarding their initial agricultural significance while the small-seeded grasses known as millets often disappear into attention scopes. Within earlier farming models millets function as secondary grain crops which hold minimal significance in agricultural planning. Evidence of millet cultivation appears in archaeological sites worldwide yet massive accumulations of millet remains are seldom discovered and they are rarely recognized as fundamental food items. This research examines early millet findings in archaeobotanical records while showing the necessity for better integration of millets into early agricultural interpretation frameworks.

Keywords: Millets, history, traditional grains, underutilized crop, health benefits, millet revival, agricultural biodiversity

Introduction

Millet derives its name from Latin “Milum” which implies grain. Small-seeded grasses belonging to the Poaceae family which farmers cultivate extensively produce cereal crops and grains for people along with animal feed for many resource-challenged farmers while maintaining crucial roles in India's ecological framework and financial stability. According to apeda.gov.in millets receive the names "coarse cereals" or "cereals of the poor." These crops have experienced intensive farming throughout numerous global regions for numerous centuries. This crop species demonstrates exceptional endurance under different environmental conditions while growing successfully in dry and semi-arid areas. Many nations across Asia and Africa consider millets their basic food source which people utilize to prepare traditional recipes such as bread and porridge. An examination of millet history explores its origins and global spread with an analysis of cultural importance throughout.

The small-seeded grasses that belong to the genus millets have served as central tools for human civilization development due to their food and forage functions and symbolic cultural significance. Ancient communities throughout Asia Africa and Europe cultivated these pre-industrial grains before the development of agriculture. Due to their ability to thrive in arid regions combined with their fast life cycle and versatile suitability millet served as essential food crops for regions that wheat and rice could not sustain. High-yield wheat and rice transformed the agricultural landscape after their introduction which resulted in dwindling millet crops throughout history. Recent concerns about climate change together with uncertainties regarding food availability and nutrition have given rise to renewed international interest in these hardy nutritious grains. Research from archaeological sites demonstrates that millets ranked among the first domesticated crops that humans cultivated beyond 10,000 years ago. In India the remains of Panicum sumatrense small millet and Setaria italica foxtail millet were discovered at places including Hallur in Karnataka dating from 1800 BCE. Scientists now believe that the staple foods of China included foxtail millet and broomcorn millet (*Panicum miliaceum*) since 8000 BCE before rice cultivation developed in some areas. Research demonstrates that pearl millet (*Pennisetum glaucum*) originated from the ancient Sahel civilizations present in today's Niger and Mali dating from 2500-2000 BCE. These early grains formed both nutritional sustenance and traditional farming practices along with dietary patterns and communal traditions. Despite being primary food ingredients millets serve functions that go beyond simple sustenance. Ancient Indian writings such as the Yajurveda and Atharvaveda demonstrate the important role millets played in both cooking and religious rituals. Through African folklore and customs millet carries crucial meanings for everyday life that represent wealth and fertility and strengthen social ties. Millets have gained popularity in marginal farm areas because they require minimal inputs which made them ideal food crops for smallholder farmers in semi-arid environments. All the nutritional advantages—the dietary fiber content together with vital amino acids and minerals including calcium and iron alongside low glycemic

index—made millets beneficial for both ancient and modern dietary needs. Millets experienced continuous declines in both growth and utilization statistics since the colonial period and through the post-colonial era despite their vital historical significance for food systems. The Green Revolution pushed agricultural production toward high-yielding wheat and rice varieties which transformed agricultural policy throughout this period. The development changed traditional grain status which caused millets to become known as "coarse cereals" alongside "poor man's food." Farmers reduced their millet cultivation which led to the disappearance of traditional applications and the declining knowledge concerning its advantages. Recent decades have initiated a new trend in millet perception. People around the world now recognize millets as future crops due to urgent requirements for climate resilience and sustainable agriculture and dietary issues leading to non-communicable diseases. Through their low environmental impact and resistance to drought and nutritional value they align perfectly with sustainable development objectives and food security needs. Through the Indian government's proposal for 2023 as the International Year of Millets global attention has focused on these grains while research institutions and corporate development programs along with national initiatives strive to bring millets back into widespread prominence worldwide. This research reviews millets' evolutionary process from their beginning roots to domestication to cultural prominence to their decline and their modern resurgence. An exploration of archaeological evidence together with historical manuscripts and ethnobotanical studies combined with contemporary research will demonstrate how ancient grains proceed toward a sustainable agricultural future.

Origin of millets

Farming of millets spanned multiple thousands of years but scientists have not yet conclusively established their origin sites. The independent millet domestication occurred throughout the world's varied regions while these crops became among the first domesticated plants. Ancient archaeological findings show that foxtail millet (Setaria italica) alongside broomcorn millet (Panicum miliaceum) were already cultivated in northern China by 8000 cal. BP (Deng *et al*., 2017) [3]. The cultivation of millets occurred simultaneously in regions spanning Africa to the Middle East to Europe beginning that same time period. The first early farmers found that millet crops required easy management and their short growth time enabled lengthy preservation capabilities. Early Yajurveda texts provide the first written mentions of millets in India which name foxtail millet (priyangava), Barnyard millet (aanava), and black finger millet (shyaamaka). This proves millets were a common part of early diet before the Indian Bronze Age 4,500 BC. India's rural communities have depended on millets as their main food source from ancient times until the present. The Deccan Plateau's dry conditions in southern India made millets perfect for rain-fed cultivation over generations. Several varieties of millets including Pearl Millets Sorghum Finger Millet Foxtail Kodo Barnyard Proso Little Millet and Pseudo Millets Buckwheat and Amaranths are cultivated in India. Among Indian agricultural outputs Bajra (Pearl millet) together with Jowar (Sorghum) and Ragi (Finger Millet) dominate the entire millet production. Based foods from millet crops include porridge alongside bread as well as dosas and pancakes and other items. Chinese agriculture relied on millets as primary crops particularly in the wheat and rice cultivation marginal northern regions. The cultural meaning of Chinese foxtail and broomcorn millet appears through the XiaDynasty (2070-1600 BC) mythical Houji. The Chinese phrase for "Lord of Millets" corresponds to “Houji” (Crawford 2014) [6]. Farmer produced porridge and dumplings and noodles using millets as their main ingredient. Modern applications of millets extended beyond human nutrition when they found use in Chinese medicine practices. Historians now confirm that Europeans began farming millet during the Bronze Age rather than the Neolithic era seven thousand years ago. This practice prospered across eastern and central Europe. People produced porridge and bread and beer by using millet seeds. People in the Balkans used prepared millet porridge called polenta as their primary sustenance dish. The millets serve as fundamental food produce across Africa particularly throughout the Sahel region where these crops form primary dietary staples. Millets grow in multiple African territories. Tef and fonio represent two millet crops which originated in Africa yet remain cultivated exclusively in African territories for the preparation of two traditional dishes: sourdough flatbread known as injera from teff millets and the ancient West African cereal called Fonio. (The Story of Millets, 2018). Researchers began studying millets as a nutritious sustainable food source with increasing intensity during the past few years. The gluten-free nature of millets gives this crop a beneficial value for patients with celiac disease and diabetes who need low glycaemic index food. The origin of millets remains controversial among scholars even though major data and theories about their presence exist. Human civilization's agricultural development depended heavily on the domestic cultivation of millets which stand among the very first crops ever domesticated throughout history. Cereal grains show distribution across different regions worldwide since their emergence occurred separately throughout multiple global locations. Early human societies across different locations adopted millets because their polycentric development matched environmental challenges with crops that survived harsh weather and little rainfall. The study of millet evolution teaches fundamental details about early farming methods as well as ancient trading networks and cultural contacts which shaped global farming practices.

Spread of Millets

Through domestication in Asia and Africa people developed millets and this basic crop completed its worldwide distribution as fundamental food staples supporting developing civilizations. These nutritionally valuable millets require between two months to four months to complete their life cycle because short cropping seasons create challenges that promote multifaceted cultivation practices and resistance against unpredictable weather events. Scientists trace the growth of millets through analysis of ancient human movements across trading connections. Early populations who moved from Africa to different global regions likely transported millet seeds they cultivated when they settled in their new lands. Embers travelled via the Silk

Road which connected East and West as different communities exchanged them across these ancient trade networks. The original African millet *Eleusina coracana* traveled to India before the Aryan period according to research done by Mehra (1963) [10]. Recent scientific research identified the highlands which extend from Ethiopia to Uganda as the most probable origin territory for *Eleusine coracana* domestication. Evidence from Kadero confirms the domestication of Sorghum bicolor within the extensive broad leaved savannah region extending from Lake Chad to eastern central Sudan. Pearl millet received domestication within the Sudan to Senegal arid savannah region (Harlan 1971) [11]. Examiners should study how pearl millet traveled to reach the Indian Peninsula using either direct land access or an alternative method. The adoption of pearls into Indian agriculture happened during the final years of the third millennium B.C. The present millets assist lower-income households with their nutritional needs and provide essential feed for cattle herds. (Singh, 1996) [12]. Desert-climate tolerant millets including foxtail millet, pearl millet, and finger millet became useful crops because they could survive with minimal rainfall. These resistant crops offered a suitable solution for farmers whose resources were limited because they resisted both pests and diseases. Throughout time millets spread across Africa, Asia, Europe, and the Americas especially in challenging growing regions through transportation by merchants, explorers and settlers. Asia accepted this crop when millets arrived in both India and Southeast Asia thus leading to widespread adoption. Humans transmitted millets to European territories so farmers began growing these crops throughout Greece and Italy. European immigrants brought millets into the Americas where they developed cultivation systems across the southern United States and South America. Many regions choose millets because these crops demonstrate remarkable survival abilities while still managing to grow in challenging soil conditions. Materials used in growing millets achieve success on infertile soils and environments receiving scant rainfall which makes these crops ideal choices for agricultural production in regions with dry climates. The fast 60-day growing season allows these crops to be profitable agricultural units in regions where traditional crops struggle to survive. The nutritional value of millets serves as their main value but they also play essential economic and cultural roles. Small-scale farmers obtain considerable economic benefits from millets while multiple global regions use these crops for both cultural observances and religious ceremonies. The interest in using millets as food crops has increased significantly in nations with developing economies where they form the main element of diets. The low-input nature of millets makes them an attractive climate change solution because farmers can use sustainable farming practices. The promotion of millets as both sustainable and wholesome food continues uninterrupted in present times. India's government launched a millet promotion initiative to support farmers while improving both small-scale farming well-being and throughout the country. Multiple varieties exist within the taxonomy of millets which carry different physical characteristics and nutritional properties alongside one another. The following is a list of the most popularly grown millets in cultivation.

Types of Millets

1. Sorghum (*Sorghum bicolour*)

Sorghum functions as a heat-loving crop that does not thrive in cold weather yet resists major pest infestations and plant diseases. The plant exists under multiple names throughout West Africa and Asia and selects parts of the Middle East. The vast majority of sorghum production in North and Central America and Oceania and South America exists for animal feed purposes (FAO, 1995) [13]. History shows Sorghum as one of humanity's oldest cereal crops and both India and Africa have established it as their major farming staple. Due to its safety profile sorghum functions as an acceptable gluten-free substitute for celiac disease sufferers as well as people sensitive to wheat proteins. The gluten free nature of sorghum allows people with wheat allergies to eat this grain. This plant contains high levels of iron nutrimental content along with protein and dietary fiber.

2. Pearlmillet (*Pennisetum glaucum*)

Studies indicate Bajra aka Pearl millet originated in Africa 5000 years ago (Andrews and Kumar 1992) [15] before arriving in the Indian subcontinent 3000 years ago. The resilient crop pearl millet demonstrates its ability to grow well in marginal soil conditions and persists through dry spells. Bajra provides excellent protein and dietary fiber followed by essential micronutrients such as iron and zinc. Magnesium in Pearl millet helps reduce asthma respiratory difficulties and alleviates migraine symptoms. Consuming fiber-rich pearl millet helps decrease the risk of developing gallstones. Ingesting insoluble fiber from pearl millet helps reduce an individual's system bile levels because excessive bile leads to gallstones (Shweta, 2015). Various value-added foods derive from pearl millet to produce items ranging from cutlets and weaning food to vermicelli and beverage powder through to bread, cakes, muffins, chapati, instant idli, kheer, extruded product, cookies, snack bar and drinks.

3. Finger Millet (*Eleusine coracana*):

African and South Asian countries consume finger millet or Ragi as a staple food which researchers believe farmers first cultivated approximately 4,000 years ago. The crop stands as an important famine survival plant owing to its ease of preservation during lean seasons (FAO, 2012) [18]. People can prepare finger millet in multiple ways because it transforms quickly yet provides excellent nutrition; they can eat it like rice or mix it into porridge or flour to make baked goods. Furthermore finger millet constitutes the base material for alcoholic beverages termed arake or areki in Ethiopian regions. Finger millet provides humans with protein in addition to fiber and multiple essential micronutrients including calcium and iron and potassium. The gluten-free nature of this cereal and its low glycemic properties provide an excellent diet choice for both diabetics and those with celiac disease.

4. Foxtail millet (*Setaria italica*)

FaoxTail millet's origin most likely stems from China although it was first domesticated during Neolithic times. Archaeological evidence indicates Foxtail millet domestication occurred during Neolithic times even though scientists believe the domestication process took place in China. Foxtail millet stands as one of the earliest grains that

European and Asian farmers planted since China delivers greater than 45% of the global production (Jiaju and Yuzhi 1994) [20]. Foxtail millet requires lower altitude environments to grow while completing its lifecycle within 70 to 120 days. Foxtail millet contains proteins with added benefits from dietary fiber as well as important mineral nutrients such as iron alongside magnesium and phosphorus.

5. Little Millet (*Panicum sumatrense Roth*.):

Archaeological evidence suggests little millet domestication started in India's Eastern Ghats approximately 2000 years ago while most production happens in the Indian states of Andhra Pradesh and Karnataka and Tamil Nadu and Kerala. Little millet demonstrates suitability for various climate conditions by permitting farmers to cultivate it successfully in both drought-prone and water-logged areas because it establishes itself early and tolerates difficult growing situations. Little millet provides a rich nutritional profile because it contains protein along with fiber and key micronutrients such as iron and calcium and phosphorus.

6. Kodo Millet (*Paspalum scrobiculatum*)

Records show that Kodo millet began in India when farmers started growing it more than 3,000 years ago. Kodo millet serves as a dominant agricultural crop throughout India's southern and western regions. The dietary benefits of Kodo millet include excellent protein value and high fiber content in addition to multiple necessary microelements including iron and calcium and potassium. Traditional grain Kodo millet matches rice in appearance while offering weight reduction support. The quick digestive nature of kodo mill*et al*so delivers antioxidants and phytochemicals to prevent numerous lifestyle diseases. Studies show Kodo millet functions as a treatment for hip and knee pain but simultaneously regulates female menstrual cycles (Deshpande *et al*., 2015) [22] People in Indian tribal regions prepare Kodo millet like rice to create various products including idli, dosa, papad and kheer.

7. Barnyard Millet (*Echinocloa esculenta A. and Echinocloa colona*)

Barnyard millet functions as a multiple-use plant which people grow for both food and animal feed. Barnyard millet originally grew in India over a period of 4,000 years. India devotes extensive cultivation space to this crop across eastern and central regions. Research shows that barnyard millet contains substantial protein content alongside excellent dietary fiber levels including soluble and insoluble fractions. The low carbohydrate content of barnyard millet combined with its slow digestion rate makes this grain a beneficial natural choice for today's sedentary human populations (Dayakar Rao B. 2017) [19]. Studies show that barnyard millet provides the most significant reduction in blood glucose and cholesterol numbers. The nutritional profile of barnyard millet includes abundant key micronutrients including iron and calcium and phosphorus. Manufacturers use barnyard millet to produce diverse value-added products including vermicelli, roti/chapati, noodles, biscuits, cookies, malt-based weaning food, extruded products, snack food, ladoo, halwa and biryani, dosa.

8. Proso millet (*Panicum miliaceum*)

Probably originating from the Manchurian region of China Broomcorn millet or Proso millet spreads cultivation across northwest China plus southern and central India as well as Australia and the USA and Europe. Broomcorn millet stands as the third most cultivated cereal crop following pearl millet and foxtail millet because it thrives well in diverse soil environments and moderate elevations from 0 to 3500 meters Paschapur 2021) [16]. The consumption of Proso millet helps people prevent Pellagra-related illness from niacin Vitamin B3 deficiencies. The grain provides abundant amounts of Niacin. People have traditionally used proso millet as a restorative food element during postpartum or illness recovery. Proso millet provides an ideal combination of proteins, dietary fiber and essential minerals including iron and magnesium. Durum millet finds its primary applications in producing traditional foods such as chakli and noodles followed by cookies and chapati and then khichari and chila before moving to idli and dosa and namkeen and biscuits and halwa and Payasam and roti and bread and ready-to-eat breakfast cereal.

Area, Production and productivity of millets in world

Users can find millets (small millets alongside pearl millet) data through the Food and Agriculture Organization (FAO) website (FAOSTAT 2018) under two distinct categories. Our research presents an overview of global millet aggregation statistics. The Indian data collection focuses exclusively on sorghum and pearl millet and finger millet (INDIASTAT 2020).

Among 93 active millet nations worldwide fewer than seven states including India possess over 1 M ha harvested acreage and around twenty-five nations work with more than 0.1 M ha cultivated land. Together these crops make up 97% of all global millet cultivated land covering 34.1 M hectares. The millet-producing nations of the world place India at the top with 15.29 M ha harvested area while Niger maintains second place with 7.03 M ha followed by Sudan with 3.75 M ha then Nigeria with 2.7 M ha followed by Mali (2.15 M ha) and BurkinaFaso (1.39 M ha) until Chad (1.22 M ha) finishes seventh. As the world's leading millet producer India holds 26.6% of the total harvested land base (FAOSTAT 2018).

In 1961, Asian farmers led millet cultivation with 27.1 M ha of harvested land while other continents stood after Asia with Africa (11.8 M ha), Europe (4 M ha), America (2.6 M ha), and Oceania (0.02 M ha). The newest data shows that Africa dominates with 20.7 M ha harvested land while Asia closes behind with 10.9 M ha followed by Europe at 0.4 M ha and America at 0.16 M ha then Oceania with 0.03 M ha. West Africa led millet cultivation across different African regions with 14.3 M hectares of planted land dominating West Africa while North Africa had 3 M hectares under cultivation.

FAOSTAT 2018 data shows that West Africa maintained 44.3% control over the worldwide harvested millet area. Four West African nations (Niger and Nigeria along with Mali and Burkina Faso) represent four of the seven countries with the largest harvested millet areas. Sudan holds the largest millet cultivation territory in North West

Africa even though Chad produces the most millet across North Central Africa. India leads millet cultivation throughout Asia while occupying a dominant 80% share of all Asian millet acres followed by China. United States (0.16 M hectares) positions itself as the main millets producer across America while Argentina follows as the second-largest grower. Ukraine together with Poland and France and Belarus form the key millet cultivation blocs within European territory.

Worldwide cultivation of millets decreases annually through a loss of 22.5 lakh ha area each decade despite their vast potential. Global numbers show that planted millet fields decreased by 25% from 1961-1963 until 2016-2018. FAOSTAT 2018 shows millet cultivation area in Asia fell by 148% from 1961-1963 to 2016-2018. Reduced food crop portfolios combined with heavy starchy food dependency and declining farm profits resulted in the significant decline of millets cropping area in Asia. African farmers now cultivate millets over 42% more land than they did in the 1961-1963 period. Western Africa experienced the most significant increase among all regions which grew from 8.8 M hectares in 1961-1963 to 14.3 M ha during 2016-2018.

Global millets area and production by region (FAOSTAT 2018)

Region	Area (lakh ha) 1961-63	1971-73	1981-83	1991-93	2001-03	2011-13	2016-18	Production (lakh tons) 1961-63	1971-73	1981-83	1991-93	2001-03	2011-13	2016-18
Africa	118.39	133.227	108.751	168.994	197.694	191.28	207.067	69.424	74.512	77.617	109.664	142.483	113.391	140.569
Eastern Africa	16.364	17.758	12.333	13.412	14.382	15.096	15.032	11.566	13.585	12.052	12.065	12.939	16.004	17.57
Middle Africa	8.017	6.804	4.945	8.119	11.43	14.655	15.962	5.147	3.996	2.974	4.021	6.609	7.78	9.356
Northern Africa	4.799	10.489	11.727	12.567	25.402	21.87	30.351	3.077	3.651	3.578	3.342	6.609	7.136	16.698
Southern Africa	0.813	1.6	1.745	1.729	2.836	2.481	2.695	0.275	0.449	0.533	0.453	0.689	0.497	0.602
Western Africa	88.397	96.576	78.002	133.166	143.645	137.178	143.027	49.359	52.831	58.481	89.783	115.637	81.975	96.342
Americas	2.657	2.529	2.457	2.259	2.149	1.67	1.676	3.257	2.983	3.067	3.355	2.885	2.448	3.628
Northern America	0.971	0.977	0.859	1.599	1.996	1.593	1.644	1.157	1.267	1.165	2.314	2.61	2.318	3.578
Central America	0	0	0	0	0.005	0.008	0.002	0	0	0	0	0.005	0.008	0.003
Caribbean	00	00	00	00	00	00	00	00	00	00	00	00	00	00
South America	01.686	1.552	1.598	0.661	0.148	0.069	0.03	2.1	1.717	1.902	1.041	0.27	0.122	0.048
Asia	271.746	272.35	229.054	174.644	144.703	121.958	109.255	152.925	181.63	178.191	142.069	137.569	142.501	139.522
Central Asia	0	0	0	6.499	0.725	0.44	0.477	0	0	0	0.68	0.532	0.458	0.53
Eastern Asia	74.31	66.337	40.679	19.771	11.76	8.014	7.49	66.283	79.594	66.976	36.292	20.99	17.772	17.317
Southern Asia	193.676	202.853	184.903	147.468	128.739	109.925	97.864	83.835	99.717	108.229	101.515	113.598	121.086	118.503
South-Eastern Asia	1.452	1.54	1.754	1.955	2.329	2.231	2.415	0.468	0.39	1.512	1.316	1.659	2.198	2.474
Western Asia	2.308	1.621	1.718	1.118	1.151	1.348	1.009	2.339	1.929	1.474	0.68	0.79	0.987	0.698
Europe	40.893	26.865	28.023	22.453	8.182	6.278	4.029	23.776	26.753	21.4	16.277	9.043	8.363	6.237
Eastern Europe	40.631	26.765	27.989	22.44	8.097	6.128	3.881	23.444	26.582	21.319	16.248	8.793	7.87	5.688
Northern Europe	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern Europe	0.226	0.081	0.019	0.013	0.015	0.009	0.014	0.286	0.127	0.034	0.029	0.033	0.016	0.026
Western Europe	0.036	0.018	0.015	0	0.071	0.14	0.134	0.047	0.044	0.047	0	0.218	0.477	0.524
Oceania	0.294	0.334	0.327	0.295	0.357	0.353	0.351	0.322	0.363	0.317	0.262	0.288	0.358	0.359
Australia & NZ	0.294	0.334	0.327	0.295	0.357	0.353	0.351	0.322	0.363	0.317	0.262	0.288	0.358	0.359
World Total	433.98	435.305	368.613	368.645	353.085	321.539	322.378	249.704	286.242	280.593	271.627	292.268	267.061	290.314

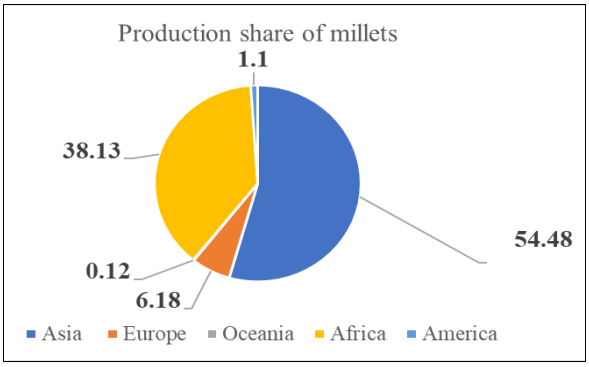
Area, Production, and Productivity of Millets in India

Period	Finger Millet Area (M ha)	Production (Mt)	Productivity (kg/ha)	Sorghum Area (M ha)	Production (Mt)	Productivity (kg/ha)	Pearl Millet Area (M ha)	Production (Mt)	Productivity (kg/ha)	Total Millets Area (M ha)	Production (Mt)	Productivity (kg/ha)
1951-1960	2.33	1.7	725.4	17.09	7.65	446	10.66	3.21	300	30.08	12.56	300
1961-1970	2.49	1.86	746.8	18.3	9.29	506.9	11.58	4	345	32.37	15.14	345
1971-1980	2.51	2.41	956.3	16.36	9.75	596.6	11.97	5.35	444.4	30.84	17.51	444.4
1981-1990	2.43	2.57	1059.1	15.83	11.09	701.6	10.94	5.08	460.4	29.2	18.73	460.4
1991-2000	1.85	2.42	1319.5	11.76	9.8	831	10.32	7.33	646	23.92	19.55	657.3
2001-2010	1.48	2.07	1395	8.76	7.27	836.9	9.39	7.87	829.5	19.63	17.2	829.5
2011-2020	1.17	1.79	1591.375	6.07	5.07	883.375	8.05	9.02	1130.1	15.29	15.88	1130.1

Millet production together with consumption occurs primarily in developing nations to the extent of 97% while other global regions contribute minimally to global millet quantities. The statistical analysis from 1961 to 1963 shows Asia leads the world in millet production (13.2 Mt) surpassing Africa (6.9 Mt), Europe (2.3 Mt), America (0.32 Mt) and Oceania (0.03 Mt). The primary millet cultivation areas exist in India, China and Nepal within Asia. India leads global millet production with ~37.5% followed by Sudan and Nigeria as secondary producers. Indian millet farmers grow their crops mostly in areas characterized by scarce and unpredictable rainfall patterns in arid regions. The farming state of pearl millet dominates India's millet sector accounting for 56% (9 Mt) of total production from Rajasthan, Uttar Pradesh, Gujarat, Madhya Pradesh, and Haryana. Of all the minor millets grown in India finger millet remains the most prominent variety because farmers cultivate 1.79 Mt from 1.17 M ha in total. The six states of Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Odisha and Andhra Pradesh sustain more than 90% of Indian finger millet output. After finger millet production kodo millet stands as India's second most cultivated minor millet crop.

The continent of Africa produces a substantial fraction of global millets because millets serve as fundamental food during meals across most areas of the continent. Five countries in Africa collectively represent the continent's largest community of millet producers: Nigeria leads followed by Sudan along with Mali and Ghana and Guinea. Local production figures show the United States stands as the top North American millet producer while Argentina leads South American mills. The production of millets in Europe occurs exclusively in the arid Eastern European regions which account for 90% of all European millet output. Producers of millets lead the industry across Oceania where Australia together with New Zealand stand at the forefront. Between 1961 and 2019 millets production in Africa increased substantially throughout West African regions while production elsewhere around the world declined. Africa produced the highest amount of millet (14 Mt) in the recent production period (2016-2018) surpassing the former leader Asia (13.9 Mt) with Europe (0.62 Mt), America (0.36 Mt) behind and Oceania (0.03 Mt) trailing the most. The African continent sustained its output growth because farmers expanded cultivation into marginal lands affected by climate fluctuations resulting in decreased plantings of water-intensive crops like maize. Asia experienced its maximum millet crop output during the 1980s yet production levels decreased steadily because of farm territory loss in both India and China. Millet production statistics in Oceania show minimal variations throughout the period from 1961 to 2018.

Indian farmers have relied on millets through numerous generations because these crops thrive under dry conditions and survive in nutrient-poor terrains. Policy focus on rice and wheat agriculture has resulted in a steady decrease of millet cultivation land from 36.9 million hectares during the 1960s to its current level of approximately 14.4 million hectares in the 2022-2023 period. Millet crop production continues to thrive because agriculture experts combine recent high-yield varieties with improved cultivation practices. The 2022-23 crop year showed India produced about 19.3 million tonnes of millet across 14.4 million hectares benefiting from productivity increases from 488 kg/ha in 1965-66 to nearly 1,340 kg/ha.Major millet cultivation takes place in Rajasthan, Karnataka, Maharashtra, Tamil Nadu, Uttar Pradesh, and Andhra Pradesh. Rajasthan stands as the foremost state in area and output of pearl millet yet Tamil Nadu and Andhra Pradesh maintain the top productivity indices because both regions receive favorable growing conditions augmented by government input programs. The International Year of Millets 2023 together with Public Distribution System integration and National Millet Mission support millet renewal and sustainable farmer income growth through climate-resilient nutritious crops.



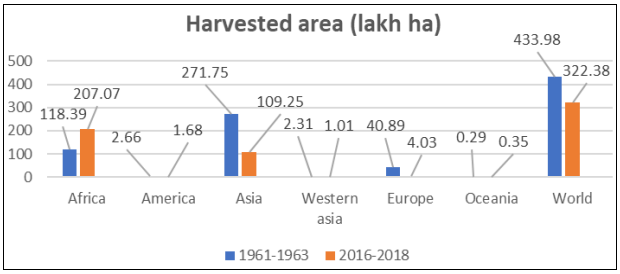
Global millets productivity by region (FAOSTAT 2018)

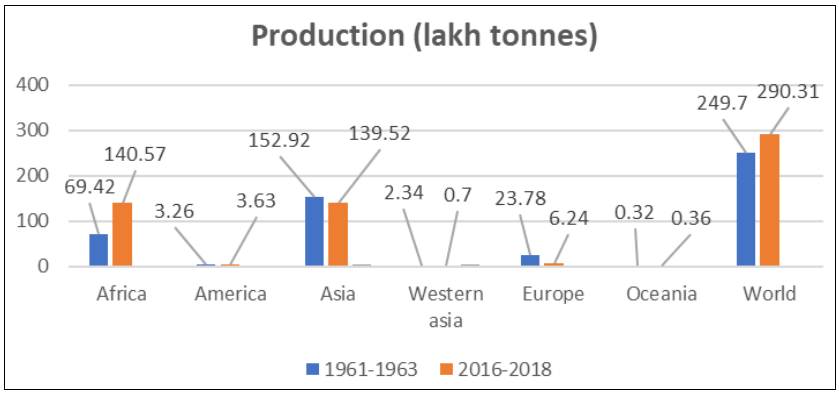
Region	1961-63	1971-73	1981-83	1991-93	2001-03	2011-13	2016-18
Africa	0586	0559	0714	0649	0720	0597	0677
Eastern Africa	0707	0766	0987	0904	0900	01061	01170
Middle Africa	0642	0586	0605	0494	0580	0522	0586
Northern Africa	0641	0360	0301	0262	0260	0319	0525
Southern Africa	0339	0281	0305	0265	0249	0201	0221
Western Africa	0558	0547	0750	0674	0804	0602	0673
Americas	01223	01176	01247	01486	01269	01361	02166
Northern America	01192	01297	01356	01448	01214	01326	02177
Central America	00	00	00	01030	0909	01000	05595
Caribbean	00	00	00	00	00	00	00
South America	01236	01087	01184	01595	01838	01763	01576
Asia	0562	0666	0777	0811	0938	01171	01276
Central Asia	00	00	00	0523	0760	01025	01104
Eastern Asia	0889	01195	01644	01846	01786	02219	02308
Southern Asia	0433	0489	0584	0686	0864	01104	01210
South-eastern Asia	0322	0254	0801	0673	0712	0985	01025
Western Asia	01013	01180	0858	0601	0682	0732	0689
Europe	0583	0982	0761	0765	01079	01301	01517
Eastern Europe	0578	0979	0759	0764	01057	01249	01424
Northern Europe	00	00	00	00	00	00	00
Southern Europe	01257	01551	01792	02252	02212	01727	01869
Western Europe	01293	02372	03129	00	03050	03400	03909
Oceania	01087	01067	0975	0855	0814	01015	01022
Australia & New Zealand	01087	01067	0975	0855	0814	01015	01022
World	0575	0656	0761	0736	0823	0832	0900

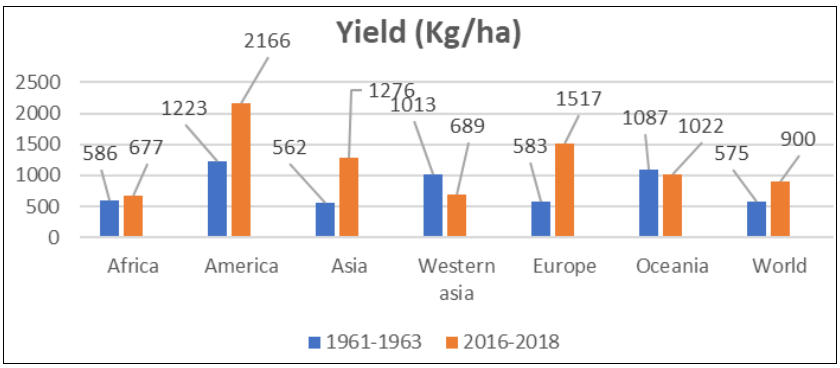
Over the past 70 years Millet production has experienced a 36% boost according to comparative productivity data from 1961-1963 to 2016-2018 throughout the continents. Europe displayed the highest yield enhancement (1517 kg/ha) followed by Asia (1276 kg/ha) then America (2166 kg/ha), with Africa's growth restricted to 13% (677 kg/ha). 62%) followed by Asia (562-1276 kg/ha; Productivity statistics show Asia leads among other continents with a 56% increase in yield levels from 562 to 1276 kg/ha. Asia follows Asia (1223-2166 kg/ha; 44%) and America (1223-2166 kg/ha; 44%) and Africa (586-677 kg/ha; 13%) yield levels have also improved.

The productivity of millet continues to decrease in Oceania with a rate of (1087-1022 kg/ha. Millet yield in Africa grew progressively from the 1960s until maximum output occurred in the 1980s then started a downward trend throughout the 1990s. During 2001-2003 the region experienced its highest productivity performance at 720 kg/ha demonstrating a 18.6% improvement over 1960s levels. Another negative growth rate in productivity followed that period. Eastern Africa demonstrated continuous yield level improvement from 1961-1963 to 2016-2018 through a 40% increase that closely matched American figures. South-Eastern Asia achieved the highest productivity gains in millet cultivation through a 69% increase from 1961-1963 (322 kg/ha) to 2016-2018 (1025 kg/ha). The maximum production output of 2308 kg/ha occurred in Eastern Asia in 2016-2018 while Southern Asia came in second. Mexico stands as the global top millet-producing nation with 15.7 t/ha productivity while Uzbekistan follows with 6.76 t/ha and Austria and Switzerland each reach 4.4 t/ha and 4 t/ha productivity respectively (FAOSTAT 2018). Over the past seventy years Indian farmers have achieved more than 73% growth in millet crop production. During the last ten years Indian farmers achieved an average millet productivity rate of 1130 kg/ha throughout the nation. Finger millet generates the most substantial production levels (1591 kg/ha) when compared to sorghum (883 kg/ha) and pearl millet (1130 kg/ha). The growth in agricultural output stems from three factors: input responsive millet cultivars and improved farming practices along with increased input usage efficiency.

Different sorghum-growing nations have demonstrated yield improvements since several years ago. The development of input-responsive varieties and hybrids together with enhanced agronomic management practices drives these results. The productivity of sorghum in India shows regional differences because different parts experience different soil conditions and rainfall patterns and growing seasons. The Indian farming sector grows sorghum twice yearly through both rainy and post-rainy periods. Rakshit and Wang demonstrate that cereal yields reach higher levels during rainy season cultivation than post rainy season farming.







Nutritional Importance of Millets

Seven varieties of millets including Pearl millet and Finger millet and Kodo millet and Proso millet and Foxtail millet and Little millet and Barnyard millet provide essential dietary nutrition to millions worldwide. These cereal crops grow under rain-fed conditions typical of regions receiving limited precipitation thereby providing essential contributions to both sustainable agriculture systems and food security approaches. Mainfood value from millets sustains poor nations yet wealthier nations mainly use millets as animal feed. Like other cereals millets represent excellent dietary sources which contain protein alongside minerals and phytochemicals. Processing techniques including soaking, malting, and boiling with decortication affect the levels and activities of anti-oxidants in food products according to Saleh *et al*., 2013. Sorghum along with the majority of millet varieties contains about 10% protein with 3.5% lipids but finger millet features protein levels of 12-16% and 2-5% lipids. Millets provide exceptional nutrient density that includes multiple essential vitamins alongside important minerals. Most sorghum protein consists of prolamin (kaffirin) molecules that show decreased digestibility during cooking yet millets contain superior amino acid profiles. Tests show that heated sorghum proteins keep their digestibility levels significantly lower than those of other grain proteins so they could offer health benefits for certain population segments. The lower cross-linked prolamins in millet proteins represent a second mechanism contributing to enhanced digestibility of these proteins.

Research shows finger millet contains 5-8% protein alongside 65-75% carbs together with 15-20% dietary fiber and 2.5-3.5% minerals. The white buckeye-shaped finger millet caryopsis with red seed coat skin is regularly used as whole grain flour for traditional dishes including roti, jumble and ambali thin porridge. Studies of whole grain cereal consumption through epidemiological investigations show that these products might help fend off diabetes mellitus while safeguarding against gastrointestinal diseases and cardiovascular conditions. The health benefits from millets whole grain utilization come from key elements found in the seed coat such as vitamins and minerals together with dietary fiber and phenolic compounds.

The nutritional qualities of millets demonstrate similarities to main cereals while simultaneously delivering exceptional levels of carbohydrates along with micronutrients and phytochemicals which provide nutraceutical effects. Each millet contains 7-12% of protein together with 2-5% fat and 15-20% dietary fiber and 65-75% carbohydrates. The protein and lipid contents of pearl millet range between 12-16% and 4-6% respectively. The protein content of finger millet reaches between 6-8 percent while its fat content ranges from 1.5 to 2 percent. The essential amino acids found in millet proteins show a superior balance when compared with maize. Finger millet contains 5-8% protein and 65-75% carbohydrates and 2.5-3.5% minerals and 15-20% total dietary fiber. Whole meal finger millet preparations including roti jumble and ambali utilize the Naked caryopsis along with brick red tinted seeds for traditional Indian cooking. Research in epidemiology shows that whole grain cereals and their products protect against diabetes mellitus and gastrointestinal diseases and heart conditions. Using millets as whole grains enables essential elements like dietary fiber and phenolics and minerals to survive into the processed meal along with the seed coat's vitamins. Biology research shows millets contain comparable nutritional properties as main cereals and also demonstrate exceptional strengths as carbohydrate and micronutrient and phytochemical reservoirs for nutraceutical benefits. These cereals contain 7-12% protein and 2-5% fat

and 15-20% dietary fiber while the overall carbohydrate content is between 65-75%. Pearl millet stands out with its high contents of both proteins (12-16%) and lipids (4-6%) between its group members. Finger millet has less protein at 6 to 8 percent and lower fat content between 1.5 percent and 2 percent. Protein from millet contains amino acid profiles that exceed the levels found in maize.

Changing Demand for Millets in the Context of Climate Change

Worldwide concern about climate change affects agricultural systems and food security as well as nutrition extensively. Soaring drought counts and hotter weather together with irregular rainfall have made it urgent to assess staple crop sustainability across changing climates. The rise of millets as "coarse grains" represents a new farming movement because these crops demonstrate built-in drought-resistance and adaptable properties. These underserved agricultural products show promise as climate-smart food systems that help create sustainable farming practices and food accessibility in vulnerable territories. The growth of millets occurs successfully in dry and semi-arid areas requiring significantly less water and fewer resources than the water-intensive cereals rice and wheat do. Their quick lifecycle along with their ability to withstand pests and diseases and capability to thrive on marginal land makes millets appropriate selections for future climate-smart farming systems. As C4 plants millets benefit from an efficient photosynthetic pathway at high temperatures and limited moisture conditions enhancing their ecological fitness in warm regions. The changing agro-ecological context has generated increased millet demand across consumer and government sectors. India and sub-Saharan Africa lead efforts by launching millet-focused policy initiatives for food networks and educational institutions and climate resilience programs. The Food and Agriculture Organization (FAO) together with the United Nations established 2023 [32] as the International Year of Millets to encourage worldwide grain usage for sustainable food systems. Meanwhile consumer demand for millets expands due to increasing recognition of their health benefits. Millets deliver fiber together with essential amino acids and antioxidants as well as important minerals including zinc and iron and calcium. Global dietary patterns now favor nutritious wholegrain diets based on studies which affirm the nutritional benefits of these grains. Millets stand apart in the efforts to combat environmental concerns and public health problems because of their combination of climate resilience and nutritional benefits. The transition to a millet-based agricultural system faces several important obstacles. Major enhancements need to be made to market infrastructure combined with value chain expansion along with consumer education about millets and agricultural extension support. Millet research needs to focus on production improvements alongside enhancements to storage practices as well as processing methods as marketing techniques to match mainstream commercial crops. The shift in millet market demand results from both climate change and changing dietary patterns but depends on proper governance support combined with innovation and public education to perform its essential role in building sustainable food systems of the future. The increasing significance of these crops reveals the urgent necessity to reintegrate lost agricultural crops in mainstream farming and dietary patterns for climate adaptation.

Nutrient Composition

Millet grains include 65% carbohydrates mostly as non-starchy polysaccharides and dietary fiber which improve digestion and lower cholesterol levels and maintain slow glucose absorption after breakdown. Data shows regular millet consumers experience decreased risk of heart diseases as well as duodenal ulcers together with reduced hyperglycemia symptoms. Millets contain essential vitamins including Thiamine, riboflavin and folic acid and niacin. Millets contain mineral and fatty acid content as high as wheat while having similar nutritional qualities to rice. Millets show remarkable differences in their carbohydrate makeup because their amylose to amylopectin proportions range between 16-28% and 72-84%.

The nutritional examination of Millet grain reveals it functions as a superior food source for energy along with protein and multiple vitamins and essential minerals including trace elements. The edible portion of millet kernels contains significant phytochemical amounts including both dietary fiber and polyphenols at 0.2 to 0.3%. The antioxidant activity of millets derives from its phytates and polyphenols and tannins which control aging and metabolic illnesses. Among the cereals finger millet holds the highest concentration of calcium with 344 mg/100g. These crops contain phytates at a level of 0.48g/100g in addition to polyphenols and tannin content at 0.61% according to Thompson.

Sorghum contains 11.9 percent water along with 10.4 percent protein and 1.9 percent fat as well as 1.6 percent fiber content. The mineral value of grain sorghum is very similar to its fibre content at 1.6 percent. Foods derived from sorghum hold 349 K cal while offering 72.6 percent of carbs according to data from Gopalan. The grain's major carbohydrate form is starch. Carbohydrate content of sorghum includes simple sugars together with hemicellulose and cellulose. The starch of different origins contains 21.28 percent amylose. The dietary fiber content in sorghum reaches 14.3 percent. Scientists calculated that sorghum delivers 25 mg of calcium and 222 mg of phosphorous and 4.1 mg of iron per 100 g of edible material.

Black finger millet possesses 8.71 mg/g dry weight fatty acid and 8.47 g/dry weight protein according to Glew. New research shows Kodo millet and small millet contain 37% to 38% dietary fiber while experts once considered this substance an 'anti-nutrient' but now recognize it as a nutraceutical with grains having the highest levels. Due to its complete nutritional value millets function as a versatile food ingredient for manufacturing snacks and processed products and infant foods while fostering food safety across developing nations.

Nutritional composition of main millets in comparison to major cereals (@ 12% moisture; per 100 g edible portion

Nutrient	Finger Millet	Pearl Millet	Foxtail Millet	Proso Millet	Wheat	Rice (White)	Rice (Brown)	Corn (White)	Sorghum	Oats	Barley (Pearled)
Proximate Composition											
Moisture (g)	013.1	012.4	011.2	011.9	012.8	013.7	012.4	010.4	012.4	08.2	010.1
Energy (kcal)	0336	0361	0331	0341	0346	0345	0362	0365	0329	0389	0352
Protein (g)	07.7	011.6	012.3	012.5	011.8	06.8	07.5	09.4	010.6	016.9	09.9
Fat (g)	01.5	05	04.3	01.1	01.5	00.5	02.7	04.7	03.5	06.9	01.2
Total Dietary Fiber (g)	011.5	011.3	02.4	-	012.5	04.1	03.4	07.3	06.7	010.6	015.6
Carbohydrate (g)	072.6	067.5	060.9	070.4	071.2	078.2	076.2	0074.3	072.1	066.3	077.7
Minerals (g)	02.7	02.3	03.3	01.9	01.5	00.6	-	-	01.6	-	-
Minerals and Trace Elements											
Calcium (mg)	0350	042	031	014	030	010	033	07	013	054	029
Iron (mg)	03.9	08	02.8	00.8	03.5	00.7	01.8	02.7	03.36	04.7	02.5
Magnesium (mg)	0137	0137	081	0153	0138	064	0143	0127	0165	0177	079
Phosphorus (mg)	0283	0296	0290	0206	0298	0160	0264	0210	0222	0523	0221
Manganese (mg)	05.94	01.15	00.6	00.6	02.29	00.51	-	-	00.78	-	-
Molybdenum (mg)	00.102	00.069	00.7	-	00.051	00.05	-	-	00.039	-	-
Zinc (mg)	02.3	03.1	02.4	01.4	02.7	01.3	02.02	02.21	01.7	03.97	02.1
Sodium (mg)	011	010.9	04.6	08.2	017.1	-	04	035	02	02	09
Potassium (mg)	0408	0307	0250	0113	0284	-	0268	0287	0363	0429	0280
Vitamins											
Thiamine (mg)	00.42	00.33	00.59	00.2	00.45	00.06	00.41	00.39	00.33	00.76	00.19
Riboflavin (mg)	00.19	00.25	00.11	00.18	00.17	00.06	00.04	00.2	00.096	00.14	00.11
Niacin (mg)	01.1	02.3	03.2	02.3	05.5	01.9	04.3	03.6	03.7	00.96	04.6
Total Folic Acid (µg)	018.3	045.5	015	-	036.6	08	020	-	020	056	023
Vitamin E (mg)	022	-	-	-	-	-	-	-	00.5	-	00.02

Conclusion

The cultivation history of millets spans human existence because they constitute an important agricultural product. вікі складають багатошаровий джерело харчових речовин введення до середовищ із пастими випадками та змученим навколишнім середовищем. The human alimentary system has utilized millets as a vital foodstuff for several thousand years while they remain essential for ensuring food reliability today. Reduced millet planting during recent years presents an ongoing cause for concern therefore we need to take steps to increase both millet farming and consumption.

Throughout thousands of years millets have developed a rich historical heritage. Numerous historical communities integrated these staple foods both nutritionally and culturally in their customs throughout time. During the 20th century many parts of the world experienced a decline in millet farming yet there is now increasing interest in its cultivation. Due to their nutritional values and sustainability characteristics small farmers in developing nations find millets to be an appropriate crop choice. Millet production's restoration as a cultivated crop presents an opportunity to improve wellness and living conditions for millions of people throughout the world. Small-seeded grasses known as millets have been domesticated for millennia throughout different global regions. Their adaptable character combined with extreme weather tolerance has made these grains essential agricultural staples for numerous arid regions across the globe.

As sustainable food sources for humans millets offer environmental benefits while providing ecological advantages alongside financial value.

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