JANUARY 2023

ISO 9001: 2015 Organization

भाकृअनुप ICAR

Indian Farming

INTERNATIONAL YEAR OF MILLETS 2023

RICH IN HERITAGE, FULL OF POTENTIAL.

#IYOM2023

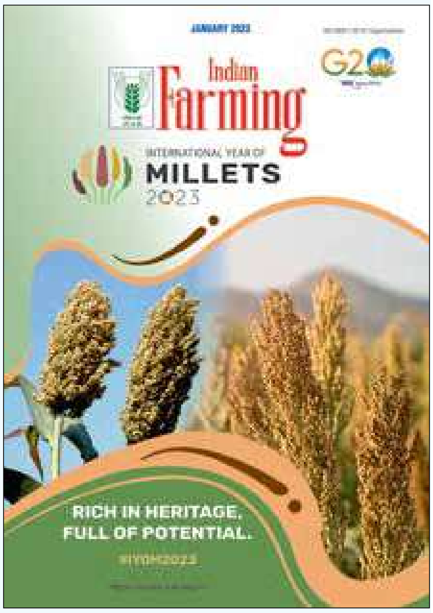
https://epubs.icar.org.in

Few dishes prepared from Sorghum

IS/ISO 9001:2015 Organization

Volume 73, No. 01 JANUARY 2023

Indian Farming



Cover I: International Year of Millets 2023

Cover IV: Awareness of Food Loss and Waste

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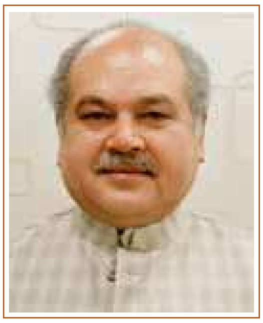
In This Issue

नरेन्द्र सिंह तोमर
NARENDRA SINGH TOMAR

सत्यमेव जयते

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
MINISTER OF AGRICULTURE & FARMERS WELFARE
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI



संदेश

यह अत्यंत हर्ष का विषय है कि अंतर्राष्ट्रीय मिलेट वर्ष 2023 के अवसर पर भारतीय कृषि अनुसंधान परिषद द्वारा मोटे अनाजों (मिलेट्स) पर फोकस करते हुए इंडियन फार्मिंग का जनवरी 2023 अंक प्रकाशित किया जा रहा है। भारत सरकार की पहल पर संयुक्त राष्ट्र संघ द्वारा 2023 को अंतर्राष्ट्रीय मिलेट्स वर्ष घोषित किया गया है जिसका प्रयोजन कुपोषण की चुनौतियों का सामना करने के लिए इन विस्मरणीय अनाजों की शक्ति का संचार करना है। इस विशेषांक में विभिन्न मोटे अनाजों की वैज्ञानिक खेती, उन्नत किस्मों और मिलेट्स से तैयार प्रसंस्कृत उत्पादों तथा साथ ही इनके खाद्य, पोषणिक एवं पर्यावरण लाभों के बारे में विस्तृत जानकारी प्रस्तुत की गई है। इन महत्वपूर्ण खाद्यान्नों से जुड़े परिषद के राष्ट्रव्यापी संस्थानों व वैज्ञानिकों द्वारा हासिल की गई उपलब्धियों का संकलन इस अंक को विशिष्ट बनाता है।

इंडियन फार्मिंग के इस विशेषांक के लिए मैं भारतीय कृषि अनुसंधान परिषद द्वारा किए गए प्रयासों की सराहना करता हूँ और आशा करता हूँ कि यह अंक किसानों व अन्य हितधारकों को मिलेट्स से जुड़ी जानकारी का प्रसार करने में उपयोगी सिद्ध होगा। मैं सभी हितधारकों से अंतर्राष्ट्रीय मिलेट्स वर्ष से जुड़े कार्यक्रमों में सक्रिय रूप से भाग लेने का आवाहन करता हूँ।

(नरेन्द्र सिंह तोमर)

कैलाश चौधरी
KAILASH CHOUDHARY

कृषि एवं किसान कल्याण राज्य मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
MINISTER OF STATE FOR AGRICULTURE
& FARMERS WELFARE
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI

सत्यमेव जयते

MESSAGE

I am very happy to learn that on the occasion of International Year of Millets 2023, Indian Farming the popular ICAR magazine has brought out an special issue.

The people have paid attention towards millet (pearl millet, sorghum, finger millet, little millet, barnyard millet, kodo millet) for their role in combating challenges of malnutrition and hunger in various countries. These millets possess greater amount of nutritional substances than wheat, rice and maize. Millets are resilient and rain-fed crops that thrive in dry regions and grow well in conditions of low soil fertility and moisture with less inputs. Growing millets is a step towards sustainability and food security.

Hon'ble Prime Minister of India has also stressed the importance of making millets a future food option. Several countries are organizing myriad of programmes to make aware the public about nutritional usefulness of the millets. I am happy to note that advantages of farming of millets and their food products and nutritional facts of these products have been documented in this unique issue. I wish success to this souvenir issue.

Best wishes for the New Year 2023.

(Kailash Choudhary)

शोभा करांदलाजे
SHOBHA KARANDLAJE

कृषि एवं किसान कल्याण राज्य मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
MINISTER OF STATE FOR
AGRICULTURE & FARMERS WELFARE
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI

सत्यमेव जयते

MESSAGE

I am happy to know that on the occasion of the onset of International Year of Millets 2023, ICAR is publishing Indian Farming as millets special issue.

I have been informed that this special issue is specifically devoted to the richness of information on millets. Articles highlighting the status and increasing demand of millets globally, fighting malnutrition and commercial importance of processed products from the millets have also been presented. Undoubtedly, the farming community can be attracted towards cultivation of millets as an alternative to traditional major crops by the knowledge provided through this issue.

Congratulations to Indian Farming team who have made efforts to enrich the publication with diverse knowledge related to millets. I offer my best wishes for the special issue put forward and hope that it shall prove as a milestone and achieve its objective.

Have a great year ahead.

(Shobha Karandlaje)

सत्यमेव जयते

डॉ. हिमांशु पाठक

सचिव (डेयर) एवं महानिदेशक (भाकृअनुप)

Dr HIMANSHU PATHAK

SECRETARY (DARE) & DIRECTOR GENERAL (ICAR)

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001

GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURAL RESEARCH & EDUCATION (DARE)
AND
INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)
MINISTER OF AGRICULTURE AND FARMERS WELFARE
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MESSAGE

It is indeed a matter of great happiness that the January 2023 issue of Indian Farming, is being brought out as special issue on millets. This is the opportune time for special issue in view of International Year of Millets being observed in 2023 across the globe. Millets, termed as 'nutri-cereals' enjoy the indispensable place in Indian dietary system, since time immemorial.

Post-Green Revolution, the acreage of millets decreased due to area expansion under irrigation and consequent area shift towards wheat, rice and maize. It is imperative to create awareness among the masses and farmers about the nutritional, health and environmental value of millets. This special issue provides precise knowledge, scientific facts, and technology on millets. The key achievements made by ICAR's institutes in these nutri-cereals have been documented. However, the millets were grown in sizeable area due to their resilience in against climatic stresses and withstand under water stressed conditions.

I hope that the information provided through this special issue, shall be of immense use to farming community and serve as our magnum opus on millets covering their important aspects for benefit of the masses.

I wish to congratulate all authors and the team of editors involved in this publication and a great success to International Year of Millets, 2023.

(Himanshu Pathak)

सत्यमेव जयते

संजय गर्ग

अपर सचिव, डेयर एवं सचिव (भाकृअनुप)

SANJAY GARG

ADDITIONAL SECRETARY, DARE & SECRETARY (ICAR)

भारत सरकार
कृषि एवं किसान कल्याण मंत्रालय
कृषि अनुसंधान एवं शिक्षा विभाग
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GOVERNMENT OF INDIA
MINISTER OF AGRICULTURE AND FARMERS' WELFARE
DEPARTMENT OF AGRICULTURAL RESEARCH AND EDUCATION
KRISHI BHAWAN, NEW DELHI 110 001

MESSAGE

I am delighted to note that ICAR-DKMA is bringing out a special issue of Indian Farming on Millets.

The Millet crops, traditionally grown in resource poor agro-climatic conditions, are gaining importance because of high level of nutritional and health benefits as compared to wheat, rice and maize. The millet grains so called nutricereals, are best alternative to address the nutritional deficiency such as protein, iron, calcium, magnesium and zinc prevalent among population.

It is matter of great pride for all of us that India is taking lead in observance of International Year of Millets 2023. Awareness is to be extended amongst masses for the benefits of millets. I appreciate the efforts of ICAR-DKMA for publication of special issue on millets which shall serve as ready reckoner of information on these important crops.

(Sanjay Garg)

अलका अरोड़ा
अपर सचिव एवं वित्तिय सलाहकार
ALKA ARORA
Addl. SECRETARY & FINANCIAL ADVISER

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
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DEPARTMENT OF AGRICULTURAL RESEARCH & EDUCATION AND
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
MINISTER OF AGRICULTURE AND FARMER'S WELFARE
KRISHI BHAWAN, NEW DELHI 110 001

MESSAGE

It is indeed a pleasure to know that ICAR-DKMA is publishing a special issue of popular magazine ‘Indian Farming’.

Millets are known for nutri-rich content and having characteristics like drought tolerance, photo-insenstivity and resilient to climate change. It is a matter of pride for all of us, that millets have now been recognized as superfood. Considering the importance of superfoods, UN accepted the Indian proposal for celebrating 2023 as the International Year of Millets.

I am confident, that throughout the country there will be good promotion of millets through various activities such as workshops, campaigns, kisan melas, road show, millets food competitions and distribution of published literature.

I am glad to know that special issue of Indian Farming is containing many useful information for the benefit of stakeholders. ICAR-DKMA deserves appreciation in this endeavour.

(Alka Arora)

Millets

are no more orphan crops

From the time immemorial, millets are one of the oldest foods known to humans and possibly first among cereal grains to be cultivated for consumption. Millets are small seeded crops from grass family that are hardy and grow well in arid and semi-arid ecosystem mostly as rainfed crops under low soil fertility and moisture condition on marginal lands. These are resilient to high temperatures and drought prone environments; require only 350 mm water as compared to 1200 mm for rice. Millets being highly adaptable to different ecological conditions are ideal crops for climate change and contingency planting.

Important millet crops grown in India are sorghum (great millet), bajra (pearl millet), ragi or mandua (finger millet), and small millets such as kutki or same (little millet), sanwa or jhangon (barnyard millet), kangni or kakun (foxtail millet), cheena (proso millet), kodo (kodo millet) and korale (brown top millet). These are traditional crops with high nutritional value and health benefits. According to FAO, the world's production of millets is 89.17 million tonnes from an area of 74 million hectare (2019–20). India is a global leader in production of millets (17.9 million tonnes, 2020–21) that are cultivated in 21 states in an area of about 12.5 million hectare with a share of more than 15% of the world's total production. Cultivation with low productivity, lack of good quality seeds, lesser shelf-life, lack of machineries for processing, absence of market linkages, lack of uniformity, standard and grades are the major problems related to millets.

Indian Council of Agricultural Research (ICAR) through Indian Institute of Millets Research (IIMR) and AICRP Project on Millets has succeeded in development of more than 90 varieties for different agro-climatic regions so far. Recently Prime Minister of India dedicated to the nation ICAR developed 3 bio-fortified varieties of millets (Finger millets, CFMN-1,2, Small millet CCLMN) with high iron and zinc contents on the occasion of 75th Anniversary of UN FAO. Apart from evolving high yielding varieties, focus has been on the development of value-chain ecosystem. To promote millet production, the undersigned, then Agriculture Commissioner developed and implemented new Sub-Mission on Nutri-cereals (Millets) under National Food Security Mission Programme in the year 2018 to increase area, production and productivity of millets in 212 districts of 14 states. Consequently, the production of millets has increased from 13.7 million (2018–19) to 17.9 million tonnes (2020–21). The other important decisions taken were changing the name from millets to nutri-cereals through a Gazette Notification of Government of India in April 2018, implementation of National Year of Millets 2018, launching of breeder seed production at 18 centers and creation of 25 seed hubs at ICAR-AICRP and KVK's.

To create domestic and global demand and to provide nutritional food to people, Government of India proposed to UN for declaring 2023 as International Year of Millets. The undersigned got the opportunity to present the proposal in UN FAO, Rome Committee on Agriculture (5 October 2018), and also in UN FAO Council (3 December 2018) which was endorsed and declared by UN on 5 March 2021. Now, India will take lead at global level as a guiding country for observance of International Year of Millets 2023. It is a matter of pride for all of us that Indian Council of Agricultural Research has got the lead role to play for promotion of millets as nutri-solution to climate and food. I call upon all stakeholders to actively participate and contribute for furtherance of nutri-cereals called millets globally through pre-run activities conducted by Government of India in the current year as well as next year.

(S K Malhotra)

Indian Farming 73 (01): 10-15; January 2023

International Year of Millets – 2023,

proposal from India – Application to UN adoption

S K Malhotra*

THE United Nations, Food and Agriculture Organization (FAO) steers international efforts to achieve food security for all and ensures that people have regular access to enough high-quality food. The Committee on Agriculture (COAG) is one of FAO's governing bodies providing overall policy and regulatory guidance on agricultural issues. It also provides advice and recommendations to the FAO conference on global agricultural policy and regulatory matters, and to the FAO council on matters relating to the organization's priorities, programmes and budgets. The COAG was established in 1971 and has over 130 member Nations, generally meets every two years to review specific matters related to agriculture, food and nutrition referred to the committee.

It was July 2018, when India received invitation for participation in 26th session of FAO Committee of Agriculture meeting scheduled from 1–5 October, 2018 at FAO, Rome, Italy. The Government of India approved the delegation, consisting of Dr S K Malhotra, the then Agriculture Commissioner as Head of delegation and Dr S K Chaudhari, the then ADG (Soil and Water Management) now DDG (NRM) with ICAR. The Head of delegation took the initiatives after consultation in the Ministry for Agriculture & Farmers Welfare to take forward the International Year of Millets agenda from India. The matter was taken up through Dr Alka Bhargav, JS (International Cooperation) and Ms Reenat Sandhu, Ambassador EoI, Rome with Dr Robert G Guei, Secretary of the Committee on Agriculture of FAO for inclusion in the agenda. But the FAO wanted a request from Agriculture Minister, Government of India for this purpose. Accordingly, in the office of Agriculture Commissioner, Minister of Agriculture & Farmers Welfare, the request letter from Hon'ble Agriculture Minister dated 14th August, 2018 addressed to Mr Jose Graziano da Silva, DG, FAO was initiated. In reply to this letter, after thorough examination by FAO concerned division, the agenda was accepted at later stage for inclusion in the already circulated agenda additionally and was communicated back by a letter from DG, FAO to Sh. Radha Mohan Singh, the then Union Minister of Agriculture & Farmers Welfare, Government of India.

After having an approval for inclusion of proposal from India for consideration of discussion in COAG, the detailed proposal on background, nutrition, multiple uses, resilience to climate change, sustainable production systems, harvest and post-harvest operations with broad objectives set for International Year of Millets were developed by Dr S K Malhotra and accordingly submitted to Secretary COAG- FAO. The proposal from India was examined by the team of Dr Hans Dreyer, Director, Plant Production and Protection Division of FAO Rome (https://www.fao.org/3/mx753en/mx753en.pdf). The proposal was fine-tuned and fitted into the FAO proposal template with executive summary in the

COAG/2018/17/Rev1 7

Annex

D.O. No. 1721 /AM

राधा मोहन सिंह
RADHA MOHAN SINGH

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
MINISTER OF AGRICULTURE
& FARMERS WELFARE
GOVERNMENT OF INDIA

F.No.11-11/2017-TC
14th August, 2018

Dear Mr. Jose Graziano da Silva,

As you will be aware millets were a staple diet for the communities in Africa and Asia, but have lately been losing prominence from their plate. Hence the demand has declined and so also the area under cultivation across the globe. Along with the high nutrients and usefulness in various lifestyle diseases including obesity, diabetes, etc, millets have an important role in enhancing resilience and risk management in the face of climate change, especially for small farmers and family farmers. Hence it is highly desirable that global efforts are stepped up to bring these nutri-cereals back to the food baskets of a wide range of consumers, rural and urban as well as rich and poor, for boosting their production as well.

In this context, you would be pleased to know that India is celebrating 2018 as the National Year of Millets and is promoting cultivation by amending cropping patterns of areas which are especially susceptible to climate change. It is an important component of our efforts to achieve the national commitment of doubling farmers income by 2022.

To garner wider global attention and action, India has mooted a proposal to FAO for declaration of an upcoming year as 'International Year of Millets', a copy of which is enclosed for your ready reference. The matter has received support of the member countries when placed in the Bureau meeting of the Committee on Agriculture held on 5th July 2018. A short presentation on the multi dimensional benefits of millets is also enclosed for your perusal.

May I request you to kindly consider inclusion of this proposal into the agenda of the forthcoming 26th Session of the Committee on Agriculture (**COAG**) meeting, scheduled to be held during 1-5 October 2018 in Rome. Adoption of this proposal by FAO with the support of its Member Nations will enable it to be moved to the UNGA for declaration of upcoming year as **International Year of Millets.**

Encl: A/a

Yours sincerely,

Radha Mohan Singh
(RADHA MOHAN SINGH)

Mr. Jose Graziano da Silva,
Director-General,
United Nations Food & Agriculture Organization,
viale delle Terme di caracalla, 00153,
Rome, Italy.

Office : Room No. 120, Krishi Bhawan, New Delhi-110 001 Tel.: 23383370, 23782691 Fax : 23384129

October 2018 COAG/2018/17/Rev1

Food and Agriculture Organization of the United Nations | Organisation des Nations Unies pour l'alimentation et l'agriculture | Продовольственная и сельскохозяйственная организация Объединенных Наций | Organización de las Naciones Unidas para la Alimentación y la Agricultura

COMMITTEE ON AGRICULTURE

Twenty-sixth Session
Rome, 1 - 5 October 2018
Proposal for an International Year of Millets

Executive Summary

Millets are often called "Nutri-Cereals" due to their high nutritional content compared to the more commonly grown cereals; wheat, rice or corn. When millets are included in diets, human and animal health is significantly improved, including that of mothers and their young. Here Millets may encompass a diverse group of cereals that include pearl, proso, foxtail, barnyard, little, kodo, browntop, finger and Guinea millets plus fonio, sorgum (or great millet) and teff. Millets were among the first plants that were domesticated and have served as a traditional staple crop for millions of farmers in Sub-Saharan Africa and Asia. Millets can grow on poor soils with little or no inputs, are resistant or tolerant to many crop diseases and pests and can survive adverse climatic conditions. The genetic diversity of millets offer opportunities for economic development through income generating activities in the food sector or on niche markets for specific professional applications (therapeutics, pharmaceuticals, specialty chemistry).

To respond to the challenges posed today by increasing populations and associated food insecurity and changes in climate, the Government of India is seeking FAO support to the next agenda of the United Nations General Assembly (UNGA), to adopt the proposal for an International Year of Millets (Annex). The Government of India recently increased the Minimum Support Price (MSP) of millets by 50 percent of cost of production to achieve the national commitment of doubling farmers' income by 2022. The Union Government has also declared 2018 as National Year of Millets in the country and millets have featured in recent initiatives such as the Adaptation of African Agriculture (AAA) and programmes such as the Technologies for African Agricultural Transformation (TAAT) funded by the African Development Bank.

While millet cultivation has been historically widespread, there is a current need to promote the nutritional and ecological benefit of millets to consumers, producers and decision makers and to improve food sector linkages to better reward growers. FAO's support to India's proposal will cement trusted partnerships and prioritize policies that advocate for inclusive value chain development for millets.

This document can be accessed using the Quick Response Code on this page; an FAO initiative to minimize its environmental impact and promote greener communications. Other documents can be consulted at www.fao.org

MX753

India has identified three main objectives for the International Year of Millets:

(i) Elevate awareness of the contribution of nutri-cereals (millets) for food security and nutrition.

(ii) Inspire all stakeholders, including national governments to work towards improving production, productivity and quality of millets.

(iii) Draw focus for enhanced investment in R&D and extension services to achieve (i) & (ii) above.

Suggested action by the Committee

The Committee is invited to:

- Review the proposal by the Government of India to establish observance of the **International Year of Millets** in 2026 and provide guidance as deemed appropriate;
- Review and amend, as needed the Draft Conference Resolution presented in Appendix A, and submit it for the consideration of the 160th session of the Council (3-7 December 2018) for adoption by the 41st Session of the Conference (22-29 June 2019).

Queries on the substantive content of the document may be addressed to:

Hans Dreyer
Director
Plant Production and Protection Division
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agenda format along with the suggested action by the Committee on Agriculture.

Secretariat of COAG conveyed the approved agenda proposal to Government of India through embassy of India with remarks for preparation of proposal in power point mode for presentation and introduction of proposal of IYOM item by the responsible officer from India. Minister of Agriculture and Farmers Welfare, Government of India, identified Dr S K Malhotra, Agriculture Commissioner as Head of delegation for presenting the proposal in FAO, COAG meeting and this item was scheduled for presentation on 4th October 2018 vide Agenda Item 4.6. The excerpts from the embassy report submitted by Sh. R Ramesh, Attache (Agriculture) Embassy of India, Rome to Ministry of External Affairs is reproduced as such.

Embassy of India

Rome

INTERNATIONAL YEAR OF MILLETS 2023

[illegible]

For kind information and records please.

(R. Ramesh)

Attaché (Agriculture)

5 October 2018

The FAO COAG (1–5 October 2018) reviewed the proposal presented by the Govt. of India to establish observance of the International Year of Millets 2023 and decided to submit draft conference resolutions for considerations and endorsement by the 160th session of FAO council (3–7, December 2018) for further adoption by the 41st session of the FAO conference (22–29, June 2019).

Presentation of IYOM proposal in FAO, COAG (04 October, 2022)

Question-answer session after presentation

4.6 Proposal for International Year of Millets

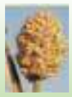
Dr. Suresh K. Malhotra
Agriculture Commissioner
Ministry of Agriculture and Farmers Welfare
Government of India, New Delhi-110001, INDIA

(Presented in FAO, 26th Committee on Agriculture meeting held at Rome on 4 October 2018)

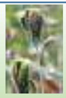
Millets: Crops for the future

Major millets

Pearl millet (*Pennisetum americanum*)



Great millet / sorghum (*Sorghum bicolor*)



Finger millet (*Eleusine coracana*)

Small millets

Little millet (*Panicum sumatrense*)

Kodo millet (*Paspalum scrobiculatum*)

Proso millet (*Panicum miliaceum*)

Barnyard millet (*Echinochloa frumentacea*)

Foxtail millet (*Setaria italica*)

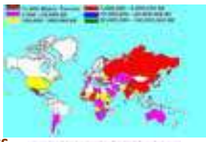
Millets are collective group of small seeded annual grasses that are grown as grain crops, in dry areas of temperate, sub tropical and tropical regions.

Origin:
- Wild African grasses in the Nile valley and the Sahel zone.
- Subsequently taken to China, India, Americas and Europe

Millets : Traditional/ancient grain of Arid, Semi-arid ecosystem

1. *Millets as Staple food*

- Millets were amongst first plants domesticated
- Traditional staple crop for million of farmers in Sub-Saharan Africa & Asia



International Crop Research Institute Semi Arid Tropics

- More than 90 million people in Africa & Asia depend on millets for food.
- 500 million people in >30 countries depend on sorghum as staple food
- Millets including sorghum are grown in 131 countries and are important for food and nutrition.

Senegalese women revive appetite for traditional grains

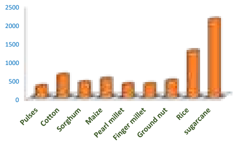
http://www.icrisat.org/senegalese-women-revive-appetite-for- traditional-grains/

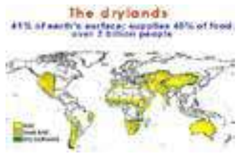
- MILLETS: Africa (Western, Eastern, Northern Africa) and Asia (Southern & Eastern Asia) leads in production (95%) in arid and semiarid agro-ecosystem
- SORGHUM: Africa (Western, Eastern, Northern Africa), Americas (North, Central and South) and Asia (Southern & Eastern Asia) leads in production (95%) in arid and semiarid, tropical subtropical and temperate agro-ecosystem

Why International Year of Millets?

1. *Millets are highly climate resilient crops*

- Climate change is affecting the crop yield and quality of many crops.
- But millets possess several morpho, physiological & biological characters- thus are adaptable to dry regions.
- Early maturity (65-85 days); high drought (150- 500 mm rainfall) and salinity tolerance; high heat tolerance (>42° C of air temperature)
- Adapted to adverse, marginal & changing environments
- Supports increased resilience to climate change



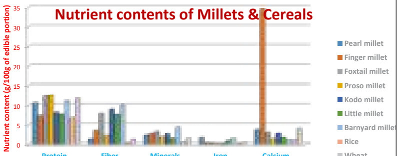


Why International Year of Millets?

2. *Millets have high nutritional value*

- Targeting some of the biggest nutrition and health needs globally.
- High in Iron, Zinc, Folate
- High in calcium
- Low GI (good for avoiding and managing diabetes)
- High in protein, dietary fiber, antioxidants.
- Gluten free.

Millets fit many of the major global health food trends



Why International Year of Millets?

3. *Millets are: Good for the planet (Take less to give more)*

- *Millets provide a viable option for the marginal farmers & Sustainable production system*

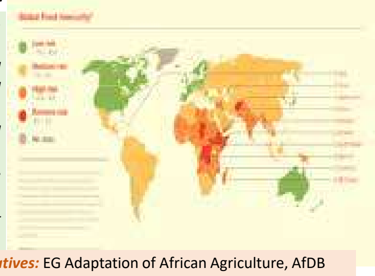
- Grows with minimal fertilizers and pesticides
- Survive with less water
- Grows faster putting less stress on the environment.

- Multiple uses as food, feed/ fodder, biofuels, brewing
- Eaten in many forms

Why International Year of Millets?

4. Attention is needed that millets is a global priority for achieving food and nutrition security, particularly in:

- Contributing to Sustainable Development Goals (SDGs) 2,3,12,13
- **SDG 2** *End hunger, achieve food security and improved nutrition and promote sustainable agriculture*
- *SDG 3 Ensure healthy lives and promote well-being for all at all ages*
- *SDG 12 Ensuring sustainable consumption and production patterns*
- *SDG 13 "Take urgent action to combat climate change and its impacts*



Millets align with some of the big initiatives: EG Adaptation of African Agriculture, AfDB TAAT (Technologies for African Agricultural Transformation)

Backdrop:

Millet cultivation: historically widespread.

- **Current need:**

i. To promote the nutritional and ecological benefit of millets to consumers, producers, decision makers.
ii. To improve food sector linkages for better reward to growers.
iii. To prioritize policies that advocate for inclusive value chain development for millets.

International Year for Millets

Objectives proposed:

i. Elevate awareness of the contribution of nutri-cereals (millets) for food security and nutrition.
ii. Inspire all stakeholders, including national governments to work towards improving production, productivity and quality of millets.
iii. Draw focus for enhanced investment in R&D and extension services to achieve (i) & (ii) above.

The Committee is invited to:

- Review the proposal by the Government of India to establish observance of the **International Year of Millets** in 2026 now 2023 and provide guidance as deemed appropriate.
- Review and amend, as needed the Draft Conference Resolution presented in Appendix A, and submit it for the consideration of the 160th session of the Council for adoption by the 41st Session of the Conference.

Reply to IYOM queries in side meetings at FAO Rome

Appraising about IYOM in side meetings at FAO Rome

UNGA adopted India's resolution for IYOM-2023

On the recommendations of FAO COAG, FAO council and FAO Conference the UN General Assembly (UNGA) adopted by consensus a resolution sponsored by India and supported by 70 nations declaring 2023 as International Year of Millets (IYOM-2023) on 3rd March 2021. India's Permanent Representative to the United Nations T S Tirumurti thanked all co-sponsors especially Bangladesh, Kenya, Nepal, Nigeria, Russia and Senegal and all Member States of UN for their strong support. The resolution considers the urgent need to raise awareness of the climate-resilient and nutritional benefits of millets and to advocate for diversified, balanced and healthy diets through the increased sustainable production and consumption of millets. It also recognizes the vast genetic diversity of millets and their adaptive capacities to a range of production environments. The U.N. member states lauded India for the initiative and its leadership in facilitating negotiations on the resolution. Prime Minister Shri Narendra Modi expressed gratitude (through twitter message) to all the nations who initiated and co-sponsored the resolution on International Year of Millets at the United Nations through a message. In his remarks he said, India is honoured to be at the forefront of popularizing Millets, whose consumption furthers nutrition, food security and welfare of farmers. He said, it also offers research and innovation opportunities for agriculture scientists and start-up communities.

Indian delegation with Ambassador Ms. Reenat Sandhu at Rome Indian Embassy

Major observations given by different countries in FAO council meeting on 4th December, 2018

Mr Mohammad Hossein Emadi (Chairperson, Committee on Agriculture) There are a wide range of millets and the important role of the millet in most of the Asian and African countries and the importance, and the diversity, of the sort of millet is known by Member Countries. In terms of reasoning for an International Year of Millets, first of all, millet is highly nutritious, climate resilient in terms of resilience to temperature, resilience to water scarcity and of course salinity and that is one of the major points that was considered by the COAG. The Council is invited to consider the proposal and recommendation of COAG and to submit the proposal for consideration to the 41st session of the FAO Conference on 22–29 June 2019. He introduced the proposal from Indian delegation on the International Year of Millets and opened the floor for comments.

Mr Yubo Xu (China) China has the honour to deliver this joint statement on behalf of the Asia group on the International Year of Millets. More than 45 million people in Asia depend on millets. We are confident that the celebration of International Year of Millets will elevate awareness about climate resilience and nutritional benefits of millets and will promote for healthy diets through increased sustainable production and consumption of millets. Asia group takes this opportunity to strongly support and advocate the proposal of India for an International Year of Millets in 2023. I would also like to make a statement on behalf of China. We would like to support the proposal from India for International Year of Millets in 2023.

Ms Elsa Simoes (Cabo Verde) Cabo Verde is making this statement on behalf of the African Regional Group. We welcome the proposal from the Government of India to promote the year 2023 as the International Year of Millets. As we all know the challenges of climate change, the increase in both under and malnourishment and the growing demography imposes an urgent need to several of our countries in Africa, especially in the Sahelian region, to overcome the pressing lack of water, thus the promotion of production and consumption of millets could be one of the solutions. Therefore, an International Year of Millets, in 2023, on an exceptional basis, could well be the opening door to promote much needed research that can enhance its production and boost its consumption.

Mr Guenter walkner (Austria) I am honoured to speak on behalf of the European Union and its 28 Member States. We would like to comment on all items under agenda item 11, International Years and Days. We are aware of the important role millet play for global food security, not just in developing countries but also in developed countries and countries with economies in transition. The topic of food waste and food losses along the whole production and consumption chain is of particular importance for the European Union and its Member States. Therefore, the European Union and its Member States support the endorsement of the proposal from India.

Mr Mohammad Jawad ranjbar (Afghanistan) The world's production of millets which grows in semi-arid tropics of Asia and Africa is estimated to be close to 30 million metric tonnes a year. The share of developing countries is 97% of this level of production. Although India and Nigeria are the two major producers of millets, the crop is grown in many countries of Asia, China, Myanmar, Pakistan, West Africa, Burkina Faso, Niger and East Africa, Eritrea and Ethiopia and in Sudan. It is rich in nutrients and superior to other cereals. Afghanistan supports the request of the Government of India to establish the observance of an International Year of Millets for 2023.

Mr Ivan konstantinopolskiy (Russian Federation) We also support the Indian initiative for the proclamation 2023 of the International Year of Millets.

Ms Jacinta ngwiri (Kenya) I want to give Kenya's support to the statements by the various Africa Regional Group countries, with respect to the observance of the International Year on Millets. However, I want to make some more observations as Kenya with respect to millets. They are grown in drought-prone areas and largely among poor communities. This makes millets important for food security among these communities. In Africa however, the production of millets crop is fairly positive signalling the importance of the crop to many countries, particularly in Africa. In Kenya the area and production of millet has stagnated over time with occasional declines during periods of drought and erratic weather. We note that the need to elevate awareness of the contribution of nutritious cereals for food security and nutrition is key. Therefore there is need to inspire and mobilize stakeholders, including national governments to work towards improving production, productivity and quality of millets. Kenya endorses the proposal to establish observance of an International Year of Millets in 2023.

Mr Thanawat tiensin (Thailand) Thailand aligns itself with the joint statement made by China and also will be made by India on behalf of the Asia Group in supporting the proposal of the International Year of Millet and the International Tea Day. And we are expecting to celebrate those international years and days which will enhance smallholder farmers, sustainable agriculture and food systems.

Ms Sadia Elmubarak Ahmed daak (Sudan) Sudan agree with the importance of this India proposal for the International Year of Millets. We would like to say that millets are an important source of food and livelihood in many parts of Sudan, especially the rainfed areas. We rely on rain for the production of millets. However, in recent years the productivity has been low in view of the climate change. Different institutions in Sudan are working on devising new varieties of high quality and high production drought resistant crops. Therefore, Sudan supports the proposal of India for an International Year of Millets and we agree with the aims and objectives of this proposal, namely the investments and better research in that area.

Mr Haitham EL hady (Egypt) Egypt supports the proposals from India for International Year of Millets.

M. Baye Mayoro diop Senegal particularly wishes to support the proposal made by the Government of India for the celebration, in 2023, of an International Year of Millet. The qualities of millet are certainly not in doubt. It is a very important cereal plant, which has several advantages, in particular that of being already very widely cultivated in the world and that of being very nutritious. Hundreds of millions of people consume millet in Africa, especially in West Africa. In Senegal specifically, more than 80% of farmers use millet as food basic household. Also, I would like to emphasize, regarding the identification of the reasons for which there is a decline worrying about the cultivation of millet, the importance of the threat posed by drought, the locust pilgrim, the increase in temperatures and the shortage of water, these are in any case the challenges that we know in West Africa. The three main objectives defined by India, within the framework of its proposal, are therefore absolutely relevant and can serve as a basis for the preparation and implementation of the activities of the Year international millet. This is how Senegal approves the proposal of the Indian Government relating to the celebration of an International Year of Millet in 2023, and looks forward to any indications that the Advice would do on this.

Mme Halimatou Kone Traore (Malí) Mali welcomes the declaration of an international year of millet 2023. I would add that in Sub-Saharan Africa, particularly in Mali, millet is a food crop of base, because of its high nutritional and energy value. In the countries of the Sahel, millet, a food crop, is important for food security and represents often more than 30% of total grain production. By celebrating it in 2023, it fits very logically into the decade of family farming. In addition, this cereal has received particular attention from African countries following the financing by the African Development Bank through a number of initiatives such as adaptation of African agriculture and the technologies for the transformation of agriculture in Africa. This celebration will be an excellent opportunity to foster connections throughout the supply chain. Production so as to make better use of the proteins and mineral salts derived from millet, to strengthen the millet production on a global scale and to get more out of it. My country supports the celebration of an international year of millet. This proclamation will contribute to culmination of several SDGs.

Mr Suresh Kumar Malhotra (India) India is honored to deliver the support statement for the International Tea Day on behalf of the Asia Regional Group. India is the second largest producer of fruits and vegetables. India produces 92 million tonnes of fruits and 178 million tons of vegetables. Considering the importance of fruits and vegetables in food, nutrition and livelihood security, India supports the proposal of celebration of the International Year of Fruits and Vegetables. Considering the one important statement on food loss and waste, food saved is food produced. India supports the International Day of Awareness of Food Loss and Waste. So my final comments on the International Year of Millets. India appreciates the Asia Regional Group, Africa Regional Group, European Union, Russian Federation and many of the other member countries for good remarks on the benefits of millets such as high climate resilience, high nutrition value, capacity of millets to take less and give more and the observance of the International Year of Millets will definitely augment production not only for the major millets: pearl millets, sorghum and finger millets, but also the minor millets: little millets, barnyard millets and foxtail millets which are in a real sense crops of adverse climate conditions. Observance for International Year of Millets will prove as a viable option for marginal farmers who contribute more for food and nutritional security. India is ready to champion and promote nutritional as well as ecological benefits of the millets.

Mr Bukar Tijani (Assistant Director-General, Agriculture and Consumer Protection Department) Thank you for the observation. There are two things I want to say to briefly conclude my own assessment. In fact, the food loss and waste is a major issue in most regions, and this is something that family farmers and others have produced a lot that goes into waste. It is so important for us to see what we can do. Secondly, FAO is working not just on productivity increases but also on building resilience, especially in dry lands, marginal lands, and that is why it has become important for us to be looking at days of observances of the millet, the rye. And we want to see that we also build resilience of populations who are not exposed to technologies and are living in marginalized lands. With regards to millet, we have observed that the productivity yields are going down and we are working very hard with the intergovernmental group and others and will continue that to make sure that these yields come back again. There are a number of countries working on improvement of millet yields, not just in Africa but also in China, and in Asia in general. India itself is looking at those. I want to assure that we will definitely be focusing on what our Members have indicated we be looking at.

Chairperson I can now conclude on our discussions on this item. 1. The Council, recalling the criteria outlined in the FAO policy on the proclamation and Implementation of International Years, as adopted by the 144th Session of Council (June 2012), and the ECOSOC Resolution 1980/67 regarding International Years and Anniversaries, endorsed the following: a) the draft Conference resolution submitted by the 26th Session of COAG on the observance by the UN System of an International Year of Fruits and Vegetables in 2021; b) the proposal by the Government of Estonia, as endorsed by the 31st Regional Conference for Europe, to establish the observance by the UN System of an "International Year of Rye" in 2025; c) the proposal by the Government of India, as endorsed by the 26th Session of COAG, to establish the observance by the UN System of an "International Year of Millets", to be held on an exceptional basis in 2023.

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IYOM proposal from India in discussion at FAO

Indian Farming 73 (01): 16-18; January 2023

INTERNATIONAL YEAR OF MILLETS 2023

Global and Indian
scenario of millets

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*Millets are the food crops adapted to dryland agro-ecologies of the arid and semi-arid tropics. In India, millets are produced in most of the regions characterized by low to moderate precipitation (200–800 mm rainfall). Major millet crops include jowar or sorghum (*Sorghum bicolor*), bajra or pearl millet (*Pennisetum glaucum*), mandua/ragi or finger millet (*Eleusine coracana*); and small millets comprising of kangni or foxtail millet (*Setaria italica*), kutki or sama or little millet (*Panicum antidotale*), kodo millet (*Paspalum scrobiculatum*), jhangora or sawan or barnyard millet (*Echinochloa frumentacea*), cheena or proso millet (*Setaria italica*) and korale or brown top millet (*Brachiaria ramosa*). Other minor millets grown are Teff (*Eragrostis tef*) and Fonio (*Digitaria exilis and Digitaria iburua*) and Job's tears (*Coix lacryma-jobi*).*

Keywords: Area, Millets, Production, Yield

INDIA is the leading producer and consumer of millet crops and their products. The people in arid and semi-arid regions of the country grow and consume millets as a staple food. Millets provide food and fodder security to the dryland agricultural communities. They are also being recognized as food grains for nutrition and health, and nearly organic in cultivation. Millets are the most secure crops to small farmers as they are the hardiest, resilient and climate adaptable crops in harsh, hot (up to 50°C) and drought environments. They are often the last standing crops in drought seasons and will be the sustainable future food source amidst of worsening climatic conditions.

Current international scenario

Millets are mainly grown in tropical, sub-tropical and slightly temperate regions of the world, with Asia and Africa accounting for major production and consumption centres. Sorghum and proso millet (common millet) are most widespread being cultivated in 112 and 35 countries respectively during 2019 (FAOSTAT database, http://www.fao.org/faostat/en/). Global production of millet is about 97.75 million tonnes from 78.43 million hectares area. Sorghum and pearl millet comprise more than 90% of the area and production. The rest of the production includes finger millet, proso millet, foxtail millet and other non-segregated millets.

Sorghum is most widespread in terms of the total area covered by the countries, which is spread all over the globe. The top 5 countries comprise Sudan, Nigeria, India, Niger and the USA possess 57% of the global area under sorghum with about 45% of global sorghum production. While Sudan has a maximum area of 7.141 million ha, the USA contributes the maximum production of 10.9 million tonnes. Average yield of sorghum in India is 1064 kg/ha which is much less than that of the world average of 1460 kg/ha (Table 1).

Pearl millet is cultivated in 36 countries in Africa, though India is the single largest country in terms of area (31.5%) and production (46.7%). Niger comes second with 24.3% area and 15.3% of production. The yield levels of India (1237 kg/ha) are much higher than the world average of 834 kg/ha. Finger millet is cultivated in 14 countries; the top 5 countries, viz. India,

Table 1. World area, production and yield of millet crops (mean of 2015–19)

Millet	Area (million ha)	Production (million tonnes)	Yield (kg/ha)
Sorghum	41.91	61.18	1460
Pearl millet	28.38	23.68	834
Proso millet	0.77	1.19	1535
Finger millet	2.31	3.33	1442
Foxtail millet	0.79	2.11	2688
Teff	3.35	5.56	1660
Fonio	0.92	0.70	790
Total	78.43	97.75	1247

Table 2. Millet crops area, production and yield in India during 2009–22

Millet	Area ('000 ha)			Production ('000 tonne)			Yield (kg/ha)		
	2009–13	2014–18	2019–22	2009–13	2014–18	2019–22	2009–13	2014–18	2019–22
Sorghum	6684	4910	4355	4290	4404	4632	913	897	1064
Bajra	8480	7142	7415	7030	8738	10149	1065	1223	1369
Ragi	1211	1104	1097	985	1710	1807	1580	1549	1647
Small millets	773	570	436	435	403	349	554	707	800
Total millets	17149	13726	12680	12740	15255	16937	1019	1111	1273

Source: estimations of Dept. of Economics & Statistics, DAC&FW, GoI, New Delhi

Ethiopia, Nepal, Uganda and Malawi in terms of area (99.4%) produce 99.6% of finger millet globally. Ethiopia has the highest yield level (2301 kg/ha). The yield in India is slightly higher than the global yield. Foxtail millet is a predominant crop of China with a production of 2.1 million tonnes from 0.79 million ha area. A large proportion (89.7%) of the area under proso millet is located in 5 countries, viz. Russian Federation, USA, Ukraine, North Korea and Kazakhstan that produce 86.4% of global proso millet. The bottom 25 countries of the total 35 countries consist 5.9% of proso millet area, producing 7.2% of global production. Foxtail millet is mainly cultivated in China, India and Myanmar.

Other Millets that are known and grown in Africa such as teff are majorly grown in Ethiopia and Eritrea which contribute more than 90% of world's production. Amhara and Orimia regions together contribute more than 85% of Ethiopia's production. It is cultivated over 3.35 million ha land and producing 5.56 million tonnes at an average yield of 1660 kg/ha. Fonio is majorly grown in Guinea and Nigeria, which account for 88% of total production. It is cultivated over 0.92 million ha and producing 0.7 million tonnes at an average yield of 790 kg/ha. Job's Tears is a native crop to south-east Asia but finds usage in China, India, Japan, Myanmar, Thailand, Borneo, Philippines, etc. It is cultivated in Assam under shifting cultivation and called as Adlay.

Millet crops' utilization varies across countries

Table 3. Area, production and yield of millets in important millet growing states (states with area of more than 10000 ha)

State	Sorghum			Pearl millet			Finger millet			Small millets			Total		
	Area*	Production*	Yield*	Area*	Production*	Yield*	Area*	Production*	Yield*	Area*	Production*	Yield*	Area*	Production*	Yield*
Andhra Pradesh	134	306	2289	34	63	1881	33	41	1248	22	17	798	222	428	1926
Arunachal Pradesh										22	27	1217	22	27	1217
Bihar	1	1	1066	4	4	1134	3	3	892	4	3	784	13	12	943
Chhattisgarh	3	4	1268				6	1	248	83	23	281	92	29	314
Gujarat	72	99	1369	423	942	2227	13	14	1076	9	12	1291	518	1067	2062
Haryana	42	22	527	483	986	2043							525	1009	1921
Jammu & Kashmir	0	0	635	15	8	563	2	1	347	7	2	294	24	11	463
Karnataka	911	954	1047	240	272	1133	666	1071	1609	30	21	721	1847	2319	1255
Madhya Pradesh	157	299	1905	308	692	2246	1	0	277	117	92	788	582	1083	1860
Maharashtra	2257	1641	727	719	594	826	86	98	1145	50	25	501	3112	2358	758
Nagaland				1	1	1014				9	11	1122	11	12	1106
Odisha	6	4	632	2	1	619	41	30	738	31	16	513	80	51	639
Punjab				1	1	616									
Rajasthan	572	433	757	4240	4193	989				10	8	722	4823	4633	961
Tamil Nadu	379	399	1053	59	142	2404	79	251	3186	24	31	1280	541	823	1521
Telangana	78	102	1296	11	10	910	1	2	1270	1	1	1084	91	113	1249
Uttar Pradesh	168	216	1287	907	1853	2044				9	6	691	1084	2075	1915
Uttarakhand							95	132	1391	56	75	1332	151	207	1369

*Expressed as Area ('000 ha), Production ('000 tonne); Yield (kg/ha)

Source: Estimations of Dept. of Economics & Statistics, DAC&FW, GoI, New Delhi.

and continents depending on the use and climate of production, and cultivars. In the USA and Europe, sorghum and other millets are grown for feed purpose with lesser concern for quality and associated traits. Hence, yields are very high. In the African and Asian countries where millet grains are consumed as a staple food, quality is important and mostly the local varieties of specific adaptation and culinary niceties are predominantly grown, which not necessarily possess appreciable yield potential. Similarly, in some countries of Africa and Asia where sorghum is used for making alcohol-based beverages, the quality is not important.

Current Indian scenario

India is the leading producer of millets. Most of the states of India grow one or more millet crop species. A total of about 16.9 million tonnes of millets food grains are produced in India from nearly 12.7 million ha area, which constitutes about 6% of the national food grain basket. Pearl millet is grown in about 7.4 million hectares yielding 10.1 million tonnes, followed by sorghum (4.35 million ha, yielding 4.63 million tonnes), finger millet (1.1 million ha, yielding 1.58 million tonnes) and other millets (0.44 m ha, yielding 0.35 million tonnes) (Table 2). Pearl millet, sorghum and finger millet account for more than 95% of the area under millets, while small millets comprising of barnyard millet, foxtail millet, little millet, kodo millet and proso millet constitute less than 5% of the area (Directorate of Economics and Statistics, DA&FW 2021).

In India, Rajasthan, Maharashtra and Karnataka are the topmost states in millets cultivation with a share of 35%, 23% and 14% to total millets area. Maharashtra and Karnataka have the maximum area under sorghum while Rajasthan, Gujarat, Uttar Pradesh and Maharashtra have more area under pearl millet. Ragi has the maximum area in Karnataka, Tamil Nadu and Uttarakhand. Small millets area is maximum in Madhya Pradesh, Uttarakhand and Chhattisgarh (Table 3).

Despite the surrender of almost 56% area during last 50 years in the country, the millet production has increased from 11.3 to 16.9 million tonnes due to an increased productivity that went up by more than two times overall while it's more than tripling in pearl millet. Development and adoption of improved varieties/hybrids have played a significant role in the productivity improvement of these crops.

SUMMARY

The global scenario of millets production has been almost stable from the perspective of sorghum, pearl millet and finger millet. In India, area under millets has been decreasing drastically over years, despite the high adaptation of these crops to difficult and niche areas, climate-friendly cultivation and highly nutritious produce made available for consumption. With the Government of India including these crops under nutri-cereals under National Food Security Mission the United Nations decided to commemorate 2023 as the International year of millets and these crops are receiving the due importance in the country and across the world. These efforts would promote the consumption of millets, necessitating expansion of area under their cultivation and enhancing productivity.

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Indian Farming 73 (01): 19-21; January 2023

Millet crops

as source of fodder

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India has the largest livestock population, however, the productivity of milk and other livestock product per animal is very low compared to other countries. One of the main reasons for the low productivity and performance of our livestock is malnutrition and under-nutrition owing to inadequate supply of nutritive fodder and feed. The country is highly deficient with respect to availability of green fodder, dry fodder and concentrates. The gaps for fodder supply are partly met by crop residues-straw and stovers. As the millets are the major cereals of dryland crops in arid and semi-arid regions, they form an important source of stover for the livestock of these regions.

Keywords: Fodder, Fodder quality, Green fodder, Millets, Stover

THE farm communities in the semi-arid and arid regions of the country are dependent on crop residues as a major form of roughages for cattle since they neither have the luxuries of green fodder from irrigated forage crop nor can afford to sacrifice the farm area for dedicated one-time green forage. Annually, millets account for 11% of the 30 million tonnes crop residues produced in India. The decision of the farmer to select the crop and variety are greatly influenced by the ability of the crop/variety to meet their fodder requirements from stover (millet plants left after harvesting the earhead). Stover's contain less of protein, total digestible nutrients and are less palatable than green forages. In regions with assured irrigation, exclusive forage producing sorghum (jowar) and pearl millet (bajra) varieties and hybrids are grown which produce superior quality fodder for feeding livestock. Many multi-cut type hybrids are available in these crops which ensure continuous supply of green fodder during *kharif* (rainy) and summer seasons. The perennial forage crop napier-bajra hybrid is popular in dairy farms throughout the country. Green fodder from most of these millets can also be made into silage and used during off-season feeding.

Stover for fodder

Stover from millets is a valued fodder, especially if cut and dried immediately after the heads have been harvested for grain. The heads are hand-harvested as they ripen and the stover is harvested as green as possible after seed harvest, and dried in the field. The nutritive value in terms of nitrogen and cell soluble nutrients is better in millet stovers as compared to slender straws of paddy and wheat. Improved varieties and hybrids of the millets yield higher, both grain and stover (Table 1). Higher stover yields of 10–15 tonnes can be obtained from sorghum and pearl millet cultivars with good management practices. Other millets produce 3–8 tonnes of fodder depending on cultural conditions. These are mostly *kharif* (rainy)-grown crops, while *rabi* (winter) sorghum and summer pearl millet are also cultivated in several states.

Finger millet stover is considered a good feed in India and Nepal. Under rainfed conditions, finger millet stover yield is about 2–3 t/ha and may reach up to 6–10 t/ha under irrigation. However, the stover obtained from the rainfed crop is relished more by cattle compared to an irrigated crop because stover of irrigated crop is tough and fibrous, and hence is less palatable.

Finger millet stover can be used to feed crossbred dairy cows in diets supplemented with a concentrate mixture (energy and protein). Such diets allow 8 to 9 kg milk yield and a body weight gain of 200–300 g/day. It can be used for growing heifers when supplemented with wheat bran (25%) or groundnut cake. Dry matter intake of stover is about 3.5 kg/day and the daily weight gain is 310–350 g. It can also be made into silage with suitable supplements.

Augmenting stover quality

Stover should not be fed without supplementation because they do not provide enough energy and protein to meet animal's requirements. The livestock rations using millet stovers can be enriched by mixing with

Table 1. Stover yield of recent cultivars of millet crops in India

Crop	Variety/hybrid	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Region recommended for cultivation
Sorghum (*kharif* jowar)	CSH 30	2013	44	141	Maharashtra, Karnataka, Madhya Pradesh, south Gujarat and north Andhra Pradesh
	CSV 20	2006	31	133	All India
	CSV 23	2007	25–30	155	All India
	CSV 27	2012	28	193	All India
	CSV 28	2012	28	170	All India
	CSV 31	2015	32	144	Andhra Pradesh, Telangana, Tamil Nadu, Rajasthan and Gujarat
	CSV 41	2020	32	159	
Sorghum (*rabi* jowar)	CSV 22R	2006	23–24	70–72	Medium to deep soils of Maharashtra, Karnataka and Andhra Pradesh
	CSV 26R	2012	13–16	45–60	Shallow soils of Maharashtra, Karnataka and Andhra Pradesh
	CSV 29R	2013	25–30	50–75	Medium to deep soils of Maharashtra, Karnataka and Andhra Pradesh
Pearl millet (Bajra)	HHB 67 (improved)	2005	31	88	Haryana
	RHB 223	2018	30	55	Rajasthan, Gujarat and Haryana
	Pusa 1201 (MH 1849)	2018	28	72	Delhi NCR
	AHB 1269Fe	2019	32	74	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra and Tamil Nadu
Finger millet (Ragi/ Mandika)	ML-365	2009	50–55	65	Karnataka
	Vegavathi (VR 929)	2019	36	77	Andhra Pradesh, Gujarat, Maharashtra, Tamil Nadu, Telangana, Odisha, Jharkhand, Karnataka and Puducherry
	CFMV 3	2021	32	87	Andhra Pradesh, Gujarat, Maharashtra, Tamil Nadu and Telangana
Barnyard millet (Sawan)	Pratap Sanwa 1	2006	15–17	50–55	Rajasthan
Kodo millet	CKMV 1 (ATL 2)	2021	28	70	Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Telangana and Tamil Nadu
Proso millet (Cheena)	GPUP 21	2004	15.7	42	Karnataka and Tamil Nadu
	Pratap Cheena	2006	15–17	48–50	Rajasthan
	TNAU 202	2017	19	37	Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Karnataka, Gujarat, Tamil Nadu and Bihar
Foxtail millet (Kakun)	Pratap Kangni-1	2004	16–18	46–50	Rajasthan
	CO-7	2006	18.6	51	Tamil Nadu
Little millet (Kutki)	Sabara	2004	12–21	52	Orissa, Madhya Pradesh and Chhattisgarh
	CO-4	2007	15.7	58	Tamil Nadu
	DHLM -14-1	2019	16	61	Tamil Nadu, Karnataka, Gujarat, Maharashtra and Odisha
	CLMV 1	2020	16	55	Maharashtra, Andhra Pradesh, Telangana, Tamil Nadu and Puducherry

legume fodder, treatment with urea, etc. to result in better animal health and performance in terms of weight gain and milk production.

Urea treatment: Treating crop residues with 5–10% urea and 25–50% moisture improves their nutritive value by increasing digestibility, palatability and crude protein content. If the stover is wet with rain or with freshly harvested stover containing much green material, urea can be applied without prior adding extra moisture. Treated stover is best kept in airtight condition. The outer (untreated) parts can be fed to animals with lower requirements, such as draught bullocks or dry cows, while the inner part is fed to growing and lactating animals. Treatment time may vary from 1–4 weeks. Temperature and treatment time are inversely correlated and more time is required in winter or in colder climates. In well-compacted stover, the temperature rises over 10°C after one week. Successful treatment is indicated by change of colour to dark yellow to brown with strong ammonia odour. Treated stover is softer, highly palatable to cattle and results in body weight gain and enhanced milk production in feeding cattle.

Green forage

Single-cut sorghum and multi-cut pearl millet varieties may be cultivated for green fodder or forage (Table 2). In rainfed conditions (*kharif*), single-cut cultivars may be taken up while multi-cut types need assured irrigation (summer and *kharif*) after each cut, to facilitate fresh foliage growth. Pearl millet uses less

Table 2. Recent millet cultivars notified for green forage production

Millet crop	Single-cut /multi-cut	Variety	Year of release	Green fodder yield (q/ha)	Dry fodder yield (q/ha)
Sorghum	Multi-cut	CSH 43MF	2021	965	219
Sorghum	Single-cut	CSH 40F	2018	560	155
Sorghum	Single-cut	CSV 38F	2019	465	145
Sorghum	Single-cut	CSV 35F	2018	529	145
Sorghum	Multi-cut	CSV 33MF	2017	1039	280
Sorghum	Single-cut	CSV 32F	2015	478	156
Sorghum	Single-cut	CSV 30 F	2014	443	140
Sorghum	Multi-cut	CSH 24 MF	2009	914	232
Pearl millet	Single-cut	TSFB 15-8	2020	420	86
Pearl millet	Single-cut	TSFB 15-4	2020	427	85
Pearl millet	Multi-cut	Moti bajra	2016	811	-
Pearl millet	Single-cut	APFB-09-1	2015	302	-
Pearl millet	Single-cut	Nutrifeed (PAC 981)	2014	479	107
Pearl millet	Single-cut	NDFB-11	2014	450-500	-
Pearl millet	Single-cut	Anand Forage Bajra-3	2011	500-525	100
Pearl millet	Single-cut	BAIF-Bajra-1	2010	380-400	80-90

water per unit of forage production, tolerates both lower and higher soil *p*H, higher aluminum concentration, and is rich in minerals as compared to sorghum. However, sorghum has a wider range of adaptability and is more widely grown. The derivatives of sorghum × sudangrass annual multi-cut hybrids are best suited for green fodder. Young plants of sorghum contain HCN and pearl millet contains oxalates which are anti-nutritional factors. Their concentration gradually reduces as the plant growth advances. Latest cultivars of these crops are tested to be safe to feed, as these constituents are far below the threshold limits to cause any toxicity at the stage of cutting for forage.

In finger millet, under irrigation with proper management, 12–14 tonnes of green fodder per hectare can be obtained in about 50–60 days. When cut 2–3 times during the growing season, it can yield up to 33 tonnes green forage per hectare. Green forage from kodo millet is readily eaten by cattle and is highly digestible up to flowering (70–75% dry matter digestibility).

Bajra-Napier hybrid

Round-the-year supply of green fodder has been made possible in India by developing perennial Bajra-Napier hybrids. Bajra-Napier hybrid, an interspecific cross of bajra (*Pennisetum glaucum*) and napier grass (*Pennisetum purpureum*), is a multi-cut fodder and has become highly popular due to its high yield, nutritive value, digestibility, palatability and survivability (perennial) for longer periods. It is a tall and high tillering grass with more dry matter production per day and high regenerability on cutting. The bajra-napier hybrids combine quick re-growth, non-hairiness, narrow long leaves, thin stems, high leaf-stem ratio, high forage quality, low oxalic acid and high forage yield. It is suited for irrigated conditions, specifically in dairy farming situations. It contains 8–10% of crude protein and 28–30% of crude fibre. It is ideal for feeding as green fodder and making silage and hay. With the increasing demand for green fodder, there was an upsurge in the requirement of bajra-napier hybrid due to its wide acceptability among farmers. Due to absence of seed setting, rooted slips are the sole method of its propagation and about 40,000 rooted slips are required to transplant one hectare area.

Way forward

Since millet stovers are the most important feed resources in the arid and semi-arid regions of India, considerable research effort has gone into improving their nutritional value through crop management and chemical treatment as well as supplementation through high protein oil cakes, and green fodder. However, the on-farm adoption of these technologies has been low due to improper fit of the technology in the farming system, low resource availability and lack of significant and visible economic benefits. The other possibility of improvement in the quality of stover would be to include a legume along with the millet crop itself.

SUMMARY

Stover from millet crops is well suited for feeding the cattle and its quality can be enhanced by treatments. The cost of stover in several millets compensates the cost of inputs in cultivation. Moreover the farmers depend on this by-product to a large extent in maintaining their milch and draught animals. In many instances the farmers are willing to sacrifice grain but not fodder. A short-duration (60–80 days) millet crop can yield up to 15 tonnes of green fodder per hectare of land. This is more appropriate in dryland (rainfed) conditions, including crop rotations systems. Millets as green forage crops assume more importance especially in scarce rainfall years. The small millet grains can also become a good substitutes for other cereal grains in the preparation of concentrate mixture of livestock and poultry, thereby reducing the cost of feed as well.

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Improved varietal technology

for enhanced productivity in sorghum

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Sorghum is a multipurpose crop that can be grown for a variety of uses like food, feed, forage and fuel, and is well adapted to different soil and weather conditions. There is distinct seasonal adaptation of grain sorghum cultivars and commodity-specific cultivars for green forage (rainfed single-cut, irrigated multi-cut), bioethanol production (sweet stalked sorghum) mark the clear-cut separate classes that exemplify the adaptation and diversity in sorghum as a crop. The research efforts over five decades have resulted in the release of more than 80 improved cultivars at the national level and more than 200 at state level with traits of high grain yield, biotic and abiotic resistance, fodder types, and sweet sorghum genotypes etc.

Keywords: Forage sorghum, Grain sorghum, Hybrids, Sweet sorghum, Varieties

SORGHUM is one of the important dryland crops which have been the lifeline of the rural communities in the arid and semi-arid regions of the globe. It is a unique crop of drylands that is the last crop to be standing under moisture stress and the fastest to recover once showers are received, coupled with highest dry matter production potential. In India, it was one of the major cereal staples during 1950s and occupied an area of more than 18 m ha, but the area has come down gradually and during 2020-21 it was recorded to be 7.38 m ha (4.38 m ha under grain sorghum and about an estimated area of 3 m ha under forage sorghum).

Sorghum crop in India is being grown in two main seasons: *kharif* (rainy) season as a rainfed crop while in *rabi* (post-rainy) season under residual soil moisture/limited-irrigated conditions. The requirements for these two seasonal adaptations are quite diverse due to different agro-climatic conditions. *Kharif* crop is exposed to vagaries of weather and highly diverse and adverse environments as this season is characterized by monsoon rains. On the other hand, *rabi* sorghum is essentially grown under receding soil moisture and the crop is generally exposed to terminal drought stress. The Most of the rainy season grain produce is used for industrial and poultry uses, while the majority of *rabi* season production is used for human consumption. In both the seasons, stover forms an important source of animal feed. The overall increase in productivity of *kharif* is far more than *rabi* sorghum. However, the loss both in area and production is greater in *kharif* sorghum than in *rabi*. The coverage with high yielding varieties (HYVs) of sorghum is nearly 80% in *kharif* and their potential under moderate input is also high (4–6 t/ha). The area loss may be due to the fact that the expansion in irrigation which has made other crops such as rice, sugarcane, cotton, etc. more attractive and remunerative thus rendering sorghum to be less competitive. The decline in consumption demand of sorghum grain was also a major factor for the decline in area. The increased productivity of sorghum has not been able to compensate the loss in area turning the production to be negative.

But sorghum is finding a niche area under rice fallows, under the zero tillage conditions where grain productivity as high as 7–8 t/ha. Now it occupies a prime area of more than 45000 hectares and is expanding further, where *kharif* hybrids are prominently grown. In the last two decades, the nature and utilization of sorghum grain has undergone a change from being a staple food to industrial uses such as livestock and poultry feed, potable alcohol, starch and ethanol production. In addition, new value added/processed food products for human consumption are emerging such as popped sorghum, papad, semolina and other ready to cook and ready to eat foods, which, though in nascent stage, are likely to be significant avenues for diversifying utilization of sorghum and thus increasing its demand.

Historical perspective of sorghum improvement in India

Focused sorghum research in India started with the establishment of the Project on Intensification of Regional Research on Cotton, Oil seeds and Millets (PIRRCOM) in 1958. In 1966 the sorghum research was shifted from New Delhi to Hyderabad as a part of IARI Regional Research. Realizing the success of hybrid sorghum in the United States of America in 1962, the Indian Council of Agricultural Research (ICAR) launched the Accelerated Hybrid Sorghum Improvement Project (AICRP-Sorghum) from the existing IARI, RRS in Hyderabad. Subsequently, in 1987 a full-fledged "National Research Centre for Sorghum (NRCS)" was established which has evolved in to Indian Institute of Millets Research (IIMR) in 2015. Currently AICRP-Sorghum functions with a total of 18 centres spread across 9 states. Sorghum improvement efforts since 1960s were focused on improved grain and fodder yields. However, with demand of sorghum as forage crop and in recent years as sweet sorghum, an alternate source of bioethanol; intensive efforts towards these ends have also been initiated. A number of hybrids and open pollinated varieties have been released for cultivation till date, specifically to suit different seasons across India both at the national level by the ICAR and at the state level by State Agricultural Universities (SAUs). The popularity of nationally released sorghum hybrids (CSH 1 to CSH 35), varieties (CSV 1 to CSV 36), forage hybrids (CSH 20MF and CSH 24MF) and sweet sorghums (CSV 19SS, CSV 24SS and CSH 22SS) are a standing testimony of success of Indian sorghum programme not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in incorporation of resistance against major pests and diseases. Some of the prevalent public sector sorghum hybrids/varieties that are adapted to *kharif* include CSH 14, CSH 16, CSH 25, CSH 30, CSH 35, CSV 15, CSV 20, CSV 23, CSV 27, CSV 31 while cultivars that are suitable for *rabi* include CSH 15R, CSH 19R, CSV 14R, CSV 216R, CSV 22R, CSV 26R, CSV 29R and M 35-1 (Table 1).

Kharif grain sorghum

The area under *kharif* sorghum is reduced drastically from 11.5 m ha in triennium ending (TE) 1970 to 5.0 m ha in TE 2000 and now stands at about 2.0 m ha. Despite

Table 1. List of popular and recently released cultivars at national level through public sector breeding efforts

Cultivar	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Plant height (cm)	Maturity (days)	Recommended for
Kharif sorghum hybrids						
CSH 14	1992	38	88	181	102	All *kharif* sorghum growing areas in the medium to heavy soil for low rainfall areas
CSH 16	1997	43	97	180	110	All *kharif* sorghum growing areas
CSH 25	2007	44	127	205	110–115	All *kharif* sorghum growing areas
CSH 30	2013	44	141	216	105	Maharashtra, Karnataka, MP, Gujarat and Andhra Pradesh
CSH 35	2016	41	126	210–215	109	Maharashtra, Karnataka, Madhya Pradesh and Gujarat
CSH 41	2018	47	124	190	106–110	All *kharif* sorghum growing areas
CSH 42	2021	40	117	170–180	98–105	Karnataka, Andhra Pradesh, Madhya Pradesh and Gujarat
CSH 45	2022	44	121	180–190	105	Karnataka, Maharashtra, Rajasthan and Telangana
Kharif sorghum varieties						
CSV 17	2002	25	68	133–140	97	Low rainfall and drought prone *kharif* sorghum growing areas
CSV 20	2006	31	133	240	109	All *kharif* sorghum growing areas
CSV 27	2012	28	193	235	116	All *kharif* sorghum growing areas
CSV 41	2019	32	159		106–110	Andhra Pradesh, Telangana, Tamil Nadu, Rajasthan and Gujarat.
CSV 42	2020	38	140	262	115–118	Karnataka, Maharashtra, Madhya Pradesh and Gujarat
Rabi hybrids						
CSH 15R	1995	32	56	190	110	All *rabi* sorghum growing areas
CSH 39R	2018	27	69	212	115	All *rabi* sorghum growing areas
Rabi varieties						
CSV 26R	2012	13-16	45–60	180–200	112–115	All *rabi* sorghum growing areas- suitable for shallow soil
CSV 29R	2013	25-30	50–75	180–200	115–120	All *rabi* sorghum growing areas- suitable for medium to deep soils

the decrease in the area of cultivation, there has been impressive enhancement of productivity from 560 kg/ha in 1970 TE to 1000 kg/ha in 2000 TE. Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu are the major states where both *kharif* and *rabi* sorghums are cultivated. Sorghum improvement till 1960s focused on selections from local land races, which were tall with low harvest index, photosensitive, late maturing after seize of monsoon and with localized adaptation. With the launching of Accelerated Hybrid Sorghum Project through Rockfeller Foundation a wide range of germplasm was made available in India. This led to significant improvement principally through manipulation of plant height and maturity. Major achievement of Accelerated Hybrid Sorghum Project was the availability of male sterile (MS) lines from the USA and diverse germplasm from Africa and South East Asia. With the release of CSH 1, the first commercial hybrid in 1964, sorghum became the second crop after maize in developing high yielding hybrids using cytoplasmic-genetic male sterility system and variety CSH 1 gained much popularity among farmers.

The increase in productivity is due to introduction of short-duration dwarf high yielding hybrids which are especially well adopted in the state of Maharashtra. The hybrids played a key role in pushing up productivity and production in *kharif* sorghum. Among the hybrids, the role played by CSH 1, CSH 5, CSH 6, CSH 9, CSH 14 and CSH 16 needs a special mention. While CSH 5 and CSH 6 had a yield potential of 3400 kg/ha, this was raised to 4000 kg/ha in CSH 9. It is now further advanced to more than 4100 kg/ha in CSH 16, CSH 25, CSH 35 and CSH 41 with distinctly superior quality grain and fodder yield. High yielding varieties, CSV 1 to CSV 41 at central level and many more at state level were released. Though there was impressive growth in terms of availability of highly productive cultivars, the area and production have drastically gone down because of lack of demand for the grain.

Opportunities for* kharif *sorghum: The utilization of *kharif* sorghum grain as a raw material in various industries is increasing, given the limited prospects of *kharif* sorghum for human consumption. The major thrust is to create demand of *kharif* grain for the nonfood sector,

CSH 41-Medium maturing hybrid

CSH 30-Early maturing hybrid

CSV 41-Dual purpose variety

CSV 27-Dual purpose variety

particularly for feed, biofuel, starch and beverage industries. Molded *kharif* grain, which fetches lower market value, is a cheap raw material for production of potable or industrial alcohol. Sorghum is the second-best grain after barley for malting. The main industries currently using sorghum in India are the poultry feed (2.0 milliom tonnes (MT) annually), animal feed (0.60 MT) and alcohol distilleries (about 0.49 MT). Sorghum is used when maize is in short supply and priced up to 20% higher than sorghum. The emerging role of *kharif* grain as feed in the domestic and international circuits is a viable opportunity that needs to be harnessed. The genetic potential of this crop to provide cultivars with good malting quality, competitive starch production and useful source of beta glucan may also receive higher recognition. There is hardly any other single dryland cereal crop which is endowed with so many desirable traits and untapped utilities. Industrial linkages for expansion, marketing and commercialization by brand promotion of sorghum products will secure a stable and profitable market for sorghum.

Major constraints for kharif *sorghum production*

- Decline in area of cultivation due to reduced demand for food.
- Development of high yielding cultivars with early maturity resulted in coincidence of grain development and maturity with late rains during certain years resulting in poor quality molded grains.
- *Kharif* grain is not as remunerative as that of *rabi* because the seed is not round and lustrous.

***Research and development strategies to overcome the major constraints*:** For *kharif*, high productivity, grain mold resistance and possibly mechanical combine harvest may minimize losses and keep sorghum competitive. Hybrids with additional traits and suitable crop canopy are now required to overcome the production problems. ICAR-Indian Institute of Millets Research (IIMR) is targeting to develop a cafeteria of cultivars to choose for different situations and specific uses.

Intercropping systems and improving cropping intensity: Climate change issues in terms of fluctuating monsoonal rains both in quantum and distribution calls for risk mitigating approaches through intercropping systems that help optimize sorghum production. Combining photosensitive pigeon pea with improved and early maturing sorghum hybrids had been successful across Maharashtra and Karnataka. Development of erect leaved sorghum hybrids with greater yield potential will help decrease the competition among intercrops and thus improve the overall productivity of the systems. Combining cereal–pulse intercropping also helps addressing the sustainability and soil health issues in the long term.

Summer cultivation of sorghum: Due to dry summer weather, grains are highly priced owing to clean and superior grain quality and have tremendous scope for export purposes. Summer sorghum caters the needs of fodder during peak shortages. Strategies to optimize genotype performance by nutrient interactions can also help stabilize the yield potential in summer. Individual State Governments across the southern states of Maharashtra, Karnataka and Telangana have been promoting various irrigation projects to expand the irrigated area thus facilitating the local farmers. Expansion of irrigated tracts will help promote food crops that have greater potential in terms of productivity especially during summer season.

Red sorghum for feed and export: Specialized red *kharif* sorghum cultivars for grain export to international market are another emerging opportunity. In order to meet the feed demand in high rainfall regions, red grain sorghum is targeted as potential raw material for poultry which imparts rich yellowness to yolk of egg. These are more tolerant to grain molds and breeding programmes are targeting development of red grain sorghum cultivars with early maturity, combining tolerance to grain molds and major pests in high yield background.

Rabi sorghum

Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu are the major states where *rabi* sorghum is extensively cultivated. Over the years, *rabi* sorghum area has remained stable as it is cultivated as dual-purpose crop, for grain and fodder purposes. Moisture stress in growth stage 2 (GS2) due to unique situation of growing the crop on receding soil moisture in medium to shallow soils, susceptibility to shoot fly, charcoal rot, and low temperature affecting crop growth as well as fertility restoration in hybrids are the major factors responsible for low yield.

Major constraints for rabi *sorghum production*

- Non-availability of quality seed of recent releases is one the biggest problem in *rabi* sorghum. The seed supply chain needs to be strengthened for the availability of quality seed at the start of planting window for *rabi* sorghum.
- Terminal Moisture stress coupled with charcoal rot disease and lodging limits the crop potential. Terminal drought is one of the major production constraints limits the use of purchased inputs like hybrid seeds and fertilizers. Therefore, research on drought tolerance involving development of early maturing *rabi* sorghum varieties and incorporation of stay-green and other drought QTL/genes needs to be taken up.
- Non-adoption of recommended package of practices (plant population, disease and pest management) by the farmer.
- Lack of Hybrids: Another important issue is the lack of substantial heterosis in *rabi* hybrids as land races (which are low community performers) are used (mainly to maintain the consumer preferred grain size and luster) in the development of both A/R parents. Restoration under cold (<12^{o}C) is another important requirement in hybrids as most hybrids are susceptible to cold at anthesis.

Achievements through genetic enhancement

- Grain yield: Recent releases like CSV 29R (Deep and medium soils), CSV 26R (shallow soils) perform better over M35-1 for both grain yield and fodder yield. A major hurdle is that they need to be effectively brought into seed production chain to replace M35-1. Many varieties at state level are available, which are superior to M35-1 for their grain and fodder yield and also for roti quality. Breeding diversified A and R lines involving exotic durra and other sorghum races can be of much help in developing heterotic hybrids adapted to *rabi* season. CSH39 has been recently released with diversified parents with *rabi* adaptive traits.
- Insect/disease tolerance: *Rabi* sorghum genotypes show better shoot fly tolerance compared to *kharif* sorghum genotypes. Charcoal rot is the major disease that comes along with terminal drought. Varieties, DSV4 and DSV5 have been released from the Dharwad centre as charcoal rot resistant
- Terminal drought: RSLG262 (Phule Maulee), CSV-26R, Phule Chitra are some important lines developed for terminal drought tolerance.
- Grain quality: In *rabi* sorghum always the breeding efforts revolved around grain quality in terms of physical appearance and *roti* making qualities. Among recently released varieties, CSV22, CSV29R, CSV26R, Phule Vasudha, Phule Chitra, Parbhani Moti, Parbhani Super Moti, PKV Kranti have very good *roti* making qualities besides being high yielders. *Roti* quality sorghum is also used for other purposes like RSSGV 46 (hurda purpose), RPASV 3 (papad making), SMJ 1, RSJ 1, PKV Ashwini (hurda purpose), AKJ 1 (flaking purpose), Phule Panchami, KMJ 1 (popping purpose) etc.

Strategies to address the major constraints

- Diversification of CMS base and R lines for increased heterosis through use of genetic diversification involving multi-parent (MAGIC) crosses, diverse germplasm lines (durra race genes from Yemen, Cameroon, Ethiopia) are required.
- Breed for dwarf CMS (100–120 cm) and medium tall restorers (150 cm): Bringing major dwarfing genes and earliness using proper donors into A/B and R lines for making hybrids less lodging, easy harvesting and amenable crop mechanical harvesting. The change in plant architecture is expected to increase heterosis levels in hybrids
- *Rabi* adapted and high input responsive hybrids for irrigated conditions: In recent times, with the availability of irrigation water in command areas, there is growing interest in cultivation of *rabi* sorghum. Hybrids which are responsive to high inputs need to be developed for these niche areas on a mission mode approach.
- Incorporate stay-green trait in varieties and parents of hybrids (CMS and restorers): Among biotic stresses drought is the main production constraint in *rabi* sorghum. Though sorghum has drought tolerance, post-flowering drought causes extensive yield losses to the crop. Major QTLs contributing towards stay green trait has been identified and are being attempted to be transferred to superior cultivars. Crossing between high yielding adapted lines and screening under stress situation has yielded release of several *rabi* adapted cultivars both at state and central level. Marker assisted breeding has been followed to incorporate two key stay-green QTL (stg3a and stg3b) into *rabi* genotypes. Preliminary analysis of trials conducted at Hyderabad, Solapur and Vijayapura, indicated significant improvement in water extraction ability and Transpiration efficiency of MAS products compared to the recurrent parents. Incorporation of QTLs also improved grain and fodder yield over recurrent parents. The results are encouraging to transfer the QTL into other recent releases like CSV29R, CSV26R and in M35-1.

CSV29R-*Rabi* sorghum variety in farmers' field

CSH39R-*Rabi* sorghum hybrid

Forage sorghum

Forage sorghum is cultivated in about 2.6 to 3.0 million ha area in India each year. They are principally cultivated in Punjab, Haryana, Delhi, western and central Uttar Pradesh, northern Madhya Pradesh, Parts of Telangana, Andhra Pradesh and Karnataka. In these states, it is grown during *kharif* and summer seasons, either as single-cut (mostly in *kharif*, as rainfed) or as a multi-cut (summer and *kharif*) forage crop. Intensive cropping, short growing season, poor growth of perennial grasses during winter, nutritional quality and the need for continuous supply of green fodder created demand for forage sorghum in northern India.

The genus *Sorghum* includes two economically important species *bicolor* (large grained type) and *sudanense* (sudan grass, smaller red to black coloured grains), among others. While *bicolor* is used for food, feed and forage in India, the other is specifically for forage purpose. The major objectives in forage sorghum breeding are to develop varieties both for single cut and multi-cut with high tonnage, better quality, good seed yield and resistance to insect pests and diseases.

In India, concerted breeding efforts for the improvement of forage sorghum were initiated in 1970 under the All India Coordinated Sorghum Improvement Project (AICSIP) and subsequently many improved single-cut and multi-cut varieties and hybrids were developed. In 1990s, development of multi-cut sorghum varieties and hybrids received lot of emphasis in India. Sorghum × sorghum cross-derived single-cut varieties were bred during 1980s and 90s for high fodder yield, better quality and wide adaptability. At this juncture, private sector also came forward to join the efforts. In addition to high green and dry fodder yields and wide adaptability, newer varieties also possessed relatively higher seed production potential (compared to sudangrass and derivatives), resistance to foliar diseases and better quality fodder.

After the 90s, several cultivars have been developed and notified in single-cut forage in public sector whereas multi-cut forage hybrids were developed by private sector. The latest varieties also exhibited higher per day productivity, dry matter digestibility and total soluble sugars with comparable protein content. The release of latest multi-cut variety CSV 33 MF, a mutant derived from Co(FS)-29, which has forage yield potential of more than 100 t/ha from 3 cuts, is also amenable for up to 7–8 cuts in favourable conditions. The hybrids and varieties released after 2000 have also been improved for forage quality besides forage yield per se. Those entries with HCN toxicity potential above threshold are rejected in the initial multi-location trial onwards. Crude protein content as well as digestibility of forage is incorporated in the variety promotion criteria.

The present nationally released bench marks for forage sorghum are CSV 35F variety and CSH40F hybrid for single-cut, CSV 33MF variety and CSH 43MF hybrid for multi-cut (Table 2). Indian institute of Millets Research along with AICRP (Sorghum) centres has been constantly addressing the challenges in forage sorghum improvement since its beginning. Facilitating germplasm procurement, distribution and utilization, diversification of genetic base, laying down stringent standards of forage quality and resistance to stresses and collaborating with animal scientists have been the major milestones in augmenting the forage sorghum productivity in the country. Recognizing the major role played by private sector in catering to the huge demand for forage sorghum, licensing and IPR sharing with private entrepreneurs (hybrids CSH 20MF, CSH 24MF CSH 43MF) has promoted the synergy which has helped the public hybrids to reach the forage sorghum farmers at an accelerated pace.

Advantages of new forage sorghum cultivars

- The improved cultivars have higher digestibility indicating more milk and meat production in livestock. It is estimated that for every 1% increase in digestibility, there is 2–3% increase in milk yield.
- These cultivars are more tolerant to stem borer and lodging, thereby minimize losses compared to earlier cultivars. Tan-coloured cultivars are resistant to foliar diseases, do away with hazardous chemical control.
- These have been tested for cyanogen (HCN inducing) safety under recommended cultivation conditions and found highly safe.

Future strategies in forage sorghum: Forage sorghum improvement programmes are beset with lack of information on variability and useful genetic stocks for various traits. Therefore, concerted and planned efforts are needed to collect, evaluate, catalog and maintain germplasm exclusively for forage sorghum. To get a regular supply of green fodder for a longer period of time, multi-cut varieties having profuse tillering, quick regeneration, faster growth and capability of giving a minimum of 4–5 cuttings should be developed. The high yield and multi-cut potential of sudangrass should be further exploited in breeding programme to develop highly adapted and high yielding stable multi-cut variety of forage sorghum. Further advances in forage sorghum improvement should pay attention to stability in production of biomass and nutrient content through resistance breeding.

Sweet sorghum

Energy sorghum, which includes Sweet sorghum (1G feedstock) and biomass sorghum (2G feedstock) has recently gained favour as bioethanol feedstock amongst numerous candidate crops. Sweet sorghum is a short duration crop of about 4 months, which produces higher biomass yield with less input. India has achieved 10% blending of petrol with ethanol recently and the next target is 20% blending by 2025. The fact remains that ethanol production from sugarcane molasses alone does not ensure optimum supply levels needed to meet the demand at any given time. Sorghum as a dryland crop offers a sustainable solution to this problem as it can be grown for feed, fodder, fuel and fibre. One of the obstacles to this crop's expansion as a biofuel feedstock is the fact that sugarcane has established dominance over the production chain of sugar and ethanol, receiving the majority of the investments.

Status of sweet sorghum research

- ICAR-Indian Institute of Millets Research along with its partnering institutions under National Agricultural Research and Educational System and

Table 2. List of popular and recently released forage sorghum cultivars at national level through public sector breeding, efforts

Cultivar	Year of release	Single-cut/ multi-cut	Green fodder yield (q/ha)	Dry fodder yield (q/ha)	Area of adaptation
MP Chari	1978	Single-cut	300	95	All sorghum growing areas of the country particularly central and northern states
Sweet sudan grass S9-3	1978	Multi-cut	570	138	All forage sorghum grown areas
HC-171	1987	Single-cut	500	160	All India
Punjab Sudex Chari 1	1994	Single-cut	218	118	All forage sorghum growing areas in Punjab under irrigated conditions.
HC-308	1996	Single-cut	530	175	All India
Pusa Chari-615	2006	Multi-cut	700	195	NCR Delhi
CSH 24MF	2009	Multi-cut	786	192	All forage sorghum growing areas of India
Pratap Chari 1080	2010	Single-cut	375	130	Rajasthan forage sorghum growing regions with loam to light soils and moderate to low rainfall
CSV 32 F	2015	Single-cut	478	156	Maharashtra, Karnataka and Tamil Nadu
Punjab Sudax Chari 4	2016	Multi-cut	1113	237	Punjab
Fodder Sorghum CO 31	2018	Multi-cut	1920/ year	-	Tamil Nadu
CSV 21F	2016	Single-cut	378	113	Gujarat
CSV 33 MF	2017	Multi-cut	1039	280	All forage sorghum growing areas of India
CSV 35F	2018	Single-cut	529	145	Delhi, Gujarat, Rajasthan, Uttarakhand, Haryana, Uttar Pradesh, Punjab, Maharashtra, Tamil Nadu, Karnataka and Madhya Pradesh
CSH 40F	2018	Single-cut	560	155	Delhi, Gujarat, Rajasthan, Uttarakhand, Haryana, Uttar Pradesh, Punjab, Maharashtra, Tamil Nadu, Karnataka and Madhya Pradesh
CSV 38F	2019	Single-cut	465	145	Maharashtra, Tamil Nadu and Karnataka
CSH 43MF	2021	Multi-cut	965	219	Haryana, Punjab, Uttar Pradesh, Rajasthan, Gujarat, Uttarakhand, Maharashtra, Tamilnadu, Telangana and Karnataka
CSV 40F	2019	Single-cut	465	150	Maharashtra, Tamil Nadu and Karnataka
CSV 47F	2021	Single-cut	430	122	Maharashtra, Tamil Nadu an Karnataka
CSV 46F	2021	Single-cut	596	163	Gujarat, Rajasthan, Haryana, Punjab, Uttar Pradesh and Uttarakhand

ICRISAT have evolved sweet sorghum varieties, viz. SSV 84, CSV 19SS, CSV 24SS, CSV 49SS (Jaicar Raseela) and hybrids, viz. CSH 22SS, RVICH 28 and Phule vasundhara which can be utilized for 1st generation biofuel production i.e., sugar based biofuel production.

- Most of these genotypes have been tested for biofuel production in various sugar mills of different states and the realized ethanol yields ranged from 40–50 litre/tonnes of cane crushed. These genotypes also offer promise as single-cut forages with high forage quality.
- Earlier techno-economic feasibility studies have indicated the cost of ethanol production from sweet sorghum to be cheaper than that of sugarcane molasses by ₹1.87/- and the current lucrative ethanol procurement prices for juice based ethanol offer a win-win situation for both the farmer and industry.
- The apprehension of sugarmills that sweet sorghum needs separate machinery for crushing was cleared through successful demonstrations of sweet sorghum crushing with the existing sugarcane machinery.
- Sweet sorghum juice was directly fermented and mixed with molasses for ethanol production in the distilleries. A combination of 40:60 (Sweet sorghum juice+molasses) yielded the highest alcohol yield in one of the study and this would reduce the water requirement and processing costs of ethanol production
- This paves way for utilizing sweet sorghum during the off-season of sugarcane crushing thereby extending the mill operations.

Major constraints for sweet sorghum production

- Lack of policy support, as there is no clear cut road map for commercialization of sweet sorghum though the crop has been listed in the National Policy on Biofuels.
- Lack of awareness among sugar industries about sweet sorghum and its utility for biofuel production.
- Non-offering of competitive price for sweet sorghum cane to the farmers by the industry.
- Lack of varieties/hybrids adapted to different growth conditions resisting both biotic and abiotic stresses, including colder climate.
- Narrow harvesting window for sweet sorghum affecting offseason crushing in sugar industries.
- Lack of mechanization.

CSV 49SS (Jaicar Raseela)

Phule vasundhara

Lorries carrying sweet sorghum awaiting their turn for unloading at Shree Ganesh Khand Udyog Sahkari Mandli Limited, Bharuch, Gujarat for big mill test

Strategies for sweet sorghum commercialization

- Commercialization of sweet sorghum cultivation is possible if the required policy support in the form of incentives from Government for both producer and processor are extended.
- Genetic enhancement of cultivars for high sugar, cane yields and resistance to important biotic and abiotic stresses.
- Development of genotypes with different maturity durations and higher ratoon ability for widening the harvest window.
- Development and optimization of sweet sorghum crop management and IPM practices for higher productivity of sweet sorghum feedstock.
- Mechanization of sweet sorghum cultivation and processing.
- The large-scale crop cultivation is recommended under contract farming with buy-back arrangement between growers and agro-industry or entrepreneurs' as similar to existing sugarcane industry.
- Greater investment in research in sweet stalk and high biomass sorghums from Govt. of India is needed to achieve the goal of enhancing biofuel production to support the government policy of reducing the oil imports.

SUMMARY

Sorghum has to face stiff competition by other cereals under better soils and rainfall where cash crops have replaced sorghum during *kharif*. However, the fact that sorghum being a C4 plant is a high biomass producer and relatively tolerant to several stress factors. This makes it difficult to be replaced in least endowed areas, especially in the climate change scenario. The major thrust, in future, will be on enhancing area of sorghum in non-traditional areas and greater emphasis on alternate uses of sorghum and its utilization as a major food, feed, fodder and fuel (bio-energy) for industrial utilization. Simultaneously, researchers are pursuing other avenues such as growing sorghum as a biofuel crop for which significant work has been done, in addition to promotion of sorghum as functional health food.

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ICAR New Portals

The Council has created the following portals for effective governance by utilizing the information and communication technology.

ICAR Data Centre and Unified Communication portals to secure institute information and information transmission.

- ICAR-Enterprise resource planning (ERP) System to this manage the human resource in information of the council including pay roll, finance and budgeting.
- KVK Knowledge Network Portal (http://kvk.icar.gov.in) to share basic information and facilities of KVKs with contingency plans, demonstration schedule, and advisories.
- Management System for Post-Graduate Education (MSPGE) enabling academic and e-learning modules while also being a repository of academic records
- E-*Samvad,* an online interface of the Council to answer citizens queries.
- KRISHI –A knowledge repository portal of digital information pertaining to research experiments, outputs, publications, etc.
- E-*Krishi Manch*, a dedicated portal for farmer-scientist interaction.

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INTERNATIONAL YEAR OF MILLETS 2023

Enhancing productivity

and nutrition with biofortified pearl millet cultivars

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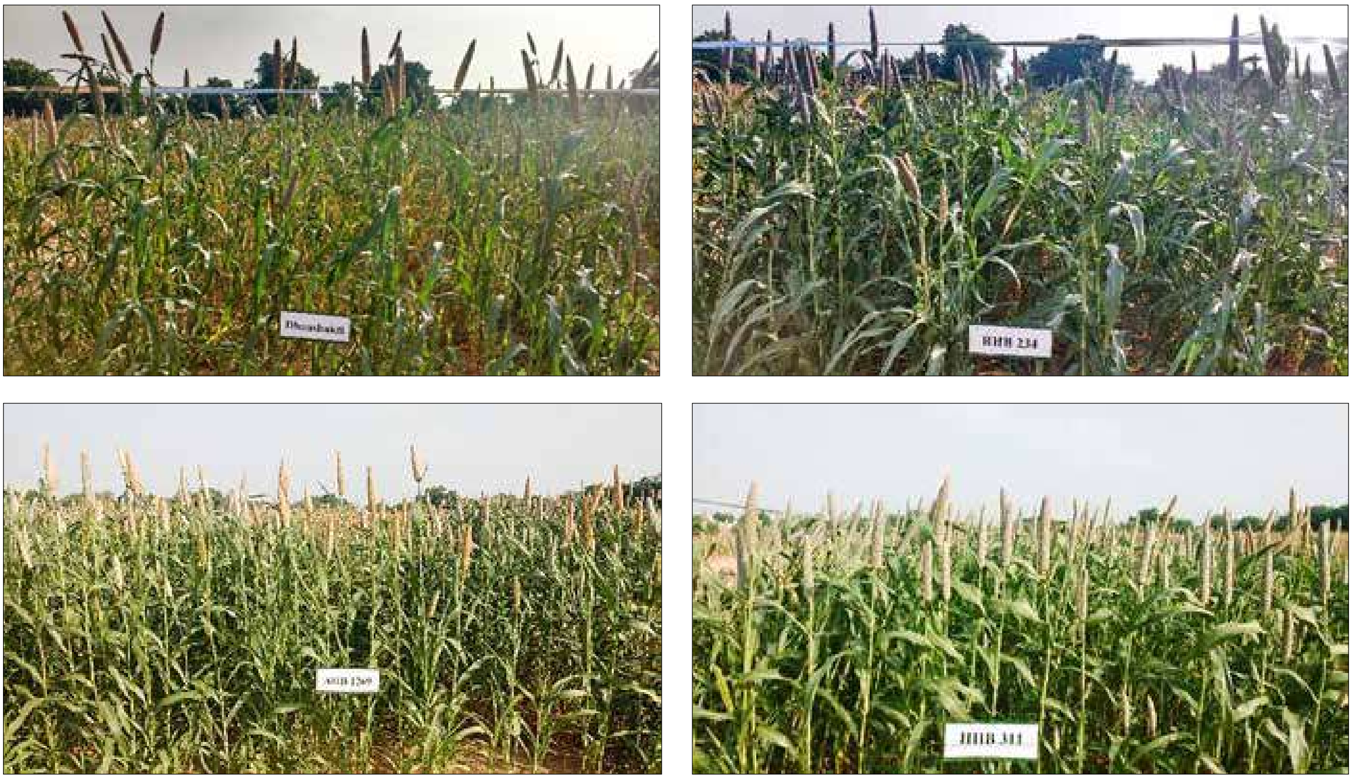
Food, economic and nutritional securities are equally important to the resource poor farmers relying on pearl millet in marginal environments. Bio-fortified cultivars of pearl millet with higher iron (Fe) and zinc (Zn) content in the grain along with high grain yield are supposed to be the best solution in this context. With the concerted efforts of Indian Council of Agricultural Research (ICAR), Harvest Plus, ICRISAT and State Agricultural Universities, biofortified varieties and hybrids are available in pearl millet. The world first high-Fe pearl millet variety 'Dhanashakti' released in 2014 has 71 mg/kg Fe and 2.2 t/ha grain yield. The first set of biofortified hybrids (AHB 1200 Fe and HHB 299) released in 2018 had 73–77 mg/kg Fe, 39–41 mg/kg Zn with more than 3 t/ha of grain yield. With similar levels of grain yield, the second set of hybrids (RHB 233, RHB 234, AHB 1269, HHB 311) released in 2019–20 had 83–91 mg/kg Fe and 39–46 mg/kg Zn.

Keywords: Biofortification, Grain yield, Hybrids, Nutrition, Pearl millet

MALNUTRITION due to micronutrient deficiency, especially with iron (Fe), zinc (Zn), vitamin A and iodine (I) is prevalent among the poor of southeast Asia and Africa, where, pearl millet [*Pennisetum glaucum* (L.) R. Br.] is grown in the harshest environmental conditions. Being a climate resilient crop, it is grown under adverse climatic conditions in the arid and semi-arid regions enduring high heat, marginal soils, poor inputs and drought besides being resilient to most biotic stresses. Pearl millet is the most widely cultivated staple food crop after rice, wheat and maize in India playing a vital role of addressing food and nutritional security in regions where other cereal crops can not be successfully grown. It is mostly consumed in the western Rajasthan and parts of Gujarat, where it is more than 50% of the total cereal consumption besides being consumed in other parts of Gujarat, Rajasthan, Maharashtra and Haryana.

Nutritional value of pearl millet

Pearl millet releases more energy (361 Kcal/100 g) on consumption as compared to rice (345 Kcal/100 g) and wheat (346 Kcal/100 g). The carbohydrate content of the grain amounts up to 62%. Pearl millet contains about 11.6% protein that is higher than rice, maize, sorghum and barley, and comparable to wheat. It has better essential amino acid composition and is a good source of the sulphur containing amino acid, methionine. Due to its high total dietary fibre (11.2 g/100 g) and slow digestion, it is beneficial to non-insulin diabetic patients. It is a decent source of fat (5–7%) and fat-soluble vitamin E (0.2 mg/100 g). Regarding the fatty acid composition, pearl millet is a source of linolenic acid, the n-3 essential fatty acid that accounts for about 4% of the total fatty acids, compared to 0.9% in maize. The n-3 fatty acids play an important role in physiological functions like platelet aggregation, triglyceride reduction and better immune system. The grain is also a good source of vitamin A and B-vitamins, viz. thiamine, niacin and riboflavin. It is rich in minerals such as calcium (Ca), potassium (K), magnesium (Mg), manganese (Mn), Zn, Fe, and copper (Cu) as compared to corn with higher levels of phosphorus (P), being important for bone mineral matrix and adenosine triphosphate which is the energy booster in the body. Pearl millet is also rich in phytochemicals including phenolic acids; the ferulic and *p*-coumaric acids found in whole pearl millet, have several health beneficial properties including the ability to suppress the proliferation of certain type of tumour cells. Being gluten free, they are boon for patients with celiac disease. It is enriched with nutrients to mitigate malnutrition and hidden hunger and hence rightly designated as *nutri-cereal* (gazette of India, No. 133 dated 13 April 2018). Efficacy studies provide evidence that the



Biofortified variety (Dhanashakti) and hybrids (RHB 234, AHB 1269, HHB 311) of pearl millet

consumption of grains from biofortified varieties would provide bioavailable Fe to meet a fully recommended daily allowance (RDA) in children, adult men and 80% of the RDA in women.

Biofortification prioritization in breeding

However, the commercially released cultivars have low levels of Fe and Zn, though they have been improved for yield significantly over the landraces. Hence concerted efforts were made to breed for high Fe and Zn cultivars with good yield levels to address the food and nutrient needs of the resource poor population, since the entire breeding efforts of the public and private sector were geared towards hybrid development for higher grain yield owing to the availability of the cytoplasmic male-sterility system. The ICAR has endorsed the inclusion of the minimum levels of Fe and Zn that have to be bred into future varieties of pearl millet across the country. The All-India Coordinated Research Project on Pearl Millet decided on a minimum of 42 mg/kg of Fe and 32 mg/kg of Zn content. It is expected that the farmers may prefer cultivation of biofortified hybrids due to high nutrition in addition to higher grain and stover yields.

Biofortified varieties

Initially, the world first high-Fe pearl millet variety 'Dhanashakti' was developed by utilizing the intra-population variability within ICTP 8203, which is an early-maturing, large-seeded, disease resistant and high-yielding open-pollinated variety that has been under cultivation in India since 1990. Dhanashakti is officially released and notified by Central Variety Releasing Committee in 2014 for the cultivation in all pearl millet growing states of India. Based on national testing trials, Dhanashakti had 71 mg/kg Fe (9% higher) and 2.2 t/ha grain yield (11% higher) compared to the original ICTP 8203. Hybrids of pearl millet with higher grain yield and high levels of Fe (>70–75 mg/kg) and Zn (>35–40 mg/kg) densities have been developed and released in India. Currently, India is growing >70,000 ha of biofortified pearl millet.

Biofortified hybrids

The first set of biofortified hybrids was AHB 1200 Fe and HHB 299, officially released at national level for A and B zones in collaboration with the agricultural universities of Maharashtra (VNMKV) and Haryana (CCSHAU) during 2018. These biofortified hybrids contained 73–77 mg/kg Fe and 39–41 mg/kg Zn. They are medium maturing having more than 3 t/ha of grain yield and 7 t/ha of fodder yield (Table 1). Apart from this, 'Phule Mahashakthi' was released for the state of Maharashtra.

The second set of hybrids was officially released at national level during 2019–20. The RHB 233, RHB 234, AHB 1269, HHB 311 were released in collaboration with agricultural universities of Rajasthan (SKNAU), Maharashtra (VNMKV) and Haryana (CCSHAU). These biofortified hybrids contained 83–91 mg/kg Fe and 39–46 mg/kg Zn. They are medium maturing having more than 3 t/ha of grain yield and 7 t/ha of fodder yield (Table 1).

In the current era, improving nutrition in staple crops through genetic biofortification needs focus as self-sufficiency in food quantity is attained. There is a need for premium price for biofortified grains and products in the market. This will enhance market opportunities for farmers and ascertain nutritional security in the

Table 1. Salient features of biofortified released pearl millet hybrids

Hybrid	Year	Bred at	Recommended area	Fe (ppm)	Zn (ppm)	Grain yield (kg/ha)	Fodder yield (q/ha)	Salient feature
HHB 311	2020	CCS HAU, Hisar	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra and Tamil Nadu	83	39	3173	72	Medium maturing, compact, conical ear heads, grey, hexagonal grains, resistant to major diseases and pest
AHB 1269Fe	2019	NARP, Aurangabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra and Tamil Nadu	91	43	3169	71	Medium maturing, resistant to downy mildew
RHB 234	2019	AICRP on PM, SKNAU, Jaipur	Rajasthan, Haryana, Gujarat, Punjab, Delhi, Maharashtra, and Tamil Nadu	84	41	3168	74	Medium maturing, greyish seed, resistant to major diseases and insect pest
RHB 233	2019	AICRP on PM, SKNAU, Jaipur	Rajasthan, Haryana, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu	83	46	3157	74	Medium maturing, greyish seed, resistant to major diseases and insect pest
HHB 299	2018	CCS HAU, Jodhpur	Rajasthan, Haryana, Gujarat, Punjab, Delhi Maharashtra and Tamil Nadu	73	41	3274	73	Medium maturing, compact panicle, greyish hexagonal shape grains, resistant to major diseases and insect pests
AHB 1200 Fe	2018	NARP, Aurangabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra, Telangana, Andhra Pradesh and Tamil Nadu	77	39	3170	70	Medium maturing, long cylindrical panicle, resistant to downy mildew, resistant to stem borer, highly responsive to fertilizers

future. Biofortified cultivars being developed through conventional breeding do not face the possible challenge of food regulations and consumer acceptance and can be easily marketed.

SUMMARY

Combining the yield and micronutrients in pearl millet hybrids has been successful with the collaboration of national and international breeding programmes. As a result, 6 biofortified hybrids has been released at national level since 2018 with comparable grain and fodder yields to commercially grown hybrids. Apart from this, one widely adapted variety, ICTP 8203 is available to the farming community. These biofortified cultivars have comparable yields to commercially grown hybrids and need to be widely cultivated for bringing nutritional security in the marginal areas, where the crop is the sole option of living to the farmers.

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Drought-tolerant rice Swarna Sukha Dhan for rainfed upland ecology of Uttar Pradesh

A drought- tolerant rice variety Swarna Sukha Dhan (RCPR 16, IET 24692) was notified and released for cultivation under drought prone rainfed upland ecology in Uttar Pradesh. RCPR-16 (IET 24692) has recorded yield advantage of 11.48 and 19.63% over NDR 97 (best check) and Shusk Samrat (local check) respectively. Swarna Sukha Dhan is a short duration (110–115 days), high-yielding (3.5–4.0 tonnes/ha), and multiple-stresses (drought, diseases and insect pest) tolerant with desirable cooking quality traits. Quality wise IET 24692 showed high hulling (78.4%), milling recovery (70.9%), head-rice recovery (68.4%), medium slender grain type with intermediate amylose content (22.32%) and alkali spreading value (ASV=4.0). It has GC content (49 mm) with very occasionally chalky and medium slender grains indicating good cooking quality.

Source : ICAR Annual Report 2021-22

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Pearl millet:

A befitting crop for the changing climate

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As per reports, global climate change might cause an increase in temperature up to 6°C by the end of 21st century which is feared to directly affect productivity of crop plants and food supply all over the world. The damage is more when temperature increase is in combination with various other kinds of biotic and abiotic stress factors. Crops that perform better under adverse and less favourable environmental conditions are the way out and pearl millet is a crop that fits in perfectly. It is a nutrient rich and climate resilient crop that can ensure increased income as well as food and nutritional security to the farming populations in arid and semi-arid regions of the globe.

Keywords: Climate resilience, Drought, Heat stress, Salinity

SCIENTIFIC predictions are realised and the globe is witnessing climatic variations characterised by an increasing temperature, extreme variations in rainfall patterns, frequent droughts and diurnal temperature variations. Global climate change is expected to increase the temperature in the range of 1.5 to 5.8°C by the end of 2100 and crop yields are predicted to decrease approximately 10% for every one-degree increase in temperature. Reduction in crop productivity affects world food supply and when combined with other biotic and abiotic stress factors, the damage is cureless. Already almost 90% of the cultivable land area is affected by various abiotic stresses, globally. Millets, in general and pearl millet which is one of the leading millet crops, efficiently withstand high temperature stress and reduced water availability during their life cycle as compared to other crops.

Pearl millet, also known as bajra in India, is the sixth most important global cereal, primarily grown as a rainfed crop in the arid and semi-arid zones of India accounting for 80% of area in Asia. India has 7 million ha area under pearl millet cultivation with a production of 8.6 million tonnes. Africa has 55% of world area under pearl millet to which the 7 countries (Niger, Nigeria, Mali, Burkina Faso, Senegal, Chad and Sudan) account for more than 80%. Pearl millet is a multipurpose cereal grown for grain, stover and green fodder. Its nutrient content is equivalent or even superior to those of other cereals with a good content of protein (11%), carbohydrate (72%), fats (4–6%), vitamins and minerals particularly iron and zinc and diverse health promoting phenolic compounds. Though millet grains are on the leaner side as far as fats are concerned, bajra is an exemption with 4–6% fat content. It is not surprising why this grain is cherished as a major energy source in the arid western states of India. A high content of fibre, the most proclaimed nutritional component in millets, is available in pearl millet making it comparable to that of whole wheat atta or even oats. Iron which is the most vital mineral for a healthy and productive population is abundant in bajra and significantly higher than rice. The NIN (ICMR) survey report on the dietary iron intake of Indian states puts Gujarat on top which is not just a co-incidence considering bajra being the major staple of the state. The crop is also an important source of green fodder and stover for the cattle and is a raw material for bio-fuel production.

MPMH 21, hybrid variety of pearl millet. Released in 2016; Grain yield, 2.5 t/ha; Dry fodder yield, 4.8 t/ha; Maturity, 75 days; Resistant to downy mildew and blast; Tolerant to drought; Responsive to fertilizer application.

RHB 223, hybrid variety of pearl millet. Released in 2018; Grain yield, 2.7 t/ha; Dry fodder yield, 7.5 t/ha; Maturity, 77 days; Resistant to downy mildew; Tolerant to drought.

Climate resilience and cultivar suitability

Bajra is regarded as a climate-resilient crop looking at its adaptability to a wide range of ecological conditions such as high temperature, low moisture levels and poor soil fertility. This crop can perform well with very low annual rainfall in the range of 200–500 mm and at elevated temperatures above 30°C. It is among the hardiest of all crops and is grown in places which are too hot and dry for most other crops to fit in. Hence, it is looked at as one of the most significant crops in the scenario of food security and changing climate conditions. Temperature is one of the key climatic factors having profound effect on the growth and development of this crop. The soil temperatures in farmers' field in India and Africa commonly exceed 45°C and the temperatures rise as high as 60°C occasionally. In India, about 25% of the pearl millet area falls in the arid zone designated as A_1 zone which comprises of parts of Rajasthan, Gujarat and Haryana receiving less than 400 mm annual rainfall. This region experiences extended dry spells, drought, heat waves and soil temperatures in farmers' fields are reported to exceed 45°C often. The cultivars suitable for cultivation in the arid zone should have early maturity (75 days of crop cycle), high tillering, good grain as well as fodder yields. Several hybrids are available for cultivation in the arid conditions, however, under extremely arid situations and where the land is poor, farmers prefer traditional landraces that have better quality over improved cultivars and use them for consumption. The OPV CZP 9802 is the outcome of landrace-based breeding and responds well to drought as well as favourable conditions. Pearl millet is also resilient to reproductive stage heat stress. The spectacular ability of this crop to endure high temperatures up to 42°C even during reproductive phase also makes it suitable as a summer crop in northern Gujarat, eastern Uttar Pradesh and parts of Rajasthan. The hybrids such as GHB 526, GHB 183, GHB 558 are suitable for summer grown conditions.

Resilience of pearl millet to low moisture and poor soil fertility

Pearl millet has a deep root system which helps it to tolerate water scarcity. It wades through drought by enhancing its root length and maintaining high leaf water status. Good water status in root tissues also helps in proper nutrient acquisition. It can grow in low nutrient soil with minimum dependence on chemical fertilizers due to its high photosynthetic efficiency, superior dry matter production capacity and excellent productivity. Pearl millet belongs to the group of C_4 plants that are more efficient in fixing atmospheric CO_2 and utilizing water effectively. Moreover, there is substantial deposition of cuticular wax in pearl millet leaves which reduces transpiration water loss and helps in reflecting radiation thereby contributing to heat and drought tolerance of the crop. Its unique ability to yield good economic returns even in poor and marginal soils and harsh environmental conditions makes it a crop of choice for the arid and semi-arid regions of the world.

MBC 2, improved open-pollinated variety of pearl millet. Released in 2011; Grain yield, 1.5 t/ha; Dry fodder yield, 4.2 t/ha; Maturity, 77 days; Resistant to downy mildew; Tolerant to drought.

Pearl millet: A preferred crop in salinity affected arid tracts

Soil salinity is a fast-emerging threat to crop production and salination of farmland is increasing due to several factors that are natural as well as anthropogenic. Salinity is more evident in semi-arid and arid regions where precipitation is less and evapotranspiration is more. Pearl millet is known to withstand salinity stress effectively and genes from pearl millet have been used to generate salinity tolerant rice and ground nut plants. It is even suggested as an alternate crop for salinity affected areas. Since, the crop is mostly free from major pests and diseases, use of pesticides and fungicides is also less, making it a sustainable crop with minimum impact on the environment.

SUMMARY

Pearl millet is among the hardiest of all crops and a great promise in climate resilient agriculture. The crop displays great potential in imparting food and nutritional security among the marginal farming communities and livestock of arid and semi-arid regions. As the crop is resilient to heat, drought, salinity and various abiotic stress factors, it's a promising alternative for the major cereal crops which might fail in the changing climatic conditions. Realizing the importance of this crop, efforts are underway for developing high yielding varieties and hybrids to suit farmers' fields in different zones of pearl millet cultivation.

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Commercialization of pearl millet:

Seed production and value addition

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Pearl millet (Pennisetum glaucum)*, is the sixth most important global cereal and the millet occupying largest area in India. As a versatile crop that provides food, feed and fodder, and survives in the arid and semi-arid tropics with minimum inputs, pearl millet is regarded as a promise for future farming. Good quality seed is a vital input for exploiting complete potential of crop production. This article elaborately describes the seed production programmes in pearl millet. The significance of value addition in the crop for food and other uses is also described.*

Keywords: Malting, Pearl millet, Shelf-life, Seed production, Value addition

PEARL millet is a hardy crop, can be grown in areas which are very hot and dry, and on soils too poor for crops like maize and sorghum. The major pearl millet growing states in India are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana, which together account for more than 90% of pearl millet acreage in the country. Most of pearl millet in India is grown in rainy (*kharif*) season (June–September). It is also being increasingly cultivated during the summer season (February–May) in parts of Gujarat, Rajasthan and Uttar Pradesh; and during the post-rainy (*rabi*) season (November–February) at a small scale in Maharashtra and Gujarat. A majority of the subsistence farmers who typically cultivate this crop are unable to take advantage of its high yield potential due to lack of improved cultivars and application of improved management practices. A robust seed production programme is central to providing high quality seeds for agricultural development and food security.

Pearl millet is a highly cross-pollinated crop. Due to protogynous nature, it is more susceptible to contamination. The emergence of the panicle from the sheath takes about 4–6 days. Flowering starts after the emergence of the panicle out of the boot, but in some genotypes style exertion commences before completion of panicle emergence. The stigma remains receptive for 18–24 h after full emergence. Anther emergence begins one day after the emergence of the stigmas is completed on the panicle. Under rainfed conditions, first-flush anthesis of a plant may take place over 12 days, and it may continue on the tillers till seed formation. After pollination, the stigmas dry up in 24 h. Seed-set can be seen in the panicle about a week after fertilization.

All the commercial grain hybrids of pearl millet are single-cross hybrids based on A_1 cytoplasmic-nuclear male sterility (CMS) system. Hybrid programmes in India accorded highest priority to grain yield and downy mildew resistance combined with maturity duration mostly in the range of 75–85 days, as per agro-ecological requirements. In pearl millet, seed is multiplied in four stages (Nucleus, Breeder, Foundation and Certified) called seed classes.

Nucleus seed production

Nucleus seed is the first stage in the chain of seed multiplication of a released variety or hybrid parents and is the only seed that can be used to produce its own seed class. The procedure for the production of nucleus seed is as follows:

Maintainer line (B-line): Initially in an isolation plot, about 1000 plants are selected and selfed at the time of flowering. Finally, 200 selfed plants conforming to the characters of the maintainer line are selected and divided into two lots. In the next season, using the seed from one lot, plant-to-row is grown and the progeny rows are studied for the diagnostic characters and rows not conforming to the characteristics of the line are rejected. The corresponding seed of the second lot for the progenies are bulked. In the third season, the bulk seed is grown in isolation and harvested to obtain nucleus seed bulk of B-line.

Male-sterile line (A-line): The A- and B-lines (nucleus seed bulk) are grown in alternate rows in isolation. The pollen shedders are rogued from A-lines. About 200–250 paired crosses between representative plants are made and labelled as A1 × B1, A2 × B2, etc. The harvested seed of each pair is kept separately. During next season, the paired crosses are sown in alternate rows retaining a portion of seed. Uniform pairs of A- and B-lines which conform to the standards of parental lines are identified. Remnant seed of the A-lines of the selected pure pairs is bulked. This forms Nucleus seed bulk of A-line.

Restorer line (R-line): This can be done in similar procedure as B-line multiplication.

Breeder/Foundation seed production

Breeder seed of hybrid parents is produced under the direct control of the sponsoring plant breeder. This class of seed is inspected by a monitoring team consisting of a breeder, seed certification officer, representatives of National Seed Corporation (NSC) and State Seed Corporation (SSC). Foundation seed is produced from Breeder seed, the production of which is carefully supervised or approved by the breeder and seed certification agency at the experimental station or recognized seed farms.

Male-sterile (A) line and maintainer (B) line: The A-line is multiplied by planting A- and B-lines in alternate set, usually in the ratio of 4:2. The B-line is planted in 4–8 border rows around the production block to ensure adequate pollen supply to the A-line. Careful and strict roguing is necessary in A- and B-lines. Pollen shedders should be removed in the A-line, if any. The B-line rows are harvested immediately after completion of flowering period. At maturity, the A-line rows are harvested and bulked. For breeder seed production of B-lines a separate production plot of 0.1 ha under isolation (1000 m) should be planted using the nucleus seed stock. Foundation seeds are produced by planting Breeder seed. The roguing and other procedures are similar to Nucleus seed production method.

Restorer (R) line: Breeder/Foundation seed production of R-lines is done by bulk planting under isolation (1000 m). Nucleus seed stock is used to produce breeder seed, and breeder seed is used to produce foundation seed (Table 1). Seed plots should be 0.1–0.2 ha for R-lines and at least 3000–5000 plants should be maintained.

The crop should be inspected at the following stages of growth to identify deviants for different characters:

- At 18 days after sowing: Deviants for early vigour
- At 30–35 days after sowing: Deviants for tillering, plant height and other traits
- Boot leaf stage: Deviants based on early flowering
- At 50% flowering: Deviants for late flowering, panicle exertion and panicle type (and pollen shedders in A-line)
- At Maturity stage: Deviants for panicle, seed type and seed colour

Identified off-type plants should be removed by uprooting as cutting of plants may lead to ratoon tillers.

Certified seed production

The stipulated isolation distance for certified seed production is 200 m. The pattern of planting and seed production is the same as for the breeder and foundation seed production. Production must be acceptable to seed certifying agency and should fulfill all the requirements of certification. Certified seeds are generally arranged through contract growers. Some private seed companies also undertake certified seed production programmes. The Certified seed of a hybrid is produced by growing A-line and R-line in 4:2 ratio in an isolated field. Synchronization of A- and R-lines is an important consideration for certified hybrid seed production. This can be manipulated by differential dates of sowing; controlling water and fertilizer application to one of the hybrid parents; and removal of extra-early tillers in A- or R-lines to synchronize the pollen shedding and stigma receptivity. Off-type plants in R-line and pollen shedders in A-line should be rogued out carefully to maintain genetic purity. A satisfactory certified seed production can be achieved if seed village concept is followed.

The calculations assume 1000 male row ratio of 4:1 kg/ha of seed yield in production plots, 4 kg/ha of seed rate and female:male ratio of 4:1.

Seed production plot of pearl millet

Table 1. Area and seed requirement for various seed classes to produce one tonne (enough to plant 250 ha) of certified pearl millet hybrid seed

Parental line	Year 1, Season 1		Year 1, Season 2		Year 2, Season 1	
	Breeder seed production		Foundation seed production		Certified seed production	
	Area (ha)	Nuclues seed (kg)	Area (ha)	Breeder seed (kg)	Area (ha)	Foundation seed (kg)
A-line	0.016	0.064	4	16	1000	4000
B-line	0.004	0.016	1	4		
R-line	0.004	0.016	1	4	250	1000
Total	0.024	0.096	6	24	1250	5000

Pearl millet value addition and commercialization

Pearl millet is a multi-purpose crop highly preferred by people living in arid regions in India as the crop survives well in such climatic conditions. The crop is used to feed livestock, poultry and fish. It is a source of high quality forage in seasons of forage scarcity. Both grain and stover of pearl millet have a better mineral profile than many other cereals. Grains are rich sources of fat, iron, calcium, essential amino acids and dietary fibre and are gluten-free.

Pearl millet flour develops a rancid odour and taste within a few days of milling due to a high lipid content which leads to fat acidity and lipolytic activity during storage. Though the polyphenolic content in endosperm restricts the efficient absorption of nutrients by the body, several processing techniques have been developed to enhance food value and shelf-life of pearl millet products and to improve the availability of starch, protein and minerals. Blanching and heat treatment are found to improve the storability and stability of flour. Acid treatment of grain is found effective in removing anti-nutritional factors and improving digestibility and shelf-life of pearl millet flour. Malting of pearl millet also increases the shelf-life. A wide range of value-added products can be prepared from processed pearl millet flour for both home consumption and commercial purpose. Pearl millet is suitable to prepare products like puffs, extruder snacks, upma, laddu, chapathi, pasta, noodles, pizza base, cookies, bread/bun, cake, instant idli mix and millet flour.

The major use (almost 70%) of pearl millet is for food purpose. Apart from this, the grains are also used as a cattle feed, alcohol industry, poultry industry and for seed. Pearl millet is an excellent cattle and poultry feed and it is nutritionally either superior to, or as good as corn. Most of pearl millet production currently is used for poultry, livestock and bird feed. The fodder from pearl millet and sorghum is preferred as livestock feed due to its superior quality with high energy and protein levels. Pearl millet-supplemented poultry feeds are generally superior to sorghum and equivalent to maize in broiler diets.

Pearl millet grains are used in the production of potable alcohol and biofuel. In India, broken rice is used as a viable feedstock for alcohol industry followed by pearl millet grain (lower grade grain quality) and sorghum. Even though, the use of pearl millet in alcohol industry is not huge at present, there is much potential in future and increasingly many distilleries are shifting now to pearl millet from sugarcane molasses. A significant portion of pearl millet, especially lower quality, and blackened grain is used in Haryana and Rajasthan for manufacturing potable alcohol. Cellulose and hemicellulose, which are the main components for cellulosic biofuel production, are found abundantly in Pearl millet (bajra) biomass making it amenable for the production of biofuel. Pearl millet has every potential to be used for commercial scale-up of ethanol production in coming future because of its suitability as a rain-fed and low-input crop, short period of crop rotation, adaptation to poor soils, high biomass yield per unit area, energy yield potential and market price.

SUMMARY

Standardized seed production technology is essential for tapping the full potential of crop production. Several hybrids and varieties of pearl millet suited to different agro-climatic zones have been developed in India by both private and public sectors. Development of pearl millet based ready-to-eat and ready-to-cook products that are storable being developed strengthening the commercial value chain of the crop. The crop is also being explored for novel uses such as potable alcohol and bio-ethanol production. Strong seed production systems and commercial exploitation of the crop helps in ensuring enhanced and assured returns to the pearl millet farmers.

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Impact assessment of "Low Tunnel Technology" of vegetable cultivation during off season

An intensive survey was conducted in Jaipur bypass, Pemasar village, Jaipur road, Narangdesar, Sagar, Raysar, Ridmalsar, Napasar, Gardwala, Kilchu, Kalyansar, Gigasar, Ambasar, Sujasar, Palana, Swarupsar, Kolsar, Bachhasar, Meghasar, Naiyo ki Bast, Jaisalmer bypass, Ganganagr Highway, Khara, Sarahkunjiya villages and surrounding areas of Bikaner in Bikaner district to collect basic data/information about the impact of adoption of "Low Tunnel Technologies" for cultivation of vegetables during off season (winter). The study revealed that the local farmers grow various vegetables (specially cucurbits) under "Low Tunnel Technologies (LTT)" during the winter for advance production to fetch more price and earning from the vegetable market/*Mandies*. "Low Tunnel Technologies (LTT)" for vegetable production has spread over 1,200 ha in Bikaner, Rajasthan and farmers get/earn ₹ 2–3 lakh net profit from one ha of land per season depending on type of vegetable, seed quality, climatic conditions, marketing demand etc.

Source : ICAR Annual Report 2021-22

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INTERNATIONAL YEAR OF MILLETS 2023

Small millets in India:

Current scenario and way forward

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In India, sorghum (Sorghum bicolor), *pearl millet* (Pennisetum glaucum) *and a group of seven small millets together constitute the millets family. The group of small millets includes finger millet* (Eleusine coracana), *little millet* (Panicum flexuosum), *kodo millet* (Paspalum scrobiculatum), *foxtail millet* (Setaria italica), *barnyard millet* (Echinochloa frumentacea), *proso millet* (Setaria italica) *and browntop millet* (Brachiaria ramosa). *These crops, known by different names in local languages have traditionally been the vital component of dry farming and hill agriculture systems in India supporting millions of poor and food insecure people.*

Keywords: Ancient grain, Dryland, Green revolution, Marginal farming, Millets

THE area under millets cultivation has been drastically decreasing over the last six decades in India, especially since the green revolution. The area under small millets (Table 1) has also declined considerably in all the states where they were predominantly grown in the past. Introduction of high yielding varieties (HYVs) of different crops; shift from millets to more profitable crops in *kharif* such as soybean, maize, cotton and sunflower in different states; changing food habits and consumer preferences due to rapid urbanization and rising income levels; difficulty in processing of small millets; poor quality of the grains and lack of market support are the major reasons for losing the area under small millets cultivation.

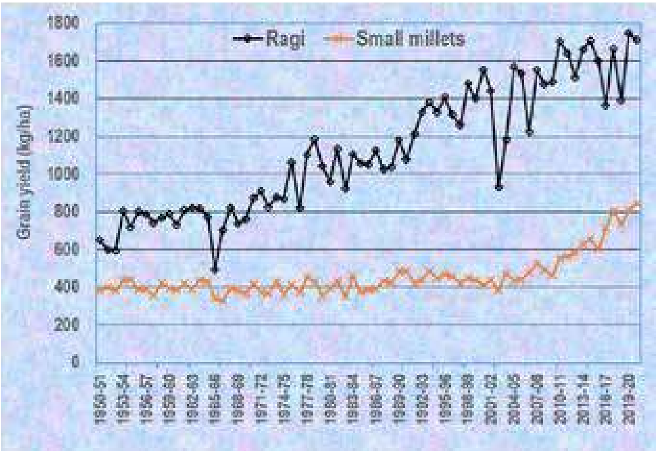
Share of small millets in the Gross Cropped Area has declined to a level of 0.88% (finger millet–0.56%, other small millets–0.32%) during the period of 2014–19, which was 4.9% (finger millet–1.6%, other small millets–3.3%) during the period of 1956–61. Share in the total food grains production has also declined to a level of 0.71% (finger millet–0.58%, other small millets–0.13%) during the period of 2016–21 which was 5.2% (finger millet– 2.5%, other small millets–2.7%) during the period of 1956–61. The period between 1951 and 2021 saw a dramatic decline in cultivated area under small millets (89.7% for small millets other than finger millet, 52% for finger millet) (Table 2). The area under finger millet remained nearly stable at around 2.50 m ha during the

Table 1. Vernacular names of small millets

Language	Finger millet	Little millet	Kodo millet	Barnyard millet	Foxtail millet	Proso millet
Hindi	Ragi, Mundua	Kutki, Savan	Kodon	Sanwa	Kangni, Kakun	Cheena, Bari
Kannada	Ragi	Same	Harka	Oodalu	Navane	Baragu
Tamil	Kelvaragu	Samai	Varagu	Kuthiravaali	Tenai	Panivaragu
Telugu	Ragulu	Samalu	Arikelu, Arika	Udalu, Kodisama	Korra	Variga
Malayalam	Moothari	Sama	Varagu	-	Thina	Panivaragu
Marathi	Nachni	Sava	Kodra	Shamul	Kang, Rala	Vari
Gujarati	Nagli, Bavto	Gajro, Kuri	Kodra	Sama	Kang	Cheno
Bengali	Mandua, Marwa	Sama	Kodo	Shyama	Kaon	Cheena
Oriya	Mandia	Suan	Kodua	Khira	Kanghu, Kora	China
Punjabi	Mandhuka, Mandhal	Swank	Kodra	Swank	Kangni	Cheena
Kashmiri	-	Ganuhaar	-	-	Shol	Pingu

period coinciding with green revolution era, but, from the early 1980s, area started declining gradually and fell below 2.0 m ha starting from 1991–92 onwards. In case of other small millets average area remained around 5 m ha till 1960 and then started declining gradually, remained above 4 m ha till 1980. In the next 25 years area fell down drastically reaching to less than 25% and then to 10% by 2020.

The total production of small millets has declined by nearly 44%, though not in the same rate as area. In case of finger millet there was a gradual increase in production corresponding to the initial area increase, reached the highest of 3.20 m t in 1978–79, and thereafter started declining gradually. Overall, total production has actually risen by 12.5% from first 5 year plan to 12th plan despite area getting reduced by more than half during the same period, because of improvement in yield levels owing to adoption of high yielding varieties and production practices by the farmers. In case of other small millets the production levels were fluctuating and fell down more than 80%, while productivity has risen marginally from 380 kg/ha during 1950–51 to 800 kg/ha during 2019–20 at all India level. Interestingly in case of finger millet the yield levels have gone up from 649 kg/ha (1950–51) to 1747 kg/ha (2019–20) due to concerted crop improvement efforts and improved crop management practices.



Trend in yield levels of finger millet and other small millets

Distribution of small millets in India

Among the small millets, finger millet is the most important crop grown in many states of India from mean sea level in coastal Andhra Pradesh to 8000 feet altitude in the Himalayas. The other small millets in decreasing order of area under cultivation are little, kodo, barnyard, foxtail, proso and browntop millet which are mostly concentrated in specific states/regions. The estimated area, production and productivity of small millets in India, and the important states for each crop are given in Table 3.

The distribution of individual millet is not uniform though small millets are grown in almost every state/region. Karnataka is the major finger millet growing state accounting to 65% of area and production (2019–20) followed by Uttarakhand and Tamil Nadu. But Tamil Nadu has highest productivity (3246 kg/ha) of finger millet followed by Karnataka (1726 kg/ha) which is above the national average yield (1697 kg/ha). In Madhya Pradesh, both kodo and little millet are predominant, while foxtail millet is important in Andhra Pradesh and Karnataka. Barnyard millet and proso millet are grown largely in hills of Uttarakhand, North-Eastern region and plains of North Bihar and western Uttar Pradesh and Maharashtra. Browntop millet, known as *Korale* (Kannada) or *Andakorra* (Telugu) occupies only a few thousand hectares in the dryland

Table 2. Quinquennial area, production and productivity of small millets in India

Year	Finger millet			Small millets		
	Area ('000 ha)	Production ('000 t)	Yield (kg/ha)	Area ('000 ha)	Prod. ('000 t)	Yield (kg/ha)
1951–55	2274	1605	704	5290	2177	410
1956–60	2454	1873	764	5022	1955	389
1961–65	2555	1888	743	4677	1889	404
1966–70	2420	1887	779	4741	1784	376
1971–75	2442	2227	909	4489	1745	388
1976–80	2588	2650	1021	4326	1743	402
1981–85	2474	2612	1054	3459	1391	401
1986–90	2306	2510	1088	2754	1198	437
1991–95	1891	2511	1331	1950	851	439
1996–00	1718	2413	1402	1492	738	435
2001–05	1563	2088	1331	1173	510	435
2006–10	1350	1976	1471	970	467	480
2011–15	1179	1915	1625	683	412	606
2016–20	1033	1674	1612	523	386	739
2021–22*	1079	1700	1576	479	370	772

*As per 4th advance estimate 2021–22. *Source*: State of Indian Agriculture -different years, Agricultural Statistics at a Glance 2020.

Table 3. Area, production and yield of small millets in India (2015–16)

Millet	Area (lakh ha)	Production (lakh tonnes)	Yield (kg/ha)	Important states
Finger	11.38	18.21	1601	Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Odisha, Andhra Pradesh, Gujarat, Jharkhand and Telangana
Little	2.34	1.27	544	Odisha, Madhya Pradesh, Chhattisgarh, Gujarat, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh and Jharkhand
Kodo	1.96	0.84	429	Madhya Pradesh, Chhattisgarh, Tamil Nadu, Gujarat, Maharashtra, Karnataka, Uttar Pradesh and Andhra Pradesh
Barnyard	0.96	0.73	758	Uttarakhand, Tamil Nadu, Maharashtra, Madhya Pradesh, Karnataka and North Eastern states
Foxtail	0.87	0.66	762	Andhra Pradesh, Karnataka, Tamil Nadu, Telangana and Rajasthan
Proso	0.41	0.22	531	Tamil Nadu, Bihar, Karnataka, Andhra Pradesh, Madhya Pradesh and North Eastern states
Browntop	-	-		Karnataka (Tumkur, Chitradurga, Chikkaballapura), Andhra Pradesh (Ananthpur)

tracts of Karnataka-Andhra Pradesh border areas. The state-wise area, production and productivity of small millets are given in Table 4 and 5.

The biggest small millets producing state is Karnataka (56% of total production) followed distantly by Tamil Nadu (14.0%) and Uttarakhand (9.3%). Rest of the states together contribute about one-fifth of the total production. In terms of cultivated area Karnataka has the highest proportion (48%) followed by Maharashtra (10.5%). Though Madhya Pradesh has more area under other small millets, its contribution to total production is less owing to poor yield levels in the predominantly grown kodo and little millet, and total production has high year to year fluctuations.

Research and development efforts

The goal of breeding small millets remains improvement of grain yield including maximization of biomass and the harvest index. Cultivars need to be developed depending on the location specific requirements of soil, rainfall, temperature, humidity, day length and cropping patterns. Nutrient-use efficiency, particularly nitrogen, both native and applied needs to be enhanced as small millets are in generally sown to poor soils. Breeding of dwarf varieties is an objective of intensive cultivation as lodging is a major problem. Being drought tolerant, water-use efficiency of these crops needs to be further improved. Non-shattering cultivars are required to prevent yield loss in the field, while post-harvest technology demands free threshing of grains and easy dehulling for minimizing human drudgery.

Compared to other crops, attention on small millets was limited till establishment of separate AICRP on small millets in 1986. The project focuses on developing high yielding cultivars and appropriate production technologies to meet regional needs through multidisciplinary approach involving centres located in State Agricultural Universities (SAUs) and other cooperating centres. Through the efforts of AICRP a number of varieties with higher yield, variable maturity, tolerance to various diseases and insect pests have been

Table 4. Area, production and productivity of small millets in prominent states of India (2019–20)

State	Finger millet			Other small millets		
	Area ('000 ha)	Production ('000 t)	Yield (kg/ha)	Area ('000 ha)	Production ('000 t)	Yield (kg/ha)
Andhra Pradesh	33.6	44.3	1320	23.3	22.1	947
Arunachal Pradesh	-	-	-	26.8	27.5	1025
Chhattisgarh	4.5	1.2	267	63.1	18.3	290
Gujarat	11.6	10.0	862	8.2	13.6	1657
Jharkhand	14.6	12.8	875	-	-	-
Karnataka	673.7	1162.5	1726	52.4	38.1	727
Madhya Pradesh	-	-	-	79.8	73.9	926
Maharashtra	82.2	87.3	1061	76.4	30.9	405
Odisha	35.9	26.2	731	32.9	17.0	517
Rajasthan	-	-	-	10.1	5.2	518
Tamil Nadu	84.5	274.5	3246	17.9	26.3	1466
Uttarakhand	91.6	130.0	1419	50.3	68.0	1351
Others	10.8	13.2	1222	20.8	29.1	1399
All India	1043	1762	1697	462	370	809

Source: Ministry of Agriculture, GoI

Table 5. Percentage contribution of states to total area and production of small millets in India (2019–20)

State	Finger millet		Other small millets	
	Area (%)	Production (%)	Area (%)	Production (%)
Andhra Pradesh	3.2	2.5	5.0	6.0
Arunachal Pradesh	-	-	5.8	7.4
Chattisgarh	0.4	0.1	13.7	4.9
Gujarat	1.1	0.6	1.8	3.7
Jharkhand	1.4	0.7	-	-
Karnataka	64.9	66.0	11.3	10.3
Madhya Pradesh	-	-	17.3	20.0
Maharashtra	7.9	5.0	16.5	8.4
Odisha	3.5	1.5	7.1	4.6
Rajasthan	-	-	2.2	1.4
Tamil Nadu	8.1	15.6	3.9	7.1
Uttarakhand	8.8	7.4	10.9	18.4
Others	1.0	0.7	4.5	7.9
All India	100	100	100	100

developed for general cultivation across the country. Keeping in view the declining area, more intensive efforts and support both in terms of research and development is needed for sustaining the production of small millets. Apart from Government support, many NGOs and SHGs (Self Help Groups) are also actively involved in promoting millet cultivation and consumption.

Future thrust areas

The area under small millets is declining year after year, which needs to be arrested with the involvement of all stakeholders. The highest decline in area has been observed in Andhra Pradesh (undivided) followed by Tamil Nadu, Madhya Pradesh including Chhattisgarh and Gujarat. The area is being diverted to more remunerative crops like cotton, maize, soybean and rice. Improving productivity is the key to enhance competitive ability in the marginal agro-ecologies together with enhancing demand, especially among the urban elite for arresting the further decline. Some of the crop improvement and management strategies apart from policy initiatives that require immediate attention for sustaining small millets cultivation are as follows:

- Breeding varieties with better tolerance of biotic and abiotic stresses.
- Mechanization to reduce cost of cultivation.
- Strengthening recombination breeding to create more variability.
- Exploitation of the available genetic potential through better crop management.
- Quality seed production of improved varieties and promoting varietal spread.
- Strengthening of research on grain processing and value addition to improve demand.
- Development of health foods, nutraceuticals and their commercialization to promote among the urban elite.
- Area expansion to non-traditional regions.
- Engaging private sector in millet popularization.
- Cooperative, collective and FPO (Farmer Producer Organization) led farming.
- Special incentive for low productive areas, organic farming, and MSP (Minimum support price), and assured procurement of produce.
- Introduction of millets in PDS (Public Distribution System), mid-day meal and other Public funded programmes.

SUMMARY

In spite of the nutritional superiority, drought tolerance and adaptability to marginal conditions the area under small millets is constantly declining. Research efforts have resulted in several high yielding varieties and improved production technologies, but the small millets are not able to compete with more remunerative crops. Cultivation of small millets needs urgent interventions by the Government agencies to make it more profitable and attractive. Market development, assured procurement and value-chain development are the key for encouraging the farmers. With the growing demand for food production from limited cultivated area and under changing climatic regimes, small millets can promote farming in a more environmentally sustainable manner ensuring food and nutritional security.

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Jai Kisan, Jai Vigyan

- A total of ₹ 788.33 crores have been sanctioned for opening six new agricultural colleges for eastern India under Central Agricultural University, Imphal, and a new Central Agricultural University in Meghalaya.
- For the establishment of two new agricultural research institutes in Asom and Jharkhand, a sum ₹ 100 crores is allocated.
- First academic session of the Rani Lakshmibai Central Agricultural University has been allocated for four new agricultural colleges in Datiya and Jhansi.
- An Memorandum of Understanding was signed for transforming the Rajendra Central Agricultural University, Pusa, Samstipur, Bihar. A proposal of ₹ 400 crores is submitted in EFC.
- Post-Graduate Institute of Horticulture is being established in Amritsar, Punjab.
- Foundation stone of the Indian Institute of Agricultural Biotechnology is laid at Ranchi for promoting agricultural biotechnology.

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High yielding varieties

for enhancing the production of small millets in India

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Small millets are a group of small-grained cereal crops, have a unique place in Indian agriculture though they contribute less than 1% to the annual cereal grain production. Traditionally these crops have been the indispensable component of dry farming system and areas where other crops can not be cultivated profitably. These crops are important in tribal and hill agriculture.

Keywords: Breeding, Early duration, Grain yield, Productivity, Tolerance

AMONG small millets (finger millet, little millet, kodo millet, foxtail millet, barnyard millet, proso millet and browntop millet), finger millet is the most important crop grown widely in India from sea level to 8000 feet altitude in Himalayas. The major states growing finger millet are Karnataka, Uttarakhand, Tamil Nadu, Maharashtra, Odisha and Andhra Pradesh. The kodo, little and foxtail millets are grown widely in Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, Odisha, Bihar, Madhya Pradesh and Maharashtra. In Madhya Pradesh, both kodo and little millet are predominant, while foxtail millet is important in Andhra Pradesh and Karnataka. Barnyard millet and proso millet are grown largely in hills of Uttarakhand, Uttar Pradesh, North-Eastern region and plains of North Bihar and Western Uttar Pradesh and Maharashtra. Nearly 68% of area under small millets is occupied by finger millet, followed by little and kodo millets (about 10%) and rest by barnyard, foxtail and proso millets.

Crop improvement

The crop improvement efforts in small millets are not comparable to other cereals. As these crops are mostly confined to marginal lands, less attention was given in spite of their nutritional superiority. With the launch of a separate All India Coordinated Research Project on Small Millets (AICRP-SM) in 1986 the focus on small millets was enhanced. AICRP-SM acts as the nodal agency to plan, coordinate and execute the research programmes to augment the production and productivity of small millets at all India level.

After the launch of AICRP-SM a number of improved varieties possessing higher yield, variable maturity, tolerance to various diseases and insect pests have been evolved and released for general cultivation across the country (Table 1). With the concerted efforts significant genetic enhancement has been achieved in case of finger millet and satisfactory yield enhancement in foxtail and barnyard millets. The improved varieties released in small millets during the last 10–15 years along with their salient features are given in Table 1–7.

Table 1. Improved varieties released in small millets

Crop	No of varieties released		Total
	Before 1986	From 1986 to 2022	
Finger millet (1918–2022)	45	97	142
Foxtail millet (1942–2022)	12	26	38
Little millet (1954–2022)	6	26	32
Proso millet (1954–2022)	8	19	27
Barnyard millet (1949–2022)	4	18	22
Kodo millet (1942–2022)	11	30	41
Total	86	216	302

Table 2. Improved finger millet varieties released in India in the last 10 years

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
Phule Kasari (KOPN 942)	2022	100-110	22-23	Maharashtra	Highly resistant to finger blast and neck blast
Gossaigaon Marua Dhan	2022	125-130	30-31	Assam	Moderately resistant to leaf blast and neck blast, resistance to lodging and shattering
Birsa Marua 3	2021	110-112	26-27	Jharkhand	Moderately resistant to neck and finger blast, resistant to brown spot, banded sheath blight and foot rot
Dapoli 3 (DPLN-2)	2021	125	20-22	Konkan region of Maharashtra	Moderately resistant to neck blast and finger blast; protein – 7.52%
ATL-1 (TNEc 1285)	2021	105-110	30-31	Tamil Nadu	Drought tolerant, moderately resistant to leaf, neck and finger blast; non-lodging, rich in protein (11.9%) and calcium (325 mg/100 g)
Chhattisgarh Ragi 3 (BR-14-3)	2021	110-115	32-33	Assam, Bihar, Chhattisgarh, Jharkhand, Uttarakhand, Madhya Pradesh	Non-lodging, non-shattering, tolerant to leaf, finger and neck blast, moderately resistant to grass hopper, Myllocerous weevil and shoot aphid
CFMV 3 (Ekvijay) (FMV-1137)	2021	120-125	32-33	Andhra Pradesh, Tamil Nadu, Telangana, Maharashtra, Gujarat	Moderately resistant to leaf blast, finger blast, neck blast, foot rot and banded blight; calcium - 470 mg/100 g, Iron - 38 mg/kg, Zinc - 24.6 mg/kg
Gowthami (PR 10-45)	2020	122-125	35-37	Andhra Pradesh	Moderately resistant to leaf blight, banded blight and leaf and neck blast, high Zinc (26.5 ppm) and calcium (341 mg/100 g)
VL-382	2020	106-108	11-13	Rainfed organic conditions of Uttarakhand hills	Suitable for processing industry
VL-378	2020	110-114	22-24	Rainfed organic conditions of Uttarakhand hills	High in calcium (361.3 mg/100 g)
CFMV-2	2020	119-121	29-31	Andhra Pradesh, Chhattisgarh, Gujarat, Maharashtra, Odisha	Resistant to leaf blast, foot rot, brown spot, grain mould and moderately resistant to neck blast, finger blast and banded blight
CFMV-1 (Indravathi)	2020	110-115	30-32	Andhra Pradesh, Karnataka, Tamil Nadu, Puducherry, Odisha	Resistant to Finger blast, Neck blast, Banded blight and Foot rot, Shoot aphids, stem borer and grass hoppers; rich in calcium (428.3 mg/100 g), iron (58.3 mg/kg), zinc (44.5 mg/kg)
VR-988	2020	110-115	28-30	Andhra Pradesh	Moderately resistant to blast, banded sheath blight; defoliators, ear head caterpillar and aphids
KMR-630	2020	95-100	28-30	Karnataka	Tolerant to neck blast and finger blast, Stem borer, Aphids, grass hopper and ear head caterpillar. Suitable for mechanical harvesting.
GN 8	2019	105-110	31-32	Gujarat	Erect and non-lodging, moderately resistant to blast, foot rot, tolerant to stem borer and aphids
Tirumala (PPR 1012)	2019	115-120	35-37	Andhra Pradesh	Tolerant to leaf blast, neck blast and finger blast, moderately resistant to leaf blight and banded blight
Vegavathi (VR 929)	2019	115-120	36-37	All states	Highly resistant to brown spot, banded blight, foot rot and *Cercospora* leaf spot; resistant to leaf, finger and neck blast
VL Mandua-380	2019	115-116	18-19	Uttarakhand	High yielding and blast tolerant, light copper colour grains
DHFM 78-3	2018	114-116	28-32	Agro-climatic Zone-3 & 8 of Karnataka	Resistant to finger and neck blast, suitable for contingency planting
Chhattisgarh Ragi-2 (BR-36)	2018	115-118	34-36	Chhattisgarh	Moderately resistant to neck and finger blast, tolerant to stem borer
VL-379	2017	105-107	30-32	Uttarakhand, Bihar, Jharkhand, Madhya Pradesh and North eastern states	Resistant to neck and finger blast, moderately resistant to banded sheath blight
GNN-7	2017	123-128	24-25	Gujarat	High crude fibre, Calcium, Phosphorous and good amount of protein, fat, carbohydrats and magnesium
Co 15	2017	115-125	29-34	Tamil Nadu	Non-lodging, resistant to leaf, neck and finger blasts, bold and copper red colour seeds
Dapoli-2 (SCN-6)	2017	118-120	25-27	Konkan region of Maharashtra	Rich in iron and calcium, moderately resistant to blast, tolerant to aphids and *Spodoptera*
KMR 340	2016	90-95	35-40	Karnataka	White ragi variety, especially for confectionary purpose, resistant to blast and blight diseases, tolerant to stem borer and aphids

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
VL Mandua-348	2016	104-112	18-20	Uttarakhand	Suitable for organic cultivation, resistant to neck and finger blast, tolerant to lodging, light copper colour seed
GNN-6	2016	120-130	28-30	Gujarat	Moderately resistant to leaf blast and finger blast
GN-5	2016	120-130	25-27	Gujarat	Late maturing, white colour seed, moderately resistant to leaf and finger blast
VL 376	2016	103-109	29-31	All states	Responsive to fertilizer and moderately resistant to blast
VL 352	2012	95-100	33-35	Uttarakhand	Moderately resistant to blast, early duration
Indira Ragi-1	2012	120-125	25-26	Chhattisgarh	Moderately resistant to neck and finger blast and tolerant to stem borer
PPR 2700 (Vakula)	2012	105-110	25-30	Andhra Pradesh	Resistant to leaf blast and tolerant to drought
VR 936 (Hima)	2012	115-120	28-30	Andhra Pradesh	Suitable for late conditions
KMR 204	2012	100-105	30-35	Karnataka	Early duration
OEB 532	2012	110-115	22-25	Odisha, Chhattisgarh, Karnataka, Maharashtra and Tamil Nadu	Moderately resistant to blast, highly tolerant to myllocerus weevil, earhead caterpillars, stem borer and grass hopper

Table 3. Improved little millet varieties released in India in the last 10 years

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
Kalinga Suan 217 (OLM 217)	2021	105-110	15-16	Odisha	Resistant to rust and grain smut, moderately resistant to sheath blight, tolerant to shootfly
Chhattisgarh Sonkutki (BL-41-3)	2021	95-100	16-19	Chhattisgarh	Early maturing, suitable for millet-niger, millet-horsegram and millet-urdbean cropping system, tolerant to rust and sheath blight
CLMV 1 (Jaicar Sama 1)	2020	98-102	15-17	Maharashtra, Andhra Pradesh, Telangana, Tamil Nadu, Puducherry	Tolerant to shoot fly, banded blight, leaf blight and brown spot diseases, high grain iron (58.8 ppm), zinc (35 ppm) and protein (12.8%)
ATL-1 (TNPsu 177)	2019	85-90	-	Tamil Nadu	Early maturity, bold grains with high bulk density, tolerant to drought, shoot fly, grain smut and sheath blight
GNV-3	2018	110-115	28-29	Gujarat Zone-I, II & III	Bold seeded, multi-tillering, non-lodging, resistant to grain smut and sheath blight, high in minerals and crude fibre
DHLM-14-1	2018	97-99	16-17	Tamil Nadu, Karnataka, Gujarat, Maharashtra and Odisha	Tolerant to shoot fly
DHLM 36-3	2018	95-100	14-16	Karnataka	Late maturing
BL 6	2016	90-95	12-14	All states	Suitable for upland cultivation, rich in zinc and calcium
Chhattisgarh Kutki-2 (BL 4)	2016	90-95	10-12	Chhattisgarh	High iron content, tolerant to major pests
GV-2	2016	115-125	26-28	Gujarat	White and bold seeds, resistant to pest and diseases
Phule Ekadashi (KOPLM 83)	2016	120-130	12-14	Sub-mountainous and Ghat zone of Maharashtra	Non-lodging
Jawahar Kutki 4 (JK 4)	2016	75-80	13-15	Rainfed areas of Madhya Pradesh	Resistant to drought, lodging, Shoot fly, moderately resistant to head smut

Table 4. Improved kodo millet varieties released in India in the last 10 years

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
ATL1 (TNPsc 176)	2021	105-110	25-26	Tamil Nadu	Tolerant to shoot fly, Grain smut and sheath blight, Non lodging and uniform maturity
Gujarat Kodo millet 4 (Dahod Kodra-4)	2021	106-113	2738	Gujarat	Moderate resistance to head smut; protein - 8.74%
Dahod Kodo (CKMV 2)	2021	107-110	28-29	Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh and Tamil Nadu	Moderately resistant to Head smut, banded blight, leaf blight and brown spot, shootfly

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
CKMV 1 (ATL-2)	2021	106-110	28-29	All States	Tolerant to Brown spot, Leaf blight and Head smut diseases, shootfly
Chhattisgarh Kodo-03 (BK-36)	2021	105-110	26-27	All India	Lower incidence of diseases
Gujarat Anand Kodra-3 (GAK-3)	2020	105-110	24-25	Gujarat	Highly resistant to shoot fly and moderately resistant to Head smut disease
Jawahar Kodo-137	2016	100-105	26-29	Rainfed areas of Madhya Pradesh	Suitable for sole as well as inter/mixed cropping, responsive to NPK, resistant to drought, lodging, and key pest Shoot fly and moderately resistant to head smut
Chattisgarh Kodo-2	2014	95-100	25-26	Chhattisgarh	Early maturing, resistant to major insect pests
Indira Kodo-1 (BK-1)	2012	100-105	22-25	Chhattisgarh	Highly responsive to fertilizers, suitable for late sown condition
TNAU 86	2012	95-110	27-30	All states	Resistant to head smut, sheath blight, brown spot and tolerant to drought
RK 390-25	2012	100-105	25-28	All states	Moderately resistant to head smut, non-shattering and non-lodging

Table 5. Improved foxtail millet varieties released in India in the last 15 years

Variety	Year of release	Maturity (days)	Av. yield (q/ha)	Area of adaptation	Special features
Renadu (SiA3223)	2020	86-90	30-35	Andhra Pradesh	High yielding, medium bold grains, tolerant to blast and downy mildew
Garuda (SiA 3222)	2020	60-62	15-18	Andhra Pradesh	Extra early variety
ATL-1 (TNSi 331)	2020	80-85	21-22	Tamil Nadu	Non-shattering, non-lodging, drought tolerant
Hagari Navane-46	2019	85-90	16-18	Zone -1, 2 and 3 of Karnataka	Bigger seed size and medium duration
DHFt 109-3	2018	86-88	28-29	Agro-climatic Zone-3 & 8 of Karnataka	Suitable for contingency planting
Suryanandi (SiA 3088)	2018	70-75	20-25	Andhra Pradesh	High seed yield, resistant to blast and downy mildew
RAU-2 (Rajendra Kauni 1)	2017	80-83	23-25	Irrigated and Rainfed upland of Bihar	Resistant to leaf blast, rust, smut, brown spot, downy mildew and leaf blight, high iron and zinc content
SiA 3156	2014	85-90	20-25	All states	High seed yield, tolerant to shootfly
SiA 3085	2011	75-82	20-30	All states	High yielding, resistant to blast and downy mildew
HMT 100-1	2008	90-95	20-25	Karnataka	High tillering, stay green character

Table 6. Improved barnyard millet varieties released in India in the last 15 years

Variety	Year of release	Maturity (days)	Av. Yield (q/ha)	Area of adaptation	Special features
Phule Barti-1 (KOPBM 46)	2022	95-105	17-18	Maharashtra	Non-lodging, shiny grey seed colour
DHBM -23-3 (DHB-23-3)	2019	88-100	23-26	Andhra Pradesh, Karnataka, Madhya Pradesh and Tamil Nadu	High grain and fodder yield
DHBM 93-3	2018	90-95	22-24	Andra Pradesh, Bihar, Karnataka, Madhya Pradesh and Tamil Nadu	Resistance to shootfly
MDU-1	2018	95-100	15-17	Southern Tamil Nadu	All seasons, no-shattering, high milling recovery
DHBM 93-2	2018	86-88	27-28	Agro-climatic Zone-3 & 8 of Karnataka	Suitable for contingency planting
Co 2 (TNAU 43)	2009	95-100	21-22	Tamil Nadu	Non lodging, profuse tillering, best for contingency planting
VL Madira 207	2008	80-90	16-18	Uttarakhand	Non lodging, non shattering
ER 64 (Pratap Sawan 1)	2008	85-90	15-17	Rajasthan	Resistant to smut and tolerant to shootfly, dual purpose variety, very early duration

Table 7. Improved proso millet varieties released in India in the last 15 years

Variety	Year of release	Maturity (days)	Av. yield (kg/ha)	Area of adaptation	Special features
ATL1 (TNPm230)	2018	72-74	21-23	Tamil Nadu, Karnataka and Bihar	Early maturing, drought tolerant
PMV 442 (GPUP 25)	2019	70-75	14-16	All states	Moderately resistant to brown spot and shoot fly
DHPM-2769	2018	70-72	24-25	Agro-climatic Zone-3 & 8 of Karnataka	Suitable for contingency planting
TNAU 202	2011	70-75	18-20	Drylands of India	Resistant to brown spot, sheath blight and rust
TNAU 164	2009	70-75	18-20	All states	Resistant to rust, non-lodging, non-shattering
TNAU 151	2008	70-75	18-20	Tamil Nadu	Resistant to rust tolerant to shootfly and drought
PRC 1	2008	70-75	10-12	Uttarakhand hills	Resistant to *Helminthosporium* leaf blight
TNAU 145	2007	70-75	18-20	All states	Resistant to rust, shootfly and tolerant to drought
Co 5 (TNAU 143)	2007	70-75	20-23	Tamil Nadu	Resistant to brown spot, rust, grain smut, tolerant to shoofly and drought

SUMMARY

Growing improved varieties in place of local varieties alone can result in incremental yield benefit of around 25–30%. Choosing appropriate variety depending on location and time of sowing is very important apart from good crop management. Availability of seeds of high yielding varieties is a limitation. By the efforts of ICAR-Indian Institute of Millets Research, 18 Seed hubs have been established at different parts of country with the funding from Department of Agriculture & Farmers Welfare (DAF&W). The objective of these Seed hubs along with enhanced Breeder seed production programme by the DAF&W is to supply the latest high yielding variety seeds at reasonable price for enhancing the production of small millets from rainfed agriculture in India.

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Foxtail millet:

Nutritional importance and cultivation aspects

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Foxtail millet (Setaria italica) *also known as Italian millet, German millet, Chinese millet or Hungarian millet, is one of the oldest cultivated millets in the world. It is cultivated in about 23 countries of Asia, Africa and America. It is a self-pollinating, short-duration, drought tolerant and C4 cereal crop good as food for human consumption, feed for poultry and cage birds, and fodder for cattle; mainly cultivated in poor or marginal soils. It plays an important role in the world agriculture providing food to millions of people dependent on poor or marginal soils in southern Europe and in temperate, subtropical and tropical Asia.*

Keywords: Climate change, Diabetes, Drought tolerance, Nutritious, Rainfed

IN India, foxtail millet is known by different names in different languages, and was an important crop in the rainfed areas of central and southern states in the early 1980s. The area under its cultivation and production has come down over the years. At present foxtail millet is grown on a limited area mostly to meet the domestic needs of the rural people. It is still used as an energy source for pregnant and lactating women, sick people, and children. Nutritionally it is rich in dietary fibre (6.7%), protein (11–12%) and low in fat (4%). Foxtail millet is recognised as diabetic food as it releases glucose steadily without affecting the metabolism of the body. The incidence of diabetes is found to be rare among the population consuming foxtail millet diet.

Geographical distribution

Foxtail millet is believed to be originated in China. It can grow in altitudes from sea level to 2000 m. It is adapted to a wide range of elevations, soils and temperatures. In India, it is cultivated on about 0.8 lakh ha area with 0.6 lakh tonnes production in Andhra Pradesh, Karnataka, Telangana, Rajasthan, Maharashtra, Tamil Nadu and north eastern states. The area under foxtail millet in India has come down by more than half during 1990's mainly due to introduction of more profitable crops like sunflower and soybean in black soils.

The important foxtail millet growing districts in Andhra Pradesh are Kurnool, Kadapa and Anantapur while Mahboob Nagar and Rangareddy districts are important in Telangana. In Karnataka it is mostly grown in Bellary, Koppal, Chitradurga, Belgaum, Gadag, Davangere and Dharwad. In North Eastern region foxtail millet is mainly grown in East Siang, Siang, Upper Siang, Lower Dibang Valley, Tirap, Longding, Changlang, Namsai, Shiyomi districts of Arunachal Pradesh and West Garo Hills of Meghalaya.

Nutritional importance and health benefits

The grains of foxtail millet are small and ovoid in shape, around 2 mm long, pale yellow to orange, red, brown or black in colour. Grain is enclosed in thin hulls and de-hulling is necessary to use as food. The foxtail millet grains have long shelf-life. It is usually cooked whole like rice or made into meal. It can be prepared as upma, pulao, khichdi or biriyani. In addition, foxtail millet is consumed as porridge called *sargati*, or as leavened bread known as *roti*, after the de-hulled grain milled into flour. Other food preparations are pudding, breads, cakes, chips, rolls, noodles, etc. Foxtail millet is fermented to make vinegar and wine in China and to make beer in Russia and Myanmar. Sprouted grains are also eaten as vegetable in some regions.

Foxtail millet is highly nutritious (Table 1) and is a rich source of fibre, protein, zinc, and magnesium. It has a moderate glycaemic index (GI) of 59. Eating foxtail millet results in slow release of sugar to the blood as compared to wheat and rice. The fibre in the form of β-glucans (42.6%) leads to increased metabolism of sugar and cholesterol resulting in lower levels of sugar and cholesterol, which is beneficial for prevention of diabetes and cardiovascular diseases. Foxtail millet is used in the preparation of low GI foods for treating diabetes, particularly type 2 diabetes and also cardiovascular diseases. Consumption of foxtail millet effectively reduces body weight, fasting blood sugar levels, improves blood pressure and lipid profile. High fibre content in foxtail millet improves digestion and eases constipation, lowers the risk of heart diseases, hypertension and stroke. It contains good amount of B vitamins such as thiamin (B1), riboflavin (B2), niacin (B3) and folate (B9). These B vitamins are essential for nervous system and brain function. Foxtail millet is also rich in antioxidants, such as flavonoids which protect neurons from inflammation, which may improve memory function.

Table 1. Nutritive value of foxtail millet vs. fine cereals (per 100 g)

Item	Foxtail millet	Wheat (whole)	Rice (raw, milled)
Carbohydrates (g)	60.9	71.2	78.2
Protein (g)	12.3	11.8	6.8
Fat (g)	4.3	1.5	0.5
Energy (KCal)	331	346	345
Crude fibre (g)	8	1.2	0.2
Mineral matter (g)	3.3	1.5	0.6
Amylose (%)	17.5	25	12-19
Amylopectin (%)	82.5	75	88-81
Ca (mg)	31	41	10
P (mg)	290	306	160
Fe (mg)	2.8	5.3	0.7
Zn (mg)	2.4	2.7	1.4
Mg (mg)	81	138	90
Na (mg)	4.6	17.1	-
K (mg)	250	284	-
Cu (mg)	1.4	0.68	0.14

Source: Nutritive value of Indian foods, NIN, 2007

Cultivation aspects

Foxtail millet varieties can mature in 75–90 days. It grows well where rainfall ranges from 500 to 700 mm and where rains fall during summer. Foxtail millet grows better between 16 and 26°C though it can tolerate up to 35°C. It can grow on sandy to heavy clay soils (except saline soils) but requires fairly fertile soils for good yields. Light soils including red loams, alluvials and black cotton soils are suitable for its cultivation. The recommended package of practices are given in Table 2.

Table 2. Recommended package of practices for foxtail millet

Operation	Practice
Land preparation	Plough once with mould board plough before the onset of monsoon, harrow or plough twice with local plough with the onset of monsoon, make the field smooth and well levelled
Time of sowing	*Kharif*: July-August (Karnataka), July (Tamil Nadu, Andhra Pradesh), 2–3rd week July (Maharashtra) *Rabi*: August-September (Tamil Nadu) Irrigated/Summer: February-March.
Seed rate	8 kg/ha
Spacing and optimum plant population	25–30 cm (row to row), 8–10 cm (plant to plant); 4–4.5 lakh/ha
Seed treatment	Fungicide: ridomil mz @2 g/kg, carbendazim @2 g/kg; Bio-fertilizer: *Azospirillum brasilense* and *Aspergillus awamouri* @25 g/kg
Manures and fertilizers (for rainfed crop)	FYM: 5–7.5 t/ha Urea: 52 kg/ha DAP: 33 kg/ha
Inter-cultivation	Using a tyne-harrow when crop is 30 days old
Irrigation/ drainage	2–5 irrigations in summer crop depending upon soil type and climatic conditions; drain out excess rain water to avoid water logging
Weed control	Isoproturon (0.5 kg ai/ha) (pre-emergent); 2,4-D (0.75 kg ai/ha) (post-emergent 15–20 DAS)
Disease control	Rogue out downy mildew affected plants, spray mancozeb @2 g/litre if diseases appear at early stage of crop growth
Pest control	1. Early sowing in the month of May wherever possible 2. In late sown crop increase the seed rate one and half times 3. Seed treatment with chloropyriphos @2 ml/litre water for 1 kg seed or imidachloprid @0.7 ml/litre water
Harvesting	Harvest when the earheads are dry either by cutting the whole plant by sickle or the ears separately
Threshing	Thresh after drying for a few days with a stone roller or by trampling under the feet of bullocks
Inter-cropping	Foxtail millet : pigeon pea (5:1), Foxtail millet : ground nut (2:1); Foxtail millet : cotton (5:1)

Blast disease is one of the major diseases of foxtail millet. Other diseases are leaf spot, downy mildew, sheath blight and rust. Shoot fly is one of the important pests, which results in dead hearts leading to yield loss. Lodging is another important yield and quality reducing factor depending on the environmental conditions. The field should be kept free from weeds for higher yields.

Improved varieties

A number of varieties with high yield potential have been released for different states (Table 3). New varieties have a yield potential of 2000–2600 kg/ha. Short duration varieties like SiA 3085 and SiA 3088 (Surya Nandi) are becoming popular in the major cultivated areas. Foxtail-chickpea system has significantly increased the income in Kurnool, Andhra Pradesh. In paddy fallows also, short-duration foxtail millet is becoming popular in Kurnool in view of limited water supply.

Table 3. Popular foxtail millet varieties

State	Varieties
Andhra Pradesh and Telangana	Renadu (SiA 3223), Garuda (SiA 3222), SiA 3088, SiA 3156, SiA 3085, Lepakshi, SiA 326, Narasimharaya, Krishnadevaraya, PS 4
Karnataka	HN 46, DHFt-109-3, HMT 100-1, SiA 3156, SiA 3088, SiA 3085, SiA 326, PS 4, Narasimharaya,

Renadu (SiA 3223)

Garuda (SiA 3222)

ATL 1

SiA 3156

High yielding varieties of foxtail millet

State	Varieties
Tamil Nadu	ATL 1, CO (Ten) 7, TNAU 43, TNAU-186, TNAU 196, CO 1, CO 2, CO 4, CO 5, K2, K3, SiA 3088, SiA 3156, SiA 3085, PS 4
Rajasthan	Prathap Kangani-1 (SR 51), SR 11, SR 16 (Meera), SiA 3085, SiA 3156, PS 4
Uttar Pradesh	PRK 1, PS 4, SiA 3088, SiA 3085, Sreelaxmi, Narasimharaya, SiA 326, S-114
Uttarakhand	PS 4, PRK 1, Sreelaxmi, SiA 326, SiA 3156, SiA 3085
Bihar	RAU-2, SiA 3088, SiA 3156, SiA 3085, PS 4

SUMMARY

Foxtail millet is a nutritious, climate change-compliant crop that grows well under marginal soils with less management. The area under the crop is declining due to competition from other crops. There is scope to expand area through organized seed production of high yielding varieties and supply to different parts of the country. Better crop management has to be adopted to realise high yield potential of improved varieties. Policy interventions to promote foxtail millet cultivation can ensure food, nutrition, fodder and livelihood security. Good processing interventions and value-added food products will definitely enhance the profitability to the foxtail millet farmer.

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Barnyard millet:

Recent advances and improved technologies

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Barnyard millet (Echinochloa frumentacea), *due to its remarkable ability to withstand erratic rainfall and varying weather conditions has been classified as one of the drought stress hardy crop. It is largely cultivated in harsh and fragile environments, with minimal use of agricultural inputs. Barnyard millet with rich nutritional profile is one of the best choices for patients with dietary based health defects like diabetic, heart related diseases and celiac diseases. Presently, crop improvement programmes in barnyard millet are targeting recombination breeding, use of molecular markers, tagging genes/QTLs for nutritional qualities, biotic and abiotic stresses, improving/modifying the crossing techniques, mutation breeding to enhance the diversity etc. However, the whole genome sequencing in Indian barnyard millet is necessary to understand its adaptability and dissecting the phenotypic characters at genotypic level and utilizing the information in improving the yield contributing traits to break the stagnated yield levels.*

Keywords: Barnyard millet, Germplasm, Recombination, Sequencing, Varieties

BARNYARD millet is becoming one of the most important minor millet in the world specifically in India because of its multiple uses like food, feed and fodder. It is scientifically named as *Echinochloa* sp. which contains two major species *Echinochloa esculenta* (Japanese barnyard millet) and *Echinochloa frumentacea* (Indian barnyard millet) cultivated for human consumption and livestock feed. Globally, India is the biggest producer of barnyard millet, both in terms of area (0.146 m ha) and production (0.147 mt) with average productivity of 1034 kg/ha during the last 3 years (IIMR 2018). It is less susceptible to biotic and abiotic stresses and mainly cultivated in marginal lands in fragile soils. Barnyard millet is a good source of protein, carbohydrates, fibre and most notable micronutrients like iron and zinc, and vitamins. Despite of its agronomic and nutritional benefits, this crop has remained as underutilized orphan crop. Recently, after the establishment of ICAR-Indian Institute of Millets Research (IIMR) and collaborative works with ICAR-National Bureau of Plant Genetic Resource (NBPGR), New Delhi and International Crops Research Institute for Semi-arid Tropics (ICRISAT), Patancheru, Hyderabad the progress has been achieved in the areas like characterization of large number of germplasm resources, identification of trait specific accessions, discoveries of genes/QTLs, transcritpome analysis studies, genome sequencing (Japanese barnyard millet) etc. In this article we are highlighting the recent advances in genetic and genomic resources development, and improved technologies in barnyard millet.

Recent advances in barnyard millet improvement

Echinochloa sp. belongs to the family Poaceae, sub-family Panicoideae, in which 35 related species are identified for their *taxa* and phylogenetic relationships through morphological, biochemical and molecular markers. Globally, 8000 germplasm accessions were conserved at different centres, viz. Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), India; Indian Institute of Millets Research (IIMR), India; National Institute of Agro-biological Sciences (NIAS), Japan and Consultative Group on International Agricultural Research like International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), India. Core collection comprising of 89 accessions was established from the main set of 736 germplasm lines representing the entire diversity based on phenotypic and genotypic characterization. Three potential and trait specific genetic stocks (easy dehulling, glumeless mutant and grain smut disease resistant) were registered with national Gene Banks (NGB) to protect from IPRs and also to facilitate the breeders to use in crop improvement programmes. In India more than 20 improved varieties were released for cultivation in different parts. Breeding methods followed in barnyard millet were mainly pureline selection and pedigree method. Most of the developed varieties were based on selections from germplasm accessions, viz. K1 released from Tamil Nadu and PRJ 1 from exotic collections released from VPKAS Almora. Recently crop improvement programmes are concentrating on recombination breeding followed by pedigree method. Presently DHBM 93-3 and VL 207 are used as national checks in AICRP on small millet system which were developed based on pedigree method of breeding. The use of chemical hybridizing agents (CHAs) for inducing male sterility was tried at ICAR-IIMR, Hyderabad in which treatment of alcohol at 15% concentration and Ethrel at 1500 ppm was found best for inducing male sterility up to 40% and 75% respectively. Contact methods crossing and hand emasculation, and pollinations were improved to get more number of hybrid seeds than selfed seeds in barnyard millet at ICAR-IIMR, Hyderabad (IIMR, Annual Report-2021). With the improved methods of crossing and identified trait specific accessions as donor parents, the improvement programme in barnyard millet has reached faster rate.

Various scientists used molecular markers to understand the phenotype at genotypic level. The scientist's team from China has released the whole genome sequence of the weedy species *E. cruss-galli* (Japanese barnyard millet) and reported that the total genome length is 1.27 Gb representing 90% of the predicted genome size. However, in Indian barnyard millet, very limited attempts have been made to discover the genomic structure and associated downstream processes due to its genome complexity and lack of research funding on this orphan crop. The genome sequence information of Indian barnyard millet has yet to be sequenced for better understanding and to bring quick improvements in the development of improved cultivars. Whole genome sequencing and publishing in the peer reviewed journals will positions India at the international levels in the scientific achievements in agriculture field.

Improved technologies in barnyard millet

With the advancement of technologies and bringing recombination breeding efforts to combine two parents has brought high yielding cultivars in barnyard millet. Five improved varieties and their yielding ability with state in which they are under cultivation are given as:

1. VL 207: Medium maturing variety

Year of release: 2008
Production condition: Rainfed/*kharif*
Recommended states: All states except Gujarat and Tamil Nadu
Salient features:

- Medium maturing (85–100 days)
- Narrow leaf with erect growth habit
- Presence of culm branching
- Green plant pigmentation at flowering
- Leaf lamina pigmented with purple colour
- Compact and pyramidal type of inflorescence
- Purple glume pigmentation at seed maturation stage

VL 207 (Barnyard millet)

2. CO2: Medium maturing variety

Year of release: 2008
Production condition: Rainfed/*kharif*
Recommended states: Tamil Nadu
Salient features:

- Medium maturing (95–100 days)
- Narrow leaves with erect growth habit
- Cylindrical and purple coloured inflorescence
- Absence of culm branching
- Compact panicle type

CO2 (Barnyard millet)

3. DHBM93-3: Medium maturing variety

Year of release: 2016
Production condition: Rainfed/*kharif*
Recommended states: All states except Uttarakhand and Himachal Pradesh
Salient features:

- Higher grain yield (24.0 q/ha)
- Higher fodder yield (5.5–6.5 t/ha)
- Compact earhead
- Sturdy tillers with lodging resistance
- Pale green leaf colour
- Tolerance to shoot fly
- Resistant to head smut and grain smut

DHBM-93-3 (Barnyard millet)

4. MDU1: Medium maturing variety

Year of release: 2018
Production condition: Rainfed/*kharif*
Recommended states: Tamil Nadu
Salient features:

- Medium maturing (100–105 days)
- Broad leaf with erect growth habit
- Presence of culm branching
- Green plant pigmentation at flowering
- Compact and pyramidal type of inflorescence

MDU1 (Barnyard millet)

5. DHBM23-3: Medium maturing variety

Year of release: 2019
Production condition: Rainfed/*kharif*
Recommended states: Andhra Pradesh, Karnataka, Madhya Pradesh and Tamil Nadu
Salient features:

- Higher grain yield (32.0 q/ha)
- Higher fodder yield (6–7 t/ha)
- Semi-compact earhead
- Panicles are glume pigmented at seed maturation stage
- Thin and more tiller bearing variety
- Tolerance to shoot fly
- Resistant to head smut, grain smut

DHBM-23-3 (Barnyard millet)

SUMMARY

Despite its agronomical and nutritional values, and health benefits, barnyard millet has remained as an underutilized crop and very less attention was given for its improvement. This crop has become orphan crop because of lack of funding from agencies and research organizations. Whole genome sequencing of crops adds an advantage of understanding the plant at its genetic and molecular level, and identification of genes and molecular markers strengthens and fastens the breeding programmes. Specifically sequencing of Indian barnyard millet species (*Echinochloa frumentacea*) is of prime importance to know the genetic architecture and compare with Japanese barnyard millet species and to identify the genes/QTLs responsible for high grain and biomass yield. However, the recent advances in recombination breeding with improved crossing techniques and identified trait specific parental lines has given more scope to break the stagnated yield levels.

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FEW FACTS

All manufacturers claim their own cooking oil is the best! Canola oil, olive oil, sunflower oil, butter, margarine, and virgin coconut oil all have their supporters. But the fact is that all liquid oils are about the same. They all provide about 120 calories per tablespoon. Unless you drink your cooking oil, or deep-fry every day, your choice of cooking oil doesn't make a huge difference. It's good that we pay attention to our oil. But the fact is, the major source of oil in our diets isn't home cooking – it's packaged foods and fast-food meals! If we're concerned about GMO (Genetically Modified Cooking Oils), it's likely that corn, soy, and canola oils are genetically-modified. There're non-GMO, organic kinds of these oils available. So check the label. Choose sunflower oil or canola oil if you wish to fry foods, as these oils have a higher smoke point. It is best not to fry with extra-virgin olive oil, as its smoke point is only about 190°C/375°F.

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Kodo millet varieties

released in India for cultivation

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Kodo millet a small seeded annual cereal grass, is one of the oldest crops cultivated in India. It is one of the hardiest crops among the small millets. In this article information on released varieties of kodo millet from 1977–2012 is collected from the report on compendium on released varieties of small millets prepared by Porject Coordinating unit, All India Coordinating small millets improvements project, GKVK, Bengaluru and also updated with information on recently released varieties up to 2021. The following information will be helpful in selecting the varieties suitable for particular agro-climatic zones.

Keywords: Disease resistance, High yielding, Kodo millet, Varieties

KODO millet (*Paspalum scrobiculatum)* is widely distributed in damp habitats of tropics and subtropics of the world. It is indigenous cereal of India mainly grown in Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Tamil Nadu, Maharashtra, Karnataka and some parts of Andhra Pradesh. It is also known as kodo (Hindi), Varagu (Tamil), Arika (Telugu), Harka (Kannada), Kodra (Gujarati, Marathi and Punjab) and Kodua (Oriya). In India, it is wide spread and grown in about 2.44 lakh ha (2005–06) in many states in south, west, central and north, producing about 0.73 lakh tonnes of grains with a productivity of about 312 kg/ha. Madhya Pradesh (0.50 lakh tonnes) and Chhattisgarh (0.17 lakh tonnes) accounts for nearly 80% area under this crop followed by Tamil Nadu (0.12 lakh tonnes), Maharashtra (0.08 lakh tonnes), Uttar Pradesh (0.07 lakh tonnes) and Gujarat (based on mean production during 2001–06). The crop possesses a number of valuable characteristics such as more herbage, branched ear, large number of seeds per raceme, high fertility and unique storage ability. It has considerable production potential in marginal, low fertility soils and chronic moisture deficit areas of the country. These characteristics of kodo millet are mainly responsible for its existence and survival in many parts of recent modernized agricultural systems. Varieties of kodo millet released from 1977–2021 are given in Table 1.


Improved varieties of kodo millet (TNAU 86, RK 390-25; released in 2012)

Table 1. Released varieties of kodo millet from 1977–2021

Name	Pedigree	Year	Days to maturity	Yield (q/ha)	Recommended area	Salient features
CKMV 1 (ATL 2)	Pure line selection from DPS 63/58	2021	106–110	28	Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Tamil Nadu and Telangana	High yielding, early maturity, drought tolerant, resistant to diseases and pests
CKMV 2' (GAK 3/Dahod Kodo)	Pure line selection from germplasm RK 286	2020	105–110 days	25	Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh and Tamil Nadu	High yielding, resistant to shoot fly and moderately resistant to head smut, non-shattering
GK4	Pure line selection from locally collected germplasm of Hilly regions of Dahod district of Gujarat and maintained with code No. DK-159	2020	106–113	27	Madhya Pradesh, Gujarat, Maharashtra, Tamil Nadu, Chhattisgarh, Andhra Pradesh and Karnataka	High yielding
KMV-543	Mutant of CO-3	2019	105–110	25–27	Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh and Tamil Nadu	High yielding
Jawahar Kodo 137	Mutant of RK 390	2018	100–105	26–29	Madhya Pradesh	High yielding and drought tolerant
RK 390-25	Mutant of RK 390	2012	100– 105	25–28	All states	Moderately resistant to head smut, high yielding, non shattering and non lodging
TNAU 86	Pure line selection from IPS 85	2012	95–110	27–30	All states	Resistant to head smut, sheath blight, brown spot and tolerant to drought, Early duration, non-lodging, high yielding and milling recovery (52–53%)
INDIRA KODO1	Pure line selection	2012	100–105	22–25	Chhattisgarh	Highly responsive to fertilizers, suitable for late sown condition
DPS 9-1	Pure line selection	2011	105–110	26–28	Madhya Pradesh	Resistant to head smut, high yielding
JK 98	Pure line selection from 317	2010	100–105	25–30	Madhya Pradesh	Moderately resistant to head smut, tolerant to shoot fly, early duration, high yielding
JK 36	Pure line selection	2009	75–80	10–12	Madhya Pradesh	Moderately tolerant to Shoot fly, very early duration
JK 65	Pure line selection	2009	105–110	25–30	All states	Resistant to head smut, Fodder yield 6.2–6.3 t/ha, high yielding
JK 106	Pure line selection	2009	100–105	19–20	Madhya Pradesh	Resistant to head smut, Fodder yield 4.7–4.8 t/ha, high yielding
JK 13	Mutant of JK 76	2007	95–100	22–30	All states	Resistant to head smut, Fodder yield 4.5–4.6 t/ha, high yielding
JK 439	Pure line selection	2004	100–110	22–23	Chhattisgarh and Madhya Pradesh	Suitable for shallow soil with marginal fertility (specially hill top soil), high yielding
KK 2	Pure line selection	2002	80–85	20–23	Uttar Pradesh	Resistant to head smut, tolerant to shoot fly and drought, suitable for saline condition, early duration, non lodging, high yielding

Name	Pedigree	Year	Days to maturity	Yield (q/ha)	Recommended area	Salient features
JK 48	Pure line selection	2001	95–100	26–27	All states	Resistant to head smut, tolerant to drought, non lodging, non shattering, high yielding
JK 155 (RBK 155)	Selection from GPLMP 251	2000	80–100	20–22	Karnataka and Madhya Pradesh	Resistant to head smut, early duration
KK 1 (ICK 7125)	Pure line selection from Deoria district of UP	1999	80–85	18–20	Uttar Pradesh	Resistant to head smut, tolerant to drought and salinity, synchronous tillering, non-lodging
KMV 20 (VAMBAN 1/ VARGU 1)	Pure line selection from pali	1996	100–110	16–18	Tamil Nadu	Resistant to head smut and tolerant to drought
GK 2 (GUJARAT KODRA 2)	Pure line selection	1993	110–115	15–18	GAU, Waghai, Gujarat	Tolerant to drought, non shattering, non lodging
APK 1 (VARAGU)	Pure line selection from PSC 5	1993	100–105	18–20	Tamil Nadu	Resistant to ergot, smut and tolerant to stem borer, high yielding, non-lodging and non-shattering
GPUK 3	Pure line selection from GPLM 826	1991	100–105	18–20	All states	Resistant to head smut and moderately tolerant to low moisture stress, photo insensitive, high yielding
JK 76	Pure line selection from local germplasm of Sidhi	1991	85–90	18–22	Madhya Pradesh	Moderately tolerant to shoot fly and tolerant to drought, early duration, high yielding and non-lodging
JK 62	Pure line selection	1986	90–100	20–22	All states	Resistant to head smut and bacterial blight, non lodging, high yielding
JK 41	Pure line selection	1986	105–110	20–22	Plains of Madhya Pradesh, Gujarat and South India	Resistant to head smut and moderately drought tolerant, non lodging, stay green character, suitable for inter/mixed cropping
PSC 1	Pure line selection from IPS 115	1986	100–105	18–20	All states	Moderately tolerant to shoot fly and drought, high yielding, non lodging
JK 2 (DINDORI 73)	Pure line selection	1982	110–120	20–22	Madhya Pradesh	Profuse tillering, high yielding
JK 1 (PALI)	Pure line selection from local bulk	1982	110–120	18–20	Madhya Pradesh	Profuse tillering, high yielding
CO 3	Pure line selection from PS175	1980	115–120	12–13	Tamil Nadu	high yielding
K 1	Pure line selection from KPS 209 (IPM 600)	1982	100–105	12–14	Tamil Nadu	Profuse tillering, high yielding
JNK 364	Pure line selection	1977	95–100	18–20	Madhya Pradesh	Tolerant to drought, early duration
GK 1 (GUJARAT KODRA 1)	Pure line selection from IPS 19	1977	115–120	20–25	Western Ghats of Gujarat	High yielding

SUMMARY

Varietal information is useful for selecting high yielding kodo millet varieties suitable for different agro-climatic zones with various key features such as resistance to head smut, sheath blight, brown spot and shoot fly, drought tolerance, non-lodging, non-shattering, early maturity and high milling efficiency.

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Millets diversity:

Genetic resources management

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The global as well as Indian agriculture has witnessed tremendous growth in food production in the recent decades; however it is also facing challenges such as climate change and malnutrition. In this regard, millets provide a great opportunity due to their hardy and climate resilient nature. They can be an alternative option to replace the conventional crops in the dry and marginal areas. In addition to their climate resilience, millets are also rich in several vital micronutrients and vitamins necessary for reducing malnutrition and provide multiple health benefits. The national genebank at ICAR-NBPGR, New Delhi and ICAR-IIMR, Hyderabad, Telangana conserves approximately one lakh accessions of millet germplasms which can be of great use in the identification and development of improved millet cultivars. This article enlists the status of millet genetic resource management which combines the activities such as collection, conservation, evaluation, documentation and distribution of the millets genetic resources to the users (researchers).

Keywords: Genetic resources, Germplasm, Millets

ICAR-Indian Institute of Millets Research (IIMR), Hyderabad, Telangana is one of the National Active Germplasm Sites (NAGS) with the responsibility to collect, conserve, evaluate, document and distribute the millets genetic resources to the bonafide user within the country.

Collection

A total of 2273 accessions collected by NRCS/DSR/IIMR from 45 explorations and 423 accessions were collected by other individuals during 2000–2021. Indigenous collection numbers for 1928 accessions were obtained from National Genebank, ICAR-NBPGR, New Delhi. All eight millets were collected during the exploration which includes sorghum (2010), pearl millet (127), finger millet (244), foxtail millet (102), proso millet (19), barnyard millet (7), little millet (146) and kodo millet (41).

Augmentation

A total of 78,429 accessions received from various National and International centres includes, sorghum (52,757), finger millet (10,704), foxtail millet (5,096), pearl millet (4,973), proso millet (1,666) and barnyard millet (1,661). A total of 58,572 accessions of millets were augmented from ICAR-NBPGR, New Delhi and its regional stations followed by 7,887 accessions from CGIAR-ICRISAT, Patancheru, Hyderabad.

Characterization

A total of 62,789 accessions of millets germplasm were characterized during 2003–2021 in which 45,092 accessions were of sorghum followed by finger millet (7,002) and pearl millet (5,395).

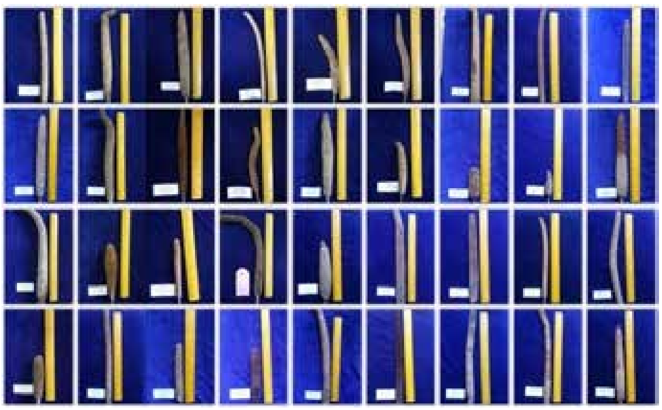
***Sorghum* (Sorghum bicolor)**: A total of 22000 accessions of sorghum germplasm were characterized at ICAR-IIMR–Hyderabad with three checks, viz.

Panicle diversity of sorghum germplasm resources conserved at ICAR-IIMR, Hyderabad

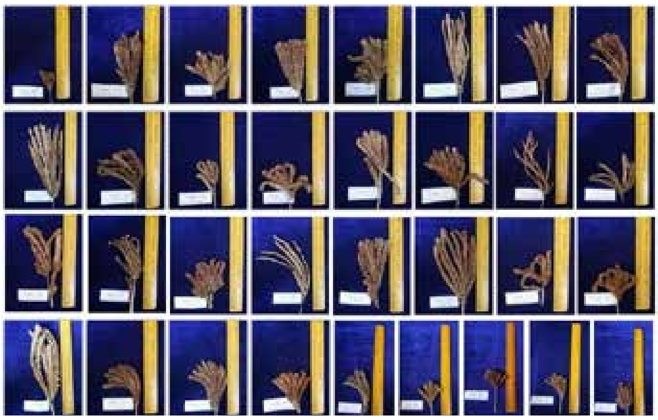
Diversity among different millet germplasm resources conserved at ICAR-IIMR, Hyderabad

M35-1, CSV 19R and CSV 27 in an Augmented Block Design. Data on 9 quantitative and 16 qualitative traits were collected. The plant height was the most variable character followed by grain weight and days to 50% flowering. A total of 106 accessions were identified for early flowering (<50 days), 319 for higher grain yield (>100.00 g/plant) and 297 for more 100-seed weight (>4.50 g).

***Pearl millet* (Pennisetum glaucum):** A total of 2016 accessions of pearl millet augmented from TNAU-Coimbatore were characterized at ICAR-IIMR, Hyderabad and data on 9 quantitative and 13 qualitative traits were collected. Total 62 accessions were identified for early flowering with less than 50 days and 25 accessions were identified for higher grain yield per plant with more than 35 g/plant.


Panicle diversity of pearl millet germplasm resources conserved at ICAR-IIMR, Hyderabad

***Finger millet* (Eleusine coracana):** A total of 5400 accessions were characterized for 14 quantitative and 18 qualitative traits. The grain yield per plant was the most variable trait followed by days to 50% flowering and leaf blade length. Total 13 accessions were identified with early flowering (<50.00 days), 64 were identified with higher grain yield (>90.00 g/plant) and 11 were identified with more 100-seed weight (>1.20 g).


Panicle diversity of finger millet germplasm resources conserved at ICAR-IIMR, Hyderabad

***Foxtail millet* (Setaria italica):** A total of 2580 accessions were characterized for 11 quantitative and 19 qualitative traits. The plant height was the most variable


Panicle diversity of foxtail millet germplasm resources conserved at ICAR-IIMR, Hyderabad

trait followed by grain yield and days to 50% flowering. Total 97 accessions were identified with early flowering (<40.00 days), 41 with higher grain yield (>70.00 g/plant) and 79 with more 100-seed weight (>0.35 g).

***Proso millet* (Setaria italica):** A total of 645 accessions of proso millet germplasm were characterized along with four checks, viz. GPUP 8, TNAU 145, TNAU 164 and TNAU 202 at ICAR-IIMR-Hyderabad for 23 agro-morphological traits including 11 quantitative and 12 qualitative traits. Total 442 accessions of trait specific germplasm were identified, in which 82 were multi-trait specific germplasm superior for 2–6 traits.

Panicle diversity of proso millet germplasm resources conserved at ICAR-IIMR, Hyderabad

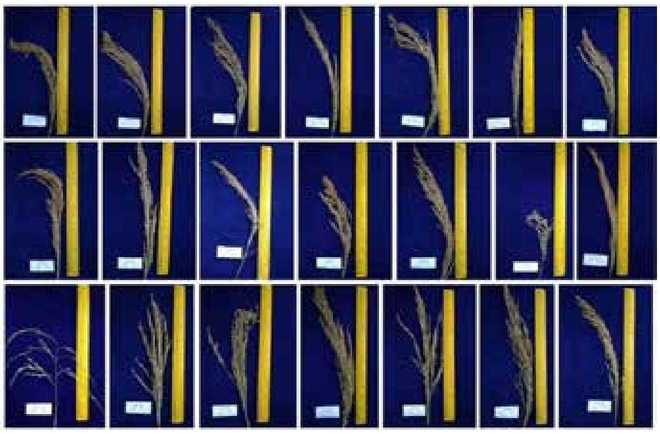
***Barnyard millet* (Echinochloa frumentacea):** A total of 553 accessions were characterized for 25 agro-morphological traits including 12 quantitative and 13 qualitative traits. Total 411 accessions of trait-specific germplasm were identified in which, 92 were multi-trait specific germplasm superior for 2–5 traits simultaneously.

Panicle diversity of barnyard millet germplasm resources conserved at ICAR-IIMR, Hyderabad

***Kodo millet* (Paspalum scrobiculatum):** A total of 69 accessions of core collections of kodo millet germplasm were characterized for 13 quantitative and 15 qualitative traits. Out of which 10 were early flowering (<56.00 days), 4 were with higher grain yield (>20.00 g/plant) and 17 were identified with more 100-seed weight (>0.40 g).

Panicle diversity of kodo millet germplasm resources conserved at ICAR-IIMR, Hyderabad

***Little millet* (Panicum flexuosum):** A total of 66 accessions of new little millet germplasm were characterized for 9 quantitative and 12 qualitative traits. The plant height is the most variable trait followed by days to 50% flowering and flag leaf length of blade. Four accessions were identified for early flowering (<55.00 days) and 4 with higher grain yield (>10.00 g/main plant).



Panicle diversity of little millet germplasm resources conserved at ICAR-IIMR, Hyderabad

Characterization at AICRP centres

A total of 94,081 accessions were characterized/ evaluated at NRCS/DSR/IIMR, AICRP on sorghum and small millets centres. The accessions include germplasm, resistant source materials and segregation materials. The maximum frequency of 62,789 accessions of millets germplasm materials was characterized during 2003–2021 in which 45,092 accessions belonged to sorghum followed by finger millet (7,002) and pearl millet (5,395); followed by 17,842 accessions for evaluation in which 11,210 belonged to sorghum followed by finger millet (2,960) and little millet (2,172).

The maximum frequency of 61,817 accessions of sorghum germplasm/segregating materials characterized/evaluated in which 26,271 were characterized/evaluated at Hyderabad followed by Akola (5,300), Rahuri (4,326), etc; followed by finger millet (18,262 accessions) in which 7,202 were characterized/evaluated at Hyderabad followed by Vizianagaram and Mandya (3,157 accessions each) etc.

Conservation

As on 31st March 2022, a total of 48,462 accessions of millets in bulk are being conserved in the Millets Genebank (MGB) (Table 1). Sorghum was maximum with 27,366 accessions followed by finger millet (8057), foxtail millet, (4573) pearl millet (4094), proso millet (1463), barnyard millet (1159), little millet (670), kodo millet (333), tef (36), browntop millet (25), quinoa (12) and jobs tears (1).

Table 1. Status of millets genetic resources conserved at the ICAR-IIMR, Hyderabad, Genebank

Crop	World				Indian origin			NGB-ICAR-NBPGR	MGB-ICAR-IIMR
	FAO Trust	Others	Total	Actual	FAO Trust	Others	Total		
Sorghum (IS)	27005	625	27630	32000	4249	28	4277	20376	27140
Pearl millet (IP)	21563	1325	22888	23881	6602	8	6610	7841	4128
Finger millet (IE)	5949	855	6804	8424	1364	36	1400	11587	7806
Foxtail millet (ISe)	1535	7	1542	1916	978	7	985	4244	4653
Kodo millet (IPs)	656	9	665	937	654	9	663	2362	344
Little millet (IPmr)	462	11	473	1083	455	11	466	1885	694
Proso millet (IPm)	835	14	849	2919	69	7	76	1005	2128
Barnyard millet (IEc)	743	6	749	799	447	6	453	1888	1705
Total	58748	2852	61600	71959	14818	112	14930	51188	48598

Utilization

A total of 48 final products were contributed using the ICAR-IIMR, Hyderabad germplasm through selection/ breeding by the AICRP on sorghum trials during 2007–2021. Maximum of 22 *rabi* sorghum varieties followed by 6 sweet sorghum varieties, 7 *kharif* sorghum varieties, 1 *kharif* sorghum hybrid, 5 single-cut forage varieties, one each of sweet sorghum variety, sweet sorghum hybrid and dual-purpose varieties, 3 specialty sorghum contributed to the trials.

Distribution

A total of 1,21,077 accessions were distributed to the bonafide users in the country and 1,079 MTAs were signed for supplying the germplasm. A maximum of 24,827 accessions were distributed to the bonafied users during 2012–13 followed by 17,981 in 2021–22. A maximum frequency of 17,000 accessions of millets germplasm were distributed and utilized for salinity and drought tolerant screening at Gujarat/Rajasthan followed by 7,500 accessions for screening leaf blast, neck blast and finger blast, and 6,160 accessions of germplasm were evaluated for yield attributing traits.

Submission to National Genebank

A total of 29,508 accessions were submitted to the national Genebank for long-term storage during 2000–2021. A maximum of 4,179 accessions were submitted during 2016–2017 followed by 2,963 during 2020–2021.

Genetic stocks registration with ICAR-NBPGR, New Delhi

A total of 112 millets genetic stocks were registered with ICAR-NBPGR, New Delhi during 2002–2022. A maximum of 84 accessions of sorghum genetic stocks were registered followed by finger millet (19), barnyard millet (4), foxtail millet (3) and little millet (2).

Registered germplasm lines from ICAR-IIMR, Hyderabad

Documentation

The data on characterization, conservation, distribution and utilization of millet genetic resources has been published regularly in the form of annual reports (19), AICRP reports (23), pedigree database (4), distribution database (4) and elite breeding stocks report (3).

SUMMARY

India being the primary origin for little millet, kodo millet and barnyard millet; secondary origin for sorghum and finger millet occupied the semi-arid regions, the adaptation, and diversity of these millets' germplasm are exclusive to India for some extent. There is a necessity for re-introduction of millets local landraces in the region of collections to rejuvenate their natural habitat. More emphasis has to be given on characterization of millets germplasm for nutritional parameters. There is an urgent need for evaluation of millets germplasm in adverse agro-climatic conditions of the country to identify the climate resilient germplasm. Increased demand for millets is created through creation of awareness owing to conduct of special drives and campaigns on the benefits of millets among the consumers. However, availability of millets to the poor may be enhanced through inclusion of millets in public distribution system.

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Improved agronomic practices

for enhanced productivity of small millets

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Small millets termed as nutri-cereals hold great promise for food and nutrition security amid burgeoning population and climate change. Nutritionally, these are superior to the cereals in terms of protein, minerals and amino acids. In India, small millets are largely cultivated under resource constraint conditions resulting in low crop productivity. Thus adoption of improved agronomic practices is the key to increase their productivity and project them as golden crops of the future.

Keywords: Agronomic strategies, Millets, Production

MILLETS are small seeded annual cereal grasses and are the oldest and first crops to be domesticated and cultivated. They are classified into major (sorghum, bajra) and minor/small millets (finger millet, foxtail millet, proso millet, barnyard millet, little millet, kodo millet and brown top millet) based on their seed size and extent of cultivation. They are a staple food with superior nutritional qualities compared to other cereals and thus referred as "nutricereals". India is one of the major producers of millets in the world and accounts for more than 40% of the global consumption. Small millets are idyllic crops to cultivate in diverse soils, climates and harsh environments and require low inputs. Their grains contain higher protein, fibre, calcium and minerals than the widely consumed fine cereals, and can ensure nutritional security to the poor people who can not afford dietary diversity. These crops are last standing crop in times of severe drought and are considered as wonder grain that has a capability to enhance nutritional security in the country. Despite their nutritional qualities and climate resilience, the area under small millet cultivation is declining due to shift in area to other remunerative crops, lack of awareness and low production levels. The need of the hour is to focus on enhancing cultivation and increasing production through improved agronomic practices.

Selection of improved varieties/cultivars

Development of high yielding varieties with wide adaptability resulted in increased production despite the decline in area under cultivation. A list of some of the promising small millet cultivars in India are given in Table 1.

Table 1. Promising varieties of small millets

Crop	Varieties
Finger millet	VR 929, VL 376, VL 379, CFMV 1, Indravathi, CFMV 2, GPU 28, GPU 66, GPU 67
Foxtail millet	SiA 3156, SiA3088, SiA 3085, SiA2644, SiA 2593
Barnyard millet	DHBM 93-3, DHBM 23-3, CO 1, CO 2, VL 181, VL 29
Little millet	CLMV 1, Sree Neelima, OLM 203, OLM 217, CO 4, DHLM 36-3, JK 8, LMV518
Proso millet	PR 18, TNAU 202, TNAU 145, GPUP 21, Bhawna, TNAU 164, TNAU 151, Sagar, Nagarjuna, CO 4, CO 3, ATL 1(TNPm230), GPUP 25
Kodo millet	GPUK 3, TNAU 86, RK 390-25, JK 41, RBK 155, ATL-2, BK-36

Climate and soil requirement

Millets are hardy crops and can withstand harsh environmental conditions better than other cereals. They can be grown in both tropical and sub-tropical regions. Millet has wide adaptability to different soil from very poor to very fertile and can tolerate a certain degree of alkalinity. The best soils for their cultivation are alluvial, loamy and sandy soil with good drainage.

Land preparation

Millets require fine tilth for crop establishment, initial root and shoot development. One ploughing followed by 2–3 harrowing and cross plantings is necessary to obtain fine tilth. Levelling of fields is necessary for adequate drainage.

Foxtail millet plant and seed

Proso millet plant and seed

Kodo millet plant and seed

Little millet plant and seed

Barnyard millet plant and seed

Finger millet plant and seed

Some promising varieties of small millets

Optimum time of sowing

Millets are grown in almost all the seasons of the year. The best time for sowing *kharif* crop is last week of June to first week of July depending on the onset of monsoon. Whereas *rabi* crop is sown in the month of October–November and summer crop in the month of January–February. In Bihar and Uttar Pradesh, these crops as grown as irrigated catch crop in the month of mid-March to mid-May.

Seed rate and spacing

Optimum seed rate and spacing ensures higher yield in millets. Seed rate depends on the method of sowing and seed size. The recommended seed rate to achieve the required plant population of ~4.0–5.0 lakh/ha for most of the millets is given in Table 2. The line to line distance at the time of sowing should be 20–30 cm and plant to plant distance should be 10–15 cm

Table 2. Optimum seed rate for higher yield in small millets

Crop	Method of sowing	Seed rate
Finger millet	Line sowing	5–6 kg/ha
	Transplanting	4 kg/ha
Other small millets	Line sowing	5–6 kg/ha
	Broadcasting	8–10 kg/ha

Fertilizers/nutrient management

Millets respond well to fertilizer application especially to nitrogen (N) and phosphorus (P). The recommended doses of fertilizers vary from state to state and with seasons. Judicious use of organic and inorganic manures enhances the fertilizer efficiency (Table 3). Entire P_2O_5 and K_2O should be applied at sowing, whereas nitrogen should be applied in 2 or 3 split doses depending upon moisture availability. In areas of good rainfall and moisture availability, 50% of recommended nitrogen should be applied at sowing and the remaining 50% in 2 equal splits at 25–30 and 40–45 days after sowing (DAS). In areas of uncertain rainfall, 50% nitrogen at sowing and the remaining 50% around 35 DAS is recommended.

Table 3. Recommended dose of fertilizers in small millets

Crop	Season/soil	Dose
Finger millet	Irrigated	60:30:30 kg NPK/ha
	Rainfed	40:20:20 kg NPK/ha
Other small millets	Irrigated	40:20:00 kg NPK/ha
	Rainfed	20:20:00 kg NPK/ha

Irrigation/water management

Millets are grown as rainfed crop and do not require any irrigation. However, based on the availability of water, 1 life-saving irrigation and 3–4 irrigations at critical stages of growth i.e. tillering, flowering and grain developmental stage needs to be given. Summer crop requires 2–5 irrigations depending upon soil type and climatic conditions.

Weed management

Millets do not compete well with weeds during early growth until 4–5 weeks after planting, thus requires special attention during this phase. Adoption of preventive measures like proper seedbed preparation (to ensure uniform stands), appropriate spacing (to ensure adequate plant populations), covering the soil surface with intercrops or cover crops and practicing proper crop rotation with densely growing legumes suppresses weeds. Application of one pre-emergence spray followed by hand weeding at 20–25 DAS, effectively controls the initial flush of weeds. Inter-cultivation/hand hoeing 2 or 3 times at 3, 5 and 7 weeks after sowing is recommended to check the weed growth, which also helps to conserve soil moisture by providing top soil mulch.

Harvesting and threshing

Harvesting at appropriate time is necessary to avoid shattering and post-harvest losses. The crop is ready for harvest in 70–150 days after sowing depending on the crop and variety.

Small millet + Pigeon pea intercropping

Finger millet + Soybean intercropping

Cropping systems

Small millets fit well in cropping systems. Some of the promising cropping systems are:

- Millet + Black gram/green gram/cowpea
- Millet + Sesamum/soybean/pigeon pea
- Millet + pigeon pea
- Millet - Niger
- Millets - Soybean

SUMMARY

Small millets have become integral components of subsistence agriculture by virtue of their high nutritional content and better resilience to adapt harsh weather conditions. Agronomically, these crops are superior to major cereals in terms of their lesser water requirement, lower occurrence of insect pests and diseases, and minimum vulnerability to environmental stresses apart from nutritional superiority. In order to enhance and sustain the millets productivity at desired levels for better food and nutritional security, refinement and adoption of improved agronomic practices needs greater emphasis.

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INTERNATIONAL YEAR OF MILLETS 2023

Emerging pests
of millets and their management

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There are about 150 insect pests reported in millets out of which shoot flies, stem borers and earhead midges are considered as major pests. In India, yield losses of 10–20% have been reported in millets due to insect pests. Shoot flies and stem borers are associated with millets and cause huge damage apart from many sucking pests. Few pests are newly observed attacking millets and few minor pests have become major in some regions. For most of the recently recorded pests, information on factors responsible for their outbreak, bionomics, yield losses etc is needed before planning their control operations. As an immediate remedy, chemicals have been used mainly on high yielding varieties and hybrids. However, a combination of cultural practices and resistant cultivars has proved to be effective.

Keywords: Insect pests, Integrated pest management, Millets, Sorghum

THE overall incidence and damage by different pests varies in time and space and is reflected in low grain yields at farmer´s fields. Some insect pests are associated with millet crops whereas pests like white grubs are specific to some region (Table 1). Sporadic attacks of blister beetles, armyworms, grasshoppers, chinch bugs, leaf beetles, head caterpillars and head bugs result in severe yield losses in certain seasons.

Table 1. Major insect pests of millets and sorghum in India and their status

Common name	Damaging stage	Plant part attacked
Pearl millet		
Shoot fly	Maggot	Growing point
Grey weevil	Grubs	Roots
Spotted stem borer	Larvae	Stem, leaves, growing point
Pink borer	Larvae	Stem, leaves
White grubs	Grubs	Roots
Kodo millet		
Shoot fly	Maggot	Growing point
Gall midge	Maggot	Spikelet
Stem or Pink borer	Caterpillar	Stem
Foxtail millet		
Shoot fly	Maggot	Growing point
Flea beetle	Adult	Leaf
Army worm	Caterpillar	Leaf
Leaf roller	Caterpillar	Leaf
Little millet		
Shoot fly	Maggot	Growing point
Gall midge	Maggot	Spikelet
Proso millet		
Shoot fly	Maggot	Growing point
Termites	Workers	Seed to seedling
Barnyard millet		
Shoot fly	Maggot	Growing point
Pink borer	Caterpillar	Stem/leaf
Finger millet		
Pink or stem borer	Caterpillar	Stem/leaf
Sorghum stem borer	Caterpillar	Stem
Earhead caterpillar	Caterpillar	Ear
Root aphid	Nymph and Adult	Root
Leaf hopper	Nymph and Adult	Leaf
Sorgum		
Shoot fly	Maggot	Growing point
Stem borer	Caterpillar	Stem/leaf
Pink stem borer	Caterpillar	Stem/leaf
Shoot bug	Nymph and Adult	Leaf
Aphids	Nymph and Adult	Leaf/panicles
Earhead bug	Nymph and Adult	Ear

Seedling stage pests

Shoot flies: Shoot fly is a seedling pest and normally occurs in the 1st–4th week after germination. The adult is small (3 mm long); dark grey housefly like with its abdominal segments marked with dark spots. The maggot enters the seedling through the whorl and destroys the growing point and exhibit `dead heart' symptoms.

Shoot fly damage in millets

Foliage pests

Leaf caterpillars: Moths of leaf caterpillars emerge with the onset of monsoon and lay eggs in clusters. Early-stage larvae feed gregariously on plants, later stages spread across the field and feed voraciously. Fully gown larvae are reddish brown and hairy all over the body causing severe defoliation.

Cutworms and army worms: They cut tender stems of young and growing plants. Larvae hide during day time in the soil and become active at dusk. In severe cases, entire foliage is eaten making the field appear as if grazed by cattle.

Sucking pests

Both nymphs and adult of aphids, shoot bugs, plant bugs, suck the sap from young leaves and whorls causing distortion, yellowing and wilting of plants leading to shrivelled and chaffy grains. Few sucking pests are also vectors of plant diseases.

Aphids: Colonies of immature and adult aphids can be seen in central leaf whorl, stems, or in panicles sucking the plant sap. Severe infestation causes yellowish mottling of the leaves and marginal leaf necrosis, and stunted plants. Aphids produce honeydew on which molds grow.

Shoot bug: The adult is yellowish brown to dark brown with translucent wings. Nymphs and adults suck the plant sap causing reduced plant vigour and yellowing. In severe cases, the younger leaves start drying and gradually extend to older leaves. Heavy infestation at vegetative stage may twist the top leaves and prevent either the formation or emergence of panicles.

Stem borers

Among the stem borers, *Chilo partellus* and *Sesamia inferens* are pre-dominant in India. Pearl millet appears to be immune to stem borer attack at initial stages of crop growth, but it becomes susceptible to internodes injury in latter stage.

Spotted stem borer: The larvae feed on the upper surface of whorl leaves leaving the lower surface intact as transparent windows. As the severity of the feeding increases, blend of punctures and scratches of epidermal feeding appears prominently. Sometimes, dead heart symptoms also develop in younger plants due to early attack. Subsequently, the larvae bore into the stem resulting in extensive stem tunneling. Peduncle tunneling results in either breakage or complete or partial chaffy panicle. During the dry season, the larva enters into diapauses and survives in harvested stalks/ stems as well as stubbles left in the field.

Ragi stem borer/pink borer: The female moth lays about 150 creamy-white and hemi-spherical eggs that are arranged in 2 or 3 rows between the leaf sheath and the stem. The pink larva bores into the stem and damages the central shoot resulting in dead heart.

Stem borer damage in millets

Earhead pests

Sorghum midge: The adult fly is small, fragile with a bright orange abdomen and a pair of transparent wings. It lays eggs singly in developing florets resulting in pollen shedding. Larvae are colourless, but when fully grown, they are dark orange. It pupates beneath the glumes and when the adult emerges the white pupal skin remains at the tip of the spikelet.

Head beetles: Several species of beetles have been recently recorded in millet growing areas. They feed on flowers and inhibit the grain formation.

Head caterpillars: They feed on the developing grains and webbings with frass are often seen on the panicle.

Head bugs: Head bugs suck the sap from the developing grains, causing distortion and shrinking. Grains are later infected by fungus, causing blackening.

Pest management

Cultural methods

- Collect and burn stubbles and chaffy ear heads which will prevent the carryover of overwintering pest.
- Deep ploughing one month before planting will expose the immature stages of insects and predators that prey upon them.
- Adopt synchronous and timely/early sowings of cultivars with similar maturity to reduce the damage by shoot fly, midge and head bugs.
- Crop rotation is recommended with cotton, groundnut or sunflower, to reduce the damage by shoot fly, midge and earhead bugs. Intercropping

sorghum with pigeon pea, cowpea, or lablab also reduces the damage by stem borers.

- Use high seed rates 1.5 times more and delay thinning (to maintain optimum plant stand) to minimize shoot fly damage.

Mechanical method

- Set up light traps till midnight to monitor, attract and kill adults of stem borer, grain midge, June beetle and other moth pests.
- Set up the fishmeal traps impregnated with insecticide @12/ha till the crop is 30 days old.

Biorational methods

- Apply balanced fertilizers having adequate NPK to promote better plant growth, that results in reduced damage by shoot fly and stem borers.

Chemical methods

- Treat the seeds with thiamethoxam 30 FS @10 ml/kg of seeds to reduce the damage by shoot fly and to some extent stem borer and sucking pests.
- When the shoot fly damage reaches 5–10% of the plants with dead hearts, the crop may be sprayed with cypermethrin 10 EC (750 ml/ha) or quinalphos 25 EC (400 g a.i./ha) or carbofuran granules (5–7 granules/plant) may be applied in the leaf whorls.
- For stem borers, carbofuran 3 G granules may be applied in the whorls @8–12 kg a.i/ha.
- For earhead bugs (1–2 bugs/panicle) and head caterpillars (2–3 larvae/panicle), the crop may be sprayed at the completion of flowering and at the milk stage with cypermethrin 25 EC @0.5 ml/litre.
- For managing sucking pests like shoot bug, aphids, apply dimethoate 0.03% and neem seed kernal suspension 0.04%+soap.

SUMMARY

The available evidence suggests that pearl millet and finger millet are relatively less affected by insect pests compared to other millets and sorghum. There is a need to generate data on yield loss due to key pests of millet crops and determine economic injury levels, the effectiveness of natural enemies and their use in existing ecosystems. There is a need to standardize screening techniques for shoot flies and borers. The traits responsible for resistance must be incorporated into agronomically suitable cultivars. New pests and changes in the status of minor or occasional pests should be closely watched. Looking to the status of the pests in changing climate, an integrated approach for management of millet pests is the need of the hour.

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Disease management

for improved millet production

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Millets are a group of cereal grains used for human and animal consumption. Many diseases come in the way of high productivity of millets. There are more than a dozen major diseases that considerably affect cultivation of various millets like sorghum, pearl millet, and small millets (finger, foxtail, kodo, proso, little, barnyard and browntop millets). Millets being grown under low input agricultural conditions, management of disease by chemical is not recommended and mostly preventive measures are followed. The article describes major diseases of millets and various cost effective and economic ways of their management for higher productivity.

Keywords: Disease, Host resistance, Management, Millets

CROP damage due to diseases is one of the major causes of concerns for improvement of millets production and productivity with intensive cultivation. Losses vary depending on growth stage of the crop infected, type of disease, plant part affected and disease intensity. Losses due to fungal diseases are more compared to bacterial and viral diseases. There are more than a dozen major diseases that considerably affect cultivation of various millets like sorghum, pearl millet, and small millets (finger, foxtail, kodo, proso, little, barnyard and browntop millets). Grain mold, stalk rot and anthracnose in sorghum, downy mildew in pearl millet and sorghum, blast in pearl millet and finger millet, rust in sorghum, pearl millet and foxtail millet, ergot in sorghum and pearl millet, and smuts in all millets are economically important diseases. These diseases occur during different crop growth stages on physiologically and economically important plant parts. They need to be efficiently managed to improve yield and quality of millets.

Diseases

***Seedling diseases*:** Root rot of seedling, damping off, anthracnose and seedling blight appear during seedling stage. Severe infection damages the roots and tender leaves, and often kills the seedling. Plant stand in the affected plot becomes less which gives a patchy look to the crop in the field. Small millets grown in poorly drained acidic soil are often affected by damping off and seedling root rot. Sorghum seedling may be infected by anthracnose and seedling blight, and depending on intensity of infection the seedling may die prematurely.

***Grain diseases*:** Many pathogens infect florets or developing grains, the most important part of the millets crops. One such most damaging disease is grain mold of sorghum. The others are ergots and smuts that appear on most of the millets grain. Production losses due to grain mold ranges from 30–100% in sorghum depending on cultivar and prevailing weather. Mold infection becomes visible in pink, orange, gray, white, or black colour fungal bloom on the grain surface. The disease reduces seed value of grain, nutritive value of food and feed, and cooking quality of the grain. Molded grains often contain mycotoxins which may be harmful to human, animal and poultry birds. Ergot or sugary disease is a serious limiting factor in production of hybrid seed. The disease is commonly observed in sorghum and pearl millet. First visible symptom is exudation of honeydew like droplets, which are thick, sticky or viscous, pinkish to brownish in colour and sweet in taste. Infected florets do not produce grain and other grains from infected panicles show reduced germination. Yield loss varies from 10–80% in sorghum and up to 50–70% in pearl millet hybrids depending on severity. The pathogen survives off seasons in the infected panicles left in the field or via sclerotia that are mixed with the seed during threshing and processing. Smut is a fungal disease that converts parts or whole of an earhead into fungal structure. Depending on symptoms, four different types of smuts namely, head smut, covered smut, loose smut, and long smut are observed in millets. Head smut is soil-borne, while loose and covered smuts are primarily

Grain mold, ergot and smut on sorghum grains

carried externally on the seed surface. Generally, smuts are observed sporadically on millets and they are of minor importance. Downy mildew of pearl millet affects earhead and transforms spikelet to leafy structure. Such earhead (called green ear disease) hardly produces any grain.

Leaf diseases**:** Leaf diseases destroy leaf surfaces meant for photosynthesis and adversely affect yield. Many types of leaf diseases occur in millet. Major categories are downy mildew, blast, rust, anthracnose, leaf blight and leaf spots. Downy mildew is important in pearl millet and sorghum and also occurs on finger and foxtail millet. Infection starts at the seedling stage and continues till death of the plant due to extensive damage of leaves. Symptoms are visible on the lower part of the leaf blade as white, downy growth consisting of conidia and conidiophores of the pathogen, which later progresses upward. Systemic infection of the plant results in a barren inflorescence in pearl millet. Losses may go up to 100% in pearl millet, 20% in sorghum and finger millet depending on the time of infection, cultivars and weather conditions. The collateral hosts serve as source of inoculums for the sorghum crop. Blast is potentially a serious disease of millets particularly pearl millet and finger millet. The disease occurs almost every year in finger millet and yield loss varies from 28–36% and may go up to 90% in endemic areas. The pathogen can infect any plant part and develop elliptical or diamond shaped lesions on the leaf, peduncle and finger. The most damaging stage is neck blast, followed by finger and leaf blast. The pathogen *Pyricularia grisea* can parasitize over 50 grasses and its life cycle is complex.

Most of the millets are also affected by rust. Generally, they appear during later part of the crop growing season, causing less damage. Sometimes, rust may infect during early growth stage of the crop and then, it becomes serious yield limiting factor. Though the disease occurs regularly in many places, it hardly becomes severe. Severely rusted plants may fail to throw panicle. Initial symptom appears as reddish brown pustules on both the surfaces of the lower leaves. Within a leaf, the upper half develops more infection than the lower half. The pathogen survives on ratoon or stray sorghum plants in the field and also on perennial and collateral hosts. Anthracnose causes substantial economic losses to grain, forage and sweet sorghum but is not observed on other millets. Pathogen can infect any plant part during entire growth stages. Symptoms appear as seedling blight, leaf blight, stalk rot and head blight. Symptoms on the leaf appear as small, elliptic to circular spots, with straw colour centre and wide margin. Adjoining spots may coalesce to give a blighted appearance on the leaf. There may be up to 50% loss in grain yield under severe epidemics conditions. Leaf blight is an economically important disease of sorghum causing significant loss on grain and forage sorghum. Millets can be infected by various types of leaf spots including zonate leaf spot, stripe, gray leaf spot and rough leaf spot in sorghum; *Cercospora* leaf spot, *Curvularia* leaf spot, *Dactuliophora* leaf spot and *Phyllachora* leaf spot in pearl millet; *Cercospora* and *Helminthosporium* leaf spot in finger millet and others. These diseases are sporadic in nature

Smuts of kodo and barnyard millets

Pearl millet downy mildew

Leaf and finger blast of finger millets

and are less damaging, unless they are favoured by congenial weather conditions. They become significant on forage millets.

***Root and stalk diseases*:** There are few important root and stalk diseases, which are soil-borne and severely impact plant stand and yield of millets. The most important one is charcoal rot which is commonly observed in *rabi* (winter) sorghum. Symptom appears as discolouration at the base of the stalk. Pathogen infects root, destroy cortical tissues and may block water movement through vascular bundles. Rotting and breaking of the basal internodes cause lodging of the crop, which in turn facilitates further loss of water from the cracks in the stalk, affecting fodder quality. Yield losses vary from 20–64%. Banded blight is another soil-borne disease, which is commonly observed on all the small millets. The disease is characterized by oval to irregular light grey to dark brown lesions on the lower leaf and leaf sheath. The central portions of the lesions subsequently turn white with narrow reddish brown margins. Later, the spots get distributed irregularly on leaf lamina. Under favourable conditions, lesions enlarge rapidly and coalesce to cover large portions of the sheath and leaf lamina. In severe cases, symptoms appear on peduncles, fingers and glumes as irregular to oval, dark brown to purplish brown necrotic lesions.

Rust of browntop and foxtail millets and *Cercospora* leaf spot of finger millet

Management

Millets are mostly cultivated under low input conditions and its cultivation is almost organic by default. Herbicides, pesticides, fungicides, chemical fertilizers are generally not used or if used they are in minimum scale. Under such situation, disease management is focussed on prevention through reduction of primary sources of inoculums, minimization of infections and need based application of bio-control agents for protection from infection and curing.

***Preventive measures*:** Practices such as deep ploughing during summer season, cleaning of field bunds after crop season, removal of crop residues from the field, regulating irrigation water from entering into other field not only reduces sources of inoculums or initial inoculums load but also lessens the chances of disease occurrence. Almost all the disease of millets can be managed or kept to a minimum by these practices.

***Clean cultivation*:** Practice of clean cultivation includes all the activities that keep the field and the surrounding clean. Removal of weeds, alternate hosts, stray crops and crop residues from fields and bunds, and crop rotation with non-host plant help in reducing pathogen inoculums. Chances of occurring downy mildew, rust, charcoal rot, anthracnose, zonate leaf spot, sheath blight, foot rot and bacterial diseases can be minimized using these practices.

***Crop rotation*:** Crop rotation is useful for management of soil-borne diseases of millets like wilt or foot rot of finger millet, root and stalk rots of sorghum, banded blight of small millets and downy mildews of all millets. The second crop in the rotation is selected in such a way that the crop is non-host for the pathogen in the first crop. Thus, pathogen population decreases in soil as it cannot get host to multiply.

***Sowing date adjustment*:** Sowing time management can be practiced in conditions where farmers have flexibility in choosing preferred sowing date. Incidence of vector borne diseases like maize stripe virus in sorghum can be minimized significantly when sowing time is shifted from early September to 3rd week of October for *rabi* sorghum. Sowing *kharif* (rainy) sorghum in 1st week of July in Tamil Nadu is helpful to reduce downy mildew incidence. Grain mold severity in sorghum can be minimized to some extent by delayed sowing so that flowering and grain filling may happen in relatively rain free conditions.

***Soil treatment*:** Promotion and utilization of disease suppressive properties of soil is one of the best methods of disease management of millets. Treatment of soil with green manures or plant and animal based soil amendments improves disease suppressive properties. Green manures reduce *Rhizoctonia* diseases and can be useful for management of banded blight of small millets. Downy mildew of pearl millet and sorghum, root and stalk rot of sorghum, and foot rot of finger millet can be well managed in a suppressive soil.

Seed treatment: Treating seeds with antimicrobial agents eradicates seed-borne pathogens. Seed can be treated with fungicides or organically produced with substances like beejamrit. Soil-borne diseases of millets (e.g. charcoal rot in sorghum, foot rot and sheath rot in small millets), for which adequate host resistance is lacking, use of biocontrol agents are useful. Bio-control agents especially strains of *Trichoderma* and *Pseudomonas* are useful for foot rot and sheath rot in small millets. Seed treatments with *P. fluorescens* @6 g/kg seed and spraying with 2 g/litre of water manages blast in finger millet. First spray should be done immediately after noticing the symptom. The second and third sprays are given at flowering stage at 15 days interval.

Crop management: Wide spacing and withholding irrigation at flowering minimizes charcoal rot incidence in *rabi* sorghum. In hybrid seed production plots of sorghum, flowering synchrony should be such that A-lines must get sufficient pollens from R-lines for fertilization. Preventing bacteria contaminated irrigation water from entering into sorghum or pearl millets field minimizes the chances of bacterial stalk rot.

Resistant cultivars: Host-plant resistance provides the most economic and environment friendly method of managing millet diseases in organic agriculture. For grain mold management, use of a cultivar that escapes the disease is the best option. Use of mold tolerant cultivar such as hybrids CSH16, CSH27, CSH30, and varieties CSV20 and PVK801, and harvesting the crop just at maturity without leaving it for more days in the field are the second best options to avoid grain deterioration and weathering. Though high level of genetic resistance is not available against charcoal rot, the present day cultivars, viz. CSV19R, CSV216R and DSV6 possess good tolerance. All recently released cultivars of pearl millet (e.g. HHB 67, ICMH 356) possess tolerance to downy mildew as they are released only after multi-location testing. GPU 28 and GPU 48 is widely used cultivar of finger millet resistant to neck and finger blast.

Removal of diseases plants or plant parts: Incidence and severity of downy mildew of sorghum and pearl millet, all types of smuts of sorghum, pearl millet and small millets, and leaf diseases like anthracnose, leaf blight, and leaf spots and viral diseases can be greatly reduced. Collecting smutted heads in cloth bags and dipping in boiling water to kill the pathogen is the popular practice that will reduce the inoculum for the next year and minimize incidence.

Prophylactic measures: Rapid curing of an established infection is probably best done by chemicals. However, chemicals can be replaced by bio-agents or botanicals for management of foliar or panicle diseases to promote organic farming. Many reports are available on millet diseases where foliar sprays with bio-agents or botanicals have controlled diseases, e.g. pearl millet blast by *Pseudomonas fluorescens*, leaf diseases of forage sorghum by *Trichoderma asperellum* and grain mold of sorghum by *T. harzianum*. Similarly, in small millets foot rot of finger millet and banded blight in all millets can be managed by soil application of *T. viride* or *T. harzianum* and *P. fluorescens*. However, prophylactic spray of pesticides for disease management should be the last option and practices described previously should be followed stringently, so that diseases do not appear on the crop or they remain in control.

SUMMARY

Diseases are one of the major constraints of millet production and improvement in productivity. Grain mold, stalk rot and anthracnose in sorghum; downy mildew in pearl millet and sorghum; blast in pearl and finger millet; rust in sorghum, pearl, browntop and foxtail millets; ergot in sorghum and pearl millet; and smuts in all millets are economically important diseases. These diseases occur during different crop growth stages on physiologically and economically important plant parts. They need to be efficiently managed to improve yield and quality of millets. Clean cultivation, sowing date adjustment, soil and seed treatment, crop management, removal and destruction of infected plants, use of resistant cultivars and need based spray with bio-control agents are some of the practices that should be followed for cultivation of disease free millets crops.

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INTERNATIONAL YEAR OF MILLETS 2023

Physiological superiority

of millet crops for climate resilience

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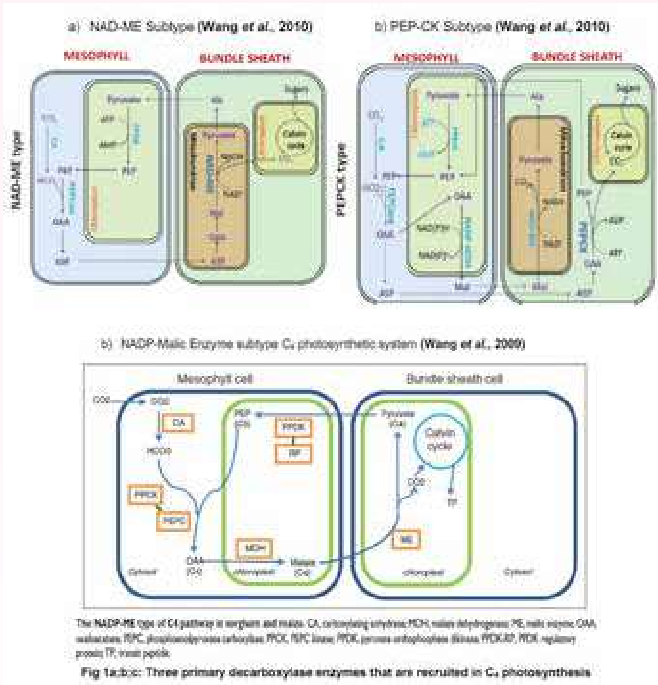
Millets are the most important category of grain crops. They are a group of small-seeded grasses that are highly tolerant to environmental stresses and have high physiological efficiency. They are an important food security crop in many parts of the world, especially in Africa and Asia. Millets have several key adaptive traits that make them well-suited for climate resilience, including their short growing season, deep root system and ability to tolerate high temperatures and drought conditions. The importance of these crops in terms of their physiological and anatomical make up is highlighted in this article, which needs to be utilized for selection of superior and high yielding germplasm for competing the yield potential of other major cereals.

Keywords: Climate smart crops, Kranz anatomy, Stress tolerance, Water use efficiency

IN the era of severe climate vulnerabilities and vagaries that affect crop production and productivity, an effective and sustainable solution for the farmers is to adapt to climate smart crops. Millet crops which include sorghum (jowar), pearl millet (bajra), finger millet (ragi), foxtail millet (kangani), barnyard millet (sanwa), proso millet (chenna), little millet (kutki) and kodo millet (kodo) are the promising crops that can cope with changing climate, sustain productivity and exhibit resilience to abiotic stresses. Their rich nutritional properties and health benefits have enabled their revival and cultivation in the recent years. Millets are considered as nutri-cereals as they hold abundant nutritional benefits, food and fodder value, ecological benefits, reduced reliance on chemical fertilizers and are less sensitive to yield declines with lower inputs. The UN Food and Agriculture Organization reports state that “Compared to the more commonly known cereals such as wheat, rice or corn, millets are capable of growing under drought conditions, under non-irrigated conditions even in very low rainfall regimes, having a low water footprint”.

Almost all the millet crops are well known for their hardiness which can withstand prolonged periods of drought, high temperatures and still yield grains and fodder. Hence, they are considered as climate smart crops. They are physiologically and anatomically superior over C_3 crops like rice and wheat to harness the available resources like light, water and other inputs. This necessitates to understand the underlying physiological traits and anatomical make up of these crops, that makes them climate suitable crops. These crops have evolved in arid, low-latitude conditions and are in general more drought tolerant, sustain elevated temperatures, are less affected by increasing atmospheric carbon dioxide



C_4 photosynthetic system operating in millet crops

Table 1. Key traits in millet crops contributing for abiotic stress tolerance

Morpho-physiological/ molecular traits	Response to stress conditions	References
Earliness, plasticity to flower as per pattern of rainfall	Early life cycle completion confers escape from water stress, temperature stress at critical growth stages	Bidinger *et al*. (2007)
Small leaf area, waxy leaves and better leaf venation	Higher photo-assimilation, transpiration efficiency and water use efficiency	Bandyopadhyay *et al*. (2017)
Early, dense and deep root system with higher water uptake efficiency	Avoids early drought and deep roots, helps in terminal drought	Li and Brutnell (2011), Kumar and Panneerselvam (2014), Passot *et al*. (2016)
Higher photosynthesis	Due to C_4 cycle and Kranz anatomy, millets have high water use efficiency under warm temperature, due to operation of MDH (Malate dehydrogenase) and PPDK (pyruvate orthophosphate dikinase) genes	Sage and Zhu (2011)
Enhanced level of secondary metabolites and osmolytes	Higher levels of antioxidants and osmolytes	Lata *et al*. (2011)
Functional genes expressed under abiotic stress	LEA (Late embryogenesis abundant protein), ARDP (ABA-responsive DRE binding protein), DREB (dehydration responsive element binding protein), NAC transcription factor, Aldose reductase, Glutamine synthetase, Pyrroline-5-carboxylate reductase, OPR (12-oxophytodienoic acid reductase), WD-40, PHGPX phospholipid hydroperoxide glutathione peroxidase), NAC transcription factors, bHLH transcription factor, Dehydrin 7, Heat shock factor, Ascorbate peroxidase, β-carbonic anhydrase, Glutathione reductase, Dehydroascorbate reductase	Bandyopadhyay *et al*. (2017)

levels, and have no/negligible GHGs emission which has been lost in major cereals as a result of intensive selection. A deeper understanding of the physiology of these millet crops is discussed in this article.

Millets as model crops for climate-resilience

Millet crops have a characteristic Kranz anatomy with C_4 pathway that is photosynthetically efficient in utilizing the light, water and CO_2, ultimately resulting in higher biomass and yield. Millet crops possess several morpho-physiological and agronomically superior traits (Table 1), viz. short life cycle (12–14 weeks from seed to seed), short stature, smaller leaf area, source-sink efficient leaf veination features, deeper root systems and hardiness to stress conditions which makes them powerful model system for dissecting C_4 photosynthesis. The short growing season length in almost all millets enables them to escape unpredictable late summer droughts, or serve as a rescue crop if another grain crop fails. Drought tolerance of millets, and other C_4 grasses express a set of unique, likely to be linked to ancestral evolution of dehydration pathways that can survive under severe drought stress typically specific to seed desiccation.

The photosynthetic enzymes, viz. carbonic anhydrase (CAH), malate dehydrogenase (MDH), malic enzyme (ME), phosphoenolpyruvate carboxylase (PEPC), phosphoenolpyruvate carboxylase kinase (PPCK) and pyruvate orthophosphate dikinase (PPDK) are reported to be maximum in all the millet species and these crops operate all the C_4 subtype pathways. Further, millets

Table 2. Photosynthetic efficiency of millet crops over other high input crops

Character	C_4 Plant	C_3 Plant
First CO_2 acceptor	Phosphoenolpyruvate carboxylase	RuBP carboxylase
Type of chloroplast	Dimorphic chloroplast-Kranz anatomy present, two types of cells contain chloroplast (Mesophyll and Bundle Sheath)	Monomorphic-only one type of cell contains chloroplast, Kranz anatomy absent
Carbon pathway	Both Calvin cycle (bundle sheath) and Hatch-Slack cycle (mesophyll)	Calvin cycle in mesophyll cells
Photorespiratory C_2 cycle	Absent	Present
CO_2 compensation point	0–10 ppm	50–150 ppm
CO_2 assimilation rate in intense light	50–70 mg $CO_2/dm^2/hr$	15–35 mg $CO_2/dm^2/hr$
Temperature optimum for photosynthesis and growth	30–45°C	10–25°C
Transpiration ratio	500 (about 500 molecules of water are lost for every molecule of CO_2 fixed by photosynthesis)	250 (about 500 molecules of water are lost for every molecule of CO_2 fixed by photosynthesis)
Water use efficiency	4.2–13.4 kg yield/ha/mm of rain	4.5–10.7 kg yield/ha/mm of rain
Rainfall requirement	200–500 mm	500–900 mm

greatly benefit from the C_4 photosynthetic trait as the Kranz anatomy increases the concentration of CO_2 in the bundle sheath, suppresses photo-respirative loss (around 80%) depending on the environment and increases the carboxylase activity of RuBisCO. RuBisCO of C_4 plants works efficiently at elevated CO_2 levels, have enhanced photosynthetic rates at warm conditions, confers higher water use efficiency (WUE) and nitrogen use efficiency (NUE) which are ~ 1.5–4-fold higher than crops having C_3 photosynthesis. In addition to WUE and NUE, the other benefits from C_4 photosynthesis are improved growth, higher biomass allocation and partitioning, and lower hydraulic conductivity per unit leaf area. These traits, make them next-generation crops with the potential to build climate-resilience and achieve sustainable yield. Realizing the stress tolerance potential of millets, using millet as a model crop is a promising option for developing climate-resilient crop species.

Some of the key photosynthetic efficient components of C_4 crops over C_3 crops are given in Table 2. To fully harness the underlying genetic potential using high-throughput phenotypic screening, conventional/molecular breeding/transgenic approaches and technologies are needed to exploit the inherent key traits in stress tolerance across millet crops.

Despite their adaptability and climate resilience traits among other cereal crops, there is a dearth of studies to unveil mechanisms that confer stress tolerance. Further, resilient traits must be utilized for selection of superior and high yielding germplasm for competing the yield potential of major cereals like rice and wheat.

SUMMARY

Millets hold enormous potential for sustainable food and nutritional security. The underlying physiological characteristics highlight millets as a crop of choice for the global population, especially under the threat of climate change. Thus, highlighting the need for climate smart crops, farmers switching to cultivation of millets from water intensive crops will achieve an assured yield of around 8–10 quintal per acre with low input costs. Further, choosing millets over rice and wheat can help to accomplish the sustainable development goals (SDGs) – mainly SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 12 (sustainable consumption and production) and most importantly SDG 13 (climate action).

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Physiological seed
priming techniques in millets

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In recent years, various strategies are being employed in order to induce the abiotic stress tolerance in plants. It is well accepted fact that physiological seed priming fastens the germination time. It is an effective, practical and facile technique to enhance uniform emergence, seedling vigour and yields in millets, particularly under rainfed or less fertile soils. Seed priming is a broad term but in this article, physiological seed priming techniques, viz. hydro-priming, osmo-priming, hormonal priming, nutrient priming and nano-priming have been discussed in detail as these techniques are cost effective, ecofriendly and simple.

Keywords: Nano priming, Seed priming, Small millets

MILLETS are small grained cereals, viz. finger, kodo, foxtail, proso, little and barnyard millets. They are the staple food of millions inhabiting the arid and semi-arid tropics of the world. Small millets are nutritionally superior to rice and wheat. They are rich source of proteins, minerals and vitamins, but are generally grown on marginal land under rainfed conditions. They have wide adaptation and can withstand certain degree of soil acidity and alkalinity. Inherently, they are resilient to moisture and temperature stress.

Millets are having wide adaptability and potential for higher yields, but are mostly grown only in hilly, marginal and sub-marginal conditions of soils where major cereals fail. Uniform and rapid germination, and emergence of seedling are essential for successful crop establishment and it is of primary importance for optimizing field production of any crop plants in arid and semi-arid regions.

Farmers require high-quality seeds with excellent germination and seed health. Seed producers have the responsibility to maintain the seed quality and deliver the seed to farmers at right time. Germination and seedling emergence are the critical stages in the plant life cycle. Insufficient seedling emergence and poor establishment are the main constraints in the production of crops in the regions receiving less rainfall for which seed priming could play an important role.

Seed priming is an effective technology to enhance rapid and uniform emergence and to achieve high seedling vigour, leading to better stand establishment and yield under adverse climatic conditions. This technology has shown promising biological and physiological improvements leading to suitable seeds with excellent physiological and agronomic performance in crop plants under adverse environmental conditions. Physiological seed priming hastens the germination process and enhances the rate of seedling emergence even under extreme climatic conditions and in problem soils. Seed priming is categorized into different types, viz. hydro-priming, osmo-priming, halopriming, hormonal priming, and biopriming, and provides extensive crop benefits. Seed priming techniques can deal with detrimental conditions in fragile lands such as drought, heat stress, salinity, nutrient stress and several environmental stresses.

Hydro-priming

Hydro-priming is a controlled hydration process of the seeds that involves seed soaking in simple water without chemicals. Among the different seed enhancement techniques, hydro-priming could be a suitable treatment for salinity and drought-prone environments. It is a simple and cheap technique, with promising effects. Hydro-primed seeds produce healthy seedlings, uniform crop stand, escape drought and hasten crop maturity.

Osmo-priming

Osmo-priming involves seed hydration in an osmotic solution of low water potential such as polyethylene glycol or a salt solution under controlled aerated conditions to permit imbibition but prevent radical protrusion. Most commonly used salts for osmo-priming are potassium chloride (KCl), potassium nitrate (KNO_3), sodium chloride (NaCl), magnesium sulphate ($MgSO_4$), potassium phosphate (K_3PO_4), calcium chloride ($CaCl_2$) and potassium hydrophosphate (KH_2PO_4). These salts provide nitrogen to the germinating seed which is required for the protein synthesis during the germination process. Osmo-priming induces rapid and uniform germination and decreases mean germination time.

Hormonal priming

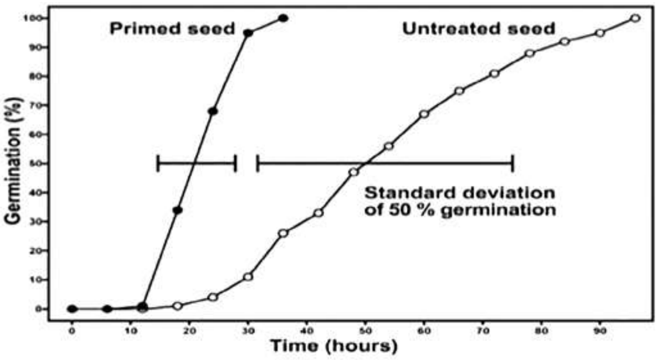
Cytokinins play a vital role in all the phases of plant growth and development starting from seed germination to senescence. Priming with optimum concentration of cytokinins has been reported to increase germination, growth and yield of many crop species. Gibberellic acid (GA_3) is known to break seed dormancy, enhance germination, hypocotyl growth, internodal length, cell division in the cambial zone and increase leaf size. GA has stimulatory effect on hydrolytic enzymes, which speed up the germination and promote seedling elongation by degrading the cells surrounding the radicle in cereal seeds.

Nutrient priming

Seed priming with micronutrients improves stand establishment, growth and yield; furthermore, the enrichment of grain with micronutrients is also reported in most cases. Many researchers proved the potential of nutrient priming in wheat, rice and forage legumes. Micronutrients, viz. Zn, B, Mo, Mn, Cu and Co are commonly used for seed treatment in most of the field crops. Seed treatment with micronutrient is a low-cost way to improve nutritional level of crops. Farmers in South Asia follow nutrient priming by soaking seeds in micronutrient solution overnight which they find very useful and simple. Seed priming with zinc salts is used to increase growth and disease resistance of seedlings.

Nano-priming

Nano-priming is an innovative technology that helps to improve seed germination, seed growth, and yield by imparting resistance to various stresses. Nano-priming is a considerably more effective method compared to all other seed priming methods. The salient features of nanoparticles (NPs) improve electron exchange and enhance surface reaction capabilities associated with various components of plant cells and tissues. The nano-priming is done using, viz. zinc and zinc oxide, iron, titanium oxide and silver. Nano-priming induces the formation of nanopores in shoot and helps in the uptake of water absorption and activates reactive oxygen species (ROS)/antioxidant mechanisms in seeds.



Effect of seed priming on seed germination
Source: http:www.seedbiology.de

Seed priming: A strategy to induce abiotic stress tolerance in millets

In barnyard millet, hormopriming with GA_3 @10 ppm recorded higher values for germination (100%), shoot length (10.85 cm) and vigour index (2353). Biopriming of foxtail millet, little millet and proso millet with *Pseudomonas fluorescens* 20% for 8 h showed early germination, higher germination, shoot and root length, increased dry matter production, high vigour index and high seed metabolic efficiency than seeds primed with KH_2PO_4. The priming procedure strengthened the antioxidant activities of POD, CAT, SOD, and APX, increased free amino acid contents, e.g. proline, and reduced MDA accumulation and electrolyte leakage in seedlings which led to the enhancement of drought tolerance in sorghum.

SUMMARY

Seed priming hastens the germination process and enhances the rate of seedling emergence even under extreme climatic conditions and in problem soils. Seed priming has a wide range of commercial applications in improving crop stand by improving germination rate and seedling vigour, and effective crop stress management. Sustainable crop improvement and crop production require the adoption of low-cost and environment-friendly physiological seed priming techniques. Hence, a comprehensive study involving the identification of physiological and biochemical changes in seed and plant stress tolerance mechanisms in millets is needed to address the changing climate scenario, for future climate change sustainability.

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Seed systems
in millets

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Seed system is one of the most vital components of agricultural system that involves activities associated with seed production, multiplication, processing and marketing to ultimate use of seed by farmers. The right mix of formal and informal supply channels, market and non-market activities, and a well-functioning seed system is used to stimulate and effectively meet the changing demand of farmers for high-quality seeds. The process of seeding is a complex one, involving many factors that need to be considered in an integrated manner to ensure successful implementation of this process. Seed system is an integral part that has been identified to enhance the quality of seeds, to provide a source for the production of a wide range of crops, and to increase the yield. This article briefly discusses the various seed systems in millets.

Keywords: Millets, Seed, Seed systems

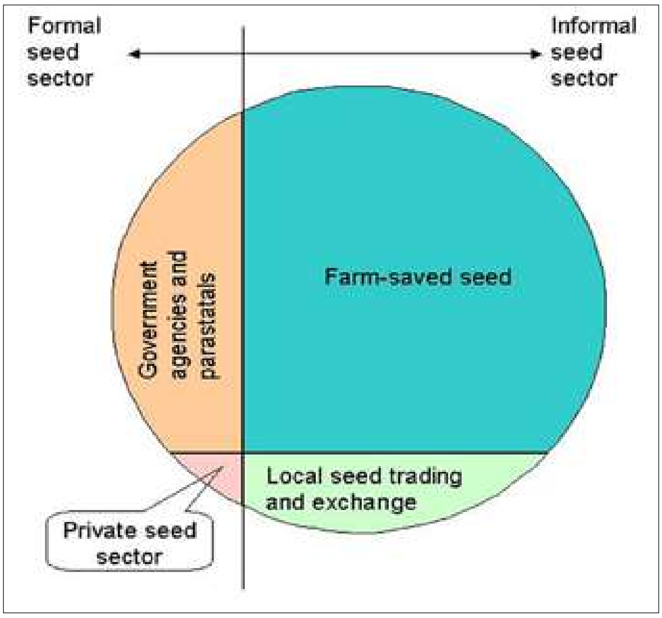
UNDERSTANDING seed systems is essential for maintaining crop biodiversity on farms in areas where it has societal relevance for future crop improvement and the resilience of the farming system as well as personal benefit to farmers. In general, seed system is mainly of two types, formal seed system and informal seed system. Considering inability of these two systems to meet seed needs to diverse groups and farming systems, recently, integrated seed system has emerged in the literature as a complementary system to make the seed system more holistic and pluralistic. Formal seed systems are easier to characterize as they are deliberately constructed, involving a chain of activities leading to clear products, i.e. certified seed of verified varieties. The chain usually starts with plant breeding and selection, resulting in different varieties, hybrid parents including hybrids and materials leading to formal cultivar release and maintenance. In practice, these systems may be constrained by their capacity to meet the diverse needs of farmers in developing countries. The guiding principles in the formal system are maintenance of varietal identity and genetic purity coupled with production of seed that possesses optimal physical, physiological and sanitary qualities.

The central premise of the formal system is that there is a clear distinction between seed and grain. This distinction is less clear in informal seed systems. Informal systems are also referred to as local, traditional or farmer seed systems. In an informal seed system, farmers themselves produce, disseminate and access seed directly from their own harvest, through exchange and barter among friends, neighbours and relatives, and through local grain markets. Encompassing a wide range of variations, local systems are characterized by their flexibility. The varieties disseminated may be landraces or mixed races and may be heterogeneous. In addition, the seed is of variable quality in terms of purity and physical, and physiological parameters. While some farmers treat seed specially, there is not always a distinction between seed and grain.

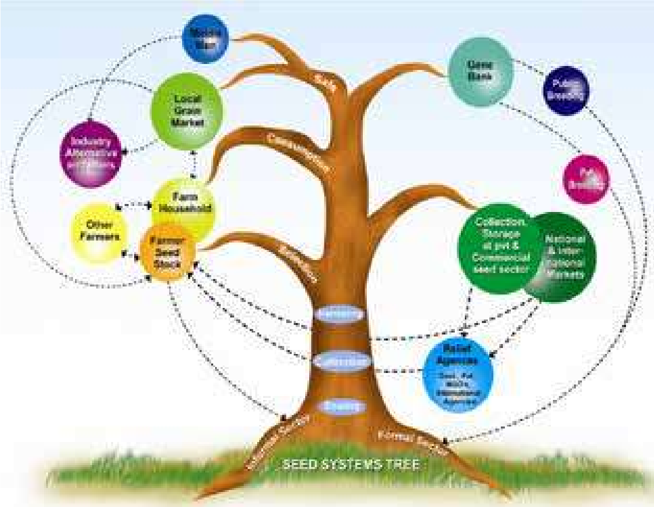
Seed sources for informal and formal seed systems

Seed systems in dryland ecosystems are basically influenced by their pace of seed replacement, seed-to grain price ratios, distance to seed sources and the quantity of seed traded by formal and informal means. Both systems have their own limitations in which farmers procure seed by different sources depending on the situation and location.

Usually formal channels for seed transactions encompass traders in the district market yards, seed exchanges through private dealers and distributors, and seeds marketed by private companies, which are branded, the transactions are monetized, and those engaged in the business are usually full-time traders. In contrast, in informal system, traders operating in weekly village markets, are part-time traders and seeds traded here are not branded, since they originate from farmers from surrounding villages or communities. To some extent, the seeds are identified by their village name or, in some cases, for e.g. by the farmer's name (if the farmer is reputed in the locality for the quality of seeds). The seed exchanges are monetized but the prices are not based on the existing market prices, nor are they fixed, they vary according to the demand and quality (physical purity) of the seeds. Seed dealers/distributors in the formal seed supply chain are a vital link between the formal seed producing firms and farming communities.



Traditional seed supply scenario of millets in dry land ecosystems



Farmers seed sources from formal and informal systems and seed flow from formal to informal channels.

Integrated seed systems

The analysis of strengths and weaknesses of local seed systems leads to the conclusion that local seed systems and the formal system are complementary, hence integrated seed systems come into play. An integrated seed system (ISS) can be defined as a system to produce near quality seeds of a specific variety by adopting some specific parameters of formal systems to improve production of quality seeds informally. In this system, the approach towards seed production of improved varieties is through farmers associations/SHGs/FPOs where the formal methods of seed production process, government procedures for seed production and certification process are not adopted completely.

Sorghum seed system

Sorghum seed system is very unique in the country with contrasting situations and systems. Hybrids are the cultivar choice in *kharif* (rainy season) sorghum, and hybrid adoption by farmers is up to 95% in states like Maharashtra though there are wide variations in adoption across the states in India. The public and private sector seed companies develop hybrids and rule the market. The seed requirement is predominantly met by the vibrant formal seed system by private sector seed companies and public sector seed agencies like National Seeds Corporation (NSC) and state seed development corporations in different states and Mahabeej in Maharashtra. In the case of post-rainy season sorghum cultivated on black soils under residual moisture condition, open-pollinated varieties are the cultivar choice because of stringent quality considerations, lack of appropriate hybrids, inadequate hybrid seed production, and supply chain.

High-yielding and improved cultivar seed availability is not a constraint in *kharif* sorghum, but the major issue in post-rainy season sorghum in India is that majority varieties are age old and still ruling the major area under cultivation. Most notable local varieties popular among the farmers include M 35-1 (Maldandi) and Dagadi grown by 80–90% of farmers in India. M 35-1, a landrace selection from Maldandi, cultivated traditionally by the farmers in these areas for several decades, was selected in 1938, nearly 75 years ago, and is still dominating the post-rainy season tracts (Maharashtra, Karnataka and Andhra Pradesh) in India.

Pearl millet seed system

Pearl millet seed system in India is dominated by formal seed system. More than 90% seed share is by private seed companies which mainly includes hybrids. Role of public sector is minimum. The low-income farmers, located mostly in water-scarce areas such as western Rajasthan, largely rain-dependent grow open pollinated varieties (OPVs) in the rainy season. Certain sections also have strong taste preference for OPV seed use. About 80% farmers purchase and re-use OPV seeds, as hybrids are unsuitable in water-scarce regions. Nevertheless, 20% farmers still use hybrids decision drivers.

Small millet seed system

Small millet seed system is mainly dominated by informal sector (>90%) (Table 1). In India, among millet crops, the seed replacement rate (SRR) is highest in pearl millet (60%) followed by sorghum (30%) and small millets (25–30%).

Table 1. Share of seed systems in millets

Crop	Area (Mha)	Seed systems	Seed share
Sorghum			
Kharif - grain	2.6	Formal	95%
Rabi - grain	4.8	Informal	85%
Forage	3.0	Formal	90%
Pearl millet			
Grain	7.6	Formal	70%
Forage	0.9	Formal	70%
Ragi (finger millet)	1.2	Informal	>90%
Other millets	0.7	Informal	>95%

Mha; Million hectares.

Approaches for sustainable seed system

Important issues providing way forward for sustainable seed value chain to meet the demand of improved variety seed of post-rainy sorghum in India are:

***Seed mission*:** This involves developing and implementing rain-fed agriculture seed mission with a built-in mechanism of supporting the cost of seed production for five years by the government by adopting public-private partnership with effective coordination and convergence mechanisms.

***Seed production*:** Promoting contract seed production program by advance indenting of the seed of specific improved cultivars to both public and private sector seed companies including KVKs and community-based organizations with technical support and capacity building program for production of quality seed is essential to make seed production effective.

SUMMARY

In order to improve production of millets and nurture a sustainable seed production system, strengthening and improving the overall efficiency of the millet seed systems is essential, including both formal and informal channels. The system should increase seed availability to farmers at lesser cost, preserve crop diversity and promote locally-adapted varieties. An enabling policy environment will help in production and dissemination of improved variety seed of rain-fed crops. Provision of funds and support for seed multiplication and dissemination activities for at least five years will make it self-sustaining. Strengthening extension services for creating awareness and demonstration of rain-fed agricultural technologies is required.

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Sorghum hybrid seed

production and quality maintenance

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Production of best quality seeds to meet the needs of the grower should be the main endeavour of sorghum improvement projects and seed agencies. Many limitations prevent or alter reproductive strategy of sorghum parental lines during hybrid seed production. Therefore, care must be taken for seed production that offer optimum climatic package during crop growth period. Seed certification agencies have an important role to play in certified hybrid seed production and distribution, because the crop performance is dependent on the quality of the certified seed used. Flowering behavior of the hybrid parents, productivity vs cost, and climatic conditions, particularly during the stages of flowering and seed filling should be important considerations to select an area for hybrid seed production. Good seed set in seed parent is possible by synchronization of flowering of pollen donor and pollen receptor, and adopting effective seed crop management practices. Regular guidance to seed growers by technical staff during the entire season of hybrid seed production facilitates the production of quality seeds of sorghum hybrid.

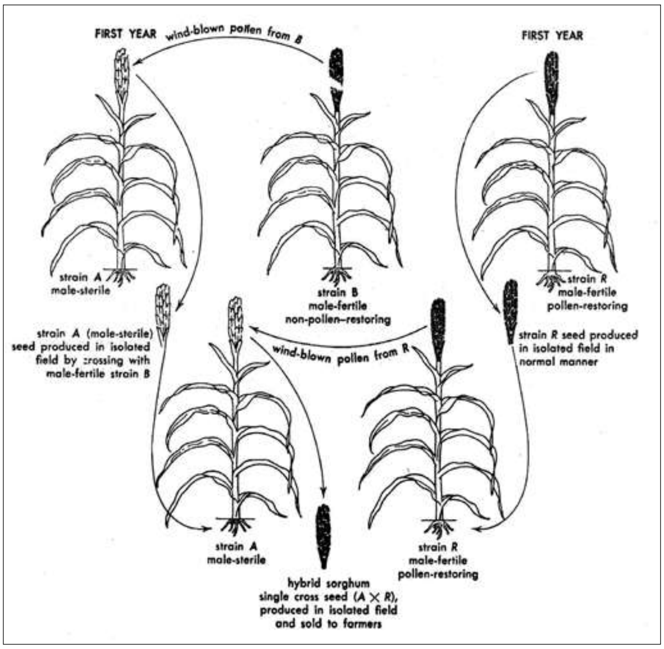
Keywords: Hybrids, Isolation, Seed quality, Sorghum

SORGHUM fits very well in a sustainable agricultural model with its ability to survive in water limiting conditions and provides an option for marginal farmers. It is a major dry land cereal and is grown primarily in Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh and Gujarat for food, feed, fodder and fuel. Sorghum research in the country can be illustrated as a glaring example, which has significantly contributed towards the green revolution in drier areas. Sorghum has originated in East Africa with its secondary center of origin in India. The amount of genetic variability available in sorghum is very high because of its wide range of adaptation in tropical and temperate climates and free gene exchange among various races. In India, sorghum is grown in rainy and post-rainy seasons, and the requirement of varieties is different for two seasons. Besides grain sorghum genotypes, forage sorghum and sweet sorghum cultivars are being developed under AICSIP (All India Co-ordinated Sorghum Improvement Program). The cytoplasmic-genetic male sterility, induced by interaction of sterility-inducing factors in the cytoplasm with the genetic factors contained in the nucleus, forms the basis of hybrid seed production.

The successful development and spread of sorghum hybrids and varieties have made a significant impact on the productivity of this crop. The private sector gained considerably from the hybrid seed production and marketing of sorghum hybrids. In fact, the largest volume of hybrid seeds sold earlier was for sorghum and pearl millet hybrids. A country's advancement on the farm front is gauged by its efficiency in quality seed production and distribution. Without the use of good quality seed, the investments incurred on fertilizers, pesticides and water will not play dividend that ought to be realized. Seed is the key input in modern agriculture as the quality of seed determines the quantum output of a crop. The high quality seed in terms of high genetic and physical purity, healthiness, high germination, vigour and viability assures the potential of crop production under suitable and favourable agro-climatic conditions. The genetically pure seed of a variety is expected to have all the unique economic and diagnostic characters. In often cross pollinated species like sorghum inbred lines and varieties, the deterioration will be faster due to contamination with undesirable pollen of other genotypes. The quality of the certified seed class of a hybrid or variety depends on the maintenance of genetic purity, physical purity, seed health, vigour, and viability potential during total seed production chain.

Hybrid (A × R) seed production

Sorghum hybrid seed production is a highly commercial venture. It is essential to maintain efficient level of crop management in order to maximize production at minimum cost. The hybrid seed is produced as certified seed under the vigilance of state seed certification agencies on a very large scale by private agencies, seed farms, experienced growers, and other extension organizations. Sorghum hybrids involve A × R seed production and are carried out according to the prescribed standards of production and processing in terms of isolation distance, genetic purity, and seed quality. Seed certification and seed law enforcement agencies have an important role to play in certified hybrid seed production and distribution, because the crop performance is dependent on the quality of the certified seed used. Although production of hybrid seed can be carried out by small individual growers, it is convenient to grow it in large compact blocks of 100–150 ha in a single or cluster of adjoining villages to avoid isolation problems. The quantities of hybrid seed required should be roughly estimated on an annual basis in advance, depending upon the projected demand for the commercial hybrid under cultivation. It is desirable to maintain significant quantities of carry-over seed as an insurance against unforeseen seed crop losses (normally an excess of 20% over the demand is produced).



Hybrid (A x R) seed production in Sorghum

Production environment

The area where the temperature during flowering ranges from 27–32°C is best suited for good seed production of sorghum. Night temperatures should not fall below 11°C for longer period since it affects the seed development. Flowering and seed development stages should not coincide with the rains, as the pollen loss and grain mold deteriorate seed quality. The fields where sorghum was not grown during the previous season should be selected. In addition, there should be no Johnson grass in the seed field or within isolation distance. The field should be well levelled and drained. The saline, alkaline or very lighter soils are not suitable. Uniform and levelled piece of land with good drainage should be selected. The *p*H should be around 5.5–8.5, good irrigation facilities are essential for sorghum seed crop.

Selection of season

Sorghum seed production is mostly undertaken during rainy (*kharif*) season in Maharashtra, Madhya Pradesh, Rajasthan and Gujarat. In the other sorghum growing areas, it is taken in winter (*rabi*) or summer season. Seed produced in seasons other than *kharif* have good germination and vigour. During *kharif*, problems due to grain mold arise frequently. The savings should be carried out before the end of June and September in *kharif* and *rabi* seasons respectively. Early sowing culminates shoot fly attack and seed crop passes through its life cycle at the most optimum environmental condition for crop growth and seed development. The seed of commercial hybrids is produced during *rabi* and summer seasons both by public and private seed agencies and marketed in summer season itself. However, seed for *rabi* has to be stored till the next *rabi*. Consequently, there is some difficulty in the availability of seed for *rabi* leading to stagnant production of *rabi* sorghum. The seed production in *rabi* is predominantly concentrated in Andhra Pradesh and adjacent part of Karnataka due to favourable ecological conditions.

Sowing method

Seed should be placed at 3–4 cm depth. Maintenance of male sterile line (A-line) involves sowing of two parents, i.e. A-line (male sterile) and B-line (male fertile, non-pollen restores). Similarly, certified seed production of hybrids includes male sterile A-line and fertility restorer R-line. The border rows (4–6) should be sown with male line all round the seed production plot. To facilitate frequent rouging operation, a spacing of 60 cm (row to row) and 15–20 cm (plant to plant) is advisable.

Male sterile (A) and restorer (R) lines in sorghum sown in alternate strips of rows

Precautions should be taken to avoid admixing two parental lines at the time of sowing. For A-line seed production, the seed rate is 7.5 kg/ha of A-line and 5 kg/ha of B-line. The usual planting row ratio of A- and B-lines is 4:2 for breeder seed production. For certified hybrid seed production, the female and male lines in 4:2 can be sown, however, the proportion can be widened to 6:2. The general seed rate varies from 7–8 kg/hectare depending on spacing.

Planting ratio

Male sterile (A) and restorer (R) lines are sown in alternate strips of rows, normally in a ratio of 4A:2R, depending on the local experience of success and the ability of the R-line to disperse the pollen. The borders on all four sides of the hybrid seed production field are sown with the restorer (R) lines to ensure an adequate supply of pollen and guard against incoming stray pollen. The ideal planting ratio between male and female lines is two male rows alternated by 4–6 female rows. The male lines have smaller earheads and shorter span of flowering compared to the female ones, therefore, it is desirable to allow only four female rows for each pair of male rows. The female rows for each pair of male rows can be increased to six as in case of the male lines having larger panicle and longer span of flowering. A five row thick border all around the seed production plots must always be provided. Economizing on male lines, both within the plots and borders may affect the seed set and is not a wise step which many seed growers tend to do.

Isolation requirement for hybrid seed plot

Getting required isolations (300–400 for foundation and 200–400 m for certified) is increasingly becoming difficult for sorghum seed production. Hence, it is necessary that the hybrid wise seed production is planned in few clusters of villages. Each cluster can have 2–3 contiguous villages with about 200 or more hectares. The number of clusters may depend on the total seed required based on demand and supply. Compact blocks are easy for the supervision, maintenance of quality, minimizing the nicking and isolation problems to a major extent and can also serve as demonstration blocks.

Plant height adjustment

Most of the parental lines of sorghum hybrids have matching heights in the *rabi* season facilitating easy pollination process. The problem of disparity of heights can be avoided to some extent by planting the short parent on the raised ridges and the taller parent in the furrows below. Selective urea sprays also enable to increase the height to some extent by elongating the peduncle.

Nicking/ensuring synchronization

It is essential that the parental lines chosen for hybrid seed production flower at the same time, i.e the viable pollen is available when stigmas are receptive. Therefore, a prior knowledge of the flowering patterns of both the parents in hybrid seed production is necessary. The male and female parents of the various hybrids, with different degrees of photo and thermo-sensitivities may react variably under different day length and temperatures at various locations or seasons. Therefore, several methods are employed to ensure synchrony. Some important measures for synchronization of flowering of male and female parents are:

- The growth stages of male and female parents should be critically examined at 4 weeks stage or even later depending upon the length of their vegetative growth period.
- The flower primordia and the apex of male and female plants be sampled randomly and observed critically by stripping the leaves of stem. The difference in the time of initiation and the size of the panicle bud would indicate the difference in their time to 50% flowering.
- The parent lagging behind can be hastened by selective measures like supplementation of nitrogen in the soil (additional dose of 50 kg N/ha) followed by foliar spray of urea (2%), soaking of seeds in water and GA spray at primordial initiation stage.
- Alternatively, selective irrigation of one parent and delayed irrigation of the other will also help in synchronizing the flowering date of the parents.
- Careful manipulation of nitrogenous fertilizers, foliar spray of GA and irrigation can synchronize the flowering of parents that differs by up to one week.
- If the male is advanced in the early stage due to adverse seasonal conditions, alternate plants are cut to allow the tillers to come up and such tillers are boosted with additional doses of nitrogen.

In case of partial seed setting, sugary disease (ergot) may occur. In such cases, spray of Thiram/Captan is used to control the disease and avoid prolonged sowings in the same areas, since the disease may invade the late sown crop in epiphytotic proportion. However, making the available pollen to achieve good seed set ensures better control of ergot disease.

Pollen viability, production and dispersal

Sorghum ear heads flower from the top to downwards over 4–9 days. Flowering commences when the glume opens and the pollen sacks emerge and release the fine pollen powder which grows down the stigma tube and fertilizes the grain ovary. Fertilization normally takes place within 2 h of the pollen landing on the stigmas. This happens soon after sunrise in the coldest part of the day. Researchers find it difficult to nominate the exact temperature below which pollen production is affected and pollen becomes non-viable, but temperatures below 10°C and above 40°C definitely reduce pollen viability. Cold weather at flowering reduces pollen viability and causes erratic seed set in late planted crops. In conditions of high moisture and humidity, pollen sacks do not dry out fast enough, their skin becomes rubbery and they do not split and shed pollen. Breeding for high pollen production is one of the key breeding goals for sorghum research and development programmes. Pollen viability

Sorghum seed production

Sorghum dispersal

is also important, as large amounts of non-viable pollen are not useful. High levels of viable pollen also help to combat ergot disease infestation. In fact, the staggered planting of the two male rows ensures adequate and prolonged availability of pollen. It is not safe to rely entirely on natural winds to aid in pollen dispersal. It is desirable to use artificial aids of pollen dispersal like tapping the male plant or blowing air through empty duster over the male heads. It is also advisable to spray 2% borax to improve the pollen production and dispersal. If the pollen is not available in the same plot, the pollen in the morning is collected from neighbouring plots and instantly sprayed with water or dust on the ear heads of the female parent. If there is dew fall hampering spread of pollen, power duster is blow emptied on the male rows to disperse pollen towards female heads or the male heads are tapped.

Stigma receptivity

Generally, the stigma retains good receptivity up to 4–5 days (MS 2219A, MS 296A and AKMS 14A) after flower opening, although in some lines it extends beyond that period as in MS 2077A. However, during the hot summer months, the receptivity is lost faster owing to desiccation of stigmas.

Rouging

Regular rouging should be followed after the commencement of flowering. Apart from off-types, pollen shedders can also be a problem in A-lines. Shedders are plants that look similar to the A-line, but exhibit fertile anthers and shed pollen. Such plants can only be identified at anthesis and should be uprooted immediately. Shaders can also arise from a partial breakdown of sterility in the A-lines due to high temperatures (>38°C). Delay in identifying shedders will result in out crossing to male-steriles and subsequently contaminate the hybrid causing genetic deterioration. Therefore, it is recommended that rouging be carried out in the early morning hours before pollen shedding takes place. The R-line should also be rouged periodically.

Harvest of hybrid seed

All possible precautions against seed contamination should be taken during harvesting of hybrid seed production plots and threshing of panicles from the A-line rows. Usually, the R-line is harvested first and the harvest is removed from the field. Later, the A-line rows are carefully inspected for off-types and other chance admixtures and then harvested. Harvesting should be done at physiological maturity stage when the black layer formation appears at the point of attachment of seed with the caryopsis. In general, the seeds harvested 35–45 days after flowering have superior seed quality.

Seed contamination in hybrid seed production of sorghum

Threshing of hybrid seed

Threshing can be done by clean machine threshers at proper seed moisture content (13–14%). Seed should be dried to 10–12% moisture content before storage. Care should be taken to avoid mechanical mixtures while threshing. Hybrid seed yield (on the A-line) depends upon the yield potential of the A-line, per cent seed set, and environmental conditions.

Seed processing

As per Indian minimum seed certification standards (2013), the threshed seeds of sorghum should be physically pure and should not contain weed seeds, disease and pest infested seed, other crop seed, other cultivar seed, undesirable seed, and damaged seeds. Seed processing is an integral part of sorghum seed technology, which encompasses steps such as drying, cleaning, grading, treating and bagging. Seeds of sorghum harvested and threshed properly can often be cleaned to the desired purity on the air screen cleaner alone. The sieve aperture sizes of top and bottom screens of air screen cleaner differ with genotypes. Generally, the top screen may be around 12/64" or 4.75 mm with round holes and the bottom screen at 9/64"or 3.5 mm with round holes. The specific gravity separator helps in upgrading the quality of seeds by rejecting the seed that is inferior in specific gravity. The seed should to be dried to a uniform moisture level of 11–12% for storage. The seed companies train supervisory staff who in turn advise and assist the seed growers in hybrid seed production across critical crop growth stages. Close communication between seed growers and the company supervisory staff during the entire season facilitates quality seed production of sorghum hybrids. The requirements of isolation distance must be satisfied by a negotiated contract between a contract grower or group of farmers living in a community (seed village) and the seed firm.

Seed certification

Genetic purity in seed production is maintained through a system of seed certification. The main objective of seed certification is to make available the seeds of good quality to farmers. To achieve this qualified and trained personnel from SCA carries out field inspections at appropriate stages of crop growth. They also make a seed inspection by drawing samples of seed lots after processing. The SCA verifies seed standards in which the seed lot must confirm to get approval as certified seed. Hybrid seed production plot should ensure field standards (general and specific requirements) of the produce for foundation and certified seed classes as per the Indian minimum seed certification standards (2013) prescribed for sorghum.

SUMMARY

Commercial hybrid seed production of sorghum must be carried out in a systematic manner. Selection of areas and seasons free from disease and pests is very important before planning hybrid seed production of sorghum. Seed production agencies have to identify suitable areas with ideal agro-climatic conditions for efficient hybrid seed production through preliminary experimentation. Areas with temperature extremities, endemic to serious disease, pest, and obnoxious weed like *Sorghum halepense* and Striga are not suitable. Areas that are prone to natural disasters such as floods, excessive rains or high humidity during the grain filling stages of sorghum could cause grain molds, discolouration, weathering, and pre-harvest sprouting, all of which affect seed germination and seed quality. The chronological adjustments of the two parents ensuring coordination of pollen shedding and stigma receptivity facilitated by prolongation of effective flowering period is vital in hybrid seed production.

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Biofortified millets

to alleviate micronutrient malnourishment

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In the 2022 Global Hunger Index, India ranks 107 out of the 121 countries and the severity of hunger is classified as 'serious'. The proportion of undernourished in the country is 16.3% (2019–21), which amounts to about 224 million people; majority of whom are women and children. Malnutrition and the resultant stunting, wasting, and nutritional deficiencies are prevalent among women and children. The bane of child and maternal malnutrition is responsible for 15% of India's total disease burden. The Government of India's POSHAN Abhiyaan or National Nutrition Mission is a flagship programme to improve nutritional outcomes for children, pregnant women and lactating mothers, and to ensure a malnutrition free India. In this regard, development of biofortified millet seems to be a convincing solution which has been discussed in this article.

Keywords: Hidden hunger, Iron, Malnourishment, Micronutrient, Millets, Zinc

MOST widespread micronutrient deficiencies are that of iron (Fe), zinc (Zn) and vitamin A. Micronutrient malnutrition, also known as 'hidden hunger' affects more than one-half of the developing world's population, especially the women and pre-school children. It is also a food related public health concern in India where almost 40% pre-school children, 24% school going children and 40% female adolescents are anemic. More than 50% pregnant women are anemic.

More than half of anemia cases are due to iron deficiency alone. About 80% of pregnant women, 52% of non-pregnant women, and 74% of children in the 6–35 months age group suffer from iron deficiency. About 52% of children below 5 years of age are zinc deficient, while in adults it is 17–32%. The intake of micronutrients in daily diet is less than 50% RDA in over 70% of Indian population, which represents the severity of micronutrient deficiency in India.

Biofortification

Biofortification is the development of staple crop cultivars with higher levels of micronutrients. It differs from fortification (addition of an ingredient in food to increase the concentration of a particular element like iodized salt) or supplementation (addition of an element to the diet to make up for an insufficiency like vitamin capsules). In biofortification, micronutrient-dense grains are produced by the crop itself through agricultural interventions. It is a food based approach to reduce the micronutrient malnutrition among the poor population.

Need

- It provides a long-term strategy of delivering more micronutrients, and is a powerful intervention tool to alleviate micronutrient malnourishment.
- Micronutrient enriched staple plant foods can significantly improve the amount of these nutrients consumed by the target populations.
- Biofortified crop varieties can be developed through conventional breeding programmes.
- Once biofortified varieties are developed, there is no additional expense involved in getting higher nutrition.

Advantages

- It targets low-income people and rural communities, and remote areas like tribal regions.
- Its recurrent costs are low, therefore biofortified varieties can be grown by farmers without extra cost and seeds can be shared.
- It is sustainable as its varieties will continue to be grown and consumed year after year.

Millets are nutri-cereals

- Millets are highly nutritious compared to fine cereals like rice.

- Millet grains contain high protein, fibre, micro and macronutrients and are gluten free.
- Millet protein has well balanced amino acid profile and good source of methionine, cystine and lycine.
- Pearl millet has the highest content of fat and micronutrients.
- Sorghum is a cheap source of energy, protein, iron and zinc next only to bajra.
- Finger millet is the richest source of calcium and potassium (400–420 mg/100 g).
- Other small millets are good source of phosphorous and iron.
- Phytochemicals in many of the millets act as antioxidants.

Dhanshakti (first biofortified variety of pearl millet)

Pearl millet HHB 311

Millets as agents for biofortification

- The base level of micronutrients is high in millets providing advantage in further enrichment (Table 1).
- They possess added advantage of other nutritional benefits like rich in antioxidants.
- Millets are readily acceptable to poor people requiring nutritional intervention.
- They are mostly grown in marginal lands and tribal regions where poor people live.
- They are consumed in the form of various traditional foods like porridge, roti, sargatti, etc.
- Millet is drought resistant crop having short-duration and less incidence of diseases and pests.
- It requires less external inputs and hence, is most suitable for arid and semi-arid regions.
- It is helpful in the treatment of diabetes, obesity, blood pressure, heart diseases, cancer, etc.
- Millets act as immune boosters due to presence of vitamins and essential minerals.
- Different value-added products can be prepared from millets to target urban population suffering from lifestyle diseases.

Dhanshakti-first biofortified pearl millet variety

Pearl millet has the highest content of iron in its grains. Large variability for both iron and zinc has been reported in pearl millet varieties and hybrids. In order to enhance the content of iron and zinc further and with an aim to reduce the micronutrient deficiency among the people consuming pearl millet as staple food, HarvestPlus in association with ICRISAT started working on pearl millet biofortification in the early 2000s.

By exploiting variability available within population of a germplasm line ICTP 8203 for iron content, an improved version, ICTP 8203 Fe-10-2 was developed. It was released as 'Dhanshakti' in collaboration with MPKV, Rahuri first in 2012 in Maharashtra and later across India in 2014. The variety is adapted to Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Gujarat, Madhya Pradesh, Rajasthan, Uttar Pradesh, Haryana and Punjab.

Three independent studies showed that consumption of 200 g of 'Dhanshakti' can meet 100% of recommended daily allowance (RDA) of iron in adult men and children in India and 60% of the RDA in non-pregnant and non-lactating women. Studies also indicated that feeding iron rich pearl millet is an efficacious approach to improve iron status in school-age children. The food products made out of Dhanshakti were readily accepted by both mothers and children.

ICAR's initiative to develop biofortified varieties

In order to accelerate the development of biofortified varieties and enhance the nutritional value of commonly consumed staples, ICAR launched a Consortia Research

Table 1. Nutritional composition of millets vs other cereals (per 100 g)

Grain	Carbo-hydrates (g)	Protein (g)	Fat (g)	Energy (KCal)	Dietary fibre (g)	Ca (mg)	P (mg)	Mg (mg)	Zn (mg)	Fe (mg)
Sorghum	67.7	09.97	1.73	334	10.22	28	274	133	2.96	3.95
Pearl millet	61.8	10.96	5.43	348	11.49	27	289	124	2.76	6.42
Finger millet	66.8	07.16	1.92	321	11.18	364	210	146	2.53	4.62
Kodo millet	66.2	08.92	2.55	332	6.39	15	101	122	1.65	2.34
Little millet	65.6	10.13	3.89	346	7.72	16	130	91	1.82	1.26
Proso millet#	70.4	12.50	1.10	341	2.20*	14	206	153	1.40	0.80
Foxtail millet#	60.1	12.30	4.30	331	8.00*	31	188	81	2.40	2.80
Barnyard millet#	65.6	06.20	2.20	307	9.80*	20	280	82	3.00	5.00
Wheat	64.7	10.59	1.47	322	11.23	39	315	125	2.85	3.97
Rice	78.2	07.94	0.52	356	2.81	7	96	19	1.21	0.65

Source: Indian food composition tables, NIN–2017; *Crude fibre; # Based on nutritive value of Indian Foods, NIN–2007

Platform (CRP) on Biofortification addressing rice, wheat, maize, sorghum, pearl millet and small millets since 2014. The programme has resulted in development of about 17 biofortified varieties of rice, wheat, maize and pearl millet. Further research efforts in all the crops are still ongoing.

Biofortified pearl millet cultivars

The All India Coordinated Research Project on Pearl Millet (AICRP-Pearl Millet) is working on development of biofortified pearl millet cultivars. Separate biofortification trials were conducted to evaluate pearl millet varieties and hybrids with high iron and zinc content. A few biofortified cultivars with higher iron and zinc content along with high grain yield were released for farmers. Since 2018, AICRP-Pearl Millet has set a minimum 42 mg/kg of iron and 32 mg/kg of zinc for promoting entries in the trials and cultivar release. Presently, many high yielding cultivars having moderate to high iron and zinc content are available to the farmers for cultivation (Table 2).

Finger millet CFMV 1 (Indravathi)

Finger millet CFMV 2 (Gira)

Sorghum

Sorghum is the second cheapest source of energy and micronutrients after pearl millet. Sorghum consumption, especially by low and middle-income rural consumers, is high in the major production regions of inland central and eastern regions of Maharashtra and inland northern region of Karnataka. In terms of nutrient intake, sorghum accounts for about 35% of the

Table 2. Latest biofortified hybrids/varieties of pearl millet

Hybrid/Variety	GY (kg/ha)	Duration (days)	Year	Fe (mg/kg)	Zn (mg/kg)	Developer	Area of adoption
Dhanshakti (ICTP 8203 Fe 10-2)	2199	76	2014	81	43	MPKV, Dhule	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Rajasthan, Haryana, Madhya Pradesh, Gujarat, Uttar Pradesh, Punjab
Mahabeej 1005 (MH 1852)	2994	81	2017	62	37	MSSCL, Akola	Maharashtra
AHB 1200 Fe (MH 2072)	3170	78	2018	77	39	NARP, Aurangabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra, Telangana, Andhra Pradesh, Tamil Nadu
HHB 299 (MH 2076)	3274	81	2018	73	41	CCSHAU, Hisar	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra, Tamil Nadu
NBH 4903 (MH 2035)	4444	85	2018	70	63	Nuziveedu Seeds, Hyderabad	Maharashtra, Karnataka, Telangana, Andhra Pradesh, Tamil Nadu
AHB 1269 Fe (MH 2185)	3168	82	2019	91	43	NARP, Aurangabad	Rajasthan, Haryana, Gujarat, Punjab, Delhi, Maharashtra, Tamil Nadu,
RHB 233 (MH 2173)	3157	80	2019	83	46	SKNAU, Jobner	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Punjab, Delhi, Maharashtra, Tamil Nadu
RHB 234 (MH 2174)	3169	81	2019	84	41	SKNAU, Jobner	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Punjab, Delhi, Maharashtra, Tamil Nadu
Phule Mahasakthi	2581	83	2019	85	37	MPKV, Dhule	Maharashtra
HHB 311 (MH 2179)	3173	80	2020	83	39	CCSHAU, Hisar	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Punjab, Delhi, Maharashtra, Tamil Nadu
Moti Shakti (GHB 1225)	3023	-	2020	76	46	JAU, Jamnagar	Gujarat
GHB 1129 (Jam Shakti)	2957	80	2021	72	43	JAU, Jamnagar	Gujarat
VPMH 7	2352	84	2021	67	52	UAS, Dharwad	Karnataka
GHB 1231 (Sawaj Shakti)	2760	-	2021	81	41	JAU, Jamnagar	Gujarat
HHB 67 Imp 2	2000	-	2021	55	40	CCSHAU, Hisar	Rajasthan, Gujarat, Haryana, Madhya Pradesh, Delhi

Table 3. Biofortified varieties of small millets

Crop	Variety	GY (kg/ha)	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Developer	Area of adoption
Finger millet	CFMV 1 (Indravathi)	3110	4280	58	44	ARS, Vizianagaram	Andhra Pradesh, Karnataka, Tamil Nadu, Puducherry, Odisha
Finger millet	CFMV 1 (Gira)	2950	4740	39	25	HMRS, Waghai	Andhra Pradesh, Chhattisgarh, Gujarat, Maharashtra, Odisha
Little millet	CLMV 1 (Jaicar Sama-1)	1580	-	59	35	IIMR, Hyderabad	Maharashtra, Andhra Pradesh, Telangana, Tamil Nadu, Puducherry

total intake of calories, protein, iron and zinc in these dominant production/consumption regions. Hence, biofortification of sorghum is a promising strategy to alleviate iron and zinc deficiency in these rural areas of dryland. Wide variability for grain iron (12–68 mg/kg) and zinc (11–44 mg/kg) has been observed among the cultivars and germplasm lines. Several of the released and popular sorghum cultivars possess moderate amounts of grain iron and zinc. Regular consumption of these would elevate the micronutrient status among the sorghum consuming population. Currently, efforts are on to developing biofortified sorghum varieties combining high yield and micronutrients.

Little millet CLMV 1 (Jaicar Sama-1)

Small millets

Small millets are highly nutritious and superior to rice for mineral content. The protein content ranges from 7–12% and fat content from 1–5%. Iron and zinc are relatively in higher concentrations in small millets compared to other major cereal crops. Varietal variations exist for both iron and zinc content. Finger millet is a very rich source of calcium (Ca), but grains also contain anti-nutritional factors like tannin (up to 3%) in larger quantities with strong negative correlations with iron and zinc. Processing techniques like soaking, roasting, boiling, germination, fermentation and malting tend to reduce tannin content and enhance the availability of micronutrients. Research efforts are going on to develop small millet varieties with high iron and zinc content. On the occasion of World Food day 2020, the Prime Minister, Shri Narendra Modi dedicated two finger millet varieties, CFMV 1 and CFMV 2 rich in calcium, iron and zinc, and one small millet variety CLMV 1 rich in iron and zinc to the nation (Table 3).

SUMMARY

Millet grains contain higher protein, fibre, calcium and mineral nutrients, and can ensure better nutrition to the poor people. Biofortification in millets is a feasible strategy to alleviate the micronutrient malnutrition among the rural poor. Several biofortified cultivars have been released in pearl millet for commercial cultivation and are being adopted by the farmers. The availability of high variability for grain micronutrient contents in sorghum and small millets holds promise to develop superior cultivars with enhanced nutritional quality. Wide adoption and consumption of such biofortified millets by micronutrient malnourished poor people will enhance the nutritional status and health condition of rural as well as urban population. Integration of biofortified cultivars of millets in Government programmes like POSHAN Abhiyaan, PDS and ICDS can make the nutritional interventions more practical and cost-effective to deliver the micronutrients to the target communities.

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Nutritional
value of millets

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Millets include a group of small-grained cereals widely cultivated and consumed throughout arid and semi-arid parts of the world. They are agronomically superior in terms of shorter growing periods, have ability to grow in marginal lands with minimum inputs and are resistant to biotic and abiotic stresses. More importantly, the millet grains are nutritious with a carbohydrate content of about 60–68%, protein content of 6–12%, fat content of 1.7–5.4% and total ash content of about 1.3–2.7%. They are good sources of dietary fibre and micronutrients including minerals and B-vitamins. Apart from this, millets contain phytochemicals including the phenolic compounds with excellent health beneficial attributes. Owing to their excellent nutritional value and the ability to survive under changing climate scenarios, these crops may serve vital role in achieving global nutritional security in a sustainable manner.

Keywords: Climate resilience, Nutraceutical, Nutritional security

MILLETS are among the oldest crops to be domesticated and cultivated by humans and have been a vital component of dry farming system in several Asian and African countries. Fine cereals including wheat and rice are generally preferred for human consumption, and millet grains have often been neglected since long. However, these 'orphan crops' remain staple food and source of nutrition to the resource-constrained farmers inhabiting arid and semi-arid tropics. Of late, with climate change and malnutrition becoming major concerns across the globe, millets have started to regain their significance owing to their nutritional quality and climate smart nature.

Millets include the major and small millets where sorghum and pearl millet are the major millets and finger millet, foxtail millet, little millet, proso millet, kodo millet, and barnyard millet are the important small millets. These millet grains are nutrient-dense and exhibit nutraceutical properties. Also, these grains are utilized as bird feed in several countries including the United States. Apart from being nutritionally superior, these crops also exhibit several agronomic benefits including the ability to grow under harsh environmental conditions, resistance to biotic and abiotic stress, and shorter growing periods. Owing to these benefits, millets are now regarded as 'smart foods' which are good for the farmer, consumer, and the environment.

Nutritive value of millets

The proximate composition of millets in comparison with the commonly consumed cereals, viz. rice, wheat and maize are presented in Table 1. The energy value of millets varies from approximately 307–347 Kcal. Millets contain about 60–68% carbohydrates, 6–12% protein, 1.7–5.4% total fat, and 1.3–2.7% total ash content. The total dietary fibre content of millet grains ranges from 6–12%. Millets are good source of micronutrients including minerals and B-vitamins as well as phytochemicals with health benefits.

Millet grains
Source: ICAR-IIMR

Table 1. Proximate composition of millet grains in comparison with rice, wheat, and maize

Grain	Protein (%)	Fat (%)	Ash (%)	Carbo-hydrate (%)	Total dietary fibre (TDF)	Energy
Sorghum	9.97	1.73	1.39	67.7	10.2	334
Pearl millet	10.96	5.43	1.37	61.8	11.5	347
Finger millet	7.16	1.92	2.04	66.8	11.2	320
Foxtail millet	12.3	4.30	2.6	60.1	10.7	331
Little millet	10.13	3.89	1.34	65.5	7.7	346
Proso millet	11.5	3.5	2.7	64.5	9.6	341
Kodo millet	8.92	2.55	1.72	66.2	6.4	331
Barnyard millet	6.2	2.20	1.3	65.5	12.6*	307
Rice, raw, milled	7.9	0.52	0.56	78.24	2.81	356
Wheat, whole	10.59	1.47	1.42	64.72	11.2	321
Maize, dry	8.8	3.7	1.17	64.7	12.2	334

Source: Indian food composition tables, NIN–2017; Nutritive value of Indian food, NIN–2007; Malleshi *et al*. 2021; *Roopashree U *et al*. 2014

***Carbohydrates*:** Similar to other cereals, carbohydrate forms the major nutritional component of millet grains. Starch constitutes the major carbohydrate in millets and represents about 55–78% of grain weight. Soluble sugars including sucrose, glucose, fructose, raffinose, stachyose form the minor carbohydrate fraction of millets.

***Dietary fibre*:** The dietary fibre components are concentrated on the pericarp and endosperm part of the grain. Millets are good source of dietary fibre. Both major and small millets possess dietary fibre higher than rice while, pearl, finger and barnyard millet possess dietary fibre comparable to or better than wheat.

***Proteins*:** Millet grains are good source of protein. They possess higher protein content as compared to rice and maize, and on par with wheat. Among the millet grains, foxtail and proso millet have the highest protein content (~12.3 and 11.5%, respectively), which is higher than the protein content of wheat (10.6%). Regarding the amino acid composition, like most cereals, millets are deficient in lysine. Pearl millet has a balanced essential amino acid composition, among the millet grains. Being gluten-free, these grains are a source of protein for people who suffer from celiac disease.

***Fat*:** Fat or lipids are mainly concentrated on the germ layer of millet grains. The fat content of these grains varies from 1.7% in sorghum to 5.4% in pearl millet. The relatively higher fat content of the pearl millet partly explains the shorter shelf-life of pearl millet flour. Regarding the fatty acid composition, millets contain unsaturated fatty acids including the essential fatty acids, viz. linoleic acid and linolenic acid.

***Micronutrients*:** Millets are rich sources of micronutrients including minerals and vitamins, especially the B-vitamins. The important minerals found in millet grains are presented in Table 2. Most millets contain good amount of phosphorus (P), magnesium (Mg), potassium (K) etc and finger millet is a rich source of calcium (Ca). In fact, the calcium content of finger millet (364 mg/100 g) is the highest known for any cereal. One hundred gram of finger millet is sufficient to meet more than a quarter of the RDA of calcium of an adult human being. Also, millets, especially, pearl millet is a good source of iron (Fe) and zinc (Zn).

Table 2. Important minerals present in millets in comparison with rice, wheat, and maize

Grain	Ca (mg)	P (mg)	Mg (mg)	Zn (mg)	Fe (mg)
Sorghum	27.6	274	133	1.9	3.9
Pearl millet	27.4	289	124	2.8	6.4
Finger millet	364.0	210	146	2.5	4.6
Foxtail millet	31.0	290	81	2.4	2.8
Little millet	16.1	130	91	1.8	1.3
Proso millet	30.0	*	153	1.4	2.0
Kodo millet	15.3	101	122	1.6	2.3
Barnyard millet	20.0	280	82	3.3	5.0
Rice, raw, milled	7.5	96	19	1.2	0.6
Wheat, whole	39.4	315	125	2.8	3.9
Maize, dry	8.9	279	145	2.3	2.5

Source: Indian food composition tables, NIN–2017; Nutritive value of Indian food, NIN–2007; Malleshi *et al.* 2021; *Data not available

Like other cereals, millets are good sources of B-vitamins, viz. B1 (thiamine), B2 (riboflavin), B3 (niacin) and folic acid (Table 3). The B-vitamins are mainly present in the bran and germ layers and hence decortication, a commonly employed processing technique to convert the small millets in to edible form, is known to reduce these micronutrients.

Table 3. Important B-vitamins present in millets in comparison with rice, wheat, and maize

Grain	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Folic acid (µg)
Sorghum	0.35	0.14	2.1	39.4
Pearl millet	0.25	0.20	0.9	36.1
Finger millet	0.37	0.17	1.3	34.7
Foxtail millet	0.59	0.11	3.2	15.0
Little millet	0.26	0.05	1.3	36.2
Proso millet	0.41	0.28	4.5	*
Kodo millet	0.29	0.20	1.5	39.5
Barnyard millet	0.33	0.10	4.2	*
Rice, raw, milled	0.05	0.05	1.7	9.32
Wheat, whole	0.46	0.15	2.7	30.1
Maize, dry	0.33	0.09	2.69	25.8

Source: Indian food composition tables, NIN–2017; Nutritive value of Indian food, NIN–2007; Malleshi *et al.* 2021; *Data not available

***Anti-nutrients*:** Millets contain certain anti-nutrients such as phytic acid that interfere with absorption of minerals. Sorghum and finger millet are known to contain tannins, polyphenolic compounds with some anti-nutritional properties. The anti-nutrients are found in the outer layers of the grain and hence, the common household processing methods including decortication, milling, soaking, roasting, germination, fermentation and cooking are known to reduce the negative impacts of anti-nutrients.

***Phytochemicals*:** Much of the health beneficial effects of millets have been attributed to the presence of abundant phytochemicals including phenolic compounds, phytosterols etc. Phenolic compounds, viz. phenolic acids, flavonoids etc which are present in millets impart bioactivities including anti-oxidant, anti-microbial, anti-diabetic, and anti-hypertensive properties. The 3-deoxy anthocyanins which are found in sorghum are known to exhibit several bioactivities including the ability to protect from certain types of cancers.

SUMMARY

Though our country has achieved the goal of combating hunger through green revolution, lack of micronutrients including iron, zinc, calcium etc in daily food intake continues. In this context, millets with their balanced nutritional composition, inherently rich micronutrient profile and nutraceutical properties are highly relevant. Millets have a low carbon footprint and excellent adaptability to survive under climate extremes. Hence, they are regarded as 'smart food' which are good for the consumer and environment. The United Nations has officially declared to celebrate 2023 as the 'International Year of Millets' following India's proposal to Food and Agricultural Organization (FAO) and is aimed at creating awareness about their nutritive value, potential health benefits and their suitability for cultivation under changing climatic conditions. This would serve to enhance awareness among people, thereby improving the cultivation and consumption of these heritage crops paving way for sustainable nutritional security.

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Health benefits

of millets

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Millets were widely cultivated across Asia and Africa before green revolution and were the staple food grains for humans. The stover from millets was an important component of livestock feed in integrated farming systems. Lack of diversity in food grains and excessive processing of rice and wheat has caused double burden of lifestyle diseases and malnutrition. Micronutrient deficiency is being manifested as 'hidden hunger' in many developing countries to which millets seem to be a probable salution. Millets like sorghum, pearl millet and finger millet are consumed as whole grains and are rich source of vitamins, minerals, and dietary fibre. Small millets like foxtail, proso, little, barnyard and kodo millets are also good source of nutrients when moderately polished after dehulling. Finger millet is a very rich source of calcium for growing children, pregnant women and elderly for maintaining bone health. Therefore, regular consumption of millets helps in diversification of diets and imparts many health benefits along with battling hidden hunger.

Keywords: Calcium, Dietary fibre, Micronutrients, Minerals, Vitamins

MILLETS are a diverse group of tiny-grained annual grasses cultivated widely in arid and semi-arid regions of the world. Millets were among the most widely consumed cereals across many parts of Asia and Africa since 8000 BC. However, wheat, rice and maize have dominated cultivation after green revolution while, millets have been neglected. These days, millets are important forage crops in many parts of the world. Moreover, millets exhibit superior agronomic benefits, viz. shorter growing periods, ability to grow in marginal lands with low inputs, resistance to drought etc as compared to most other cereals. Millet grain is commonly used for human food and animal feed, and straw for animal feed. Also, millet grains are resistant to pests and diseases. Millets are now considered as 'smart foods' and 'nutri-cereals' as they contribute for food, health, and feed in a sustainable manner.

Millets for nutritional security

When our country achieved sustainable food production for combating hunger through green revolution, we attained food security. However, the lack of important nutrients such as proteins and micronutrients such as vitamins and minerals in daily food intake continued to cause 'hidden hunger' or nutrient deficiency in the population. Nutritional insecurity is a major threat to populations that are based on a cereal based staple diet as cereals are generally considered deficient in micronutrients. Millets are nutritionally diverse and offer a range of micronutrients for consumption. The balanced nutrient content of millet grains is contributed by carbohydrates (60–70%), proteins (7–12%), fats (1.5–5.5%) and dietary fibres (6–11.5%). Millets are gluten-free and are safe for people suffering from celiac disease. Proso millet has the highest amount of protein among grains (~12.5%) and barnyard millet is an excellent source of fibre. Further, millet grains are abundant sources of minerals and B-complex vitamins.

Altogether, millets offer a broad spectrum of micronutrients and other important nutritional components, and thereby paving way for nutritional security of the population. Even though millets are referred to as a single unit, each of them has their unique features in terms of nutrient profile.

Health benefits of millets

***Sorghum (Jowar)*:** Sorghum grain is consumed in different forms. Sorghum-based beverages are popular in African countries. In India, traditionally, sorghum is consumed as roti/chapati (unleavened flat bread) and as cooked rice. Sorghum based composite flour can be made into bread and other delicacies. Sorghum is well known for its slowest starch digestibility, and is also a good source of fibre and B vitamins including thiamine, riboflavin, folic acid etc. The grains contain good amount of potassium, phosphorus, calcium and sufficient amounts of iron and zinc. Consumption of sorghum is associated with a number of health benefits including prevention of chronic lifestyle disorders. Sorghum, being rich in resistant starch, helps in maintaining colon health and also prevents obesity and related complications. Sorghum phytochemicals are known to impart potential beneficial effects including reduction in certain types of cancer, promotion of cardiovascular health as well as protection against diabetic complications.

***Pearl millet (Bajra)*:** Pearl millet is consumed as cooked grains after removing seed coat or unleavened bread made from flour. In combination with legumes, it is used to prepare weaning foods in many parts of the world. In India, it is mainly consumed as bajra roti and in Africa, fermented or unfermented pearl millet porridges are widely used. Nutritionally, pearl millet has high fat content, hence is energy-rich. It is a good source of protein that is relatively high in the amino acid lysine compared to other millets. Besides, they are good sources of vitamins and minerals. Pearl millet is relatively rich in iron content compared to all cereals and millets. Moreover, iron rich pearl millet Dhanshakti (iron >70 ppm) was also released for cultivation. Pearl millet contains slow-releasing sugars and hence its consumption would be helpful for people suffering from diabetes. The high iron and zinc content of pearl millet grains makes it ideal for inclusion in the diets of anaemic subjects and also for pregnant and lactating women. The phytonutrients are known to exhibit anti-cancerous activity and antioxidant activity, thus reducing the risk of cardiovascular diseases.

***Finger millet (Ragi/Mandua)*:** Finger millet is an important weaning food, especially in India. It is also consumed in the form of ragi rotis, dosa and porridges. Its composite flour is widely employed for making bread. Finger millet is known to be rich in amino acid and methionine. It is also rich in dietary fibre as well as minerals especially calcium, iron and magnesium and is highly beneficial for pregnant and lactating women. In fact, finger millet has the highest calcium content as compared to most cereal grains (350 mg/100 g). Owing to its high calcium content, consumption of finger millet helps in strengthening of bones in growing children and elders. Consumption of finger millet is known to be beneficial for reducing fractures especially those related to osteoporosis. Further, the fibre, slow digestible carbohydrates and phenolics of finger millet are beneficial in reducing the risk of diabetes and also improve gut health.

***Foxtail millet (Kakum/Kangani)*:** Foxtail millet grains contain a thin layer of husk which needs to be removed before consumption. Foxtail millet is consumed as cooked rice, porridge and roti. Its composite flour is used in the preparation of puddings, breads, cakes and noodles. Foxtail millet is rich in protein as compared to rice. It is also rich in mineral matter content. Its low glycaemic index and high fibre content is highly beneficial for the prevention of type II diabetes and cardiovascular diseases. Phytochemicals present in foxtail millet impart several health benefits owing to free-radical scavenging properties.

***Little millet (Kutki)*:** Little millet is mainly consumed as cooked rice and as other fermented products like idly, and dosa. Recently, multi grain flours are employed in making bread and bakery products including biscuits and cakes. Little millet is a good source of protein, fat and an excellent source of dietary fibre. Little millet is also rich in iron, magnesium and zinc. Little millet is known to be hypoglycaemic and hypolipidemic. Hence, its regular consumption is beneficial in the management of diabetes and cardiovascular diseases. Further, its grain has faecal bulking effect and hence alleviates constipation.

***Proso millet (Chena/Bari)*:** In India, dehulled grain of Proso millet is often consumed as cooked rice while, in some parts of the country it is grounded to make roti and consumed. Proso millet grains are well-acclaimed for their high protein content (up to 12.5%). Proso millet protein is known to be abundant in leucine, isoleucine and sulphur containing amino acids, such as methionine and cysteine. Its grains are a rich source of B-vitamins including niacin and folic acid. Further, it is a good source of minerals, viz. manganese, iron and potassium. As with other millets, proso millet is also rich in dietary fibre and polyphenols. Studies suggest that consumption of proso millet offers several health benefits including elevation of HDL levels, thereby regulating cholesterol metabolism, protection from liver injury and beneficial effects on type 2 diabetes and obesity. Further, consumption of proso millet is also known to impart neural health benefits owing to its high lecithin content.

***Kodo millet (Kodon)*:** Kodo millet is easy to digest and is traditionally consumed as rice. It is also used in the preparation of idly, dosa, roti, and soup. Kodo millet is rich in total dietary fibre and B-vitamins including niacin, pantothenic acid, biotin and folate. Because of its high folate content (39.5 mg/100 g), kodo millet is suitable for inclusion in the diet of people suffering from anaemia. Kodo millet is also a good source of minerals including calcium, iron, potassium, magnesium and zinc. It has high amount of lecithin and hence, is used as supplement for strengthening nervous system. Also, it houses numerous phenolic phytochemicals. The antioxidant activity of phenolic phytochemicals of kodo millet helps to impart beneficial effects on human health including reduction in the risk of cardiovascular diseases and hypertension.

***Barnyard millet (Sanwa)*:** Barnyard millet is dehulled, cooked and consumed as rice. Its porridge is famous in Himalayan regions while in the southern parts of India, its grain is mainly used in traditional preparations, viz. idly and dosa. Barnyard millet composite flour is nowadays widely employed in making bakery products such as biscuits, noodles and bread. Barnyard millet grains are excellent sources of protein, dietary fibre and mineral nutrients including magnesium, iron and zinc. High iron and zinc content makes its grains a suitable diet for pregnant and lactating women. Also, high fibre content makes it a beneficial food for people suffering from type 2 diabetes and obesity. Further, the abundant phenolic phytochemicals present in its grain are known to impart several beneficial effects on human health including antioxidant, anti-carcinogenic, anti-inflammatory and antimicrobial properties.

SUMMARY

Millets like sorghum, pearl millet and finger millet are consumed as whole grains while other millets are subjected to dehulling and polishing before consumption. Whole grain millets and moderately polished millets are rich sources of micronutrients like vitamins and minerals. Moreover, they are also rich source of protein and dietary fibre. Proso millet is a rich source of protein and foxtail millet is a rich source of dietary fibre. Dietary fibre helps in improving gut health and promotes slow digestion of carbohydrates which is beneficial for people with type 2 diabetes. Iron and folic acid play important role in preventing anaemia in children and pregnant women. Finger millet is very rich in calcium and is beneficial for improving bone health and prevention of osteoporosis in elderly. Apart from well known nutrients, millets are a rich source of phytochemicals like polyphenols and anthocyanins with antioxidant and anti-inflammatory properties useful for preventing chronic lifestyle disorders. Regular consumption of millets not only diversifies the diet but, also imparts many health benefits.

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Pop sorghum

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Sorghum is a multipurpose crop and its use as food is the key component. Rotis and cooked sorghum are primary consumption patterns, while there are other foods and snacks locally popular in India. One such delicacy is the sorghum pops, as described in this article. Popped sorghum is easy for digestion and is used as weaning food. Sorghum pops are traditionally made with elaborate procedure of soaking, shade drying and popping in pans. In this article, sorghum popping was tested using popcorn maker, a small device that can be purchased with a low cost. The advantage of this procedure is that this pop-maker can be used to pop a handful of seeds and it takes 2–3 min only for the same. It can be explored as an additional income source. There are many varieties released for popping, e.g. Phule Panchami (RPOSV-3), Pop11 and other lines in pop series. Advanced lines having high popping and high yield through breeding efforts are in the pipeline.

Keywords: Low phytic acid, Pop percentage, Pop volume, Sorghum snacks

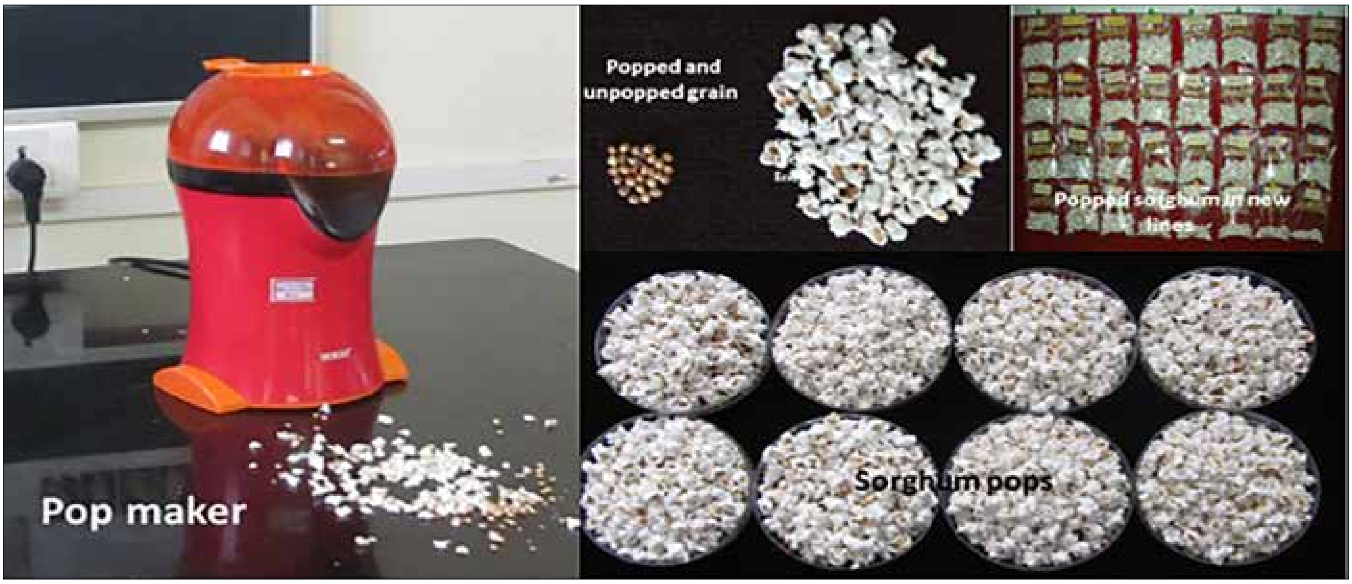
SORGHUM grain is consumed in the form of food and snacks in many parts of India. Roti and cooked grain are the most popular forms of food preparations, nevertheless, many other products for snacks and tiffins are available in different parts of India. Among them, popped sorghum is a kind that is used as weaning food and snack, which can be explored and popularized. Popped sorghum is fluffy white flower like structure which resembles popcorn, but is smaller in size. Sorghum pops are crispy, tasty with a pleasant fragrance that makes them tastier. Sorghum pops are low in calories and fat, gluten-free and completely devoid of hull. Because of their easy digestibility, sorghum pops are used as weaning food and for feeding the old recovering patients. Sorghum grain is recommended for celiac patients as it is gluten free. Popping treatment reduces phytic acid content in the grain and thus, improves starch digestibility. Sorghum pops do not have bran like rice pops and it makes them easy and ready for use.

Pop sorghum

Sorghum grains are popped and made to flour. They are made to laddus with jaggery and consumed during Tholi ekadasi (July) in Telugu speaking states. Karnataka state is popular for making sorghum pops. It may be available in many other states but no such record was found. Traditional methods of preparation of sorghum pops are elaborate which poses to be a reason for its less usage. Sorghum grain is soaked, shade dried and popped in big pans. During the soaking procedure, the grain moisture is brought to 14–16%, and it is exposed to sudden dry heat in a pan. The pan is covered with a mesh dome to avoid spilling of popped grains. In this study, a simple procedure was developed for popping sorghum with the help of a small popcorn maker, costing around ₹2000–3000. It can be used for roasting of other items. In this machine, a handful of grains can be popped in 2–3 min, unlike the conventional popping machines that require large quantities of grains. This procedure takes short time and a small quantity can be popped. Sorghum seed harvested during the winter season (*rabi*) or post-rainy season can be readily used for popping till 5–6 months due to inherent moisture. Later, they can be washed, kept in refrigerator for 1 hr and then popped. Use of pop maker for making popped sorghums is easy and can be done in a short duration.

Types

Central India, especially Karnataka, has diverse types of pop sorghums. Sorghum varieties for popping have been identified in the series as Pop 1–Pop 120. Among them, germplasm lines, viz. POP 16 (IC 308651), POP 31 (IC 308660), POP 32 (IC 308661), POP 37 (IC 308664), POP 38 (IC 308665), POP 47 (IC 308671), POP



Sorghum pops

49 (IC 308673), POP 50 (IC 308674), POP 54 (IC 308678), POP 58 (IC 308682), POP 59 (IC 308683), POP 60 (IC 308684), and POP 62 (IC 308685) were identified with more than 70% popping ability in studies conducted a decade ago. Later, there were special releases like Phule Panchami (RPOSV-3) from Rahuri (MPKV University) for popping. In our recent study, it was found that guinea race germplasm lines are suitable for semolina and popping. Other breeding like C43 and Pop 11 were found to be very good for popping. A dedicated program to combine popping and high yield resulted in identifying 5–6 lines that have more than 80% popping percentage and 70–100% popping expansion volume.

Need

There is a need to develop end-use specific lines to promote linkages of farmers and food industry. Under the Indian Council of Agricultural Research, the All India Coordinated Research Projects (AICRP) are conducted for multi-location testing of varieties and hybrids. Under AICRP on sorghum, a coordinated multi-location trial for popping was being arranged to encourage breeding and production of sorghum lines having high popping volume (the size of the grain after popping should be large) and popping percentage (the percentage of grains popped should be more). In order to increase the popping trait, concerted efforts in breeding are active. Considerable genetic variability was found for popping efficiency (both in terms of popping percentage and pop volume). Thus, breeding specifically for popping efficiency is taken up at ICAR-Indian Institute of Millets Research, Hyderabad.

Popping sorghum grain changes the starch granules into thin lattices of interconnecting sheets. Popped starch is more digestible in comparison to native starch and exhibits higher susceptibility to *in vitro* enzymic (pancreatin) digestibility. Significant decrease in carotenoid, moisture content and increase in protein and carbohydrate content was observed upon popping in sorghum.

Uses and benefits

There are two ways by which the popping in sorghum can reach different strata of society. One is through commercial scale popping on large scale, in which large quantities of seeds are popped in machines. The other one is by popping small quantities of sorghum in the households as and when required in small machines. It can be used as an additional source of income in rural areas, where sorghum pops can be sold in popular places in small quantities. Pop sorghum can be sold for a few hours to generate additional income with low investment. Due to high digestibility and improved access to protein and starch reserves, popped sorghum can be commercially explored for instant food mixes and weaning foods. Sorghum is a rich source of micronutrients and phytochemicals, and its instant popping can be a popular food product made from sorghum due to its easy to prepare and oil free preparation. The availability of sorghum cultivars whose grains exhibit superior popping quality without any pre-treatment should be of significance to food technologists and breeders. Utilization of these popping sorghums in breeding programs aimed at improved popping quality can be rewarding.

SUMMARY

In central and southern India, popped sorghum is a common traditional snack dish with good commercial potential. It is a major source of carbohydrates and in comparison to raw sorghum grain, has greater starch and *in vitro* digestibility. Popped sorghum is typically cooked over dry heat. As nutritious as popcorn, sorghum grains that have been popped have a pleasant flavour. Additionally, because it is soft and contains less hulls, popped sorghum is also said to be superior to popped corn.

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INTERNATIONAL YEAR OF MILLETS 2023

Promising millet production

and processing technologies in rainfed areas

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Many millet production technologies are available with research organizations which need to be evaluated in farmers' fields for their wider adaptability. For this, an initiative was taken by the ICAR-IIMR, Hyderabad under farmer FIRST project wherein improved practices gave substantially higher yields and net returns compared to existing farmer's practices especially from de-hulled finger millet and little millet grains which fetched up to 2–5 times more profit. Backyard farming with improved breed of poultry birds and goat gave additional income. Diversification of millet-based farming should be encouraged to reach targeted productivity and profitability with support from government policies. Latest knowledge, timely input support and promotion of value-addition of millets through group approach were found to be the key elements in millets value-chain development.

Keywords: Crop module, Enterprise module, Farmers' income, Livestock module, Millets

MILLETS cultivation in India covers an area of 17 million ha with an annual production of 18.66 million tonnes (Mt). They are grown in different seasons, offering food for human consumption, fodder, feed for livestock and industrial raw material. They are climate smart, versatile and highly adaptable to harsh weather conditions. Millets are one of the cheapest sources of energy which possess higher content of digestive fibres, proteins, vitamins and minerals, popularly referred as "nutri-cereals". They play a major role in the agricultural gross domestic product (GDP) of major growing states of Maharashtra, Karnataka, Telangana, Rajasthan, Tamil Nadu, Gujarat, Madhya Pradesh, Andhra Pradesh, Chhattisgarh, Odisha, Uttarakhand and Haryana. Millets are pre-dominantly grown by small and medium farmers which account for 90% of the sorghum and pearl millet area in the country. With the threat of climate change looming large, millet crops productivity, area under cultivation and consumption are declining due to low remunerative price, low productivity, high drudgery involved in their processing, fine cereals negative perceptions as a poor's food and policy neglect when compared to other crops. Furthermore, sorghum productivity is low as compared to other cereals due to lack of marketing facilities, buy back assurance, reliance on monsoon rains, lack of use of soil type-based high yielding varieties (HYVs), non-adoption of soil moisture conservation practices and improved production technologies, and rapidly changing food habits of people.

Although, lots of millets production technologies have been developed by the research organizations, there exists a wide gap between the potential yield of the improved technologies and yield obtained by the farmers in their fields due to several reasons such as lack of knowledge and skill, and input support at grass-root level, etc. Therefore, promotion of millets has a large scope to mitigate the productivity risk in agriculture unlike other food crops in drought-prone and rainfed regions. Suitable intercropping of pulse crops with these millets and allied farming is a viable option towards nutritional and economical security in sustainable way.

There are four key pathways to achieve the goal of enhancing farmer's income which are, (i) by increasing productivity; (ii) by reducing cost of cultivation; (iii) by increasing market opportunities and; (iv) by developing sustainable value chain. For this, millet technologies along with allied enterprises were demonstrated and evaluated in the farmer's fields by ICAR-Indian Institute of Millets Research (IIMR), Hyderabad which has taken an initiative through millets-based modules, viz. (i) crop module, (ii) livestock module, and (iii) entrepreneurship module. Total 6 villages in Nyalkal and Raikode mandals of Sangareddy district of Telangana state were selected to test above modules along with existing farmer's practices for comparison and provided primary processing and secondary processing facilities at village through participatory approach during three years (2017–18, 2018–19 and 2019–20). Under crop module, high yielding varieties of redgram, *rabi* (winter season) sorghum, *kharif* (rainy season) sorghum, foxtail millet, little millet and brown-top millet and intercropping of pigeon pea with foxtail millet were undertaken in farmers' fields. In the livestock module, poultry birds of improved variety were introduced. Moreover, post-harvest processing facilities on millets were also introduced by establishing primary and secondary processing units including roti making machines at a village under entrepreneurship module to enhance millets consumption and farmer's income.

Crop module

Keeping millets cultivation related problems of the project area in view, a total of 7 crop production technology related and 1 horticulture related interventions were evaluated. The crop-based interventions gave better net returns than the farmers' practices; redgram variety ICPL 87119 (29.9%), *rabi* sorghum varieties; Phule Suchitra (176.9%), little millet; DHLM 36-3 (23.3%), brown-top millet (24.7%), *kharif* sorghum variety; CSV 27 (26.3%), foxtail millet; SiA 3088 (24.7%), intercropping of pigeonpea with foxtail millet in *kharif* season gave net profit of ₹47,248/ha. Improved millet crop interventions gave substantially higher yield and resulted into higher net returns ranging between 23–176% (Table 1 and 2).

Livestock module

***Intervention of improved backyard poultry technology*:** In view to enhance farmer's income through millets farming system, improved poultry technology was introduced in the project area. It has link with millet production system as millet by-products (broken grains) were major feed support to this enterprise. Vanaraja poultry breed developed by ICAR–PDP, Hyderabad was introduced in these villages to 80 families, and 10 birds were supplied to each family. In an average

Table 1. Performance of different cultivars of millets under farmer's practice and improved practice

Crop cultivar	Cultivation practice	Yield (q/ha)	Cost of cultivation (₹/ha)	Gross income (₹/ha)	Net income (₹/ha)	Difference between IP and FP income (₹)
Red gram (ICPH 87119)	IP	14.1	26,000	80,370	54,370	12,500
	FP	13.7	28,000	69,870	41,870	
Rabi sorghum*	IP	22.35	24,258	94,525	70,268	44,887
	FP	9.75	20,527	45,908	25,381	
Kharif sorghum	IP	29.4	10,700	1,15,248	1,04,548	21,748
	FP	26.20	10,210	93,010	82,800	
Little millet	IP (with de-hulling)	9.03	18,010	52,374	34,364	4750 (without de-hulling)
	IP (without de-hulling)	13.9	8,980	34,750	25,770	
	FP	12.5	9,100	30,000	20,900	
Brown-top millet	IP (with de-hulling)	11.95	26,400	3,34,600	3,08,200	40,590 (without de-hulling)
	IP (without de-hulling)	23.9	7,800	2,12,710	2,04,910	
	FP	22.7	8,200	1,72,520	1,64,320	
Foxtail	IP (with de-hulling)	15.33	21,930	93,513	71,583	9,660 (without de-hulling)
	IP (without de-hulling)	21.9	6,600	52,560	45,960	
	FP	18.00	6,900	43,200	36,300	

*Phule Suchitra and Phule Anuradha as rabi varieties; IP- Improved practice; FP- Farmer's practice.

Table 2. Performance of intercrop of redgram with foxtail millet indicator

	foxtail millet	Redgram
Yield (q/ha)	9.5	10.2
Cost of cultivation (₹/ha)	3,900	29,792
Gross income (₹/ha)	22,800	58,140
Net return (₹/ha)	18,900	28,348
Net profit from the intercropping in *kharif* season: ₹47,248/ha.		

Pearl millet (HHB 67) crop at harvesting stage

Redgram (ICPH 2740) at harvesting stage in project village

120–150 eggs were produced by each bird annually and farmers sold these eggs at ₹10/egg which helped them to earn additional income of ₹13,000/year (Table 3). Most of the beneficiaries enhanced their income, as well as achieved partial nutritional security of their family by using sorghum feed and by-product wastage.

Table 3. Income obtained from improved Vanaraja poultry breed

Indicator	Intervention output
Average no. of eggs/year/bird	130
% of birds mortality	20
No. of eggs produced from 10 birds/year (in ₹)	130*10 = 1300
Market rate (₹/egg)	10
Additional income/year/family (₹)	13,000

Entrepreneurship module

***Intervention of primary processing facilities for millets*:** To address the problem of low remuneration and drudgery reduction, millets processing facilities were established at village namely Gangapur in Raikode mandal where, machineries like de-huller, grader, pulvarizer, shifters were placed. Due to this intervention, farmers obtained additional returns up to 11 times more than un de-hulled grains of finger millet and little millet sold in the market (Table 1). Therefore, a primary processing centre of millets was run on the basis of custom hiring for millet farmers of accessible distance of surrounding villages. Skill development programs as well as exposure visits were organized for women and for other local entrepreneurs in view to promote value-added products through entrepreneurship development.

Primary processing facilities at Gangapur village, Sangareddy district, Telengana

Benefits of improved millet technologies

Although, adoption of improved millet technologies was proven to be profitable under crop module in this study, millets and allied enterprise like, livestock and enterprise module could also assure the enhancement of farmers' income to a substantial level in rainfed areas. Millets-based farming like backyard poultry enabled to earn additional income utilizing by-products and farm-waste which could be an imperative move for optimum output. Marketing of de-hulled small millet grains fetched up to 2–5 times more profit to the farmer. Skill development programmes could raise entrepreneur confidence for business in secondary processing of millets especially, preparation of value-added food products. However, there were a few challenges which were realised in promotion of these interventions.

Challenges in millets cultivation

Even though diversified millet-based farming enhances farmer's income to substantial level, it needs to be supported at policy level, viz. support for buy back arrangements with fixed MSP, crop insurance, inclusion of millets in MDM and Public Distribution System (PDS), infrastructure for farm gate processing and warehouses to encourage farmers to sustain millet cultivation. Farmers with more market opportunities and standard facilities would let them reach the goal of enhancing their farm income. The factors for decline in consumption of nutri-cereals need to be addressed such as easy availability of millet grains like fine cereals, rice and wheat at a cheaper price to that of nutritious cereals under PDS. Nutritious cereals are socially less valued which accelerates the decline in their consumption on rising of capita income therefore, awareness needs to be created.

SUMMARY

Overall, the demand for sorghum and millet in India is projected to increase from 8.1 Mt in 2010 to 10.1 Mt in 2050. Further, the demand for millets utilization is expected to increase from 9.9 Mt in 2010 to 11.06 Mt in 2050. The demand for feed and other industrial uses of sorghum and other millets are the main driving forces for increase because of vibrant livestock sector and industrial growth. Increase in demand for feed and nutrition prompts it critical to increase the productivity of these crops from the current level of 1 tonne/ha. The increasing demand for animal-based products in India with increasing population and rising incomes is another driving force for increasing the productivity. However, the targeted productivity increase should come from the area that is continuously shrinking under these crops over last few years. So, it is important to make best use of the available genetic, natural resources and markets to enhance the productivity and profitability from millet cultivation in India.

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INTERNATIONAL YEAR OF MILLETS 2023

Performance of post-rainy (*rabi*) sorghum

production technology under FLDs for enhancing productivity and profitability

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*Sorghum is mainly grown during rainy (*kharif*) and post-rainy (*rabi*) season. Post-rainy sorghum is mostly used for human consumption due to its good grain quality. Increasing productivity with improved cultivars based on soil conditions where* rabi *sorghum is grown on residual soils is of much importance in climate change scenario. Apart from the adoption of improved cultivation practices, adoption of soil moisture conservation practices like deep ploughing, compartmental bunding or ridge and furrow method are beneficial in reducing water stress, improve yield and net returns compared to traditional practices. Total 3699 frontline demonstrations (FLDs) on* rabi *sorghum were organized in major sorghum growing areas of Maharashtra, Karnataka, Telangana and Gujarat since 2012–13 to 2021–22 with improved* rabi *sorghum technologies which gave 49% more grain yield than the farmer's practice (FP) and resulted into 49% more net returns.*

Keywords: Frontline demonstrations, Improved production technologies, Net returns, Post-rainy sorghum, Yield advantages

ONE of the major alternative for wheat and maize is a great millet commonly known as sorghum, which is vernacularly known as Saloo Jwari (Marathi), Juar (Bengali, Gujarati, Hindi), Jola (Kannada), Cholam (Malayalam, Tamil), Janha (Oriya), Jonnalu (Telugu), Milo and Chari. It is one of the most important cereal crops grown in both *kharif* (rainy) and *rabi* (post-rainy) seasons in the semi-arid regions of the country. In India, *rabi* sorghum is grown in an area of 3.01 million hectare (mha) as compared to 1.75 mha under *kharif* sorghum. As *rabi* sorghum is consumed without polishing due to its cleanliness, the total dietary fibre and minerals are easily available for human body.

Maharashtra (1.98 mha), Karnataka (0.69 mha) and Andhra Pradesh (0.11 mha) are the major *rabi* sorghum growing states in the country. Although the productivity of *rabi* sorghum is low, it has better economic value for farmers as compared to *kharif* sorghum because of its better grain quality for food and is a major source of fodder for animals during lean summer period. The inputs required for *rabi* sorghum are lower than other cereals like wheat, rice and maize that make it more profitable.

Much of the *rabi* sorghum is grown on residual and receeding soil moisture on shallow, medium and deep soils. Therefore, the progress in hybrid *rabi* sorghum breeding is limited. The variety M35-1 is a popular landrace grown by farmers in *rabi* tracts of Maharashtra, Karnataka and Telangana since 1976. Most of the present-day improved varieties are the result of pure-line selection practiced among the local/popular varieties and their crosses. The varieties for specific soil types (shallow, medium and deep) have been released. Moreover, improved cultivation practices including crop management are also available and evaluated under farmer's fields in sorghum growing regions. The potential varieties have lustrous, bold and globular size grains which are recommended for different states (Table 1).

Table 1. Recommended *rabi* sorghum varieties and hybrids for different states

State	Hybrids	Varieties
Maharashtra		
Rainfed areas (Medium to deep soil)	CSH 39R, CSH 19R, CSH 15R	Phule Rohini (RPASV3), Phule Suchitra (RSV 1098), CSV 216R, CSV 29R, CSV 22R, CSV 18R, Parbhani Super Moti
Irrigated areas	CSH 39R, CSH 19R, CSH 15R	PKV Kranti, CSV 22R, Phule Vasudha
Shallow soil	-	CSV 26R, Phule Anuradha, Phule Chitra

State	Hybrids	Varieties
Karnataka		
Dry zones (Deep soil)	CSH 15R	BJV 44 (SPV 2034), SPV-2217, CSV 29R, M 351, DSV 4
Transitional zones (Medium soil)	CSH 15R	BJV 44 (SPV 2034), SPV-2217, CSV 26R, DSV 5
Irrigated zones	CSH 39R, CSH 19R, CSH 15R	BJV 44 (SPV 2034), SPV-2217, CSV 29R, CSV 22R, DSV 5
Telangana		
All areas	CSH 15R	CSV 29R, CSV 26R, CSV 22R
Normal *rabi* areas	CSH 15R	CSV 29R, CSV 26R, CSV 22R, CSV 18R
Tamil Nadu		
Entire *rabi* area	CSH 15R	CSV 29R, CSV 26R, CSV 18R, CSV 22R
Summer sorghum areas	CSH 15R	CO 26, CO 24, COFS 29, CSV 33MF, CSV 31 (Forage Sorghum)
Gujarat		
Entire *rabi* zone	CSH 15R	CSV 29R, CSV 26R, CSV 18R

Improved cultivation practices of post-rainy sorghum

Preparation of land

One deep ploughing with mold-board plough in summer followed by 3–4 harrowing is recommended to attain good seed bed and to maintain weed free conditions. To improve the water retention, compartmental bunds of 10 m × 10 m in the month of August are recommended to conserve the rain water.

Method and time of sowing

The crop is sown by bullock drawn seed drills with 2 or 3 coulters at 5–7 cm depth in the soil. The seeds are covered by one harrowing after sowing by seed drill. It is also sown by tractor drawn seed drill with 4 coulters with simultaneous covering of seeds by blade attached to the seed drill.

Time of sowing

The optimum sowing time for *rabi* sorghum is 2nd fortnight of September to 1st fortnight of October. In double cropping practice, sowing is extended up to 2nd fortnight of October.

Seed rate spacing and plant population

Seed rate of 8–10 kg/ha or 3 kg/acre is recommended. Spacing between row to row distance of 45 cm and plant to plant of 15 cm is recommended. Plant population in rainfed conditions is 1.35 lakh/ha and in irrigated conditions is 1.50–1.80 lakh/ha. High seed rate @10–12 kg/ha is recommended in case of delayed sowing.

Nutrient management

For rainfed (shallow to medium soil): Apply 40:20:00 kg of NPK per ha as basal dose.

For rainfed (deep soil): Apply 60:30:00 kg of NPK per ha as basal.

For irrigated conditions: Apply 80:40:40 kg of NPK per ha (N in two equal splits, 50% as basal and 50% at 30–35 days after sowing, full P and K at time of sowing is recommended) (Table 2).

Table 2. Recommended fertilizers dose for post-rainy sorghum

	Soil type	Inorganic fertilizer (kg/ha)		
		N	P	K
Rainfed	Shallow	25	-	-
	Medium	40	20	-
	Deep	60	30	-
Irrigated	Medium	80	40	40
	Deep	100	50	50

Nutrients can also be provided through organic sources like, bio-fertilizers and bio-agents by;

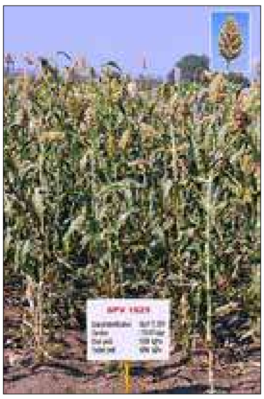
- Addition of locally available crop residues @5–10 t/ha in alternate years to build up soil organic matter.
- Regular application of FYM @5 t/ha and vermicompost @2 t/ha gives good yield.
- Seed and soil inoculation with *Azospirillum* or *Azotobacter* helps to save 25–45 kg N/ha.

Insect-pest and disease management

A few insect-pest and diseases attack on sorghum crop. These can be controlled by adopting cultural and chemical practices (Table 3).

Inter-cultivation and weed control

Inter-cultivation 2 or 3 times at 3, 5 and 7 weeks after sowing should be done to check the weed growth, which also helps to conserve soil moisture by providing



CSV 26R

CSV 18R

CSV 29R

Table 3. Pest and diseases identification symptoms and their management practices

	Key identification symptoms	Control measures
Insect pest		
Shoot fly	Occurs in seedling stage, wilting and drying of central leaf appearing as 'dead heart'	Sowing at the end of September to 1st week October, seed treatment with thiamethoxam 30 FS @3 g/kg and spray of cypermethrin 20 EC (200 ml/ha) or quinalphos 25 EC (400 g a.i./ha) or carbofuran granules (5–7 granules/plant) in leaf whorls during severe damage
Stem borer	Scratches on upper whorl leaving lower surface as transparent windows, dead heart symptoms in young plants due to early attack, peduncle tunnelling forming complete or partial chaffy panicles	Uproot or burn the stubbles and remove stems/stalks to prevent carryover and apply carbofuran 3 G @8–12 kg a.i./ha at 20–35 DAE* in whorls
Shoot bug	Heavy infestation during *rabi*, when it rains in seedling stage, nymphs and adults suck sap causing yellowing and reduced plant vigour, young leaves start drying extending to older leaves in severe cases or sometimes plant death occurs	Remove alternate host grasses, soil application of dimethoate 0.03% and neem seed kernel suspension 0.04%+soap
Aphids	Adults and nymphs feed leaves and suck the sap at boot stage causing poor panicle exertion, yellowish blotches and necrosis appears during heavy infestation	Application of dimethoate 0.03% and neem seed kernel suspension 0.04%+soap
Fall army worm (FAW)	1st and 2nd instar larvae scrape the leaves by skeletonizing upper epidermis, 3rd instar make ragged edged holes on whorl, 5th instar larvae starts feeding voraciously with 1–2 larvae in each whorl	Deep ploughing exposes larvae and pupae to sunlight and natural enemies, collect and destroy egg masses/ larvae, deploy pheromone traps @15 traps/acre and erect bird perches @25/ha soon after emergence
Diseases		
Charcoal rot	Softening of stalk at base, premature lodging affecting seed size, grain yield, quality or quantity of fodder	Apply minimal dose of nitrogen, maintain low plant density and mulching with wheat straw as check for disease, and seed treatment with *Pseudomonas chlororaphis* @10 g/kg seed
Strip virus	Appearance of continuous chlorotic stripes/bands between veins, stunted growth, early infected plants die sooner or later without emergence of ear head, dwarf plant with short internodes and partial exertion of ear head with few or no seeds during late incidence	Avoid sowing in early September and late October, for vector control spray metasystox 35 EC or methyl –S-demeton 35 EC @5 ml/10 litre water at 15 days interval from 20 DAE

top soil mulch. Weed control by application of atrazine @0.5 kg a.i/ha by spraying on the soil as pre-emergence application immediately within 48 hours after sowing is found effective.

Water management

Although sorghum is a drought tolerant crop, it responds well to irrigations and is well suited for limited irrigations. It is also known as water sipping crop as it uses water very efficiently. Water availability to plant largely depends on soil texture. To increase productivity, sorghum crops need between 425 and 610 mm of water. The mature sorghum plant roots can draw moisture from the soil up to a depth of 2 m, although yields are greatest when moisture is present in the top 76 cm of the soil. It can also be grown on residual soil moisture with limited irrigation facilities.

Critical stages for irrigation in sorghum

The period of 40–85 days after sowing during flowering and grain formation stages is very sensitive to moisture stress. The critical growth stages of sorghum in relation to water requirement are mentioned in Table 4. In case, water is available for providing irrigation at all four stages, it would be advantageous. Under irrigated conditions in medium–deep to deep soils, three irrigations first at germination, second at panicle initiation and third at grain filling stage are desirable. Optimum irrigation schedule consists of five irrigations each at 35, 55, 75, 85 and 105 days after sowing which coincides with physiological stages of panicle, primordial initiation, boot leaf, flowering, milky and dough stages, respectively. In case of limited availability of irrigation water, it can be restricted to one irrigation and should be at flower primordial stage or boot leaf stage depending on the soil moisture situation.

Table 4. Critical growth stages of sorghum

Critical stages	Days after sowing
Initiation of grand growth stage	20–25
Flag-leaf stage or boot stage	50–55
Flowering stage	70–75
Grain-filling stage	90–100

Soil-moisture conservation practices for rabi *sorghum*

- Deep ploughing with mould board plough followed by 3–4 harrowing during summer (May–June) helps to conserve rainwater in deeper soil layers for a longer period.
- Compartmental bunding involves making square or rectangular compartments on the field to retain rain water and to arrest soil erosion in medium deep black soils. After receipt of early rains in June and

Preparation of compartment bunding to conserve monsoon rains

Rainwater stored in compartments

Rainwater stored in ridges

July, land is harrowed to remove the germinating weeds. Then the compartmental bunds (0.15–0.25 m height) are formed using bullock or tractor-drawn bund former. The size of bunds varies from 3 m × 3 m to 4.5 m × 4.5 m depending on the slope. The cost of constructing these bunds is between ₹1500–3000/ha. These bunds are retained till the sowing of *rabi* crop during second fortnight of September to first fortnight of October. Compartmental bunds provide more time for water to infiltrate into the soil and help in conserving soil moisture.

- Ridge and furrow method; in this system, ridges and furrows are formed across the slope by bullock-drawn plough before monsoon. The height of ridges is around 20 cm and width of furrows is 45 cm. The rainwater is stored in furrows and infiltrates into the soil, and help in conserving soil moisture. Besides, opening of furrows in preceding (*kharif*) legumes (cowpea, mungbean, urdbean, soybean) after every 3rd or 4th row by baliram plough conserves soil and moisture, improves drainage, and increases the productivity of *rabi* sorghum.

Comparative to the flat-bed method, *in situ* moisture conservation techniques such as tied ridges and compartment bunding were found to be more effective at preserving higher soil moisture, grain yield and net returns. Application of organic mulch (straw of preceding legume crops) in between rows after 3 weeks of sowing helps in conserving soil moisture by reducing evaporation. Spraying 2% urea at the times of soil moisture stress experienced by crop also helps to overcome moisture stress.

Crop-based cropping system

Rabi sorghum is sown after a fallow period of rainy season (*kharif*) in medium to deep soil where the rainfall frequency is high. However, double cropping of blackgram/greengram/cowpea (fodder) and *rabi* sorghum is recommended wherever found operationally feasible as legumes save about 10–20 kg N/ha. Soybean + *rabi* sorghum sequence cropping is found feasible and profitable in irrigated conditions. Intercropping of sorghum with safflower with 4:2 or 6:3 ratio is recommended on deep soils. As the moisture is a limiting factor during post-rainy sorghum production, intercropping is feasible only in deep soils. Sorghum + chickpea and sorghum + safflower are the important intercropping systems in *rabi* sorghum growing regions of Maharashtra and Karnataka.

Harvesting and threshing

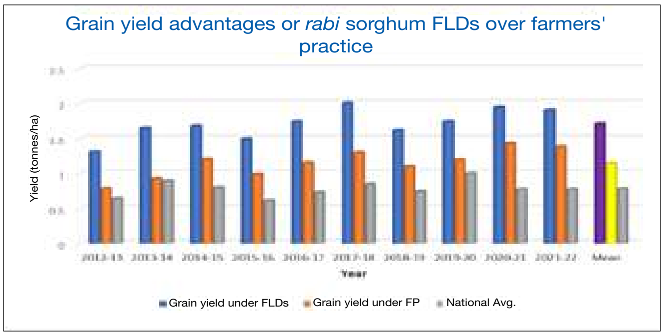
Crop should be harvested at physiological maturity (110–120 days after sowing) depending upon the genotypes duration. The harvested panicles are left in the field for about a week for drying and thereafter the grains are separated from panicles by threshing or manually. The panicles are harvested first and remaining plants later.

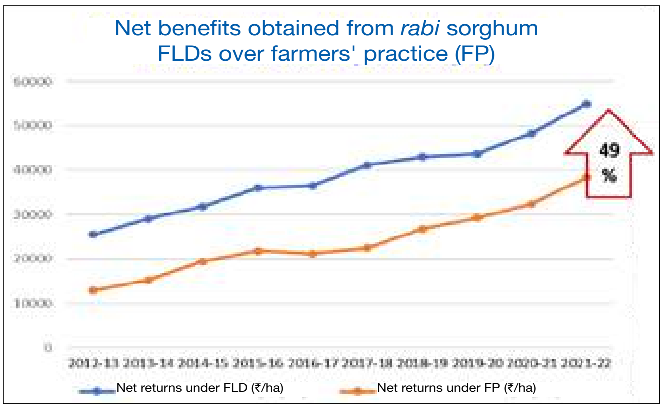
Drying and Bagging

After threshing, the grains are sundried for 1–2 days to reduce the moisture content up to 10–12%. Bagging of the grains is done in plastic or gunny bags for immediate marketing.

Performance of the demonstrated technologies in farmer's fields under FLDs

The area under *rabi* sorghum reduced with little extent recently in last decade. However, due to concerted efforts made by the scientists, extension workers, developmental agencies and farmers, average productivity has now increased to 989 kg/ha in 2019–20 from 894 kg/ha in 2007–08 under rainfed conditions. Total 3699 FLDs were organized since last nine years,





Net benefits obtained from *rabi* sorghum FLDs over farmer's practice

Field view of FLDs on *rabi* sorghum at Parbhani

(2012–13 to 2021–22) with improved *rabi* sorghum cultivars, viz. CSV 26R, CSV 29R, CSV 18R, CSV 22R, PKV Kranti, Phule Vasuda, Phule Yashodha, Phule Revati, Phule Chitra and Parbhani Moti, and recommended package of practices in major sorghum growing states Maharashtra, Karnataka and Telangana. They gave 49% more grain yield than the farmer's practice (FP) which was 2–3 times higher than the state average productivity. The higher yield of the FLDs resulted into same 49% more net returns than the FP.

SUMMARY

At all the locations, the demonstrated improved sorghum production technologies took over the yields and profits of the local varieties. The yield gap of 49% was bridged in grain and obtained same 49% of additional returns by adopting the improved sorghum production technologies, which indicated that sorghum farmers could increase yields and profits by adopting these technologies in their fields. Therefore, the sorghum farmers in different regions should be exposed to latest sorghum technologies to realize its impact by following the improved cultivation practices and timely crop management. Non-trial farmers also need to be exposed to the proven technologies by organizing extension programmes like field day programmes, farmers' day for wide adoption. There is more demand for seeds of the demonstrated varieties from the farmers across the regions.

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Role of FPOs

in strengthening millet value chain

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In India, majority of the farmers are small and marginal farmers involved in agriculture and allied activities for their livelihood. To help small and marginal farmers, Government of India has initiated a concept of Farmer Producer Organization (FPO). Farmer Producer Organizations of Indian Institute of Millets Research (IIMR) are playing a major role in bringing farmers together by helping them in identifying markets, creating a unique platform for collective purchase of inputs and marketing of produce in bulk, thereby eliminating or reducing the number of intermediaries in the existing supply channel.

Keywords: Forward and backward linkages, FPOs, Markets, Supply chain

RISKS in agricultural production have been a major concern for small and marginal farmers in India, and to eradicate the same, a concept of Farmer Producer Organization (FPO) has been initiated by Government of India. FPOs consist of farmers who are the producers of agricultural products that can form groups and are intended to mobilize small farmers for forward and backward linkages. FPOs have potential to address key gaps in agricultural supply chain by eliminating intermediaries, collective bargaining to small and marginal farmers, strengthening the market linkages, farm gate processing units at villages etc.

ICAR-IIMR FPOs

ICAR-Indian Institute of Millets Research (IIMR) is a nodal agency that is working exclusively on millets and acting as Cluster Based Business Organization (CBBO) for 41 FPOs in four states, viz. Andhra Pradesh, Karnataka, Telangana and Madhya Pradesh (Table 1). The implementing agencies for ICAR-IIMR, FPOs across the states are SFAC, NABARD, WDD (Govt. of Karnataka), NCDC and NFSM.

List of commodities available with FPOs

FPOs of ICAR-IIMR have diversified commodities as shown in Table 2. In Karnataka, most of the FPOs have millets, pulses and oilseeds as their prime commodities and in Telangana millets, mangoes, pulses, groundnut and paddy are the major commodities available with FPOs. In Andhra Pradesh, diversified products like millets, spices, honey, seasonal fruits, cashew, groundnut and pulses are available and in Madhya Pradesh, all type of millets are available (Table 2).

Table 1. List of FPOs promoted by ICAR-IIMR

State	Agency	FPOs
Karnataka	SFAC	12
	NFSM Nutri-cereals Submission	2
	Govt. of Karnataka (WDD)	9
Andhra Pradesh	NABARD, Andhra Pradesh	7
	NFSM Nutri-cereals Submission	2
Telangana	NABARD, Telangana	5
	National Cooperative Development Corporation	2
	NFSM Nutri-cereals Submission	1
Madhya Pradesh	NFSM Nutri-cereals Submission	1
Total		41

The year 2023 will be celebrated as the International Year of Millets (IYM) and to support and promote IYM-2023, ICAR-IIMR is implementing its “Millets FPO Model” through its FPOs by focusing on area, production, productivity, and market linkages of millets.

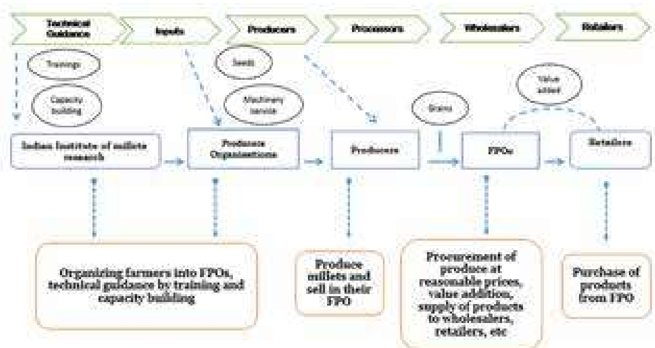
Supply chain of millets and FPO

In the traditional supply chain of millets, small and marginal farmers have faced various challenges like less price, lack of market, lack of processing unit, no technical knowledge on value addition of millets, lack of awareness on business opportunities of millets etc. To

Table 2. Commodity wise list of ICAR-IIMR FPOs

State	District	No. of FPOs operating	Major commodity
Andhra Pradesh	Visakhapatnam	8	Spices, Pineapple, Custard and Millets
	Anantapur	1	Groundnut, Redgram and Millets
Telangana	Medak	2	Paddy, Millets
	Mahabubnagar	6	Mango, Redgram, Millets
Karnataka	Bidar	4	Oilseeds, Pulses and Millets
	Gulbarga	2	Pulses and Millets
	Bijapur	2	Sunflower, Pulses, Citrus, Groundnut and Millets
	Yadgir	1	Soybean and Millets
	Bagalkot	3	Sugarcane, Maize, Pulses, Onion and Millets
	Raichur	2	Millets and Pulses
	Koppal	5	All types of Millets and Pulses
	Dharwad	4	Pulses, Maize and Millets
Madhya Pradesh	Dindori	1	Millets
Total		41	

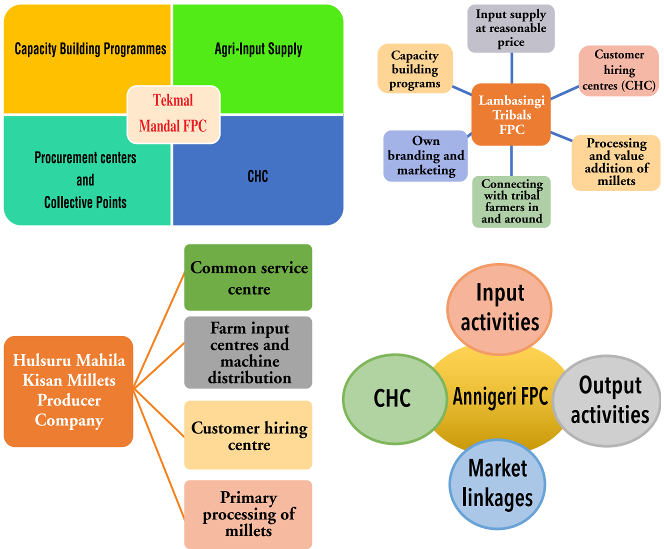
address these issues, there is a need to alter the existing supply chain of millets and this can be achieved with the intervention of FPOs. ICAR-IIMR aims to strengthen the millet cultivation in India by highlighting the climate resilient nature, importance, and health benefits of millets through its FPOs.



Supply chain of millets and FPO

Successful business models of ICAR-IIMR FPOs

With the technical and institutional support from ICAR-IIMR, the FPOs are running successfully by creating their own models. Successful models of four FPOs are Annigeri, Tekmal, Hulsuru and Lambasingi. Annigeri and Hulsuru Farmer Producer Company (FPC) are Karnataka based which help small and marginal farmers in and around by providing farm input services, direct market linkages, customer hiring centres, common service centres and primary processing facilities of millets. Tekmal Mandal FPC is from Medak district of Telangana that is involved in providing timely inputs services to farmers at nominal cost and is also engaged in procuring paddy from the nearby villages. Lambasingi FPC is from tribal areas and deals with unique and diversified products through e-platforms. The Lambasingi FPO is also involved in capacity building, input supply, processing and value addition of millets, and does own branding and marketing by engaging the tribal, small and marginal farmers in and around.



Successful business models of ICAR-IIMR FPOs

SUMMARY

It can be stated that Farmer Producer Organizations of IIMR are playing a major role in bringing farmers together by helping them in identifying markets, creating a unique platform for collective purchase of inputs and marketing of produce in bulk, thereby eliminating or reducing the number of intermediaries in the existing supply channel. IIMR is involved in integrating FPOs with both forward and backward linkages in agriculture with the objective of bringing economies of scale to the farmers, by having developing business models for each of the FPOs based on the crops grown and the nature of activities that the FPO could be able to undertake. FPOs are also involved in facilitating technical guidance, providing inputs like good quality millet seeds and fertilizer, aggregation of produce, processing of produce, storage, and distribution of produce with better market linkages between the members of FPOs-food industries-organization.

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Value addition

in millets through agricultural processing techniques

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Millets play a major role in eradicating the malnourishment and are poor man's crop. Major millets include sorghum, bajra and ragi, and minor millets include proso, barnyard, little, foxtail and kodo millet. Value addition is defined as any activity that is done to improve the value of the product by both primary and secondary processing. Value addition in millets includes destoning, grading, cleaning and aspirating the dirt from the freshly harvested millets. Machines used in processing of millets generally reduce the drudgery of human effort and the time involved in processing. Dehulling is done for minor millets and polishing is done for major millets to make value added products. Puffed and flaked millets are produced to gain revenue for the underutilized marketable millets and to fetch most out of the millets.

Keywords: Dehulling, Millets, Nutritional value, Puffed and flaked, Value addition

THE value-addition of millets produces a variety of marketable products. The millet grains are grinded into flour, coarse flour usually called semolina and fine flour known as atta. For semolina preparation, first the millet grains are roasted at higher temperature for a specified time to improve the taste and shelf-life of the product. Then, it is conveyed through the pneumatic conveyor and it ends up in a pulverizer unit where the grain is coarsely grinded and passed through a set of sieves of different mesh sizes and the coarse grain of different grades are obtained. These different grades of semolina are used as idly rawa, khichadi rawa, upma rawa and atta.

Agricultural processing techniques used in millets

The atta that is prepared from coarse grains is used as raw material for making muffins, cakes, biscuits, cookies both sweet and spicy and bread. The hot extruded products produced include subjecting the flour prepared by sprinkling water and then extruding at high temperature. The cold extruder helps in extruding the flour in cold conditions through the die of different shapes to make pasta and vermicelli. This pasta and vermicelli are packed in different polyethylene packets and stored in refrigerated conditions. Quality control of these value added products includes estimation of shelf-life of the developed product that includes moisture content estimation through hot air oven method by working out the difference in weight or by infrared moisture meter. Water activity meter is used to measure water activity as and then packed and accelerated shelf-life studies are tested using environment chamber. Temperature and relative humidity are tested for determination of longer shelf-life.

Different types of millets

Different puffed millets

Texture analyzer is used to analyse the firmness, adhesiveness, cohesiveness, springiness, gumminess, hardness and chewiness ability of the developed product. Calorific value, energy value is determined for each and every value added product that is developed out of millet. The nutritional significance of the developed value added product of carbohydrates, protein, fat, ash, mineral content and crude fibre are determined for all the value added product developed consisting of cakes, biscuits, vermicelli, pasta, bread, muffins, chikki bar and murukku using standard procedure.

The nutrient content and gluten free nature of millets even though makes it unsuitable for making certain value added products of bread and other cakes, if fortified with other cereal flour of wheat can be utilized for converting it into value added products. These value added products serve as snack food and at the same time are more nutritious, and can help in developing farm oriented small scale business at cottage level and then industry oriented technologies. The equipments and machinery are under development for both primary and secondary processing of these millets. The existing equipments are redesigned to suit the processing of both major and minor millets.

Drying is mainly done to eradicate/remove the excess moisture present in the product by tray drier of different capacity. Rotating tray driers are also used for drying value added products of vermicelli and pasta. Steamer is used for gelatinization of starch that is present in the millets to improve the digestible nature of the grain through amylase and amylopectin content determination. Color sorters are used for removing unwanted chaff, ill-filled and impure grain from good grain. Metal detectors are used to detect metal parts or staple pin in the packed value added products.

Ready to eat snack extruded food

Different flaked millets

Puffed and flaked millet value added products are prepared by roasting the grain in the roaster at a higher temperature for less time which are then puffed in a puff gun machine at a higher pressure. For flaking of millet grains, first the grains are soaked and then roasted in a roaster at a higher temperature for less time. The roasted grains are then pressed in an edge runner for getting thick flakes of millets. The gap between the rollers and the periphery is adjusted in such a way that the thickness of the flaked rice can be adjusted. Thin flakes are obtained by pressing the roasted grain in the roller flaker mill. Both circular roasters and conical roasters are used for roasting the grain for making semolina. Specific gravity separators are used in millet processing for separating the grain according to the differences in specific gravity. Rotary ovens are used for baking muffins and biscuits at a higher temperature. Paddler type wet cleaners are used for cleaning the millets before subjecting to processing. Dry cleaning is done using cleaner cum grader cum aspirator. Destoning is done by difference in density of the grains and the stones.

Dehulling in millets is mainly done to remove the outer seed coat called testa. This testa hinders the edible nature of the food, as it is cooked and causes indigestion problem. Moreover, the anti-nutrients such as tannins and phytic acid are removed by removing the testa. The wear and tear of the machinery can be drastically reduced by removing the outer testa. The polishing is done to remove the bran that is present outside the grain that contains oil content and to remove the germ of the grain that also contains oil content. This presence of oil in the outer layers of the grain causes rancidity that reduces the shelf life of the millets. Free fatty acids present in the grain can be estimated to know the shelf life of the grain. Microbial counts are estimated using laminar flow chamber. Environment stability chambers are used to determine the accelerated shelf life of the stored millets for commercial prospects. For enriched nutrients, sprouted nature of the millets is preferred. Water activity meters are used for determination of water activity in the prepared value added products to determine the storage stability. Ball milling is used to reduce size of the flour obtained for making different value added products like vermicelli, pasta, ready to eat kurkurae, flaked breakfast cereals, etc. Tray driers and vacuum driers are used for drying of value added products such as vermicelli and pasta.

Primary processing is defined as the processing to clean the grains from un-wanted debris and farm level impurities, then the grains are graded for commercial usage and de-hulling is done to remove the outer husk called as milling. Cleaning and grading use different types of sieves and the perforation in the sieve varies in shapes of square, rectangle and oblong depending upon the shape of the millet that is to be cleaned and graded. The disadvantages of using these type of machineries are such that the initial investments are high, consume more power, and maintenance of machine is difficult in remote villages where electricity is not available. Polishing is mainly done to improve the appearance of grains for increasing the commercial value and attractiveness of the packaged product.

Infrared moisture meters are used to estimate the moisture in the millet grains in a batch process. *p*H meters are used to measure the *p*H of the millet milk beverage by measuring the difference in electric potential using two electrodes. Total soluble solids are measured using drying method of tray drier. Three types of conveyors are used for conveying value added products, viz. belt conveyor, screw conveyor and pneumatic conveyor. Flour pulverizing machine consisting of two stone rollers as grinding mechanism where the gap between the two rollers can be adjusted and fine atta can be achieved through the designed outlet chute fitted with sieve mesh of specified size depending upon the requirement. Baking of biscuits of different shapes can be done in a baking oven. The time taken to bake the biscuits in a closed tunnel varies from 5–6 min. The biscuits are cut in the shape of the fixed die which slowly moves through the mesh on baking zone and gets collected through the outlet as baked biscuits. Then the biscuits are tested for their taste, flavour, texture, hardness, chewiness, gumminess, breaking ability using a texture analyzer and then calorific value is determined using a bomb calorimeter. Sensory analysis is done for acceptance among consumers by trained panel of 9 members with a score card prepared using hedonic scale with parameters of body and smooth texture, flavour and acceptability as standard procedure for any value added product.

Packaging of millet based products: Packaging is done of three types which includes nitrogen flushing packaging, vacuum packaging and ordinary form fill, and seal packaging for all the value added products developed using both major and minor millets. Hand sealing machines are used for sealing various value added products. Ziplock covers are used for storing the samples for analysis in refrigerated conditions. With different types of packaging for the value added products made from all different millets and their cultivars, the quality of the product at the consumer end is assured for extending the future market of millets in the international scenario.

SUMMARY

Millets being a gluten free food are best recommended for diabetic patients having a high sugar and blood pressure which can be regulated using value added products in their daily diet. Eating millets at regular intervals causes the body to function properly owing to its nutraceutical properties. Being rich in all minerals of calcium, zinc, phosphorous and magnesium needed for growth of vital organs of infants and growing children is good for health. Healthy life leads to a wealthy life. Hence eating of millets as day-to-day food is a must. Farmer friendly technologies can ensure to engage more land under millet, both in cultivation and related to agricultural processing of millets that will pave a way to success in global market.

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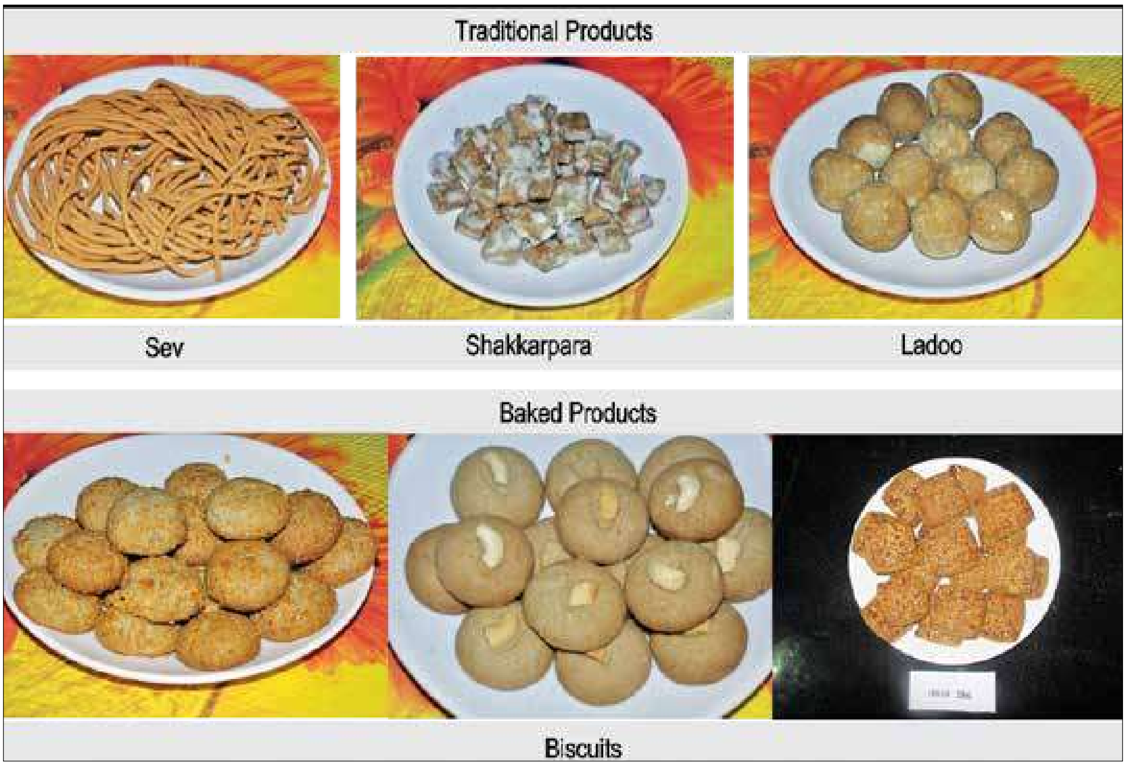
Nutritional Potential and value added products of pearl millet



Type	Food products
Traditional products	*Chapati, rabbari*, porridges, *khichri, kheer, churma, bakali, suhali, shakarpara mathi,* namkeen sev, *matar, ladoo,* popped *ladoo, burfi, pakora, chat, dhokla*
Baked products	Biscuits, *nan-khatai,* walnut cake, chocolate cake, chocolate muffin, sweet biscuit, coconut biscuit, sweet and salty biscuits, bun, pizza base, etc.
Extruded products	Pasta, macroni, vermicelli and its products.
Weaning foods	Weaning mixtures with combination of pulses.
Products for diabetes	Sweet and salty biscuits, *chapatti* mix, *dhokla* mix, instant *idli* mix, pasta.
Gluten free products	mathi, khichri, upma, cutlet and sweet biscuits and Sweet salty Ajwain biscuits
Sugar free products	Clove biscuits and Sweet and Salty biscuits
Convenience Mixes	Ladoo, halwa, upma, idli, dhokla, kheer, khichri mixes

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Proso millet:

Importance and cultivation

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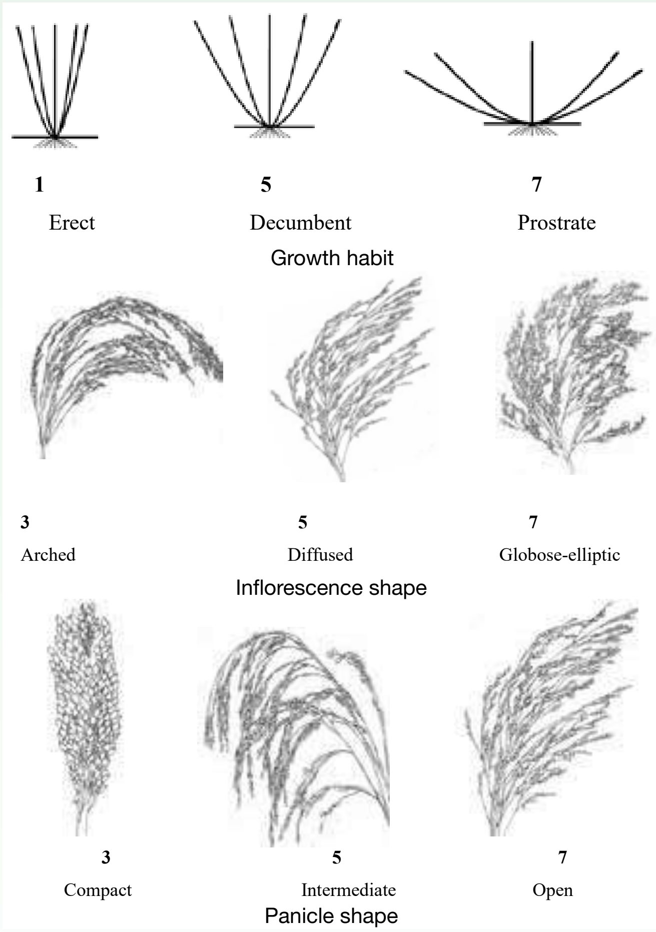
Proso millet is one of the oldest cultivated and among the first domesticated crops, mainly distributed in the semi-arid region of Asia (East Asia, West Asia, and South Asia) and Europe. It is used as bird feed in the US, but is used for human consumption in many parts of the world including Russia, China, Korea and India. It is rich in protein and starch. The probable reason of proso millet in the first league of domesticated crops is its short-duration, minimum crop management, resilience to abiotic stress and being nutritionally rich. These could be the important attributes that also made proso millet spread over Asia and Europe.

Keywords: Climate smart crop, Proso millet, Varieties

PROSO millet (*Panicum miliaceum*), is also commonly known as broomcorn millet, common millet, hog millet, kashfi millet, red millet and white millet. In India, it is known as chena (Hindi), baragu (Kannda), panivaragu (Tamil), variga (Telugu) etc. Archeobotanical studies indicate that proso millet was domesticated in China as early as 10000 years ago. As the human settled during Neolithic era, proso millet was cultivated. It is a warm climate crop with high water and nitrogen use efficiency. It matures in 60–75 days and has shallow root system which makes it suitable for any cropping system and intercropping. Proso millet produces 3–4 tillers, its plant type can be erect, decumbent or prostrate. The plant height reaches up to 100–120 cm. There are three types of panicles, viz. lateral, vertical-loose, and dense panicle. It produces small round seeds covered by a smooth and glossy hull. Its seeds may be cream, yellow, orange-red, or brown in colour. These traits help in identification of varieties of proso millet. Farmers can remember the growth habitat and inflorescence characters to identify the varieties.



Nutritional profile

Proso millet is rich in protein (13–17%) and carbohydrates (60–75%). In china, waxy type proso millet (100% amylopectin) are grown for making sticky rice and other cuisine. The recent study at ICAR-IIMR suggests that protein content in proso millet could be as high as 21% or even higher. It is a rich source of plant-based protein and can be used for formulating new energy foods for sport-person etc. Proso millet is free from gluten which suits the patients with celiac diseases. The biological value of proso millet protein varies between 42–56, similar to bean and wheat flour.

Proso millet contains 156–230 mg phosphorus, 78–140 mg magnesium, 8.20 mg calcium, 0.80–5.20 mg iron and 1.40–2.60 mg zinc per 100 g of dehulled proso millet. It is also a rich source of trace elements, dietary fibre and vitamins. Proso millet grains contain components with healing benefits, which decrease the level of low-density lipoprotein cholesterol in the blood. The phenolic compounds like antioxidants and beta-glucans present in proso millet have many health benefits.

Proso millet cultivation

Proso millet can be cultivated in varied soils, light to deep black and sandy to clay. The soil must be well drained and must be well tilled. Its fertility can be maintained by applying farmyard manure at a rate of 4–10 tonnes/ha. Proso millet being a short duration crop, requires relatively less water and nutrients compared to other cereals. General fertilizer recommendations under irrigated condition are 40–60 kg nitrogen (N/ha), 30 kg phosphorus (P_2O_5/ha) and 20 kg potassium (K_2O/ha). At the time of sowing, 50% of N and 100% of P and K may be applied as basal dose. The remaining half of N should be applied at the time of the first irrigation. It is recommended to use only half of the recommended dose, if the crop is grown under rainfed condition.

Proso millet can be sown in rainy season (*kharif*) soon after the onset of monsoon. In summer, February–March is the optimal time for sowing. Proso millet can be sown soon after the winter crop (*rabi*) harvest. The seeds can be sown using a drill/line sowing manually or even broadcasting. Recommended seed rate is 10 kg/ha for line sowing and 15 kg/ha for broadcasting. The distance between rows must be 22.5 cm and 10 cm between plants. After 15 days of germination, thinning can be done to maintain plant population and reduce intra-plant competition. There are no major pest and diseases in proso millet to cause huge economical damage, however shoot-fly could be a major insect pest.

As the water requirement is less, 2–3 light irrigations may be given at pre-flowering, post flowering and grain filling stage. Harvesting is done when 80% of the panicles are dry in the entire field. With improved varieties and package of practices, proso millet has the potential to yield up to 20–23 quintals grains per hectare (q/ha) and 50–60 q/ha straw under irrigated conditions (Table 1). Under rainfed conditions, proso millet is expected to yield 10–15 q/ha grain and 30–40 q/ha fresh straw.

Proso millet panicle

Table 1. Proso millet varieties released in India for commercial cultivation

Year of release	Crop	Variety	Released for State
2020	Proso millet	PMV 442 (GPUP 25)	Andhra Pradesh, Bihar, Karnataka, Tamil Nadu, Telangana and Puducherry
2018	Proso millet	DHPM-2769	Karnataka
2017	Proso millet	TNAU 202	Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Karnataka, Gujarat, Tamil Nadu and Bihar.

Post-harvest and processing

Proso millet panicles must be dried in sun for 2–3 days till the grains become brittle and hard. The grains must be threshed out from panicle mechanically. Like any other cereal, proso millet is vulnerable to storage pest. The pest infestation increases if the grains are dehulled. In the hills of Arunachal Pradesh, the grains are stored in huge bamboo granaries. These grains must be subjected to primary processing to remove the husk attached with the grains. Hulling removes husk from the grains. Grading and polishing can also be done (over-polishing leads to loss of nutrients from the grain). Minimum polishing is recommended to make the grain lustrous and attractive at the same time retaining nutritional value of proso millet grains. It is found that the shelf-life of the dehulled grains is about three months. Air-tight packaging enhances shelf-life of proso millet grains and flour. The grains must be kept in air-tight container to prevent from storage pest infestation. Millets in general are not the staple food these days. Value addition of millets will diversify the food platter.

SUMMARY

Proso millet cultivation can help farmers in arid and semi-arid regions of India. It can be cultivated as a sole crop or intercrop. Most of the fallow lands in summer can be brought into proso millet cultivation with limited irrigation, which will generate additional income if grown as an intercrop. Proso millet is a good source of plant-based protein and its value addition can enhance acceptance among consumers. The demand for millets has increased many folds, the market linkages are in incipient stage but sooner the market will face scarcity of raw material for making value added products. The major constraint of millet cultivation was yield, but with the availability of improved cultivars and practices, farmers can harvest profitable yields.

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INTERNATIONAL YEAR OF MILLETS 2023

Kodo poisoning

and its management

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Kodo millet is a nutricereal, and staple food for many tribal and economically weaker sections in India. It is one of the hardiest crops, drought tolerant with high yield potential and excellent storage properties. But, its production and consumption are on the decline due to various factors. Kodo poisoning is one of the major factors impeding its consumption and this problem needs an immediate attention for effective management. The fear of kodo poisoning has emerged as a serious economic constraint for kodo millet cultivation, consumption and popularisation. This article would help in management of kodo poisoning thereby enabling its prevention, and enhancing the consumption and popularisation.

Keywords: *Aspergillus*, Cyclopiazonic acid, *Fusarium*, Kodua poisoning, Mycotoxin

MANY small grained annual grasses of the rainfed ecosystem, commonly referred as small millets are ancient grains, which fed the human population before wide spread adoption of fine cereals. Looking at the nutritional benefit of such grains along with other millets, they are collectively called nutri-cereals. Kodo millet (*Paspalum scrobiculatum*) is one such nutri-cereal grown on marginal and degraded lands producing high grain yields even with limited water. In India, it is grown largely in tribal regions and under poor environments, and finds place in the diet of poor people either as whole grains or in the preparation of traditional food products like idli, dosa, chapati, pongal, soup, etc. Apart from food uses, several medicinal properties of its grains as well as leaves are also known.

Despite all the beneficial properties, the kodo millet cultivation or consumption is limited by an enigma called kodo poisoning. Some early reports suggested that grains of kodo millet were poisonous and not fit for consumption based on a few poisoning incidences that had taken place in some of the kodo millet cultivating regions of North India, especially Uttar Pradesh and Madhya Pradesh. This had happened due to the consumption of kodo millet grains whose maturing and harvesting had coincided with rainfall, resulting in fungal infection of the grains leading to poisoned kodo locally known as Matawna kodoo or Matona kodo. Limited research studies on this aspect concluded that it was solely due to the contamination of the seeds with mycotoxin producing fungi belonging to *Aspergillus* and *Penicillium* genus. The association of the mycotoxin, cyclopiazonic acid (CPA), with kodo millet seeds causing kodo poisoning was first identified during mid-80s and so far, no studies have shown kodo millet grains producing any inherent toxin naturally inside grain leading to poisoning. To enhance the consumption and production of kodo millet, the management strategies for prevention of kodo poisoning have been discussed in this article.

Management

In integrated management system, mycotoxins contamination should be minimized in every phase of production, harvesting, processing and distribution. Prevention through pre-harvest management is the best method for controlling mycotoxin contamination. Although, if contamination prevails, the risk associated with the toxins must be managed through post-harvest methods.

***Pre-harvest management*:** Pre-harvest mitigating strategies include breeding for resistant cultivars. There have been several efforts to breed resistant cultivars for reduced mycotoxin contamination in several crops. In case of sorghum for management of grain mold disease complex, using host plant resistance was the major focus for development of less susceptible varieties and hybrids. In case of kodo millet, screening for mycotoxin (CPA) resistance needs to be initiated to manage the CPA contamination before harvest like in other crops. The common pre-harvest management practices for mycotoxins in sorghum or maize or peanut are good crop management practices, such as crop rotation, timely planting and harvesting, adjusting the planting date to avoid end-of-season rains coinciding with the harvest time, maintaining the optimal plant population in the field, taking necessary precautions to control the pest and diseases of the crop by adopting pest management practices, harvesting the crop at right maturity (18–20% moisture in the grains) and avoiding over maturity of the crop. These cultural practices can very well be used in kodo millet for reducing or avoiding the contamination by CPA in the field.

***Post-harvest management*:** Kodo poisoning can be minimized by employing proper post-harvest grain management practices. In the post-harvest control measures, drying, storage and processing are the significant aspects where contamination can be prevented in grains. Drying is an important step in ensuring good quality grain that is free of fungi and microorganisms. The harvested field crops should be dried as quickly as possible to recommended moisture levels of 10–13% for cereals. During storage, the moisture, temperature and relative humidity of the grains are the three main factors to be controlled to keep the growth of fungi in control. A relative humidity of 70% or less and grain moisture content of 12% or less will reduce the growth of storage molds and their toxins. Water activity of less than 0.7 will not favour any fungal growth/mycotoxin production in the grains. Proper drying of harvested kodo millet immediately and avoiding further moisture contact by storing in dry, air tight conditions can prevent the fungal contamination to a great extent.

Temperature is another key factor that prevents the growth of molds in the stored grains. Ideally, grain should be cooled after drying and maintained at 1–4°C for the duration of storage. At low or cold temperature, fungal contaminants are not killed, but their growth and metabolism are minimal. Levels of mycotoxins in contaminated commodities prior to consumption can be reduced by food processing methods such as wet and dry milling, grain cleaning, autoclaving, roasting, baking, frying, extrusion cooking, etc. It has been reported that in case of rainfall affected kodo millet, it was never eaten as flour but as rice and was well washed before being cooked which produced no bad effects.

To prevent poisoning, grains must be carefully removed from the glumes, lemma and palea or in other words milled before cooking. When different rice cooking methods used by Indians were compared, it was found that pressure cooking at 15 psi for 5 min gave maximum destruction (72%) of aflatoxin in comparison to the method of ordinary cooking (50%) and cooking with excess water (50%). Pressure cooking of rice not only destroyed the maximum amount of aflatoxins but also preserved nutrients in rice. These management practices can be effectively used for mitigating mycotoxin in different food grains. As CPA is also a secondary metabolite of *Aspergillus* and *Penicillium*, like aflatoxins, it may be presumed that similar practices can be employed for reducing the CPA contamination in kodo millet.

***Bio-management*:** Different microorganisms have been tested to limit fungal development and mycotoxin production as a possible alternative method. These microorganisms may control plant diseases through one or more mechanisms like induction of host resistance to the disease by production of antimicrobial compounds or direct antagonism to the pathogens and competition with pathogens for space and nutrients. Bio-control agents have been tested successfully as control agents for cereal diseases caused by *Fusarium* species. *Trichoderma* was found efficient in inhibition of mycotoxin production in rice by *Fusarium culmorum* and *F. graminearum.* Inhibition of 6 major rice fungal pathogens has been achieved by the use of *Streptomyces corchorusii* strain UCR3-16. In managing the grain mold pathogens in sorghum, *Trichoderma viride*, *T. harzianum* and *Pseudomonas* spp. showed promising results both at laboratory and field levels. As kodo poisoning is caused by different strains of *Aspergillus,* the above practices may be useful and can be practiced to reduce or minimize the contamination of mycotoxin, CPA.

Way forward

So far studies have been mainly concentrated on detecting the causal organism and its toxin, CPA. Though many other agricultural crops suffer from CPA contamination, major adverse effects have been recorded only in kodo millet because of lack of scientific management. Agro-climatic requirements of the crop, micro-climates surrounding seed, chemical composition of grain, husk and leaves are some of the aspects that should get immediate research attention to unveil the mystery of kodo poisoning. In addition to CPA, *Aspergillus* species also produces aflatoxin. Any synergistic effect of co-presence of CPA and aflatoxins on kodo millet needs further investigation. Efforts should also be made to examine all parts of the plant including green leaves, grain with husk, dehulled grain and fodder for finding out if traces of CPA occur naturally in the crop.

SUMMARY

To reduce the risk of CPA contamination, integrated management system needs to be adopted for kodo millet and utmost care should be taken at every stage of the crop (pre-harvest to processing) to limit poisoning. Pre-harvest management of mycotoxin contamination is vital to harvest clean grains and to maintain contamination levels near to zero. Breeding for cultivars or traits showing resistance to fungal infection and use of antifungal crop protection chemical agents that are non-toxic to human beings are important measures that can be thought of to nullify kodo millet poisoning and popularising the crop.

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INTERNATIONAL YEAR OF
MILLETS
2023

Creation of demand
through value chain development in millets

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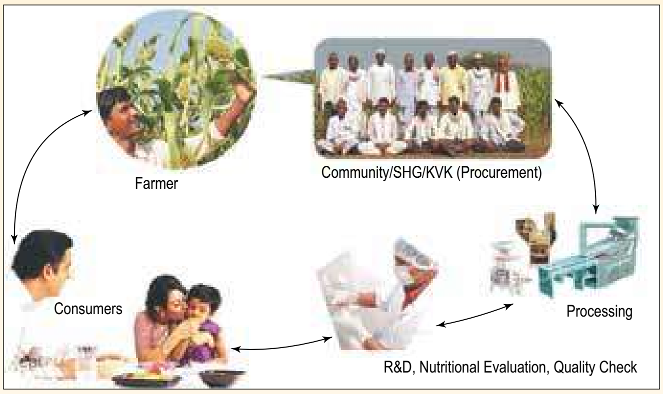
Millets (small-grained cereals including, sorghum, pearl millet, and other small millets) are known for their hardiness and adaptation to low input and harsh environments of Asia and Africa. They are major means of sustainable livelihood of poor in the dryland regions of the country providing both food and fodder requirement. However, their area has declined from 36.34 million ha (1955-56) to 17.0 million ha (2011-12). The major causal factors responsible for such a decline in area of millet crops are; relatively higher demand and profitability of competing crops, lower market prices of millets vs. competing crops many of which are artificially supported, declining role as a food crop at aggregate level, urbanization, and income growth. One of the important determinants of millets economy is the consumption parameter. The consumption of millets in general declined overtime.

Keywords: Commercial, Market, Millets, Value-addition

THE contribution of coarse cereals (millets plus maize) was 10% of food grains in 2003-04 (16.5 kg /person/year). This has declined to 8% by 2011-12 (13.2 kg/person/year). The major determinants for this decline are changes in food habits, time-consuming and cumbersome procedure of food preparation and strong policy disincentives.

The agricultural and food policies of national and state governments are tilted largely towards rice and wheat. Public Distribution System (PDS) policy which resulted in significant changes in the food habits of people across the country that led to complete neglect of the so called "coarse grains", especially millets, which are otherwise extremely nutritious. On supply-side, subsidies on farm inputs (irrigation, electricity and fertilizers) for production of rice and wheat have increased faster than even population growth rate. Some isolated half-hearted efforts were made in the past to include sorghum in the PDS in Maharashtra state. However, some storage problems and logistic issues led to its discontinuation. Now, there is a need to re-work ways and means to include millets in PDS as they form the core of dryland farming and are consumed as staple food in these regions. Thus, policy dis-incentivisation towards millets was two-pronged both on supply side and demand side. This has impacted adversely the country's millet production and consumption, and in turn stability of small farmers' sustenance in dryland. This calls for change in strategies on agricultural policy and R&D to ensure food security of the country, at least to those populations where millets are grown and still consumed as dominant staples.



The major millets value chain showing different stake holders

Innovative interventions taken place under NAIP on millets value chain

The objectives of this Public Private Partnership project (PPP), mooted by the Indian Institute of Millets Research, Hyderabad included; (1) Market-driven millets cultivation for specific end products, procurement and primary processing for continuous supply-chain

Farmers participating in IIMR end-product specific sorghum cultivation

management, (2) Fine-tuning the technologies for development of millet food products and up-scaling, (3) Nutritional evaluation and safety of selected millet foods, (4) Consumer acceptability, market strategies, social and policy imperatives, (5) Entrepreneurship and appropriate strategies to promote and popularize millets for commercialization through value-addition, branding as health foods. The consortium partners are National Institute of Nutrition (NIN), State agriculture universities (SAU's), private partners such as ITC and linkages with Defence Food Research Laboratory (DFRL), Central Food Technological Research Institute (CFTRI), CIAE, Central Institute of Post-Harvest Engineering and Technology (CIPHET) and Home Science Colleges.

End-product specific sorghum production: The backward integration model of product specific on-farm production covering 3,000 acres in Parbhani (*rabi*) and Nanded (*kharif*) of Maharashtra and in Adilabad (*kharif* for two seasons) in Andhra Pradesh was tested for four successful years under e-choupal market assured model of ITC (ABD). The beneficiaries are technology backstopped by IIMR product specific cultivars (M 35-1, CSV 216R, Parbhani Moti, Phule Vasudha and Phule Revati in rabi season and CSH-14, CSH-16, CSH 23, CSV 20 and SPH 1148 during *kharif*). The recommended package of practices (PoP) for receiving better yield and quality was extended in PPP mode of farm extension services. The impact is visible through increased farm productivity. The average increase in income of the participating farmers in *kharif* season was 222% and 69% in *rabi* season over baseline.

The product specific on farm production led to procurement, aggregation and linking further with other stakeholders in the value chain ultimately linking from producers to consumers. This existing sorghum value chain is in a disintegrated manner. Since the Fair Average Quality (FAQ) grains and their quantity were predetermined under the PPP, both the parties could rely on each other; it provided a better price to the farmers and sufficient quantity and desired quality of sorghum to the processors for smooth functioning of their business. In fact, backward integration resulted to overall improvement in the crop scenario such as the quality of the produce (sorghum grain), better utilization of fallow land, and commercial colour to the crop through sustainable linkage among all the stakeholders in the value chain.

Development of novel sorghum/millets based products: More than 30 products were developed and standardized, out of which the shortlisted products that have been successfully commercialized on pilot scale under the IIMR brand Eatrite are Jowar rawa, Jowar pasta, Jowar vermicelli, Jowar flakes, Jowar biscuits, Jowar pops and Jowar based multigrain atta. This proves the feasibility of processing and commercialization of sorghum and millets in both rural and urban areas, irrespective of traditional and non-traditional areas.

Nutritional evaluation and certification (by NIN): The organoleptic study of 15 sorghum products conducted by the NIN showed that sorghum products are superior than rice products and on par with wheat based products. This study was followed by nutritional benefits of sorghum products in diabetes and school children. The studies established that sorghum offers better nutrition in general over the market available products made from wheat, rice and maize. The amino acid profile of pulse (Soy blend) incorporated jowar products were containing better amount of lysine, which is a limiting factor in jowar and also overcome the deficiency of micro nutrients. Glycemic Index of *jowar* foods was analyzed to determine the mean glycemic response for reference and test foods using international standards. The study reported that there was a decrease in the mean incremental area under glucose curve (IAUC) levels after consuming jowar products.

Entrepreneurship development: Entrepreneurship Development (ED) programme on sorghum cultivation, processing, and marketing of jowar based products was jointly organized by ITC and IIMR with active participation from institutes like IIMR, ITC, ANGRAU, NIN and College of Home Science, MAU. Machineries of standardized sorghum products were demonstrated to the farmers. Approximately 40,000 farmers were benefited through various trainings initiated by ITC and IIMR. Approximately 2,000 rural women and another 3,000 SHG's, farmers, urban entrepreneurs were trained

Demonstration of secondary processing at IIMR for entrepreneurs

Promotion of sorghum products

on development in sorghum food processing.

Promotion and popularization: IIMR launched its own brand as "Eatrite" and the products are popularized as healthy foods while ANGRAU has branded their products as ANGRAU foods. The sorghum products are now labeled and branded as healthy foods based on nutritive value established by NIN studies and targeting separately for urban and rural markets. For promotion of Eatrite products, nutritionists/doctors/dieticians were sensitized by IIMR and for commercial portal IIMR launched *www.iEatrite.com* website.

Simultaneously, outsourcing through the event managers was done for popularization of sorghum products (360 degree communication, brand designing logo, etc with BTL and ATL strategies implemented) in urban markets and New age Media. Massive awareness is created on sorghum as health and nutria food through road shows (100+) in public parks, malls, and institutes etc in Hyderabad and in exhibitions in imparting awareness of sorghum to across 40,000 consumers through fabricated Jowar Rath in Pune, Bangalore, Jabalpur, Chennai, Coimbatore, and New Delhi etc. Rural consumer drive was undertaken by ITC rural choupal haats to sensitize the convenience and nutritional aspects of the outputs from the sub-project.

Commercialization: The pilot commercialization of sorghum products at Hyderabad started with launching of IIMR brand "Eatrite" with a tag line 'Eat Jowar –stay healthy'. The range of products under this brand included: sorghum rich multigrain flour, sorghum semolina, sorghum pasta, sorghum vermicelli, sorghum flakes and sorghum biscuits/cookies. Suitable packaging, labeling, marketing and pricing strategies are adopted for targeting them to urban markets. These interventions made possible to provide convenient options for consumers among sorghum foods.

Policy sensitization

First initiative on public private partnership (PPP) in a big way happened when IIMR linked MoU with ITC (ABD) in 2008 under NAIP. Many other linkages across the millets growing belts are followed with Government's programme INSIMP (Initiative for Nutritional Security through Intensive Millets Promotion) launched in 2011-12 for promoting millets across the country with budget allocation of ₹300 crore under 12th Five-Year-Plan. Ultimately 200 processing clusters were set up for millets processing across the country with IIMR monitoring as the Centre of Excellence providing handhold trainings to the beneficiaries.

SUMMARY

An innovative intervention was initiated by IIMR led consortium under NAIP to create demand of millets in the country through production to consumption value chain. Backward integration of sorghum value chain was enabled with ITC (ABD) Ltd support under *e-choupal* platform where beneficiary farmers are market assured to ascertain their functionality, feasibility and sustainability of intensive sorghum cultivation. It is relatively a new phenomenon in India's millets scenario, which paved the way for supply chain management and further strengthened the development and commercialization of sorghum products, positively impacting both farmers and entrepreneurs. The novel product development *vis-à-vis* determining their nutritional values, and simultaneously promoting and marketing them has enhanced the awareness and created more demand for these nutria-cereal based products. The value chain approach thus provided end to end solutions and forward integration is enabled for processing and commercialization by the small and medium scale entrepreneurs.

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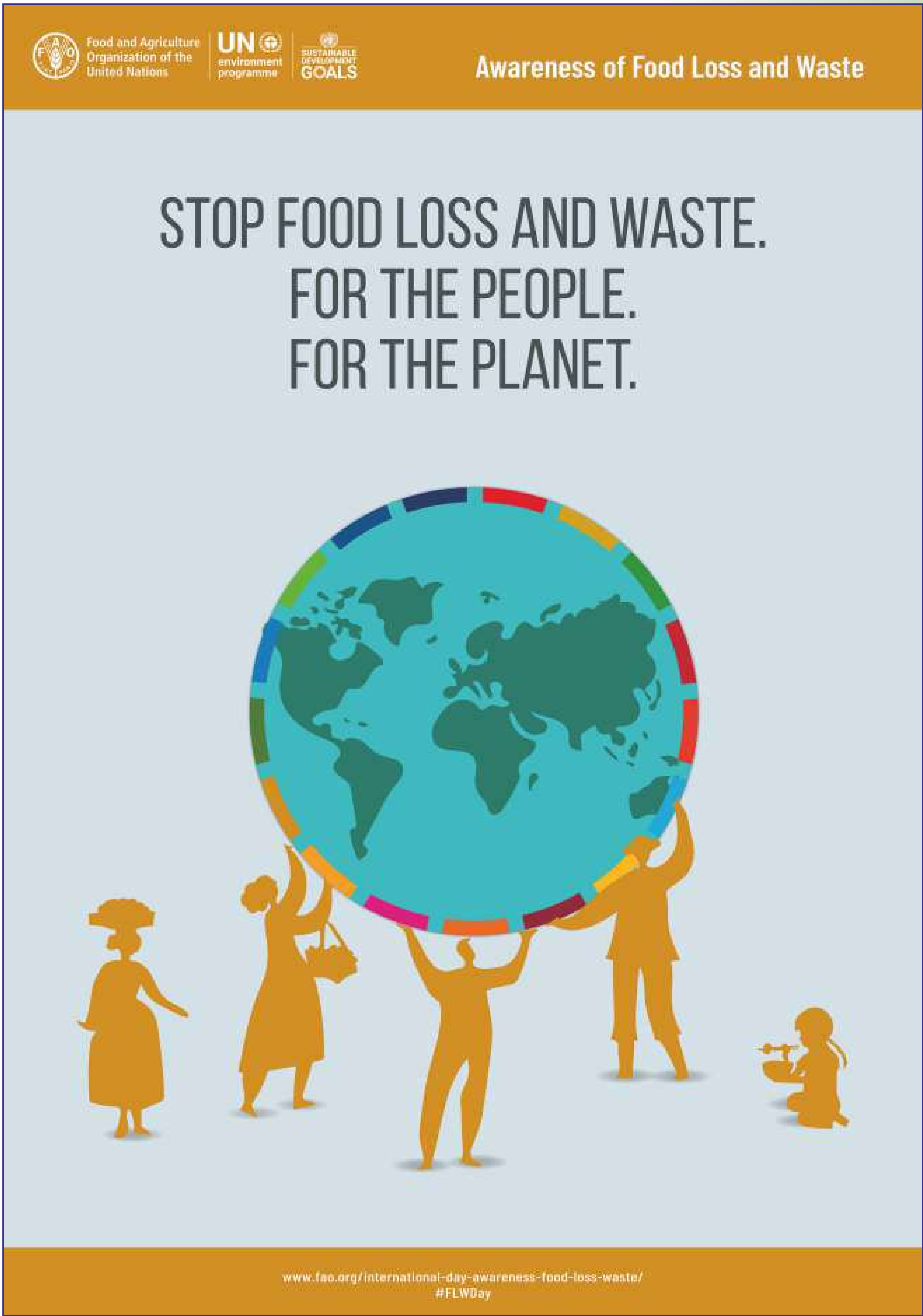

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