Global Millet Trends, Outlook, Challenges, and Opportunities

Kumara Charyulu Deevi, Nedumaran Swamikannu and Jyosthnaa Padmanabhan

1 Introduction

Millets are a group of small-seeded coarse cereals grown mainly in Asia and Africa. They are grown on soils which typically are too poor to support any other crop. They are significant contributors to the food security of the people living in Africa and Asia. They are grown mostly in developing countries (McDonough et al. 2000) located in Africa (Niger, Nigeria, Sudan, Mali, Burkina Faso) and Asia (India, China, Pakistan, Myanmar, Nepal) for food, feed, and fodder. Millets account for <1% of global cereal production and 3% of coarse cereal production. They are thinly traded with <2% of total millet production being exported. The most important millets by area cultivated and production quantities are pearl millet, finger millet, proso millet, and foxtail millet. The area covered by these millets, excluding sorghum, is 76% for pearl millet, 19% for finger millet, 9% for tef, and 4% for fonio (Obilana 2003). Sorghum and pearl millet are the two most important global members in the millets group, and these two have the largest area among the millets and occupy the fifth and sixth positions in total global crops, respectively, after rice, wheat, maize, and barley. With this background, the present chapter starts by highlighting the importance of millets, especially pearl millet in Asia and Africa. It also describes the major producing regions and trends in area, production and productivity across major growing countries in the world. Pattern of millets utilization among different regions is also furnished. The economic impacts of pearl millet research across different ecologies are reviewed and tabulated. The region-wise projected millet demand and supply between 2030 and 2050 are summarized and the widening gap among them identified. Major challenges in millets cultivation across ecologies are summarized and the potential opportunities among those are discussed at the end.

1.1 Importance of Pearl Millet

Pearl millet (*Pennisetum glaucum* R. Br.) is an important crop in the semiarid and arid ecologies of South Asia (SA) and sub-Saharan Africa (SSA) that are characteristically challenged by low and erratic rainfall and high mean temperature and simultaneously have soils with low organic carbon and poor water-holding capacity (Serba et al. 2020). Pearl millet is valued for its nutrient-rich grain for human consumption (Parthasarathy Rao et al. 2006) and its green fodder and dry stover for livestock (Andrews and Kumar 1992; Parthasarathy Rao and Hall 2003) and forms the basis of livelihood and nutritional security for >90 million people in

K. C. Deevi (✉) · N. Swamikannu · J. Padmanabhan
ICRISAT, Patancheru, Hyderabad, India
e-mail: Kumaracharyulu.deevi@icrisat.org

R. Srivastava et al. (eds.), *The Pearl Millet Genome*, Compendium of Plant Genomes,
https://doi.org/10.1007/978-3-031-56976-0_1

SSA and SA (Serba et al. 2020). Pearl millet demand is anticipated to increase in the future because of increasing human and livestock populations in SSA and SA and as a healthy food and other industrial uses (Rai et al. 2008). Its cultivation may further extend in the areas where maize and sorghum are cultivated because of depleting water resources. Pearl millet production is likely to become more challenging because of predicted intense drought stress, rise in temperature, and greater disease incidences in SSA (Sultan et al. 2013) and SA (Rama Rao et al. 2019). Therefore, its production must be increased at a much faster rate and more so in challenging agro-ecologies.

Presently, millets are cultivated mostly in Africa (~ 20 million ha) and Asia (~ 11 million ha). In Asia, India has the largest area (~ 10 million ha) under this crop. Global area, production, and productivity data for millets are not available separately for all kinds of millets in FAOSTAT. Hence, the present study used millets data which include pearl millet and other small millets. Approximately, pearl millet represents about 3/4th of global millet area in the world. Africa accounts for about 64% of global millet area while Asia represents nearly 34%. Rest of the world only occupies 2% of global millet area. In most parts of the world, pearl millet is grown as a subsistence crop for local consumption. Commercial millet production is risky, especially in Africa, because the absence of large market outlets means that fluctuations in output cause significant price fluctuations, particularly in areas where millet is the main food crop. Apart from grain production, millet is also cultivated for grazing, green fodder, or silage. Livestock are an important component of most millet production systems, and millet crop residues contribute significantly to fodder supplies (Parthasarathy Rao and Hall 2003).

2 Global Millet Production and Utilization

African countries account for 63% of the global area under millets and 48% of global production (Table 1). Much of the crop is grown on marginal lands with low inputs and consequently yields in this region are relatively low. Asian countries are the second most important block of millet producers, accounting for 34% of the global area and 49% of the global production. Yields are close to double here compared to Africa, as improved/hybrid seeds are widely used (Kumara Charyulu et al. 2014), though the total area in these countries has been falling as farmers shift to other, more remunerative crops.

Globally, the area under millets has come down from 35 to 32 million ha during the last decade (2011–2020) period. The millet cropped area is much stable in Africa region while it has declined significantly in case of Asia region. Except in case of Europe, millet cropped area under Americas and Oceania regions exhibited stability during study period. The global millet production has declined marginally due to reduction in area. Africa region (specifically West Central Africa) indicated remarkable

Table 1 Area planted to millets by region, 2018–20

Region	Area ('000 ha)	Production ('000 tons)	Productivity (kg/ha)
Global	31,862 (100)	30,142 (100)	945
Africa	20,128 (63.2)	14,488 (48.0)	718
Eastern Africa	1331 (4.2)	1954 (6.5)	1468
Western Africa	13,813 (43.3)	10,082 (33.4)	729
Americas	183 (0.5)	287 (0.9)	1580
Asia	11,100 (34.8)	14,791 (49.1)	1331
Europe	413 (1.3)	539 (1.8)	1297
Oceania	35 (0.1)	36 (0.1)	1018

Note Figures in the parenthesis indicates % to column total

decline in crop production during the last decade. The reasons might be significant millet area reduction in Nigeria coupled with decline in mean productivity levels in the region. Contrary to area trend in Asia, the millet production has increased marginally due to enhancement in productivity over last one decade (Kumara Charyulu et al. 2017). The production has significantly gone down in Europe when compared with Americas and Oceania regions. Overall, millets area and production have come down globally and across major regions during the last decade period.

2.1 Region-Wise Production and Productivity Trends

Region-wise long-term trends of millets production and productivity levels across major regions are summarized in Figs. 1 and 2 respectively. The global millet production is almost stable (hovering around 28 m tons) during the last twenty years period. The production in case of Africa has gone up and reached to a peak during 2008 (19 m tons) and afterwards it has come down to 13 m tons. The production in Asia region has not changed much

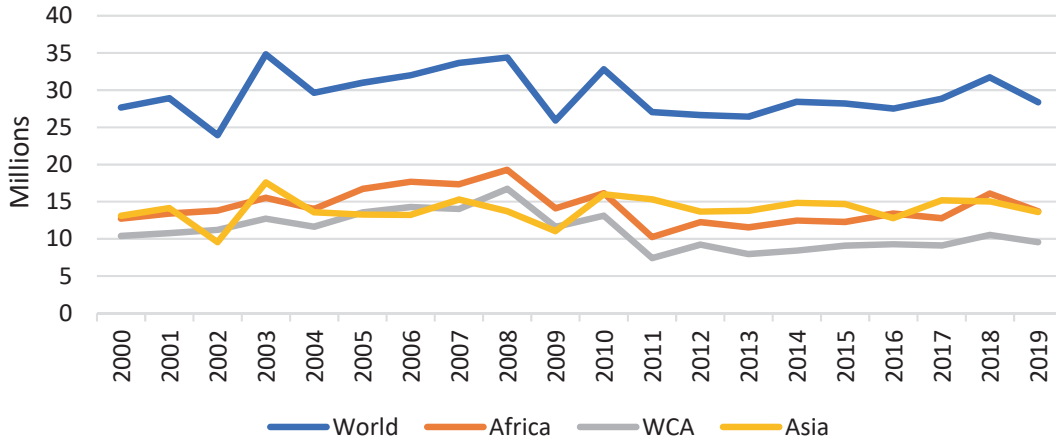

Fig. 1 Region-wise production trends, 2000–2019

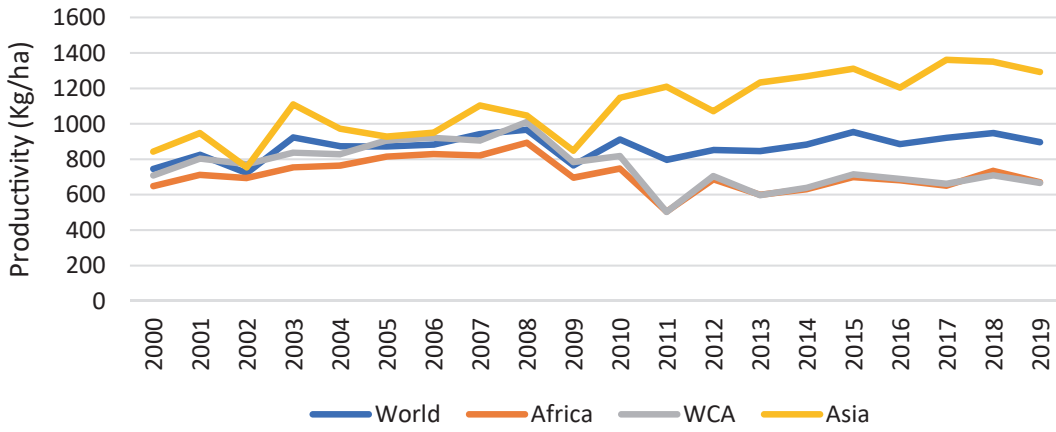

Fig. 2 Region-wise productivity trends, 2000–2019

(13 m tons) over study period (2000–2019). In case of Western Central Africa (WCA) region, there is significant decline in millet production (10.4–9.5 m tons) during two decades period (Fig. 1).

Historical region-wise productivity trends during 2000–2019 across major millet growing regions are furnished in Fig. 2. Among all, Asia region exhibited consistent productivity growth and has increased from 800 to nearly 1400 kg per ha. This may be due to access and adoption of improved cultivars combined with improved management practices in Asia (Yadav et al. 2021; Venkata Rao et al. 2018). Millet productivity level in case of world is stable and hovering between 800 and 900 kg per ha. The mean productivity scenario in case of Africa and WCA has consistently been declined over time (from 800 to 600 kg per ha). Decline in cropped area during study period coupled with decrease in productivity levels in Africa led to significant decline in crop production in the region (Jukanti et al. 2016; Pucher 2018).

2.2 Major Millet Producing Countries

The performance of millet over last one decade across major producing countries in the world is furnished in Table 2. With respect to acreage, the top 10 countries include seven in Africa (Niger, Nigeria, Sudan, Mali, Burkina Faso, Chad, and Senegal) and three in Asia (India, China, and Pakistan). Among all major countries, India stood on the top in terms of cropped area followed by Niger and Nigeria. There is significant decline (about 25%) in millet cropped area in India during the study period. The production has marginally reduced due to enhancement in productivity by 20%. The millet cropped area is stable in case of Niger (7 m ha) with marginal improvement in productivity. Nigeria has lost almost 50% of the cropped area and production due to decline in productivity (− 20%) during the study period. Millet cropped area under Mali, Sudan, Angola, Burkina Faso, Chad, China, and Ethiopia have expanded

Table 2 Millet performance across major countries, 2009–2019

Country	2009–11			2017–19			% change		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
India	11,158	11,576	1037	8921	11,142	1248	− 25.1	− 3.8	20.3
Mali	1660	1428	913	2101	1737	830	21.0	21.6	− 9.1
Niger	6939	3092	444	6954	3639	523	0.2	17.7	17.8
Nigeria	3659	3790	979	2421	1873	781	− 51.1	− 50.6	− 20.2
Sudan	NA	NA	NA	3093	1553	477	NA	NA	NA
Angola	197	43	217	274	63	232	39.1	46.5	6.9
Burkina Faso	1253	982	780	1264	995	785	0.9	1.3	0.6
Chad	1067	469	421	1189	711	598	11.4	51.6	42.0
China	780	1455	1867	846	2396	2841	8.5	64.7	52.2
Ethiopia	403	603	1494	452	1064	2349	12.2	76.5	57.2
Nepal	268	298	1112	263	311	1183	− 1.9	4.4	6.4
Pakistan	494	314	636	488	357	733	− 1.2	13.7	15.3
Russian Fed	355	425	1058	258	324	1247	− 27.3	− 23.8	17.9
Senegal	954	701	724	917	860	937	− 3.9	22.7	29.4
Tanzania	365	353	975	282	337	1206	− 22.7	− 4.5	23.7

Note Area in '000 ha; production in '000 tons and yield in kg/ha

Table 3 Utilization pattern of pearl millet in different regions, 2016–18 ('000 tons)

Region	Domestic supply	% share to domestic supply			
		Food	Feed	Other uses[a]	Losses
Global	27,936	76.9	12.0	4.6	6.9
Africa	13,252	73.0	9.9	7.1	10.7
Eastern Africa	1717	70.5	2.3	22.0	5.6
Western Africa	9543	71.9	11.8	5.3	11.8
Americas	254	0.0	93.3	0.0	6.7
Asia	13,823	84.1	10.2	2.4	3.3
Europe	571	30.8	61.5	3.9	5.4
Oceania	36	0.0	94.4	0.0	5.6

[a] Includes non-food, seed and processing

when compared to base period (2009–11). On contrary, the area under millets has declined marginally in Nepal, Pakistan, and Senegal during the study period. Both Russian Federation and Tanzania nearly lost one quarter of millets cropped area over the decade. The highest productivity is recorded in China (2841 kg/ha) followed by Ethiopia (2349 kg/ha), India (1248 kg/ha), Russia Fed (1247 kg/ha), and Tanzania (1206 kg/ha) during 2017–19 period. Between 2009–11 and 2017–19, there is significant jump in productivity growth in case of Ethiopia, China, and Chad countries. The mean productivity growth (from 1037 to 1248 kg/ha) in case of India during study period was around 20%.

Globally, the availability of millets has gradually increased due to enhanced in their production over time. Millets are consumed primarily as food in most of the developing countries. It is highly nutritious, high-energy food and in recent years an important component of processed baby foods. The form in which millets are consumed varies across regions—as a thick porridge or as flatbreads (rotis). Millets are also used as bird feed, but this use is largely restricted to developed countries. However, the utilization pattern is changing even in developing countries where its use in alcohol manufacture and as livestock and poultry feed is growing. Millet fodder is an important feed resource in the dryland systems of Africa and Asia, particularly in the post-monsoon seasons when other feed resources are not available or scare.

The recent millet utilization pattern across major regions of the world is furnished in Table 3. FAOSTAT data available for the triennium period 2016–18 is used for better understanding about utilization scenario of millets across regions. Globally, nearly 3/4th of domestic supply is used for food purpose and the rest is used for feed and other uses. The pattern of utilization is also quite similar in case of Africa region as well. Relatively, the proportion of utilization towards food in domestic supply is slightly lower in case of ESA region (70%) when compared with WCA region (72%). Americas and Oceania regions allocate almost their domestic supply for feed purposes. Among all regions, Asia region allocates significant chunk (84%) of their domestic supply for food purpose followed by feed.

The details about country-wise pearl millet utilization pattern have been summarized in Table 4. In general, major share of domestic supply among study countries has been diverted towards food purpose. It was followed up by feed and other uses. Extent of utilization towards food is more than 90% in case of India and Burkina Faso countries. Countries such as Nepal, Chad, Nigeria, Sudan, Angola, and Ethiopia have allocated close to 80% of their millet production for food purpose. Niger, Senegal, and Mali have diverted about 70–60% of their production for food followed by feed purposes. China, Pakistan, Russia, and Tanzania had diverse pattern of utilization of millet production beyond food uses.

Table 4 Utilization pattern of millets across major countries, 2016–18 ('000 tons)

Country	Domestic supply	% share to domestic supply			
		Food	Feed	Other uses[a]	Losses
Angola	55	74.5	5.5	14.5	3.6
Burkina Faso	971	92.1	0.0	3.4	4.6
Chad	706	84.0	0.0	1.7	14.3
China	1698	46.6	46.1	2.4	4.9
Ethiopia	981	79.3	1.8	15.6	3.3
India	10,914	93.4	1.5	2.3	2.8
Mali	1711	62.8	13.3	12.2	11.7
Nepal	312	88.8	0.0	1.9	9.3
Niger	3846	71.7	13.8	3.4	13.1
Nigeria	1724	81.7	5.0	3.2	10.1
Pakistan	344	43.9	48.5	1.7	5.8
Russian Fed	327	40.1	48.3	4.9	7.0
Senegal	643	61.0	19.6	3.6	15.7
Sudan	1031	79.2	11.4	1.6	7.8
Tanzania	321	42.1	1.9	43.6	12.1

[a] Includes non-food, seed and processing

3 Economic Impacts of Pearl Millet Research

This section summarizes about the economic impacts of pearl millet improved cultivars documented under various studies across Asia and Africa regions. Development of improved cultivars with broad range of maturity (60–110 days), profitable seed production and marketing systems, and highly developed seed sector leading to quality seed production and its timely delivery, etc., have promoted the adoption of improved technologies significantly across regions. The adoption of high-yielding and disease resistant cultivars (especially down mildew resistant) increased the productivity gains consistently over time. The magnitude of yield improvement in pearl millet under rainfed conditions is a successful demonstration of technology-led development and it also emphasizes the role of hybrid technology in raising crop productivity even in marginal environments (Yadav and Rai 2013). The tabulated data (see Table 5) clearly reveals the significant productivity gains across ecologies as well as their corresponding return on research investments.

4 Global Millet Outlook

The International Model for Policy analysis of Agricultural Commodities and Trade (IMPACT)[1] was developed by IFPRI to make long-term global food projections. The IFPRI's IMPACT (Robinson et al. 2015) model has been used for making the baseline projections (2005 base) which includes several commodities and not just the dryland cereals (millets). This gives a realistic picture because of the interactions of the demand and supply of all the crops. The effect of the fall in the prices of the competing crops and the shift in demand to livestock products will have substantial implications for demand and supply of dryland cereals (millets). The effect of trade policies has also been included in the model to reflect the price differential that exists between the country-level prices and the single world price that the IMPACT model calculates. The export and import quantities of the countries are endogenous values just as the world price is calculated based on the global demand and supply. A variable called stock change is introduced to capture

[1] Further details about IFPRI's IMPACT model can be access at https://www.ifpri.org/project/ifpri-impact-model.

Table 5 Economic impacts of pearl millet research

Agro-ecology	Year	Nature of economic impacts	References
Nigeria	2020	Using PSM, the study reported a productivity gain of 26%, a gross margin gain of 55% and an increase in dietary diversity of 21%, etc., in Nigeria. It has contributed to a decrease in poverty status of around 8%. Returns on investments in the production of pearl millet were 83% for adopters and 43% for non-adopters	Vabi et al. (2020)
Semi-Arid Tropics	2019	Potential nutritional and food security benefits of bio-fortified pearl millet varieties documented	Govindaraj et al. (2019)
India	2018	Pearl millet ICRISAT HPRC hybrids covered about 60% of pearl millet hybrid area in three major pearl millet growing states during 2013–14. The hybrids have provided at least 20% higher grain and fodder than the varieties/hybrids they replaced. Total benefits accrued due to ICRISAT HPRC hybrids in the three study states added up to US $133.7 million per year. Benefits could surpass US $150 million per year at all India levels if we include the contribution of HPRC hybrids in other states as well	Venkata Rao et al. (2018)
Semi-Arid Tropics	2003	The results indicated that the pearl millet farmers adopted improved varieties based on their early maturity, yield gains, and profitability, etc., based on documentation of research on returns by ICRISAT's pearl millet research in India	Bantilan and Deb (2003)
Mali	1998	Considering research and extension costs, the net present value of benefits from research on improved varieties of millet in Mali was estimated at US $25 million each, representing an internal rate of return (IRR) of 69% and 25% respectively	Yapi et al. (1998, 2000)
Zimbabwe	1999	Internal rate of return (IRR) for pearl millet research in Zimbabwe from SDMV 89,004 were estimated at 4.4%. Farm-level studies in Namibia showed that the internal rate of returns to pearl millet research was 5.0%, with a net present value (NPV) of more than US $10 million in 1998	Rohrbach et al. (1999)
Maharashtra, India	2016	The unit cost reduction (UCR) due to post-2000 released improved pearl millet cultivars was estimated at USD 156 per ton which was lower than (USD 182.1) pre-2000 released cultivars in Maharashtra. The welfare gains estimated due to improved technology was at USD 103.3 million during the study period, i.e., 1993 and 2022	Kumara Charyulu et al. (2017)
India	2009	Conservative estimates by the World Bank indicated that the annual returns to India's farmers from pearl millet improved cultivars developed by ICRISAT totaled to US $50 million—it is > 12 times the cost of its investment in pearl millet research	Pray and Nagarajan (2009)
Tamil Nadu, India	2000	Improved pearl millet cultivars offered large yield and income benefits compared to local cultivars. The yield gains relative to local cultivars are about 100% for ICMS 7703 and CO 7 and 150% for Pioneer hybrids. The unit cost reduction ranges from Rs. 610 to Rs. 860/ton for improved cultivars resulting from larger grain yields	Ramasamy et al. (2000)
Rajasthan, India	2012	Returns to investment in research analysis revealed that NPV was estimated to the extent of 489.94 million. The internal rate of returns in research on pearl millet improvement was estimated at 28%. The estimated B:C ratio was worked out at 1.41	Shaktawat et al. (2012)

(continued)

Table 5 (continued)

Agro-ecology	Year	Nature of economic impacts	References
India	2012	The total factor productivity of pearl millet increased by 1% and the internal rate of returns on research investment was estimated at 31% for the period during 1975–2005	Chand et al. (2012)
WCA	2006	Synthesis of the impact studies on pearl millet and sorghum improved cultivars was documented for different countries in WCA region	Camara et al. (2005)
Uganda	2020	Using DREAM model, ROI on R&D investments was estimated at US $48 for the period between 1965 and 2030 in case of Uganda	Orr et al. (2020)

Table 6 Demand and supply projections of millets among regions in the world

Region	2030	2040	2050	2030	2040	2050
	Demand ('000 tons)			Supply ('000 tons)		
Global	48,505	57,091	66,524	49,139	57,725	67,158
Africa	30,153	37,584	46,032	31,784	39,882	48,907
Eastern Africa	3068	3834	4677	3726	5042	6630
Western Africa	23,701	29,772	36,651	24,610	30,347	36,604
Americas	313	328	347	466	593	737
Asia	17,008	18,180	19,171	15,154	15,240	15,220

any mismatch between net trade and surplus/deficit production.

The global millets demand is increasing over time from 48.5 million tons in 2030 to 66.5 million tons by 2050 (Table 6). Correspondingly, the global supply projections are anticipated to increase from 49.1 million tons in 2030 to 67.1 million tons by 2050 with the available technologies. Africa and Asia are the major regions contributing for significant millet demand and supply in the world. Africa region alone contributes for nearly two-thirds of share in global millet demand and supply. Western and Central Africa (WCA) region has lion (75%) share in the total Africa region millet demand and supply. Asia region has only one-third of share in global millet demand and supply.

Africa region is projected to supply the burgeoning millet demand in the region during the study period. Except Asia region, rest of the millet growing regions in the globe are expected to supply the projected demanded of millets in their respective regions. In case of Asia region, the projected supply is lower than the regional demand in all the study periods. This clearly indicates the widening gap between projected supply and demand in the study period. There is a need for enhancing millet production in the region through introduction of climate SMART cultivars and management practices.

The global millets area projections for the world, Asia and Africa regions, have been summarized in Figs. 3, 4 and 5 for the period 2020–2050. The millet area is globally expected to increase (21%) from 39 to 47 m ha (Fig. 3) over the next thirty years period. The millet area projections for Asia region are indicating a decline of 14.5% from 13.1 to 11.2 m ha during the study period (Fig. 4). This might be due to severe competition from other economically high-value crops. However, the productivity in the region is expected to increase (Fig. 6) with improvements in genetic gains and enhanced access to improved seeds. The millets production is expected to stabilize (Table 6) over time (2030–2050) without any big quantum jumps in it. Southern Asia has lion share (nearly 88%) in the total millets area in the region when compared to Eastern Asia and South-Eastern Asia regions.

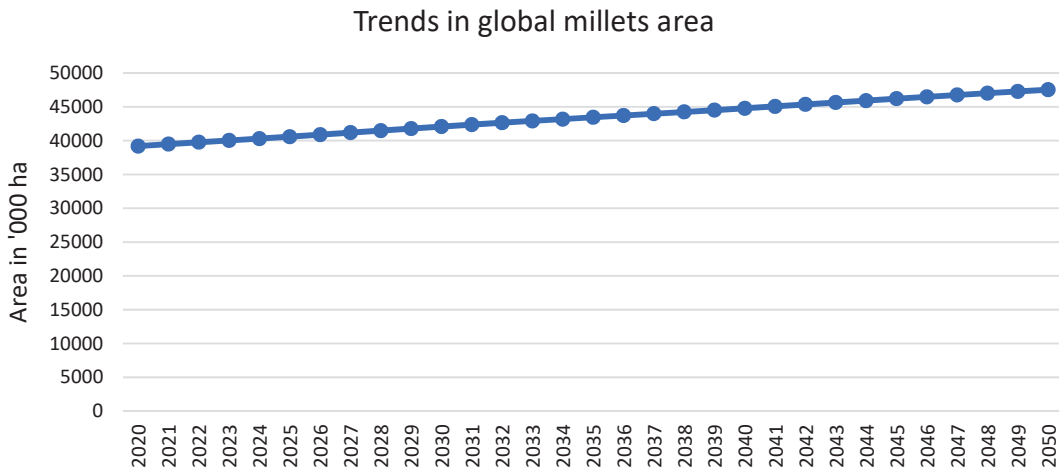

Fig. 3 Global millet area projections for 2020–2050

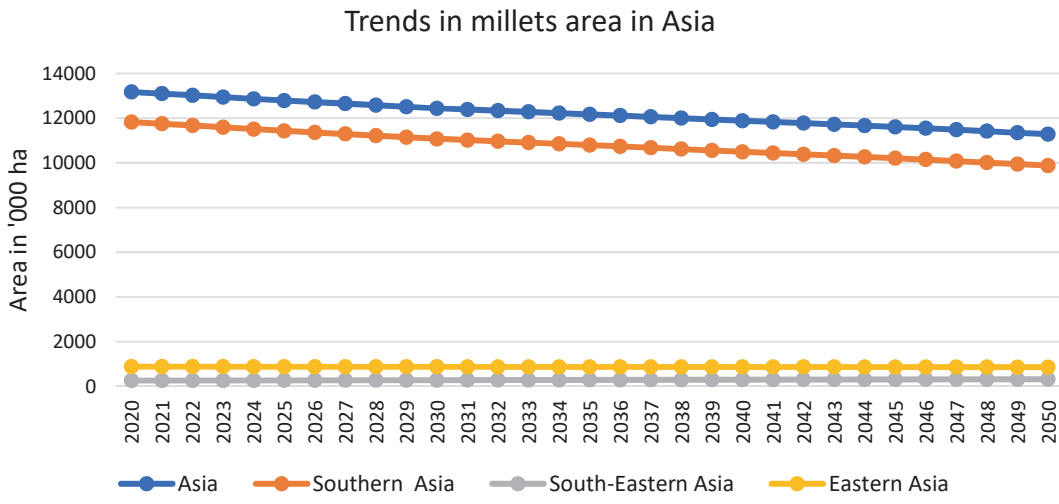

Fig. 4 Millet area projections for Asia from 2020 to 2050

Contrary, the millets area in Africa is projected to expand from 24.7 to 34.8 m ha during the same period (Fig. 5). Western-Central Africa region played a crucial role in millet area expansion in the region when compared to Eastern-Southern Africa. Relatively, the projected productivity gains in the Africa region are marginally lower when compared to Asia region (Fig. 6). However, remarkable production gains in millets were observed in WCA region followed by ESA region (Table 7). In the long-term (2050), the millet productivity per ha is projected to be plateau in Asia region when compared to Africa region.

The country-wise projected demand and supply of millets for respective time periods are summarized in Table 7. India and Nigeria stood on the top for projected demand and supply of millets in the globe. Among WCA countries, Nigeria and Burkina Faso showed marginal gap between projected demand and supply over the study period. Sudan and Angola countries

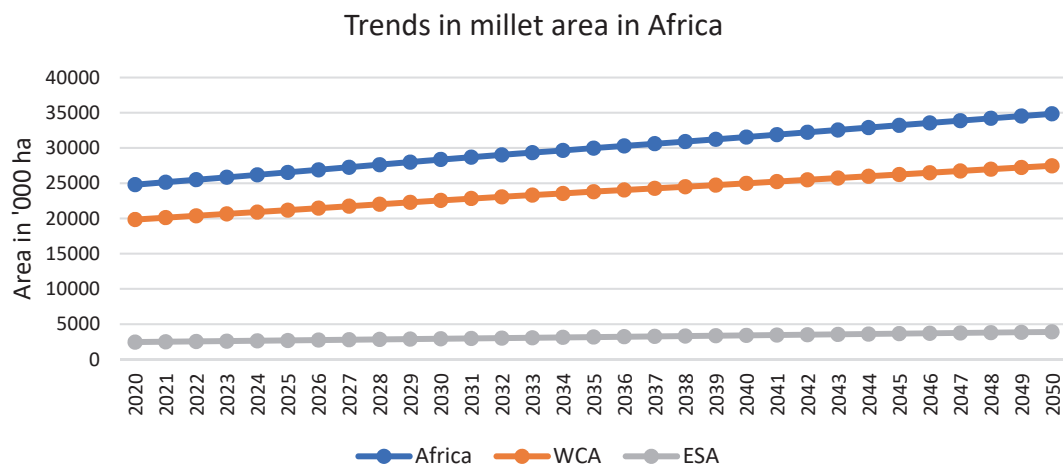

Fig. 5 Millet area projections for Africa from 2020 to 2050

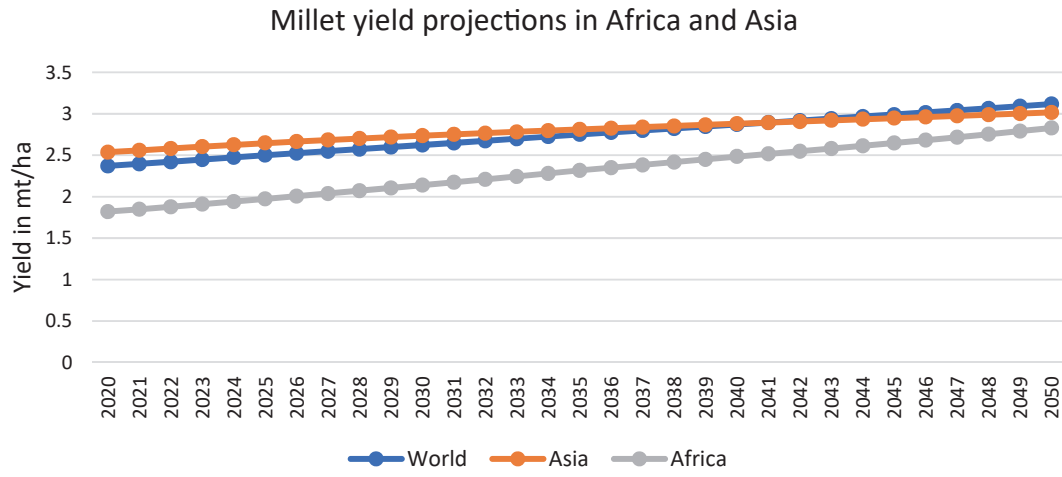

Fig. 6 Millet yield projections for Africa and Asia, 2020–2050

in ESA region exhibited anticipated supply is lower than the projected demand of millets during the study period. Among all millet growing countries, the conspicuous difference between millet demand and supply was noticed in case of India. Other Asian countries such as China, Nepal, and Pakistan also showed widening demand and supply gap of millets over the study period. All other millet growing countries in the globe are expected to meet their millet demand through their supplies over time. There is a strong need for enhancing the millet production in a few targeted countries in Africa and Asia regions for achieving millet global self-sufficiency.

5 Challenges in Its Cultivation and Opportunities

Being a rainfed crop and grown on marginal soils, pearl millet faces numerous challenges in its cultivation across different ecologies. Broadly, these challenges can be categorized

Table 7 Projected demand and supply of millets in major countries of the world

Country	2030	2040	2050	2030	2040	2050
	Demand ('000 tons)			Supply ('000 tons)		
India	13,430	14,452	15,341	**11,946**	**11,895**	**11,747**
Nigeria	12,200	15,178	18,603	**12,178**	**14,146**	**15,973**
Niger	5113	6784	8811	5364	6939	8769
Burkina Faso	2227	2734	3233	**2068**	**2519**	**2991**
China	2023	1994	1923	**1990**	**1991**	**1978**
Mali	1925	2354	2788	1975	2531	3259
Sudan	1600	1831	2024	**1374**	**1661**	**1905**
Uganda	1370	1762	2209	1436	1840	2288
Chad	857	1079	1324	1184	1577	2041
Ethiopia	767	880	977	1066	1434	1864
Senegal	721	842	959	1093	1519	2043
Russia	692	662	633	1182	1348	1511
Guinea	585	741	903	678	968	1279
Angola	532	597	812	**340**	**485**	**684**
Tanzania	439	542	649	615	906	1288
Nepal	430	476	515	**335**	**353**	**374**
Ghana	358	444	532	436	596	788
Pakistan	339	399	465	**275**	**304**	**326**
USA	274	284	299	434	552	683
Myanmar	234	232	227	299	346	401
Gambia	220	258	290	318	430	562
Ukraine	165	160	157	381	453	530
Yemen	147	178	208	**93**	**107**	**119**
Kenya	138	177	216	164	232	321

Bold significance are the projected supply is lesser than demand in that respective country

in to three types: abiotic stress; biotic stress; and socio-economic constraints, etc. Recurrent droughts followed by prolonged dryspells and soil moisture stress during crop growth period are the biggest challenge in both Africa (such as Eritrea, Ethiopia, Ghana, Kenya, Namibia, Sudan, Tanzania, Uganda, and Zimbabwe) and Asia (arid region of India) regions. Application of low-inputs as well as poor management practices further harvest low productivity levels. Downy mildew, blast, rust, and striga are the dominant biotic constraints for pearl millet. Striga, a parasitic weed menance, is the biggest challenge in African countries such as Ethiopia, Zimbabwe, Uganda, Rwanda, and Kenya. The second biotic challenge was bird damage to millet panicles during maturity stage. The extent of damage varies depending on growing conditions as well as stage of the crop. There will be 100% loss in case of isolated fields and unprotected conditions. This is the most severe problem in African countries, specifically in Ethiopia, Kenya, and Rwanda. The major socio-economic challenges in case of pearl millet are farmers grow it for self-sufficiency purpose rather than for market, thinly traded globally, low market demand, and lack of sufficient value addition opportunities, etc. Contrary to Asia region, the pearl millet cultivation in Africa is dominated by local varieties and land races. Relatively, the farmers in Africa have limited exposure towards good management practices in pearl millet cultivation. Beyond all, the coarse cereals cultivation is skewed with irrigated agriculture (paddy and wheat) favorable policies (minimum support prices), and subsidies (promoted in public distribution system). This has created a irrevocable impact on coarse cereals cultivation as well as its demand, especially in the Indian context. The rancidity issue during the storage of flour in

pearl millet limits its value addition opportunities. On the other hand, the drudgery in the primary processing of millets has led to a decrease in their consumption. Hence, it is critical to fabricate machinery to improve the dehulling of millets without causing a loss of the nutritional content (the outer seed coat is inedible).

Though there are many challenges for promoting pearl millet, abundant potential opportunities also exist across different regions. They are as follows:

(1) The United Nations General Assembly has declared 2023 as the '**International Year of Millets**'. India has the largest biodiversity of millets as well as millet products in the world. Therefore, the announcement in the 2022–23 Union Budget of giving support to post-harvest value addition, enhancing domestic consumption and branding of millets, nationally and internationally, is a step in the right direction.

(2) There is ample scope to expand in the semiarid and arid ecologies for mitigating the climate change (reduced GHG emissions and water footprint) as well as malnutrition impacts.

(3) India produces about 80% of Asia's and 20% of the global millet production that is led by Africa and the Americas. Our current millet exports touched $26 million during 2020. There is significant potential to expand further after COVID pandemic as well as increasing awareness about health and nutrition.

(4) Over the years, there has been a shift (2–3 million ha area) from the production of millets to other competing crops, such as soya bean, maize, cotton, and sunflower. Thus, there is a need for a promotion impetus to millets through new high-yielding varieties and package of practices, farm gate processing, price support and value addition, etc. This will not only enhance the productivity but also promote its demand.

(5) Sourcing quality millets as well as their steady marketing by entrepreneurs, there is a dire need for linking small and marginal millet farmers to online marketing platforms, such as the Electronic National Agricultural Market (e-NAM). The setting up of farmer producer organizations (FPOs) can also enhance the millet producers' bargaining power in both the domestic and global markets.

Case: *The Dharmapuri District Minor Millets Farmer Producer Company (in Tamil Nadu) is a classical example of one of the 100 FPOs that provides technical assistance to 1000 farmer members, other than supplying seeds and machinery at subsidized costs. It is also involved in the procurement of the produce from the farmers at reasonable prices. More importantly, it is involved in the value addition of millets, such as cookies, flour, sprouted flour, and rice in the brand name of 'DMillets'.*

(6) Millets have more protein than rice and are rich in vitamins A and B, iron, phosphorus, magnesium, and manganese. The usage of millets in infant food and nutrition products is increasing and many manufacturers are expanding their business operations by acquiring smaller firms.

(7) The gluten-free property of millets is expected to provide lucrative opportunities to produce gluten-free and low Glycemic Index (GI) food products. Breweries have also started to add gluten-free beer option to increase their consumer base.

(8) Malnutrition became a persistent issue in many developing countries in Africa and Asia regions. Numerous developing nations (such as India) and federal governments across the world are framing long-term policies to roll out nutrition programs (focus on millet-based products) aimed at tackling malnutrition.

6 Conclusions

Millets are recognized as a photo-insensitive, resilient to climate change hardy crops that have a low carbon and water footprint. They can

withstand high temperatures and grow on poor soils with little or no external inputs. Globally, area under millets occupies sixth position after rice, wheat, maize, barely, and sorghum crops. Approximately, pearl millet (*Pennisetum glaucum* R. Br.) represents 75% of global millet area in the world. India is the world's largest producer of millets followed by China, Niger, and Nigeria. During the last decade, globally area under millets has come down by 3 million ha mainly due to decline in area in Asia led by India. However, owing to rising productivity in Asia, production levels continued to be robust while they declined in Africa. Is the decline in millet area an indication of slowing demand for the crop? Projections based on IFPRI's IMPACT model indicate a growing demand for millets between 2030 and 2050 from 48.5 to 66.5 million tons. Africa accounts for 75% of the demand share and is able to meet its demand with domestic supplies in excess of demand. For Asia, however, there will be a shortfall in supply as production will not keep pace with demand. Thus, opening trade opportunities for millets that are presently thinly traded with less than 2% of its production entering global trade. The review on economic impacts of pearl millet research across ecologies noted significant welfare gains perceived by farmers and investors.

Globally, nearly 3/4th of domestic supply of millets is used for food purpose and the rest used for feed and other uses. Developed countries mainly use millets for animal/bird feed. The nutritive and gluten free nature of millets have provided ample scope across globe for developing several nutrition-based products, beverages, and baby foods. The enhanced demand from this sector is projected to expand the millet crop area and production across the globe.

Since millets are grown under marginal environments, they face several biotic and abiotic constraints. Fungal diseases such as downy mildew, blast, smut, rust, and ergot. Striga, a parasitic weed, is another serious constraint to millet production in Africa causing extensive yield losses. Bird damage of millet grains is now considered a potential threat to millet growers. Among abiotic constraints, drought is the most important constraint followed by poor soil fertility and low water-holding capacity that are the very characteristics of the environments under which millets are grown. Poor market access for both inputs and output, lack of credit facilities are among the several socio-economic constraints that millet farmer's face. It is thus pertinent that researchers and policymakers address the constraints facing millet production so the crop can be competitive with stable yields and acceptable quality standards for grain and fodder for consumers and processors.

References

Andrews DJ, Kumar KA (1992) Pearl millet for food, feed and forage. Adv Agron 48:89–139. https://doi.org/10.1016/S0065-2113(08)60936-0

Bantilan MCS, Deb UK (2003) Impacts of genetic enhancement in pearl millet, pp 215–240

Camara Y, Bantilan MCS, Ndjeunga J (2005) Impacts of sorghum and millet research in West and Central Africa (WCA): a synthesis and lessons learnt. Working paper series no. 22

Chand R, Kumar P, Kumar S (2012) Total factor productivity and returns to public investment on agricultural research in India. Agric Econ Res Rev 25(347-2016-17004):181–194

Govindaraj M, Rai KN, Cherian B, Pfeiffer WH, Kanatti A, Shivade H (2019) Breeding biofortified pearl millet varieties and hybrids to enhance millet markets for human nutrition. Agriculture 9(5):106

Jukanti AK, Laxmipathi Gowda CL, Rai KN, Manga VK, Bhatt RK (2016) Crops that feed the world 11. 2016. Pearl millet (*Pennisetum glaucum* L.): an important source of food security, nutrition and health in the arid and semi-arid tropics. Food Secur 8(2):307–329. https://doi.org/10.1007/s12571-016-0557-y

Kumara Charyulu D, Bantilan C, Rajalaxmi A, Rai KN, Yadav OP, Gupta SK, Singh NP, Moses Shyam D (2014) Development and diffusion of pearl millet improved cultivars in India: impact on growth and yield stability. Working paper series no. 52. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 76 pp

Kumara Charyulu D, Moses Shyam D, Bantilan C, Borikar ST, Gupta SK, Rai KN (2017) Pearl millet technology adoption and impact study in Maharashtra. Research report 71. http://oar.icrisat.org/9993/1/Research%20Report%20No%2071%20-%20Pearl%20Millet%20Technology%20Adoption.pdf

McDonough CM, Rooney LW, Serna-Saldivar SO (2000) The millets. In: Food science and technology: handbook of cereal science and technology, 2nd edn. CRC Press, Boca Raton, FL, pp 177–210

Obilana AB (2003) Overview: importance of millets in Africa. Accessed 10 July 2015. http://www.afripro.org.uk/papers/Paper02Obilana.pdf

Orr A, Schipmann-Schwarze C, Gierend A, Nedumaran S, Mwema C, Muange E et al (2020) Why invest in research & development for sorghum and millets? The business case for East and Southern Africa. Glob Food Secur 26:100458

Parthasarathy Rao P, Hall AJ (2003) Importance of crop residues in crop-livestock systems in India and farmers perceptions of fodder quality in coarse cereals. Field Crops Res 84:189–198. Order code 787

Parthasarathy Rao P, Birthal PS, Reddy BVS, Rai KN, Ramesh S (2006) Diagnostics of sorghum and pearl millet grain-based nutrition. International Sorghum and Pearl Millet News Letter (ISMN), pp 45–47

Pray CE, Nagarajan L (2009) Pearl millet and sorghum improvement in India, vol 919. International Food Policy Research Institute

Pucher AI (2018) Pearl millet breeding in West Africa—steps towards higher productivity and nutritional value. Doctoral thesis (unpublished) submitted to Stuttgart Hohenheim, Germany

Rai KN, Gowda CLL, Reddy BVS, Sehgal S (2008) The potential of sorghum and pearl millet in alternative and health food uses. Comp Rev Food Sci Food Saf 7:340–352. https://doi.org/10.1111/j.1541-4337.2008.00049

Rama Rao CA, Raju BMK, Rao AVMS, Reddy DY, Meghana YL, Swapna N et al (2019) Yield variability of sorghum and pearl millet to climate change in India. Indian J Agric Econ 74:350–362

Ramasamy C, Bantilan MCS, Elangovan S, Asokan M (2000) Improved cultivars of pearl millet in Tamil Nadu: adoption, impact, and returns to research investment. International Crops Research Institute for the Semi-Arid Tropics

Robinson S, Mason-D'Croz D, Islam S, Sulser TB, Robertson RD, Zhu T, Gueneau A, Pitois G, Rosegrant MW (2015) The international model for policy analysis of agricultural commodities and trade (IMPACT): model description for version 3. IFPRI discussion paper 1483. International Food Policy Research Institute (IFPRI), Washington, DC. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825

Rohrbach DD, Lechner WR, Ipinge SA, Monyo ES (1999) Impact from investments in crop breeding: the case of Okashana 1 in Namibia. International Crops Research Institute for the Semi-Arid Tropics

Serba DD, Yadav RS, Varshney RK, Gupta SK, Mahalingam G, Srivastava RK et al (2020) Genomic designing of pearl millet: a resilient crop for arid and semi-arid environments. In: Kole C (ed) Genomic designing of climate-smart cereal crops. Springer, Cham, pp 221–286. https://doi.org/10.1007/978-3-319-93381-8_6

Shaktawat S, Singh IP, Nagaraj N, Sharma S (2012) Resource use efficiency and returns to investment in research of pearl millet in Rajasthan. Indian J Econ Dev 8(4):1–11

Sultan B, Roudier P, Quirion P, Alhassane A, Muller B, Dingkuhn M et al (2013) Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. Environ Res Lett 8:014040. https://doi.org/10.1088/1748-9326/8/1/014040

Vabi MB, Abdulqudus IA, Angarawai II, Adogoba DS, Kamara AY, Ajeigbe HA, Ojiewo C (2020) Adoption and welfare impacts of pearl millet technologies in Nigeria

Venkata Rao N, Rao KPC, Gupta SK, Mazvimavi K, Kumara Charyulu D, Nagaraj N, Singh RN, Surinder Singh S, Singh SP (2018) Impact of ICRISAT Pearl Millet Hybrid Parents Research Consortium (PMHPRC) on the livelihoods of farmers in India. Research report 75. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 100 pp. ISBN 978-92-9066-595-3

Yadav OP, Rai KN (2013) Genetic improvement of pearl millet in India. Agric Res 2:275–292. https://doi.org/10.1007/s40003-013-0089-z

Yadav OP, Gupta SK, Govindaraj M, Sharma R, Varshney Rajeev K, Srivastava Rakesh K, Rathore A, Mahala RS (2021) Genetic gains in pearl millet in India: insights into historic breeding strategies and future perspective. Front Plant Sci. https://doi.org/10.3389/fpls.2021.645038

Yapi A, Kergna AO, Debrah SK, Sidibe A, Sanogo O (1998) Impact of sorghum and millet research in Mali. In: Assessing joint research impacts: proceedings of an international workshop on joint impact assessment of NARS/ICRISAT technologies for the semi-arid tropics, 2–4 Dec 1996, vol 502. ICRISAT, Patancheru, India, p 76

Yapi AM, Kergna AO, Debrah SK, Sidibe A and Sanogo O (2000) Analysis of the economic impact ofsorghum and millet research in Mali. Impact Series No 8. Patancheru 502 324, Andrha Pradesh, India:International Crops Research Institute for the Semi-Arid Tropics. p 60