GOOD AGRICULTURAL PRACTICES (GAP) MANUAL FOR SUSTAINABLE MILLETS PRODUCTION IN INDIA

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सत्यमेव जयते

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FOREWORD

Millets are the backbone of agriculture in India's harsh and fragile ecologies/regions where farming is largely dependent on erratic monsoons, frequent moisture stress, and high temperatures on coarse-textured soils. These challenges are compounded by multinutrient deficiencies and imbalanced fertilization practices, often limited to organic manures and nitrogen application. As a result, millet cultivation has traditionally focused on survival rather than profitability.

Women farmers play a central role in millet production, with pest management (including weed control, insect and disease management) and mechanization receiving minimal attention. This contributes to consistently low yields per unit effort/energy. However, rising consumer awareness of the nutraceutical and health-promoting properties of millets is driving demand, particularly among urban and elite consumers. This shift presents a timely opportunity to revitalize millet production systems.

Despite their resilience and nutritional value, millets remain underutilized. A significant yield gap persists between farmers' fields and research plots, largely due to the limited adoption of Good Agricultural Practices (GAP) as a holistic package. Bridging this gap is essential to unlock the full potential of millets for food, nutrition, and income security.

I am pleased that ICAR–Indian Institute of Millets Research (IIMR) is publishing a comprehensive guide on Good Agricultural Practices for Millets Production in India. This compilation not only covers major millets but also introduces emerging crops such as fonio, teff, and job's tear, offering new avenues for diversification and resilience. The collaboration with the Food and Agriculture Organization (FAO) in this initiative is commendable.

I congratulate the authors for presenting the content in a clear, accessible, and user-friendly format. I am confident that this publication will serve as a valuable resource for farmers, researchers, extension personnel, and policymakers working to promote sustainable millet cultivation across India.

4 September 2025

(Mangi Lal Jat)

PREFACE

Millets have long served as staple crops in India's harsh agro- ecological zones, cultivated under low-input conditions with modest yields and limited profitability. Despite their resilience and nutritional value, these crops have remained underutilized in mainstream agriculture. To address this gap, the book *Good Agricultural Practices (GAP) for Sustainable Millets Production in India* presents a comprehensive synthesis of agronomic advancements developed through the concerted efforts of the National Agricultural Research System (NARS), led by the ICAR- Indian Institute of Millets Research (IIMR), Hyderabad, India. This compilation covers 12 millet crops, categorized by their geographic relevance: **Pan- India crops**: *pearl millet, sorghum,* and *finger millet* − richly documented with state-specific practices, especially in nutrition, irrigation, and moisture conservation. **Region-specific crops**: *foxtail, kodo, little, barnyard,* and *proso millet* − with emerging data and localized recommendations. **Minor and niche crops**: t*eff, fonio,* and *job's tear* − grown on a limited scale, with minimal but valuable information.

Each crop chapter follows a standardized structure to ensure consistency and ease of reference: **Agro-ecological context**: climate, soil requirements, land preparation; **Crop establishment**: recommended varieties, sowing windows, seed rate, spacing; **Nutrient and water management**: organic and inorganic inputs, irrigation, moisture conservation, **Crop protection**: weed control, pest and disease management, **Harvest and utilization**: yield benchmarks, grain uses, export potential; **Economic and policy dimensions**: minimum support price, seed production (with detailed protocols for hybrid seed production in pearl millet and sorghum).

The book integrates **tables, figures, and source-attributed visuals** to enhance comprehension and practical utility. It is designed to serve as a vital resource for **researchers, educators, extension professionals, policymakers, and practitioners** committed to advancing millet-based farming systems.

By bridging scientific knowledge with field-level applicability, this compilation aims to catalyse the transformation of millet cultivation into a more productive, profitable, and sustainable enterprise − especially for smallholder farmers operating in marginal environments.

This compilation is the outcome of the FAO-supported project *"Enhancing Capacity on Sustainable Value Chain Development of Millets for Food and Nutrition Security in India" (TCP/RAS/3909)*. The financial assistance and strategic guidance provided by the Food and Agriculture Organization of the United Nations (FAO) are gratefully acknowledged, as they played a pivotal role in enabling the development and dissemination of this resource. This publication draws upon research insights generated over several years and gratefully acknowledges the contributions of the National Agricultural Research System (NARS), whose sustained efforts have laid the foundation for the advancements documented herein. We are also thankful for the photographs shared by researchers from NARS and other sources that were duly acknowledged. We are sure that this compilation will serve as useful reference for all stakeholders.

Authors

ABBREVIATIONS

AICMIP	All India Coordinated Millets Improvement Project
AICRP-SM	All India Coordinated Research Project on Small Millets
AICSIP	All India Coordinated Sorghum Improvement Programme
AICSMIP	All India Coordinated Small Millets Improvement Project
ASSOCHAM	Associated Chambers of Commerce & Industry of India
ATP	Adenosine triphosphate
BBF	broad bed and furrow
BMR	brown midrib
BCKV	Bidhan Chandra Krishi Viswavidyalaya
CACP	Commission for Agricultural Costs and Prices
CMS	cytoplasmic male sterile
CFTRI	Central Food Technological Research Institute
DAT	days after transplanting
DAS	days after sowing
DASM	depletion of available soil moisture
DTPA	diethylene triamine pentaacetic acid
EMS	ethyl methane-sulfonate
FAO of UN	Food and Agriculture Organization of United Nations
FPOs	Farmers Producers Organizations
FICCI	Federation of Indian Chambers of Commerce and Industry
FIRB	furrow irrigated raised beds
FLDs	front line demonstrations
FSSAI	Food Safety and Standards Authority of India
FYM	farmyard manure
GAP	good agricultural practices
GVO	gross value output
HCN	hydrogen cyanide
IARI	Indian Agricultural Research Institute
ICAR-AICRP	Indian Council of Agricultural Research - All India Coordinated Research Projects
ICAR-IIMR	Indian Council of Agricultural Research - Indian Institute of Millet Research
ICDS	Integrated Child Development Services
ICMR-NIN	*Indian Council of Medical Research*-National Institute of Nutrition
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFCT	Indian Food Composition Tables
IGFRI	Indian Grassland and Fodder Research Institute
IIFSR	Indian Institute of Farming Systems Research
INR	Indian rupees
LCC	leaf colour chart
MCPD	more crop per drop
MSP	minimum support price
NAD	National Accounts Division
NADH	nicotinamide adenine dinucleotide
NADPH	nicotinamide adenine dinucleotide phosphate
NADP_ ME	nicotinamide adenine dinucleotide phosphate-malic enzyme
NAD-ME	NAD_ dependent malic enzyme
NARS	National Agricultural Research System
NBPGR	The National Bureau of Plant Genetic Resources
NPOF	Network Project on Organic Farming
NSC	National Seeds Corporation
NSKE	neem seed kernel extract

OAA	oxaloacetic acid
OPVs	open-pollinated varieties
PDS	public distribution system
PEP	phosphoenolpyruvate
PEPC	phosphoenolpyruvate carboxylase
PEP-CK	phosphoenolpyruvate carboxy-kinase
PSB	phosphorous solubilizing bacteria
RDF	recommended dose of fertilizer
RDN	recommended dose of nitrogen
RuBisCo	ribulose-1,5_ isphosphate carboxylase/oxygenase
SAR	sodium absorption ratio
SDHI	succinate dehydrogenase inhibitors
SFCI	State Farms Corporation of India
SFMI	System of Finger Millet Intensification
SRgI	System of Ragi Intensification
SFMI	System of Finger Millet Intensification
SSC	State Seeds Corporation
STCR	Soil Test Crop Response
USD	United States Dollar
USDA	**United States Department of Agriculture**
VC	vermicompost
WUE	**water use efficiency**

COMMON UNITS

Unit	**Symbol**
active ingredient per hectare	a.i./ha
colony forming units per gram	cfu/g
deci-siemen per metre	dS/m
gram per kilogram	g/kg
irrigation water applied/ cumulative pan evaporation	IW/CPE
kilo joule per gram	kJ/g
kilogram per hectare	kg/ha
lakh per hectare	lakh /ha
litre	l/L
mega joule per tonne	MJ/tonne
million hectares	Mha
million tonnes	Mt
millimole	mmol
parts per million	ppm
square metre	m^2
tonnes/hectare	t/ha
micromole	µmol

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CHAPTER 1: INTRODUCTION

What are millets?

Millets are small-seeded cereal staples as evidenced from their low single-seed weight ranging from as low as 0.3 mg in teff to 35 mg in sorghum. In general, millets cultivated for fodder purpose (sorghum and pearl millet) tend to have lower seed weights than grain types. This is because they are bred for high biomass, leafiness and their potential for regrowth often at the expense of seed weight. Grain types, on the other hand, are bred for higher seed density, uniformity and nutritional value which results in higher seed weight. The test weight (1000 seed weight) of millets is presented in Table 1.

TABLE 1. General test weight of millets

Millet	Test weight (g)	
	Grain purpose	Fodder purpose
Job’s tear	30–40	–
Sorghum	20–30	15–20
Pearl	5–7	3–5
Proso	4–6	–
Finger	2–6	–
Browntop, barnyard, kodo, foxtail, little	2–3	–
Fonio	0.5–0.6	–
Teff	0.3–0.4	–

Source: Authors’ own elaboration

Of the 15 common types of millets cultivated worldwide (sorghum, pearl millet, finger millet, foxtail millet, proso millet, little millet, kodo millet, barnyard millet, browntop millet, black fonio, white fonio, raishan, job’s tear, teff and guinea millet), all except guinea millet have been cultivated and consumed in India for centuries. Teff was recognized as an important millet and included in the small millets group during the First Small Millets Workshop held in Bengaluru in 1986. In recent years, teff has also been grown on an experimental scale in Karnataka.

Gross value of output (GVO) of millets

According to the National Accounts Division (NAD, 2024), the gross value output (GVO) of millets at 2011/12 constant prices for 2022/23 was INR 19 020.87 crores. Of this total, pearl millet with GVO of INR 10 898.09 crores contributed 57.7 percent. Sorghum (INR 6037.86 crores), finger millet (INR 1725.06 crores) and small millet (Rs 359.86 crores) contributed 31.7 percent, 9.07 percent and 1.93 percent of the GVO respectively. The top five states contributing to the GVO of each millet crop is presented in Table 2. Rajasthan recorded the highest overall contribution to GVO from millets. On the whole, cereals recorded a GVO of INR 419 300 crores of which millets had a meagre share of about 4.5 percent.

TABLE 2. The top five states contributing to GVO of millets (%)

Pearl millet (%)	Sorghum (%)	Finger millet (%)	Small millets (%)
Rajasthan (41.0)	Maharashtra (34.6)	Karnataka (63.0)	Madhya Pradesh (33.4)
Uttar Pradesh (15.7)	Karnataka (19.4)	Tamil Nadu (14.9)	Arunachal Pradesh (7.8)
Gujarat (14.0)	Rajasthan (10.4)	Maharashtra (7.7)	Maharashtra (7.2)
Haryana (10.7)	Tamil Nadu (6.7)	Uttarakhand (7.2)	Odisha (6.7)
Madhya Pradesh (9.5)	Uttar Pradesh (5.8)	Odisha (2.3)	Karnataka (5.9)

Source: Authors' own elaboration

Nutritive value of millets

ICMR-National Institute of Nutrition (ICMR-NIN) has extensively documented the nutrient composition of millets in the *Indian Food Composition Tables* (IFCT), some in collaboration with ICAR-Indian Institute of Millet Research (ICAR-IIMR). Based on the report, it is inferred that millets are rich in complex carbohydrates, dietary fibre, essential minerals (iron, zinc, and calcium) vitamins and many phytochemicals. Finger millet particularly stands out for its high calcium content, little millet and barnyard millet exhibit notable iron content and proso millet has high protein content. Millets have a low glycaemic index, making them suitable for managing diabetes and cardiovascular diseases. Sorghum-based diets have shown improved glycosylated haemoglobin and lipid profiles in diabetic patients. Millets are gluten-free, making them suitable for coeliac diets. Since 2015, biofortified pearl millet cultivars enriched with zinc (Zn) and iron (Fe) have evolved and now all pearl millet cultivars released are biofortified. Similar biofortification efforts in other millets have met with limited success. However, some biofortified varieties enriched with Zn, Fe and Ca were released in finger millet and little millet. Consequently, three millets are now enriched with iron and zinc. The typical composition of millet grains is presented in Table 3.

Millet capabilities emanate from C_4 photosynthesis mechanism

Millets are characterized by their use of C_4 photosynthesis mechanism. Three biochemical subtypes of C_4 photosynthesis are recognized. In the first subtype, NADP-ME (Nicotinamide adenine dinucleotide phosphate-malic enzyme), mesophyll cells fix atmospheric CO_2 into oxaloacetic acid (OAA) through PEPC (phosphoenolpyruvate carboxylase) that moves into bundle sheath cells, where it is converted into malic acid through NADP-ME releasing CO_2. This two-cell system minimizes photorespiration and boosts efficiency under high light and temperature environments. This subtype relies heavily on mesophyll chloroplasts for adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH).

In the second subtype, NAD-ME (NAD-dependent malic enzyme), the initial CO_2 fixation occurs in mesophyll cells via PEPC forming OAA that is converted into aspartate by ATP and is transported to bundle sheath cells. In bundle sheath mitochondria, NAD-ME decarboxylates malate and releases CO_2. The released CO_2 is then fixed by RuBisCo (ribulose-1,5-bisphosphate carboxylase/oxygenase) in the Calvin cycle. Pyruvate is transported back to mesophyll cells. PEP-CK type C_4 plants have bundle sheath cells with strong mitochondria and less chlorophyll, while mesophyll cells contain a moderate number of chloroplasts. This setup makes them efficient under higher CO_2 and moderate light conditions, suitable in semi-arid regions. The NAD-ME subtype shifts more energy demand to bundle sheath mitochondria and has lower ATP demand compared to the NADP-ME type. Flexibility in decarboxylation pathways allows adaptation to fluctuating light and temperature.

TABLE 3. Nutrient composition of millets (per 100 g edible portion) in comparison to fine cereals

Millet	Carbohydrate (g)	Protein (g)	Fat (g)	Energy (Kcal)	Dietary fibre (g) total	Ash (%)	Ca (mg)	Mg (mg)	P (mg)	Zn (mg)	Fe (mg)	Thiamin (mg) - B1	Riboflavin (mg)-B2	Niacin (mg)-B 3	Folic acid (Microg) - B9
Pearl [1]	61.78	10.96	5.43	348.0	11.49	1.37	27.35	289	124	2.7	6.42	0.25	0.20	0.86	36.1
Sorghum[1]	67.68	9.97	1.73	334.1	10.22	1.39	27.6	274	133	1.9	3.95	0.35	0.14	2.10	39.4
Finger [1]	66.82	7.16	1.92	320.7	11.18	2.04	364.0	210	146	2.5	4.62	0.37	0.17	1.34	34.7
Proso [1]	66.19	12.30	1.72	331.7	6.39	1.72	15.27	206	153	1.4	2.34	0.29	0.20	1.49	**30-40**
Little [1]	65.55	10.10	3.89	346.0	7.72	1.34	16.10	130	91	1.8	1.26	0.26	0.05	1.30	36.2
Foxtail [2]	60.90	12.30	4.30	331.0	8.00	**2.0-2.5**	31.00	188	81	2.4	2.80	0.59	0.11	3.20	15.0
Barnyard [2]	65.50	6.20	2.20	307.0	9.80	**2.5-3.2**	20.00	280	82	3.0	5.00	0.33	0.10	4.20	**35-40**
Browntop [*]	71.00	8.00	4.00	331.0	4.92	**2.2-2.9**	26.20	**114**	**290**	2.9	7.00	**0.42**	**0.19**	**2.80**	**20-40**
Kodo [3]	66.60	9.80	**1.30**	353.0	5.20	3.30	35.00	**112**	**284**	**0.6**	1.70	0.15	0.09	2.00	**40-50**
Fonio**	75.00	8.50	1.50	365.0	3.00	**1.8-2.5**	30.00	70	**93**	3.2	34.6	0.17	0.22	1.15	-
Teff***	73.00	9.60	2.00	336.0	3.00	**3.03**	159.00	170	378	2.0	5.8	0.30	0.18	2.50	**40-60**
Job's tear****	65-70	13-15	4−5	**356.0**	6-8.0	**0.7-2.6**	20-30	90-100	200-250	**0.4**	4-6	**0.28**	**0.19**	**4.30**	**30-40**
Wheat (whole) [1]	64.72	10.59	1.42	321.9	11.23	1.42	39.36	315	125	2.8	3.97	0.46	0.15	2.68	30.1
Wheat (flour) [1]	64.17	10.57	1.28	320.3	11.36	1.28	30.94	**137**	**323-346**	**3-5**	4.10	0.42	0.15	2.37	**30-40**
Rice (brown) [1]	74.80	9.16	1.04	353.7	4.43	1.04	10.93	96	19	1.2	1.02	0.27	0.06	3.40	9.3

Sources**:** [1]Indian Food Composition Tables, ICMR-NIN (Longvah *et al.*,2017)
[2]Nutritive Value of Indian Foods, ICMR-NIN, 2007
[3]NRC, 1982
* Ponnapalli, Karkannavar and Hemalatha, 2023
** Michael Joseph, 2025 https://www.nutritionadvance.com/fonio-nutrition/
*** Barretto *et al.*, 2021
****Chaisiricharoenkul, Tongta and Intarapichet, 2011
Text in bold is collected from various sources

The third subtype, PEP-CK (phosphoenolpyruvate carboxykinase), utilizes both malate and aspartate. Decarboxylation occurs in cytosol, balances the use of ATP and NADPH, making it versatile. It is seen in *Panicum maximum*, *Urochloa* spp. It is potentially more efficient under low light intensity or stress conditions. The PEP-CK subtype adds flexibility, particularly under fluctuating light conditions.

The three C_4 photosynthesis subtypes are distinguished and their presence in different millets is listed in Table 4

.

TABLE 4. C_4 photosynthesis subtypes and characteristics.

C_4 subtype	Decarboxylation enzyme	Decarboxylation location	Main C_4 acid	Energy source	Key traits
NADP-ME	NADP-ME (malic enzyme)	Bundle sheath chloroplasts	Malate	NADPH	High light use efficiency. Reported in foxtail millet, sorghum, barnyard millet, fonio, finger millet, kodo millet.
NAD-ME	NADP-ME	Bundle sheath mitochondria	Aspartate to malate	NADH	Suited to shade conditions. Reported in pearl millet, teff, little millet and proso millet.
EP-CK	PEP-CK (carboxylase)	Bundle sheath Cytosol	Aspartate	ATP	Flexible energy use, often co-exists with NAD-ME (browntop millet) and NADP-ME (job's tear).

Source: Authors' own elaboration

The process of CO_2 fixation and concentration between mesophyll and bundle sheath cells is illustrated in Figure 1 (Wang *et al*., 2014).

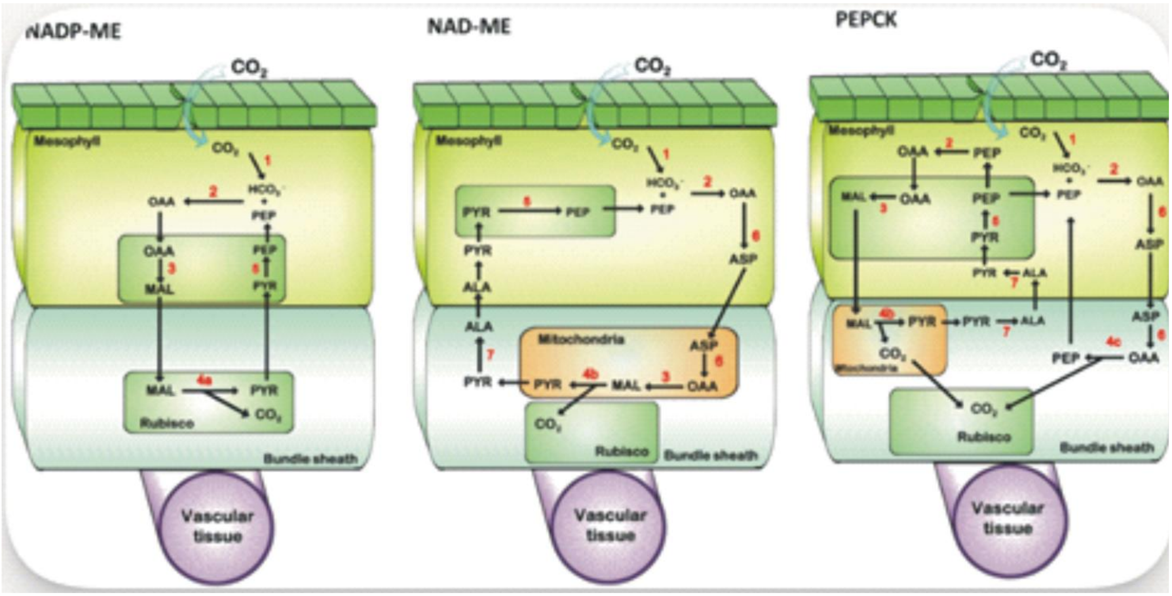

FIGURE 1. C_4 photosynthesis subtypes

© Wang *et al*., 2014

Nitrogen use efficiency in C_4 vs C_3 plants: a physiological perspective

Plants utilizing the C_4 pathway possess a specialized CO_2-concentrating mechanism involving PEPC and bundle sheath cells, which significantly reduces photorespiration. This adaptation allows C_4 species to achieve high photosynthetic rates with lower concentrations of RuBisCo, thereby decreasing their nitrogen requirement for carbon fixation. RuBisCo is the most abundant protein in plant leaves that is N-rich (approximately 16 percent N on a dry-weight basis) making it a major N sink.

C_4 plants typically allocate 5−9 percent of total leaf N and about 30 percent of soluble leaf protein to RuBisCo. C_3 species allocate about 20−30 percent of total leaf N and about 50 percent of soluble leaf protein to RuBisCo. The high investment in RuBisCo by C_3 plants is attributed to its relatively slow catalytic turnover and dual carboxylase/oxygenase activity, which necessitates large quantities of RuBisCo to sustain photosynthesis under ambient CO_2 conditions.

Thus, the CO_2-concentrating mechanism in bundle sheath cells, combined with a reduced RuBisCo content in C_4 plants results in enhanced nitrogen use efficiency (NUE), particularly under high and varying light intensities and elevated temperatures. This makes C_4 crops highly suitable for dryland agriculture with low external application of N through fertilizers. By reducing N demand − while maintaining or even enhancing productivity−these crops offer a strategic pathway toward sustainable intensification and resource-efficient farming.

Water requirement and use efficiency: C_4 photosynthetic mechanism

Plants that use C_4 pathway possess a CO_2-concentrating mechanism that actively transports CO_2 into bundle sheath cells, thereby suppressing the oxygenase activity of RuBisCo and minimizing photorespiration. This adaptation enables C_4 species to maintain high photosynthetic rates even under conditions of partial stomatal closure.

Compared to C_3 plants, C_4 species exhibit lower stomatal conductance**,** which reduces transpiration without compromising C assimilation. As a result, they demonstrate significantly higher intrinsic water use efficiency (WUE), defined as the ratio of net photosynthesis to stomatal conductance. This physiological advantage becomes even more pronounced under water-limited conditions. Quantitatively, the WUE of C_4 plants ranges from 3–6 µmol CO_2 per mmol H_2O transpired which is over two times that of C_3 plants (1–3 µmol CO_2 per mmol H_2O transpired)**.** This enhanced WUE makes C_4 crops such as sorghum, pearl millet and finger millet particularly well-suited for dryland agriculture, where optimizing water productivity is critical for sustaining yields under climate variability and limited irrigation.

As a result of the high intrinsic WUE, water requirement of millets (defined as the amount of water required to compensate the evapotranspiration loss from the cropped field, USDA Soil Conservation Service (1993) remains one of the lowest among staples. Finger millet has the least water requirement of approximately 350 mm, while pearl millet and sorghum require comparatively more water, in the range of 350−500 mm.

Millets tend to survive in adverse climates and arid regions. Because of this they were mostly cultivated in rainfed regions. Despite the planned irrigation development of the past 75 years, 86 percent of the total millet production in India is from rainfed cultivation.

The journey of millets in India: from major staple to minor staple

Since independence, the role of millets as a staple in India has undergone a dramatic transformation. Once central to national food security, their contribution to total food grain production peaked at 13.55 percent in 1992/93 (25.09 million tonnes (Mt) out of 185.17 Mt). However, by 2024/25, this share had declined 2.66-fold to just 5.09 percent (18.02 Mt out of 353.96 Mt). (According to the Third Advance Estimate of Production of Food Grains as on 28 May 2022, UPAg portal).

This decline in the share of millets in food grain production is linked to the substantial reduction in the areas of its cultivation. Between 1950−60 and 2010−20 the decadal mean area under millet cultivation reduced by 60 percent from 39.35 Mha to 16.13 Mha. Facilitated by enhanced irrigation facilities, farmers replaced millet cultivation with more profitable crops such as rice, wheat, maize, sugarcane as well as soybean, Bt cotton, etc. in rainfed regions. This loss of acreage is continuing and between 2020 and 2023, 2.98 Mha millet area was lost (13.15 Mha in 2023/24). Continuous loss of millet acreage could be attributed to their modest productivity (1.34t/ha) which limits economic returns. Comparative income disparities are stark (Nuthalapati *et al.*, 2023). Farmers cultivating pearl millet, sorghum and finger millet earn about 33 percent, 32 percent and 8.7 percent, respectively, of what an average wheat farmer earns. In India, during 2025/26, the minimum support price (MSP) per tonne grain was announced for only three major crops: pearl millet (INR 27 550), finger millet (INR 48 860) and sorghum (Maldandi was INR 37 490 and hybrid sorghum was INR 36 990). However, farmers are often unable to realize MSP because of various infrastructure constraints, especially with storage and processing. Some states procure millets for distribution through public distribution systems (PDS), midday meals, and Integrated Child Development Services (ICDS) programmes. Notable examples being Odisha's *Mission Shakti* and Karnataka's *Raithasiri.*

According to the Commission for Agricultural Costs and Prices (CACP), sorghum farmers in Maharashtra realized profits in only 10 out of the 37 years (in the period between 1971/72 and 2010/20). Pearl millet farmers in Rajasthan profited in just two out of 41 years (Narayanamoorthy, 2023). These observations reflect chronic economic vulnerability despite the ecological importance of millets and substantial productivity improvements.

In spite of a steady decline in cultivated area under millets, productivity gains have been significant**,** driven by the development of improved varieties and appropriate production technologies. However, even after dramatic productivity gains, national average yields remain lower than what was demonstrated under optimal conditions at research stations and in front line demonstrations (FLDs). The estimated yield gap between optimally managed research farms/FLDs and the farmers' field, ranges from 33–60 percent (Table 5). Bridging this gap presents a major opportunity to enhance millet production at the national level.

To effectively bridge this yield gap, it is essential to look at the good agricultural practices (GAP) developed and validated by research institutions and extension personnel. These practices when adapted to local agroecological conditions, can empower farmers to achieve higher productivity, resource efficiency and climate resilience. In this context, a comprehensive GAP framework for millet production has been prepared crop wise for clarity and targeted adoption.

TABLE 5. Estimated yield gap in millets in India

Millet	Grain yield (kg/ha)		Yield gap (%)	Source
	Mean realized in 2024/25	Potential/FLD demonstrated		
Sorghum (kharif)	1234	3487	64.6*	Murthy *et al.*, (2007)
Sorghum (rabi)	1237	1737	28.8*	
Pearl	1441	2317	40.0*	
Finger	1492	2314	37.8	AICSIP (Small Millets), FLD, 2022–23
Small AIC	992	1630	39.1	AICSIP (Small Millets), FLD, 2020–21 (mean of 5 crops)

Source: Authors' own elaboration
*Reworked taking 2024–25 mean grain yields of the country.
FLD: front line demonstrations

Millets and farming systems

Millets, being well-adapted to harsh and resource-constrained ecosystems, serve a dual purpose: as staple grains and as a critical source of dry fodder, especially for draught and dairy animals (during their non-lactating periods). Millet stover, the straw or residue left after the grain harvest, is integral to livestock nutrition in dryland regions where availability of green fodder is limited. It is an invaluable dry fodder resource. Based on a grain-to-stover ratio of 1:2.5, out of 17.572 Mt of millet grain produced in 2023/24, approximately 43.93 Mt of stover/straw was generated. According to the estimates of Associated Chambers of Commerce and Industry of India (ASSOCHAM, 2022), the quantity of produce of pearl millet, sorghum and finger millet that is utilized as livestock feed is 15 percent, 12 percent and 13 percent, respectively.

CHAPTER 2: Pearl millet

(*Pennisetum glaucum* (L.) R. Br.)

FIGURE 2. Pearl millet crop at flowering stage

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Pearl millet is the most extensively cultivated and produced millet staple in India. Approximately 15 percent of the grain produced is used as animal feed and about 10 percent is utilized in the brewing industry (ASSOCHAM, 2022). Pearl millet stover from grain cultivation serves as feed for livestock and plays a significant role in alleviating dry fodder shortage especially in rainfed areas of the country. According to *Vision 2050* formulated by ICAR-IGFRI (ICAR-Indian Grassland and Fodder Research Institute) a shortage of 10.95 percent in pearl millet was reported in 2013. In addition to stover, pearl millet is also cultivated for fodder purposes on 0.9 million hectares (Mha). The fodder is used as feed for diary animals in India, with the taller plants having fewer tillers and thick stems being high-yielders. Pearl millet fodder is characterized by a higher leaf-to-stem ratio of 1.5 and a lower lignin content of 35−63 g/kg (dry matter) compared to sorghum, which has a leaf-to-stem ration of 0.92 and lignin content of 83 g/kg (dry matter). Pearl millet fodder is free from prussic acid (hydrogen cyanide or HCN), tannins and is low in oxalate. However, it contains high and potentially toxic levels of nitrate concentration, particularly under drought conditions. The process of ensiling can be used to reduce the high nitrate concentration. In India, pearl millet was planted on 7.357 Mha (2024/25) producing 10.716 Mt of grains. Out of the total production, 90.17 percent came from the kharif season and 9.83 percent from summer. Rajasthan, Uttar Pradesh, Gujarat, Haryana, Madhya Pradesh and Maharashtra are the major pearl millet-producing states in India. Rajasthan alone accounted for 58.14 percent of area and 41.34 percent of production during 2024/25 (Table 6). Pearl millet is widely recognized as one of the most drought- and heat-tolerant crops with high water use efficiency. With the introduction of pearl millet hybrids in the mid-1960s and with improved production technology, productivity rose significantly from 365 kg/ha in 1966/67 to 1453 kg/ha in 2024/25.

TABLE 6. State-wise information about area, production and yield of pearl millet in 2024/25

State	Area (Mha)	% of total	Production (Mt)	% of total	Yield (kg/ha)	% irrigated area
Rajasthan	4.288	58.14	4.430	41.34	1033.1	4.34
Uttar Pradesh	1.010	13.69	2.195	20.48	2173.3	0.41
Gujarat	0.520	7.05	1.306	12.19	2511.5	77.49
Haryana	0.528	7.16	1.160	10.82	2197.0	98.65
Madhya Pradesh	0.388	5.26	1.003	9.36	2585.1	3.28
Maharashtra	0.404	5.48	0.246	2.30	608.9	5.09
Rest of the states	0.237	3.21	0.376	3.51	–	–
Total	7.357	100.00	10.716	100.0	1453.0	15.74

Source: Directorate of Economics and Statistics, DAC&FW
Note: Status arranged in descending order of their percent share in production.

Pearl millet cultivation zones in India

In India, pearl millet cultivation is classified into three zones: A_1, A and B, based on rainfall and soil type. north Rajasthan, with less than 400 mm rainfall and sandy soils, is A_1; south Rajasthan, Haryana, Gujarat and Uttar Pradesh with more than 400 mm rainfall and sandy loam soils are A; central western India with more than 400 mm rainfall and heavy soils is zone B. The relative share of these three zones (mean of 1998−2017) in area, production and their productivity given in Table 7 (Garin *et al.*, 2023) shows that both A_1 and A zones are major contributors to area with A_1 contributing 38.5 percent of the total area of the three zones and A zone contributing 37.2 percent. While A zone is a major contributor to production (58.6 percent), A_1 zone has the least productivity of the three.

TABLE 7. Pearl millet distribution in A_1, A and B zones in India

Parameters	Zone		
	A_1	A	B
Area (Mha)	2.93	2.83	1.85
Production (Mt)	1.38	4.14	1.55
Productivity (kg/ha)	499.3	1571.6	913.1

Source: Garin *et al.*, 2023

Climatic requirements

Pearl millet is a warm-season crop and requires 500−600 mm of rainfall during its growth period. However, because of its drought hardy nature, it can be cultivated in areas with rainfall ranging 100−750 mm. For proper vegetative growth, moist weather is needed, yet it cannot tolerate waterlogging. High rainfall during the reproductive phase is not conducive as it promotes the spread of fungal diseases, especially ergot. It is susceptible to frost damage; hence it is predominantly grown as a rainfed kharif crop. Though pearl millet germinates well at 23−30 °C soil temperature, germination gets hampered at temperatures above 45 °C. The optimum temperature for growth is 25−30 °C. High temperatures at early stages induce flowering, while low temperatures promote ergot incidence. This climate-resilient crop can endure high temperatures up to 42 °C during its reproductive phase which makes it suitable for cultivation even in adverse conditions.

Most of pearl millet in India is grown during rainy (kharif) season (June−September). Its summer cultivation (February−May) is becoming popular in the states of Gujarat, Rajasthan, Uttar Pradesh, Tamil Nadu and Karnataka. Post-rainy season *(*rabi*)* cultivation of this crop (November−February) is done on a small scale in Maharashtra and Gujarat.

Soil

Pearl millet can be raised on a variety of soils but the crop prefers light-textured soil of low inherent fertility and mild salinity. The soil should be deep and free from stones and concretes. This crop does not tolerate soil acidity. In India, pearl millet is successfully cultivated in black cotton soil, alluvial soil and red soil.

Land preparation

The concept of tillage is changing in pearl millet cultivation. Traditionally, a pearl millet crop needs fine tilth as the seeds are too small. Fields are prepared by summer ploughing with mould board plough before the onset of monsoon followed by harrowing twice or thrice or by ploughing with a country plough after the onset of monsoon. Planking is done to break the clods and the soil is finally levelled. When compared to conventional levelling, laser-assisted land-levelling equipment fitted with a drag scrapper for smoothening the land surface (within ±2 cm of average micro-elevation) was found promising in light- and medium-textured soil where pearl millet is rotated with mustard/chickpea/lentil/field pea. However, excess tillage was found harmful in light-textured (sandy) soil as it disintegrates the clods and exposes the soil to erosion. Deep tillage is useful in sandy loam soil as it increases the moisture storage of the entire soil profile. Reduced tillage in vertisols (Solapur, Maharashtra) and aridisols (Hisar, Haryana) and zero-tillage (ZT) in cropping systems of pearl millet/chickpea/ mustard/wheat is gaining wider acceptance in India.

Varieties

At present, varieties in pearl millet have been replaced with hybrids to a major extent. This shift began with the release of the first cytoplasmic male sterile (CMS) hybrid 'HB 1' in 1965 by Punjab Agricultural University, Ludhiana, Punjab). Of the 176 pearl millet cultivars released between 1986−2020, 84.7 percent are hybrids which have 25-30 percent higher yields over open-pollinated varieties (OPVs). Since 2020, only biofortified pearl millet cultivars having a minimum of 42 ppm iron (Fe) and 32 ppm zinc (Zn) are being released. Hence biofortified cultivars are rapidly replacing earlier released non-biofortified varieties and hybrids. Between 2010−2025, 87 hybrids and six OPVs that are biofortified were released. Hybrids cover 85 percent of area cultivated, while varieties cover 15 percent. Varieties are mainly preferred in drought-prone ecologies and for household consumption. The list of hybrids and improved varieties of pearl millet is presented in Table 8.

TABLE 8. Pearl millet cultivars released for different seasons across states in India between 2018−2025

Region/ State	Crop/ season	Hybrid	Variety
Rajasthan	Kharif	AHB 1200 Fe, PB 1705, HHB 299, RHB 223, GK 1116 (MH 1974), Balwan (NBH 4903), BHB 1202, PB 1720, PB 1756 (PA 9072), MP 7878, AHB 1269Fe, DHBH 1397, RHB 233,	

		RHB 234, PB 1852, Central Pearl Millet Hybrid BHB-1602, GHB 1294 (Maru Moti), MPMH 42 (Shree Anna Bajri 42), GHB 538 Improved (Maru sona), HBH 191294 (HT4252), MPMH 35 (Maru Sampada), 86M94, HHB67 Improved 2, NBH 5929, RHB 228, Proagro Marutej, MP 724 (MH-2626), PA 9010 (PB-1939); GHB 1305, RHB 273, CZH 267, HHB 344, VNR 106 (MH 2712), MP 7173 (MH 2709)	
	Kharif arid parts	GHB 1305, RHB 273, CZH 267, HHB 344	
	Summer	86M22, PB 1879 (PA9898), BLPMH-109, SVPMH 101 (MSH 361), PB1877 (PA9385), MP 7366,	
Gujarat	Kharif	AHB 1200 Fe, HHB 299, PB 1720, MP 7878, AHB 1269Fe, DHBH 1397, RHB 233, RHB 234, JKBH 1326, PB 1852, Central Pearl Millet Hybrid BHB-1602, GHB 1225 (Moti Shakti), GHB 1229 (Jam Shakti), GHB 1231 (Sawaj Shakti), GHB 1294 (Maru Moti), MPMH 42 (Shree Anna Bajri 42), HBH 191294 (HT4252), 86M94, HHB67 Improved 2, NBH 5929, MP 724 (MH-2626), PA 9010 (PB-1939), VNR 106 (MH 2712), MP 7173 (MH 2709)	
	Kharif arid parts	PB 1756 (PA 9072), MPMH 35 (Maru Sampada), GHB 1305, RHB 273, CZH 267, HHB 344	
	Summer	86M22, GHB 1351 Banas Nayan, PB 1879 (PA9898), BLPMH-109, SVPMH 101 (MSH 361), PB1877 (PA9385), MP 7366	
Haryana	Kharif	PB 1705, PB 1720, AHB 1269Fe, DHBH 1397, RHB 233, RHB 234, JKBH 1326, PB 1852, HHB 311, Central Pearl Millet Hybrid BHB-1602, RHB 223 (MH 1998), HHB 299 (MH 2076), AHB 1200 Fe, MP 535 (Pusa Composite 701) MP 7872, MP 7792, HHB 272 (MH1837), HHB 67, HHB67 Improved 2 , MPMH-21, MPMH 17, KBH 108, GHB 905, 86M89, Kaveri Super Boss, Bio 448, 86 M 86 , 86M66, RHB-173, GHB 1294 (Maru Moti), MPMH 42 (Shree Anna Bajri 42), GHB 538 Improved (Maru sona), Proagro-9001 (MH2440), HBH 191294 (HT4252), 86M94, NBH 5929, MP 724 (MH-2626), PA 9010 (PB-1939), VNR 106 (MH 2712), MP 7173 (MH 2709)	MBC 2, PC 443, HC 20, JBV 3, PC 383, HC 10, ICMV 221, Raj 171
	Kharif – arid parts	PB 1756 (PA 9072), HHB 234, Bio 70, HHB-226, RHB-177, MPMH 35 (Maru Sampada), GHB 1305, RHB 273, CZH 267, HHB 344	CZP 9802
Punjab	Kharif	PB 1705, PB 1720, MP 7878, DHBH 1397, RHB 233, RHB 234, JKBH 1326, PB 1852, HHB 311, HHB 299 (MH 2076), AHB 1200 Fe, MP 535 (Pusa Composite 701) MP 7872, MP 7792, PHB 2884, KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, 86M86, 86M66, RHB-173, NBH 5929, MP 724 (MH-2626), PA 9010 (PB-1939), VNR 106 (MH 2712), MP 7173 (MH 2709)	PCB 164, ICMV 221, Raj 171
Delhi	Kharif	PB 1720, MP 7878, DHBH 1397, RHB 233, HHB 311, Pusa 1201 (MH 1849), HHB 299 (MH 2076), AHB 1200, MP 535 (Pusa Composite 701) MP 7872, MP 7792, KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, 86M86, 86M66, RHB-173, HBH 191294 (HT4252), 86M94,	JBV 3, PC 383, ICMV 221, Raj 171

		HHB67 Improved 2, NBH 5929, VNR 106 (MH 2712), MP 7173 (MH 2709)	
Uttar Pradesh	Kharif	PB 1705, PB 1720, MP 7878, PROAGRO 9450, DHBH 1397, RHB 234, JKBH 1326, PB 1852, MP 535 (Pusa Composite 701) MP 7872, MP 7792, KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, 86M86, 86M66, RHB-173, NBH 5929, MP 724 (MH-2626), PA 9010 (PB-1939), VNR 106 (MH 2712), MP 7173 (MH 2709)	JBV 3, PC 383, ICMV 221, Raj 171
	Summer	86M22, PB 1879 (PA9898), BLPMH-109, SVPMH 101 (MSH 361), PB1877 (PA9385), MP 7366,	
Madhya Pradesh	Kharif	PB 1705, PB 1720, MP 7878, DHBH 1397, RHB 234, JKBH 1326, PB 1852, MP 535 (Pusa Composite 701), MP 7872, MP 7792, KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, 86M86, 86M66, RHB-173, HBH 191294 (HT4252), 86M94, HHB67 Improved 2, NBH 5929, MP 724 (MH-2626), PA 9010 (PB-1939), VNR 106 (MH 2712), MP 7173 (MH 2709)	JBV 4, JBV 3, PC 383, ICMV 221, Raj 171
Maharashtra	Kharif	NBH 4903, Phule Mahashakti (DHBH 1211), AHB 1269Fe, RHB 233, HHB 311, HHB 299 (MH 2076), AHB 1200 Fe, Phule Aadi shakti (DHBH 9071), Kaveri Super Boss, Pratap, PKV Raj, Shine, MP 7792, 86M86, PAC 909, 86M64, 86M53, US 7713 (MH 2717), APHB 126 (MH 2682)	ABPC4-3, PC 612, Parbhani Sampada, Samrudhi, ICMV 221, Raj 171, ICMV 155
	Summer	Nandi 72, Nandi 70, 86M64, 86M22, PB 1879 (PA9898), BLPMH-109, SVPMH 101 (MSH 361), PB1877 (PA9385), MP 7366	-
Tamil Nadu	Kharif	AHB 1269Fe, RHB 233, RHB 234, HHB 311, HHB 299 (MH 2076), AHB 1200 Fe, TNBH 1619 (CO 10), CO 9, Kaveri Super Boss, Pratap, Shine, MP 7792, 86M86, 86M64, 86M53, PAC 909, US 7713 (MH 2717), APHB 126 (MH 2682)	PC 612, CoCu 9, Samrudhi, ICMV 221, Raj 171, ICMV 155
	Summer	Nandi 72, Nandi 70, 86M64, 86M22, PB 1879 (PA9898), BLPMH-109, SVPMH 101 (MSH 361), PB1877 (PA9385), MP 7366,	-
Andhra Pradesh	Kharif	NBH 4903, AHB 1200 Fe, Kaveri Super Boss, Pratap, Shine, MP 7792, 86M86, PAC 909, 86M64, 86M53, US 7713 (MH 2717), APHB 126 (MH 2682)	PC612, Samrudhi, ICMV 221, Raj 171, ICMV 155, Ananta
Telangana	Kharif	NBH 4903, AHB 1200 Fe, PBH 1625 (Palem sajja-1625), US 7713 (MH 2717), APHB 126 (MH 2682)	
Karnataka	Kharif	NBH 4903, Kaveri Super Boss, Pratap, Shine, MP 7792, PAC 909, 86M86, 86M64, 86M53, VPMH 7, US 7713 (MH 2717), APHB 126 (MH 2682)	PC612, Samrudhi, ICMV 221, Raj 171, ICMV 155

Source: Authors' own elaboration

Sowing windows

The time of sowing a rainfed pearl millet in kharif season is contingent to the onset of the southwest monsoon. Accordingly, the sowing time varies from the first fortnight of June in south and central India, to mid-July in north India. In Marathwada region (Maharashtra) dry sowing prior to the onset of monsoon is recommended.

While sowing too early hampers germination and emergence–and persist rains, may wash away pollen−delayed sowing (up to 17 August) leads to high seedling mortality, quick reproductive life cycle and low yield due to the incidence of ergot disease. Even under delayed conditions, pearl millet remains the best choice for sowing in dry lands. Direct seeding beyond the optimum time of sowing results in poor plant stand, poor grain setting and consequently low grain yield. Hence under delayed sowing conditions, transplanting is advised. Transplanting 30-day-old seedlings results in higher yields over seeding because of enhanced tillering and better ear development.

In Tamil Nadu pearl millet is grown as a rabi rainfed crop in regions with northeast monsoon. The optimum time for sowing is the first fortnight of October. Irrigated summer crop is seeded between February and March in Zone A and A1. In Zone B sowing in the last week of January to the first week of February is ideal.

Pearl millet sowing is generally done using one of the three systems: on a flat surface, on ridges in the ridge and furrow system, and on broad-bed in the broad-bed and furrow (BBF) system.

Seed rate and spacing

A seed rate of 4−5 kg/ha is required for line sowing behind a drill or country plough. Pearl millet can produce more than one tiller per plant and thus has plasticity for plant population. The final plant population can vary with the cultivar, its duration, seed size, sowing time, planting method and growing conditions. A planting geometry of 50 cm × 10−12 cm is ideal and the optimum plant population can vary from 1.5−2.0 lakh/ha.

In arid western plains of Rajasthan, Haryana and Kutch region of Gujarat (A_1 zone), pearl millet should be planted in rows 60 cm apart, maintaining a population of 1.00−1.25 lakh/ha. For areas receiving rainfall more than 450 mm (Zone A and B), the crop should be planted at a geometry of 45 cm × 10−15 cm maintaining a plant population of 1.75−2.0 lakh/ha. For soil under irrigation or highly productive soil with intense management, a population of 225 000 plants per hectare is recommended. On extremely sandy, drought-facing soils, a population of ≈90,000/ha is sufficient. For proper germination seeds should not be sown deeper than 3 cm.

Nursery raising and transplanting

For transplanting, a seed rate of 2 kg/ha can provide optimum seedlings. Seeds are sown on flatbeds in rows of 10 cm and depth of 2 cm in a nursery size of 500 square metres (m^2). Nitrogen at 30 kg/ha is applied at the time of sowing. The seedlings are ready for transplanting in three weeks. Under rainfed conditions, transplanting is advised only after the arrival of rains. The benefits of transplanting include: early maturity at 10−15 days, mitigating the effect of low temperature on grain filling, ensuring optimum plant stand, and producing more tillers and earheads as compared to direct seeding. However, the limited moisture periods available in rainfed situations for transplanting, and the high labour requirement often hinder its wider adoption.

In Tamil Nadu 15-day seedlings raised in a dapog nursery were successfully transplanted resulting in early maturity of the crop by 10−15 days.

Seed treatment

Seed treatment with biopesticides (*Trichoderma harzianum* at 4 g/kg) or thiram 75 percent dust at 3 g/kg seed helps to protect the crop against soil-borne diseases. Seed treatment with 300-mesh sulphur powder at 4 g/kg controls smut disease. Seeds can be soaked in 10 percent salt solution to segregate ergot-affected seeds from the healthy ones. Seed treatment with metalaxyl at 6 g/kg controls downy mildew.

Manure and fertilizers

Pearl millet responds very well to manure and fertilizer application. Application of 10−15 tonnes per hectare (t/ha) of well decomposed farmyard manure (FYM) or compost in summer ploughing or prior to sowing can meet the nutrition needs of local pearl millet varieties. In addition, it also aids in conserving precious moisture in soil. A fertilizer dose of 40−20 kg/ha of N-P_2O_5 in arid regions and 60−30 kg/ha of N-P_2O_5 in semi-arid regions is recommended for sole pearl millet. For irrigated pearl millet hybrids, an extra dose of 25 percent nitrogen is recommended in A and B zones (Aurangabad, Maharashtra). To avoid leaching loss, nitrogen application in two equal splits (basal and top dressing at 20−25 days after sowing) is desired, particularly in light soils.

Foliar fertilizer application of nitrogen as urea (1−1.5%) has been found advantageous for rainfed pearl millet. In situations of excess soil moisture during the vegetative phase, an additional dose of nitrogen at 20 kg/ha is recommended. At Parbhani and Aurangabad (Maharashtra), studies have indicated a reduced downy mildew incidence and higher grain yield of hybrid pearl millet with 50 kg/ha application of phosphorus when compared to a non-phosphorus fertilizer.

Long term fertilizer experiments have demonstrated that a balanced application (NPK) is essential to realize optimum yields. Accordingly, fertilizer application based on the Soil Test Crop Response (STCR) along with 10 t/ha FYM application was found promising for pearl millet–wheat crop rotations. Pearl millet seeds are sensitive to fertilizer burn, therefore, fertilizers should be applied as side dressing rather than in the seed furrow or very near the seed row after sowing. A leaf colour chart (LCC) was developed by the Indian Institute of Millet Research (IIMR) for guiding nitrogen top dressing and enabling the achievement of optimum crop yields with an appropriate dose of fertilizer. The chart monitors nitrogen in the crop through leaf colour and adjusts crop nutrition for optimum performance (Gangaiah and Tara Satyavathi, 2024).

In zinc-deficient soils, the application of 10 kg zinc sulphate ($ZnSO_4$) per hectare or 0.2 percent $ZnSO_4$ foliar spray at tillering to pre-flowering stage is recommended. In iron-deficit soils (DTPA iron less than 4.5 ppm), foliar spray of ferrous sulphate ($FeSO_4$) at 0.50−0.75 percent is recommended at 25−30 days after sowing. Borax application of 10 kg/ha was also found promising. The fertilizer recommendation (NPK) for different states for pearl millet crop is given in Table 9.

Summer pearl millet

For summer pearl millet (cv. GHB-744) at Navsari (Gujarat) integrated nutrient management through seed inoculation with: *Azotobacter* and phosphorous solubilizing bacteria (PSB), application of 2.5 t/ha FYM and 120-60 kg/ha N-P_2O_5 was recommended. At Aurangabad (Maharashtra), summer pearl millet fertilization with 120-45-45-20 kg/ha N-P_2O_5-K_2O-$ZnSO_4$ was found to be promising.

Biofertilizers

Azospirillum brasilense a bacterial biofertilizer has been found promising for pearl millet. Its effectiveness is relatively more when applied along with a lower dose of nitrogen (10−40 kg/ha). Phosphorous solubilizing bacteria (PSB) is also effective in augmenting phosphorus supplies to the crop. Liquid-based biofertilizers for seed treatment (i.e. a biomix of *Azotobacter*, *Azospirillum* and PSB) at 100 ml/kg proved promising to their carrier formulation. Liquid biofertilizers can also be applied as foliar spray.

For inter-cropped pearl millet with pigeon pea/soybean (2:1 row proportion) under rainfed conditions, the application of 40-30 kg/ha N-P_2O_5, along with biofertilizer *Azospirillum* and PSB, was found to be more promising when compared to sole pearl millet in zone B. This practice also resulted in a saving of 20-10 kg/ha of N-P_2O_5.

TABLE 9. Recommended plant population and fertilizers for pearl millet

State	Optimum plant population (million)	Fertilizer dose (N-P_2O_5-K_2O kg/ha) Rainfed (irrigated)
Rajasthan	0.15–0.20	20-2-:20 (40-20-20)
Maharashtra	0.175–0.20	40-20-20 (variety); 70-30-30 (hybrid); (60-20-40)
Gujarat	0.18–0.20	80-40-20
Uttar Pradesh	0.175–0.20	40-20-20 (60-20-40)
Haryana	0.175–0.20	40-20-20 (120:60:40)
Karnataka	0.15–0.175	40-20-20
Andhra Pradesh	0.15–0.20	20-20-20 (40:20:20)
Tamil Nadu	0.145–0.15	60-80-20
Madhya Pradesh	0.175–0.20	40-20-20

Source: Authors’ own elaboration

Organic nutrition

Organic manures, biofertilizers, seaweed extracts and rock phosphate were found useful in organic pearl millet nutrition. Seaweed extract spray (abundantly available on the west coast) (equivalent to 25 percent nitrogen substitution) along with 75 percent recommended dose of nitrogen (RDN) from farmyard manure /vermicompost (VC) could meet nutrition needs of pearl millet. At Aligarh (Uttar Pradesh), application of 7.5 t/ha FYM was found promising for nutrition of organic pearl millet–chickpea cropping system. As manuring is done based on nitrogen recommendations, any deficiency of phosphorus (common) and potassium (rare) are met through application of permitted fertilizers of rock phosphate and potassium sulphate. Rock phosphate can be applied directly in acidic soils, however, in non-acidic soils, phosphorus solubilizers are added to enhance the dissolution and thus its effectiveness. Use of liquid *Azotobacter* and PSB biofertilizer formulation (*Azo-phosphoteeka*); or with biomix (*Azotobacter*, *Azospirillum* and PSB) for seed inoculation was found to augment the supply of nitrogen and phosphorus to the pearl millet crop.

Weed management

Pearl millet is predominantly a rainy season crop in India. Since it is slow growing and less competitive than many common weeds, it faces severe weed infestation problems. The crop suffers most losses from weeds during three to six weeks after sowing. Therefore 15−30 days after sowing (DAS) is identified as the critical period of crop-weed competition. Competition of weeds with pearl millet could reduce grain yields by 25−50 percent. Timely weed management is essential to realize optimum yield. Proper weed management is also needed for conserving precious moisture by curtailing the wasteful use of water by weeds. A complex weed flora (grasses, broadleaved weeds and sedges) was reported in pearl millet. Anjan grass (*Echinochloa colonum*), doob (*Cynodon dactylon*), motha (*Cyperus rotundus*), sathi (*Trianthema portulacastrum*), kewal (*Digitaria sanguinalis*) and makra (*Dectyloctenium aegyptium*) are some of the common weeds of pearl millet across the country.

The crop requires two to three intercultural operations (at 15 and 30 DAS) between three to six weeks after sowing. During the first interculture, thinning and/or gap filling should be done along with the removal of weeds. Integrating hand-weeding and inter-row cultivation controls most weeds. Pre- and post-emergence herbicides are recommended for timely, effective and economical weed management − particularly in rainy season crops, where intermittent rainfall and high soil moisture conditions make it difficult for manual and animal-drawn implements to operate.

For sole pearl millet, pre-plant application (7 days before sowing) of saflufenacil at 50 g a.i./ha, or fluchloralin at 1.0 kg a.i./ha, or pre-emergence application of oxadiazone at 1.0 kg a.i./ha, oxyfluorfen at 0.2 kg a.i./ha, or atrazine at 0.5 kg a.i./ha are effective herbicides. For intercropped pearl millet with legumes, pre-emergence application of pendimethalin at 1.50 kg a.i./ha is recommended. Using a pre-emergence herbicide along with one hand-weeding provides effective and economical weed management throughout the season. Atrazine at 0.5 kg a.i./ha applied at 10 days after sowing (DAS), 2,4-D sodium salt at 0.5 kg a.i./ha applied at 25–30 DAS, or tembotrione at 90–120 g a.i./ha applied at the 3–4 leaf stage (15–18 DAS) have been found promising for weed management. Tembotrione at 80 g a.i./ha applied at 10–15 DAS along with hand-weeding at 30 DAS can effectively manage all weeds in pearl millet and eliminate the need for pre-emergence herbicides.

For control of the parasitic weed *striga*, hand pulling of plants along with roots and post-emergence application of 2,4-D on striga leaves is recommended. In regions with severe striga infestations, cultivation of non-pearl millet crops every two years is advised. Crop rotation with trap crops such as cotton, sunflower, groundnut, castor, dolichos bean, and linseed is also effective for striga management. Recommended herbicides according to their time of application and cropping system are listed in Table 10.

TABLE 10. Recommended herbicides for pearl millet

Time of application	Crop	Herbicide (a.i/ha)
Pre-plant (7 days before sowing)	Sole pearl millet	saflufenacil (50 g) or fluchloralin (1.0 kg)
Pre-emergence	Sole pearl millet	oxadiazone (1.0 kg) or oxyfluorfen (0.2 kg) or atrazine (0.5 kg)
	Intercropped pearl millet with legumes	pendimethalin (1.50 kg)
Early post emergence (10−15 DAS)	Sole pearl millet	90−120 g/ha tembotrione or 0.50 kg/ha atrazine
Post emergence	Sole pearl millet	0.5 kg 2,4-D Na salt at 25−30 DAS

Source: Authors' own elaboration; Note: active ingredient/hectare (a.i/ha)

Cropping systems

Pearl millet is a component of many mixed and intercropping systems, crop rotations and even agroforestry systems.

Mixed cropping of pearl millet with sesame (north India) and legumes such as black gram, green gram and cluster bean is most common in the arid parts of Rajasthan. In the Kumaon Himalayan Bhabhar region (Uttarakhand), a diverse system of mixed cropping involving paddy, pearl millet, horse gram and cucurbits is practised.

Various intercropping patterns involving pearl millet have been adopted to reduce the risk of crop failure under moisture stress conditions and to enhance productivity per unit area under favourable moisture conditions. A pattern of intercropping pearl millet with pigeon pea (1 to 7 rows of pearl millet for every row of pigeon pea) is widely followed in different parts of the country. Under scarce rainfall (dryland) conditions in Maharashtra, 3:1 pattern is promising. This system is also seen in pearl millet with groundnut (1:1−6) and pearl millet with mung bean (1:1−7). To enhance and diversify millet production in the country, a system of intercropping in paired rows of pearl millet with barnyard millet (2:2) in Jamnagar (Gujarat) and Coimbatore (Tamil Nadu); and pearl millet with foxtail millet (2:2) in Vijayapura (Karnataka) was developed based on the AICRP studies during kharif 2024. The important intercropping systems of pearl millet in India are given in Table 11.

TABLE 11. State-wise intercropping systems of pearl millet in India

State	Intercropping system
Rajasthan	Pearl millet with cluster bean/moth bean/ sesame
Haryana, Gujarat, Uttar Pradesh	Pearl millet with green gram/sesame/castor/ barnyard millet
Madhya Pradesh	Pearl millet with black gram/soybean
Maharashtra	Pearl millet with moth bean/pigeon pea
Karnataka, Andhra Pradesh, Telangana	Pearl millet with pigeon pea/ground nut/ Castor/foxtail millet
Tamil Nadu	Pearl millet with cowpea/sunflower/ barnyard millet

Source: Author’s own elaboration

The most important crop rotations of pearl millet include:

- pearl millet–wheat−green gram
- pearl millet–wheat−pearl millet
- pearl millet–barley/gram/pea/wheat/berseem
- pearl millet–potato−mung bean/urd bean
- pearl millet–potato−wheat
- pearl millet−mung bean or urd bean
- pearl millet–rapeseed−wheat
- pearl millet–berseem
- pearl millet–toria−wheat

A new cropping system of pearl millet with fenugreek (*Trigonella foenum-graecum*), also known as *methi* (seed spice), has recently emerged in northwest India. Fenugreek is a leguminous crop valued for its utility both as vegetable and spice. Out of 0.21 Mha under this system about 57 percent lies in Rajasthan alone. Pearl millet with cumin is another potential cropping system for arid regions.

Pearl millet is an important component of many agroforestry systems in the arid and semi-arid regions of India. It is cultivated as an intercrop with *Prosopis cineraria* in Haryana, *Ziziphus mauritiana* in Rajasthan, and with *Populus* spp (poplar) in Himachal Pradesh, Haryana and Uttarakhand. In the lower hills of Punjab (Kandi area), an agri_silviculture system of pearl millet with *Acacia nilotica / A. catechu, Anogeissus latifolia, Butea monosperma, Dalbergia sissoo, Grewia optiva, Zizyphus* sp trees is practised.

TABLE 12. State-wise cropping systems of pearl millet in India

State and extent	Cropping system
Semi-arid Agro-Eco Region IV of India, particularly in southwest Uttar Pradesh, Rajasthan, Haryana, Gujarat and western Maharashtra; extent of 2.5 Mha	Pearl millet−wheat
North, west, and central India (Rajasthan, Uttar Pradesh, and Madhya Pradesh); extent of 1.0 Mha	Pearl millet–mustard
In Punjab, Haryana, western plateau and hill regions of Maharashtra, Madhya Pradesh, Rajasthan (western dry region with 400 mm rain and regions with 680−1040 mm rainfall)	Pearl millet–lentil
In regions with assured rainfall (eastern Uttar Pradesh, Bihar, West Bengal); and regions with irrigation (Punjab, Haryana, western Uttar Pradesh)	Pearl millet–chickpea
Northwest India	Pearl millet−fenugreek
Pearl millet Zone B	Pearl millet–soybean
Pearl millet Zone A_1 (2-year rotation)	Pearl millet−moth bean/cluster bean

Source: Authors' own elaboration Note: – is rotation

Irrigation and water (moisture) management

Pearl millet is primarily a rainfed kharif crop and under normal rainfall. it hardly needs irrigation. However, when rainfall is uneven or irregular during the kharif season moisture stress conditions are created, leading to poor yields. Pearl millet is cultivated with protective and need-based irrigations during winter and summer respectively, resulting in high productivity.

During prolonged dry spells, providing life-saving irrigations at critical stages of crop growth (tillering, flowering and grain development) significantly boosts grain yield. Irrigation at anthesis or flowering stage is particularly beneficial. As many as 3−4 irrigations may be required in the event of complete monsoon failure. Studies have indicated that after germination, tillering, ear head emergence (heading) and grain filling are the most critical stages for irrigation.

When water is abundant, pearl millet is generally irrigated by flooding. In Gujarat, application of 40 mm water at 1.0 IW/CPE ratio was found promising for summer season pearl millet. In Marathwada region, irrigation of summer pearl millet at intervals of 15 days in February, 10 days in March and 7 days in April is recommended. However, when water for irrigation is limited, sprinkler and drip irrigation methods are recommended, with drip irrigation being the most suitable and water efficient. Drip irrigation at 150 percent pan evaporation combined with fertigation (with 125 percent nitrogen) is promising under conditions of limited availability of water.

Pearl millet exhibits high tolerance to saline water irrigation with minimal yield penalties. However, a high sodium absorption ratio (SAR) can reduce the infiltration rate of the soil. To mitigate this adverse impact, practices such as gypsum application, leaching of built-up salts with good quality irrigation water, and drip irrigation are recommended. Solar-powered irrigation systems, using both good and saline waters, have been developed enabling zero-carbon-footprint irrigation for pearl millet.

Pearl millet has a much lower water requirement of 250−350 mm (average 140−150 mm of water per tonne of grain produced) when compared to maize, sorghum and finger millet which require 500−600 mm of water.

Moisture conservation / management

Seed treatment with 0.2 percent potassium nitrate (KNO_3) is effective for seed hardening and aids the crop in withstanding moisture stress conditions. Reducing plant density, while retaining 1.25 lakh plants/hectare, is one of the important mid-season correction techniques followed to save a drought-hit pearl millet crop. Removal of plants within rows is more beneficial than removing alternate rows. The removed plants may be used as mulch. Modified land configurations like bunding, or ridge and furrow systems improve moisture conservation compared to flat sowing. The ridge and furrow system is suitable in light soils and particularly so in sloping lands. Deep summer ploughing coupled with application of farmyard manure at 10 t/ha enhances moisture storage in soil and contributes to moisture conservation and utility.

Spraying of salicylic acid at 100 parts per million (ppm) − 1.5 g for 15 l of water − or thioglycolic acid at 100 ppm or thiourea at 1000 ppm during the grain filling stage has been found effective in mitigating the adverse effects of terminal heat stress in pearl millet. Wearing hand gloves while spraying of thioglycolic acid (Zone IIIA) is an essential precautionary measure.

Applying crop residue mulch at 5 t/ha along with 7.5 kg/ha of hydrogel application in seed furrows has been found effective in moisture conservation. The hydrogel applicator developed by Indian Institute of Agricultural Research (IARI), New Delhi that can be attached to a ferti-cum-seed drill was found to be useful in simultaneous sowing and hydrogel application in a single operation.

Insect pest management

In most of the pearl millet growing areas in India insect pests are relatively less significant, and therefore formal insect resistance breeding programmes are not emphasized. However, precautions are taken to ensure that cultivars susceptible major insect pests are not released. In pearl millet, white grub, shoot fly and grey weevil are the major insect pests and several cultural control measures have been developed to minimize their damage.

White Grub *(Holotrichia consanguinea)*

White grub is a common pest in Gujarat and Rajasthan. The grubs (larvae) attack the roots of growing seedlings leading to complete withering of affected plants, resulting in uneven plant stands. Grubs cause maximum damage during July and August. The adults emerge from May to July with the pre-monsoon and monsoon showers and feed on the flower and grains in the milky stage. In Rajasthan the extent of damage by grub was 5−25 percent.

Management

Intercropping pearl millet with sunflower and/or pigeon pea was found to reduce the incidence of white grub. With the onset of monsoon, adult beetles congregate on neem/*Acacia* trees for mating. Collecting and destroying the adult beetles immediately after the first showers (preferably within 2−3 days) by spraying chlorpyriphos 0.2 percent on tree hosts is recommended. Mixing carbofuran 3 G at 12 kg/ha with pearl millet seeds before sowing is effective in managing white grub infestation. Seed treatment with imidacloprid 600 FS 8.75 ml/kg or clothianidin 50 WDG at 7.5 g/kg seed with sufficient water is effective in controlling white grub.

Termites (*Odontotermes obesus*)

Termites are social insects that live underground in colonies, attack young seedlings as well as fully-grown plants. They initially attack the roots and as the infestation progresses, they feed on the stems as well. Infested plants wither and ultimately die.

Management

Deep ploughing after harvest followed by collecting and burning stubbles or plant refuge is useful in termite management. The use of well decomposed farmyard manure, and timely irrigation are also effective. Seed treatment with 8.75 ml/kg of imidacloprid 600 FS or 7.5 g/kg of clothianidin 50 WDG applied with sufficient water is effective in controlling termite. For a standing crop, application of 1.25 l/ha of chloropyriphos 20 EC along with irrigation water may be used as a last resort to save the crop.

Shoot Fly (*Atherigona approximata*)

Shoot flies are common pests in Gujarat and Tamil Nadu. The larvae destroy the growing point of seedlings, resulting in the characteristic dead heart (Figure 3 to Figure 6). In advanced stages of the crop life cycle, they attack the earheads and cut down panicles. Infestations are typically more severe in crops that are sown late.

FIGURE 3 Shoot fly damage (dead heart) on pearl millet
© Kalaisekar A, ICAR-IIMR, Hyderabad

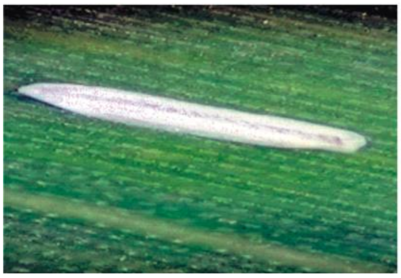

FIGURE 4. Shoot fly egg

FIGURE 5. Shoot fly larvae
© Kalaisekar A, ICAR-IIMR, Hyderabad

FIGURE 6. Adult shoot fly

Management

Sowing the crop as soon as monsoon begins (typically within 10–15 days of the first monsoon showers) and avoiding staggered sowing in the neighbourhood will reduce the buildup of shoot fly population. For a late-sown crop, transplanting is recommended. When direct seeding is practised, a seed rate of 4 kg/ha can be used and affected seedlings can be thinned out within 15 days of sowing. Seed treatment with imidacloprid 600 FS at 8.75 ml/kg along with the removal of shoot fly dead hearts, the installation of fish meal trap at 10/ha and spraying of dimethoate 30 EC 0.003 percent at 35 days after germination, effectively manages not only shoot fly menace in pearl millet, but also that of white grub and termites.

Alternately, seed treatment with imidacloprid 600 FS at 8.75 ml/kg followed by a spray of imidacloprid 17.8 SL at 0.009 percent/dusting of fenvalerate 0.4 percent at 20 kg/ha / spraying NSKE 5 percent/fipronil 5 SC at 0.01 percent at 35 days after germination is effective for shoot fly management.

Grasshopper (*Hieroglyphus nigrorepletus* – Bolivar)

Grasshoppers lay eggs in the soil at depths of 7.5–20.0 cm. Both hoppers (nymphs) and adults feed on foliage and can cause severe defoliation of the crop. Adults are short winged and can fly only short distances (Figure 7).

FIGURE 7. Grasshopper (*Hieroglyphus nigrorepletus)*
© Prakash Kumar, Sirohi, Rajasthan

FIGURE 8. Earhead bug on pearl millet earhead
© Kalaisekar A, ICAR-IIMR, Hyderabad

Management
Weed-free cultivation, deep summer ploughing after harvest of the crop to expose egg pods present in the soil, scrapping of bunds and dusting the crop with four percent fenvalerate dust at 25 kg/ha; or spraying with fenvalerate 20 EC at 0.02 percent helps in grasshopper management.

Grey weevil (*Myllocerus* sp)

Adult beetles of this polyphagous insect feed on green leaves and cause serious damage when seedlings are infested.

Management
On appearance of the pest, dusting of quinalphos 1.5 percent or malathion 5 percent @ 25 kg/ha is recommended.

Earhead Bug (*Calocoris angustatus*)

Earhead bugs are common in southern parts of the country. Nymphs and adults suck the sap from tender grains at the milk stage, making them chaffy/shrivelled (Figure 8). Early planting reduces infestation.

Stem borer (*Chilo partellus*)

Stem borers are nocturnal moths, inconspicuously brown in colour. The caterpillars feed on foliage and bore into the stem causing dead hearts. They also tunnel the stem and bore into earheads.

Management
An integrated stem borer management module could include: treating the seed, at 35 days after germination, with imidacloprid 600 FS at 8.75 ml/kg followed by spray of imidacloprid 17.8 SL at 0.009 percent/dusting of fenvalerate 0.4 percent at 20 kg per hectare/spraying 5 percent neem seed kernel extract (NSKE). Alternatively, seed treatment at 35 days after

germination, with imidacloprid 600 FS at 8.75 ml/kg along with the removal of shoot fly dead hearts, installation of 10 fish meal traps for every hectare and spraying of novaluron 10 EC at 0.01 percent is recommended. Releasing *Trichogramma chilonis* at 75 000 per week for every hectare is also recommended.

Blister Beetle (*Mylabris postulata*)

Blister beetles feed on many kinds of plants. Adult beetles feed on flowers and tender panicles preventing grain formation.

Chaffer beetle management

To manage these insects, use a light trap (200-watt electric bulb/ha or petromax) for 15 days at 50 percent flowering stage or on appearance of the pest.

Hairy Caterpillars (*Amsacta moorei*)

Hairy caterpillars, commonly found in Gujarat and semi-arid regions of Rajasthan, attack crop sporadically. The larvae cause heavy defoliation in plants. Hairy caterpillars also feed on earheads and cause grain yield losses (Figure 9).

FIGURE 9. Hairy caterpillar on pearl millet panicle
© Kalaisekar A, ICAR-IIMR, Hyderabad

Cutworm (*Agrotis ipsilon*)

Cutworm caterpillars generally feed on seedlings and cut seedlings at the ground level. Re-sowing is necessary when attack is severe.

Management

For management of both hairy caterpillars and cutworm it is recommended to release *Trichogramma chilonis* at 75 000/ha at weekly intervals.

Stunt nematode (*Tylenchorhynchus vulgaris*) and Root knot nematode (*Meloidogyne incognita*)

Pearl millet is the second most preferred host for *Meloidogyne graminicola.* In northwestern regions of India, particularly Gujarat, this nematode poses serious problems; especially when it occurs along with downy mildew (*Sclerospora graminicola*). When both the organisms (nematode and fungus) infect simultaneously, they interact synergistically and increase the severity of the disease while reducing plant growth.

Pearl millet hybrids differ in their resistance to nematodes. The primary damage is to the roots and the degree of damage depends on the age of the plant. Symptoms are most severe when pests feed on the plants during the first few weeks after planting. The roots reduce and become stubby; with dark, shrunken lesions, particularly at the tips. If the root tip is destroyed, the plant may produce new roots above the damaged area. Plants not severely damaged by the initial feeding may recover and produce near-normal yields under optimal growing conditions. To control this pest, pearl millet can be rotated with nematode-resistant crops. Studies with 36 entries (9 hybrids and 18 parental lines and 9 restorer lines) indicated that ICMB 843-22, ICMB 94555, HMS 47 B and HMS 53 B are moderately resistant against root-knot nematode.

Oxamyl (systemic carbamate) used to treat seeds was found to be highly effective because it inhibits nematode feeding. More recently, fluopyram, a succinate dehydrogenase inhibitor (SDHI) fungicide, with demonstrated nematocidal activity has emerged as a promising option for nematode control.

Birds

Birds are increasingly becoming a threat to millet cultivation, especially in areas where millet is cultivated in isolated patches.

Manual guarding and the use of coloured ribbons are traditional methods used to scare birds. Sound guns and even drones (Africa) are modern methods being employed to protect pearl millet from birds.

Disease management

Though over 50 diseases in pearl millet have been reported in India, only a few (downy mildew, smut, ergot, rust and blast) cause reduction in grain yield. Ergot can also reduce grain quality along with reduced yield.

Use of resistant cultivars is the most cost-effective method to manage pearl millet diseases. Through a sound understanding of epidemiology of diseases, effective screening techniques have been developed that clearly distinguish between resistant and susceptible genotypes. Several selections from germplasm accessions have exhibited a high degree of stability for resistance across multiple sites and years. The identified sources of resistance have been successfully utilized in developing downy mildew resistant male-sterile lines and pollinators at AICPMIP centres. Moreover, mutation-induced resistance was also successfully utilized. The residual variability for downy mildew resistance could also be exploited to improve the resistance level of susceptible material.

Downy mildew [*Sclerospora graminicola* (Sacc.) Schrot]

Downy mildew symptoms initially appear as chlorosis on the second leaf and all the subsequent leaves and panicles of the infected plant exhibit symptoms. Leaf symptoms begin as chlorosis at the base of the leaf lamina and successively higher leaves show a progression of greater coverage of leaf area with the symptoms. The infected chlorotic area produces massive amounts of asexual spores, generally on the lower surface, giving the leaf a ‘downy’ appearance. Systemically infected plants remain stunted, fail to produce panicles, or develop malformed panicles. In many affected plants, ‘green ear’ symptoms appear on the panicles as a result of partial or total transformation of floral parts into leafy structures, and such plants fail to produce seeds or produce very few seeds (Figure 10a to Figure 10c). Later in the season, the infected leaves produce sexual spores (oospores) in the necrotic leaf tissue. The life cycle of downy mildew is illustrated in Figure 11 (Shetty *et al.,* 2016).

Currently cultivated pearl millet hybrids exhibit highly variable downy mildew incidence, with some hybrids showing more than 90 percent incidence at the farmers’ field. This disease can assume alarming levels when a single genetically uniform pearl millet cultivar is repeatedly and extensively grown in a region. Yield losses within the region can reach 30−40 percent.

FIGURE 10a

10b. Green ear

FIGURE 10c. Malformed panicle
Downy mildew symptoms of pear millet

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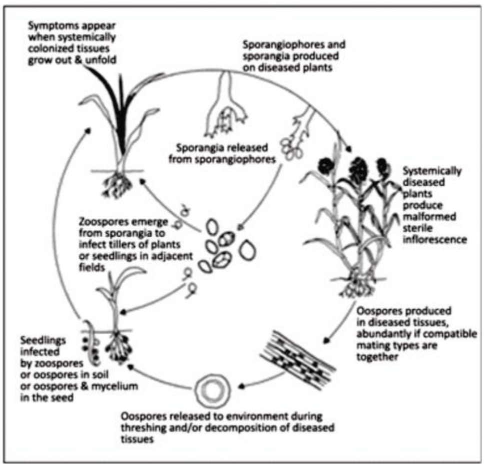

FIGURE 11. Pearl millet downy mildew disease cycle
© Shetty *et al.* (2016)

Management

Downy mildew disease can be most effectively managed by integrating chemical, biological and cultural practices. The use of resistant cultivars is important, and rotating hybrids with different varieties alternately helps keep soil inoculum under control. Seed treatment with metalaxyl at 6 g/kg of seed, *Bacillus pumilus* (INR7), or chitosan at 10 g per kg of seed can reduce infection. Infected plants should be rogued out promptly and destroyed by burying them in the soil or burning. Seeds can also be treated with cymoxanil at 8 g per kg, followed by a foliar spray cymoxanil at 2 g per litre. A foliar spray of cymoxanil (100 ppm) after 21 days of sowing is recommended if infection exceeds 2–5 percent. Downy mildew-resistant cultivars introduced recently (2022–2024) include: GHB 538 Imp, PBH-1625, GHB 1351 Banas Nayan, PB 1879, HBH 191294, 86M22, GHB 1294, MPMH 42, TNBH 1619, 86M80, BLPMH 109, SVPMH 101, MPMH 35 and 86M94.

Smut [*Moesziomyces penicillariae* (Bref.)]

Smut disease is of greater significance in India particularly with the adaptation of hybrids. The disease is more severe in cytoplasmic male sterility (CMS)-based single-cross hybrids than in open-pollinated varieties. Infected florets produce sori that are larger than grains and appear oval-to-conical in shape. Initially the sori are bright green but later turn brown to black (Figure 12). The estimated grain yield loss caused by smut infestation is 5−20 percent. The disease occurs during the months of September and October. Early sown crops generally escape smut infection. The disease cycle of smut is illustrated in Figure 13 (Thakur and Singh, 1988b)

FIGURE 12. Smut affected pearl millet earhead
© Gopi Kishan, ICAR-IIMR, Gudamalani

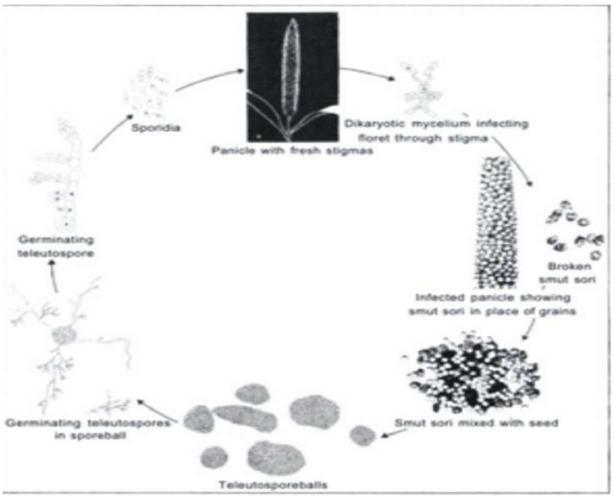

FIGURE 13. Disease cycle of smut in pearl millet
©Thakur and Singh (1988b)

Management

Smut disease is most effectively managed by integrating chemical, biological and cultural practices. The use of resistant cultivars is important and several hybrids were released after 2020 including MPMH 35, RHB 228, GHB 1231, GHB 1225 and Central Pearl Millet Hybrid BHB-1602. Seed dressing with Thiram 75 at 3 g per kg of seed helps protect against infection. Spraying panicles at the boot leaf stage with mancozeb (0.2 percent) followed by chlorothalonil (0.2 percent) reduces disease incidence. In addition, smut-infected ears should be removed from the field to prevent further spread.

Rust [*Puccinia substriata* var. *penicillariae.* (Zimm.)]

Rust is considered a disease of less significance in most of the pearl millet growing areas because it usually appears after the grain-filling stage, causing little or no yield loss. The symptoms first appear on lower leaves as typical pustules containing reddish brown powder (uredospore). Later, dark brown teliospores are produced. Symptoms can occur on both upper and lower surface of the leaves, but commonly on the upper surface and the stem. Highly susceptible cultivars develop large pustules on leaf blades and sheaths (Figure 14).

Management

Rust can be best managed by integrating chemical, biological and cultural practices. The use of resistant hybrids or varieties is important and several rust-resistant cultivars have been released after 2020, including 86M80, 86M94, PB 1877, GHB 1231, and GHB 1225. Sowing the crop with the onset of the monsoon helps reduce disease pressure. Collateral hosts such as *Ischaemum pretosum* and *Panicum maximum* growing on field bunds should be destroyed to prevent the spread of rust. For chemical control, dusting fine sulphur at 17 kg per hectare and applying two sprays of Mancozeb at 0.2 percent concentration at 15-day intervals are effective measures

FIGURE 14. Rust-affected pearl millet leaf
© Gopi Kishan, ICAR-IIMR, Gudamalani

Ergot [*Claviceps fusiformis* (Loveless)]

The disease is easily identified by the presence of a honeydew-like exudate, of creamy to light pinkish colour that oozes out of the infected florets. The exudate contains numerous conidia. Within two weeks, these droplets dry and form hard, dark black sclerotium that are larger than seeds and protrude from the florets in place of grain. The loss in grain yield is directly proportional to the percentage of infection as the infected seed is fully transformed into sclerotium (Figure 15a and Figure 15b). The disease life cycle is illustrated in Figure 16 (Thakur and Singh, 1988a). The occurrence and spread of the disease is highly influenced by weather conditions during flowering. Ergot has become more important in India because of the cultivation of genetically uniform single-cross F1 hybrids based on cytoplasmic male-sterility system, which are known to enhance susceptibility to this disease.

Management

Mechanical removal of sclerotia from seed and washing the seed in two percent saltwater helps reduce infection. Adjusting sowing dates so that ear emergence does not coincide with periods of heavy rainfall is also effective. Ploughing the field soon after harvest ensures that ergot bodies are buried deep in the soil. Three foliar sprays, starting from 50 percent flowering, can be applied using thiram at 0.2 percent, copper oxychloride at 0.25 percent, or ziram at 0.2 percent. The use of ergot-resistant varieties is recommended. Several cultivars have been released after 2016 including GHB 1231, PB 1756, PB 1720, GK 1116, PB 1705, XMT 1497, KBH 3940, Bio 8145 and 86

FIGURE 15a. Ergot-affected pearl millet **FIGURE 15b**. Close view of ergot-affected pearl millet
© Gopi Kishan, ICAR-IIMR, Gudamalani

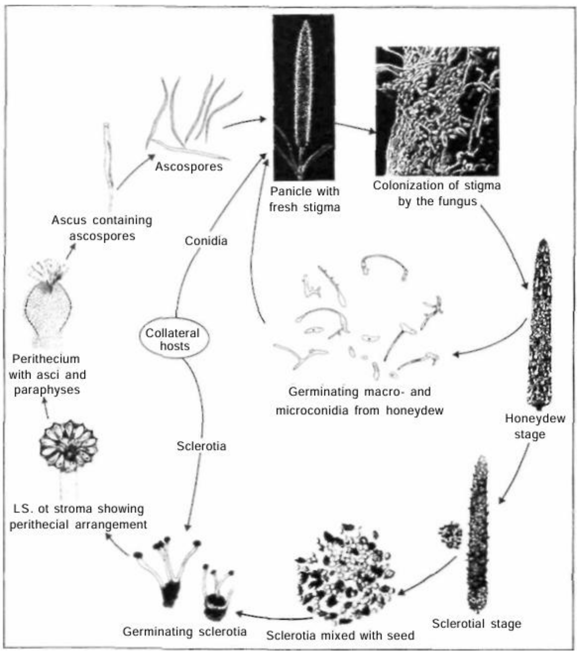

FIGURE 16. Disease cycle of ergot in pearl millet
©Thakur and Singh (1988a)

Blast (*Pyricularia grisea* (Cooke) Sacc) [telemorph: *Magnaporthe grisea* (Herbert) Barr.]

Blast, also known as leaf spot, has emerged as a serious disease of pearl millet in recent years. The disease affects both the quality and yield of forage and grain. The symptoms appear as distinct, large, indefinite, water-soaked, spindle-shaped lesions with grey centres and purple-grey horizons surrounded by a yellow margin. The lesions result in extensive chlorosis and premature drying of young leaves (Figure 17 and Figure 18).

Management

Cleaning the fields, proper cultivation and removal of crop residues help in reducing the disease incidence. The use of resistant cultivars is important, and several blast-resistant hybrids have been released after 2020, such as Central Pearl Millet Hybrid BHB-1602, GHB 1225, Proagro Marutej, MP 7366, GHB 1231, RHB 228, MPMH 35, MPMH 42, GHB 1294, HBH 191294, Proagro 9001, and GHB 538. If leaf symptoms appear, a foliar spray of carbendazim at 0.1 percent can be applied. Seed treatment with microbial consortia consisting of mycorrhiza, PSB, pseudomonas, and trichoderma at 8 g/kg of seed is also effective. Alternatively, a foliar spray of trifloxystrobin combined with tebuconazole at 0.04 percent concentration can be applied at 20 and 40 days after sowing.

FIGURE 17. Early stages of blast on pearl millet leaf **FIGURE 18.** Advanced stages of blast on pearl millet leaf

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Harvesting

The crop should be harvested when the grains become sufficiently hard and contain about 20 percent moisture. Generally, two methods are adopted for harvesting the crop: (i) cutting the earheads first from the standing crop, followed by cutting the remaining plant (ii) cutting the entire plant by sickles and then staking the harvested plants for 5−6 days in the sun to dry. The grains are separated either by beating the earheads with sticks or trampling them by bullocks. The threshed grain should be cleaned and dried in the sun to reduce the moisture content to 12−14 percent, which is suitable for safe storage.

As manual harvesting of crops is expensive, mechanical combine harvesters are being used in recent years, particularly in northwest India. The declining importance of stover as fodder has contributed to increased use of mechanization for harvesting. According to the Federation of Indian Chambers of Commerce and Industry (FICCI, 2015), 20−30 percent of the area on which pearl millet is cultivated practises mechanical harvesting and threshing. Studies indicate that mechanical threshers exhibit a high threshing efficiency (96.8 percent) and low energy consumption (8 mega joule/tonne of input crop) compared to manual methods. The cost of operation for a mechanical thresher was only INR 85 per tonne of grain. This is significantly lower than the cost of threshing by animal trampling (INR 312.5 per tonne) and manual beating (INR 1650 per tonne).

For fodder purposes, the pearl millet crop is harvested at the flowering stage. Harvesting is done either manually with a sickle or mechanically using a reaper.

Yield

The mean grain yield of pearl millet in India during 2023/24 was 1453 kg/ha. The productivity in summer was more than it was in the kharif season, as is evident from the mean productivity of 2579 kg/ha in summer and only 387 kg/ha in the kharif crop. This seasonal trend was consistent across other states: Gujarat (2960 kg/ha in summer and 1776 kg/ha in kharif), Rajasthan (1471 kg/ha and 1030 kg/ha) and Maharashtra (902 kg/ha and 579 kg/ha).

Stover yields can range from 3−9 t/ha. The national production of pearl millet stover has increased from 8.8 Mt in 1950 to 21.8 Mt in 2010. Based on the mean stover-to-grain ratio in 2010, (2.25:1), it is estimated that 24.1 Mt of stover was produced during 2023/24. Pearl millet stover is an important component of maintenance ration of livestock in harsh environments. During droughts, stover often fetches a higher price than grain in western parts of the country.

Fodder yield

The green fodder yield of pearl millet varieties is around 30 t/ha. The three-way cross-hybrid PAC 981 has a green fodder yield of 41 t/ha and a dry fodder yield of 9.6 t/ha. Multicut hybrids have a significantly higher yield of green fodder at 100 t/ha.

Forage pearl millet cultivars

Rijko Bajra, ICMV 08111, PCB 15, PCB 141, PCB-164, Raj Bjara Chari 2, AFB 2, AFB-3, AFB-37, APFB-09-1, TNSC-1, RBB-1, DRSB-2, CO 8, TSFB-15-4. TSFB-15-8, TSFB-17-7, K-25, Narendra Chara bajra-2, BAIF Bajra 1 and Avika Bajra 19 are some important single-cut forage pearl millet varieties. Mondoria Rijko Bajri (MRB)-8, MRB-9, MRB-15 and JCB-2 are promising as summer forage cultivars. HHB 67-2 (rainfed conditions), HHB 223 (irrigated and high fertility conditions), FMH 3, GHB 15, GHB 235 are some single-cut hybrids. ADV 0061, BAIF Bajra 5, BAIF Bajra 6, Moti Bajra, Giant Bajra, OL-125, FBC-16, TSFB 18-1, HTBH 4902, DFB-1 and PAC 981 (nutrifeed) are multicut forage pearl millet cultivars.

Utilization pattern

According to FAO estimates, the total pearl millet grains produced in India during the years 2016-2018 was 10.914 Mt. Of this, 93.4 percent was used towards food, 1.5 percent towards feed, 2.3 percent towards other uses (non-food, seed and processing) and 2.8 percent was lost. A more recent estimate from ASSOCHAM (2022) shows that 15 percent of the grain is used as animal feed and 10 percent is used by the brewing industry. The use of stover in cardboard manufacturing and biofuel production is also being explored.

Exports

During 2022, 58 370 tonnes of pearl millet worth USD 19.46 million was exported.

Support price

Pearl millet is one of the three millet crops in India for which the government announces a minimum support price (MSP). This is the price at which the government procures grain. The price is fixed at 1.5 times the cost of cultivation (C_2). Although the cost of cultivation varies by state, the MSP is the same nationwide. For 2025/26, the MSP of pearl millet grain was INR 27 550/tonne.

Seed production

Pearl millet is a highly cross-pollinated crop and for certified seed production, an isolation distance of 200 metres is required. Open pollinated varieties (OPV) for grain purpose have a seed multiplication ratio of 330, while forage types have a seed multiplication ratio of 200−250.

Hybrid seed production

Hybrid seed production is an important economic activity. Private companies are engaging in certified hybrid seed production and entering into contracts with farmers.

Production of certified seeds involves planting A lines (female line) and R lines (restorer line, male parent) in the ratio of 5:2 with five rows of R line around the plot for pollen supply. A-line is planted at a spacing of 60 cm × 15 cm (3−4 kg/ha seed) and R line is planted in 60 cm x 15 cm (2−3 kg/ha seed). Seeds should be sown at a depth of 2.5−3.0 cm. Transplant of seedlings at 2–3 weeks after sowing is recommended if the stand is poor. Transplanting is done practically in all southern states to save valuable seed material. A nursery of about 0.03 hectares can provide seedlings sufficient for a hectare of the main field. Transplanting reduces the life span of the crop in the main field by 18–21 days and also enables easy adjustment of staggered plantings.

Synchronization of flowering is important for seed set; so sowing time adjustment is standardized for each production site. The use of growth regulators, MH 500 ppm (delays flowering in early parent) and CCC 300 ppm (used to synchronize lagging parent) aids in synchronization. Controlling irrigation, fertilizer application to one of the hybrid parents, and removal of extra-early tillers in A- or R-lines aid in synchronizing the pollen shedding and stigma receptivity. Isolation of seed plots from other pearl millet fields is essential for hybrid seed production. For certified seed production, an isolation distance of 1000 m is to be maintained. Rogueing is an essential activity during seed production. It involves removal of off-types in R line, pollen shedders in A line and diseased plants daily during flowering. Harvesting and threshing should be done separately − male rows first, then female (hybrid seed). Harvested seeds are treated with 2 g/kg of thiram and halogen mix for storage protection. Under optimal conditions, the yield of hybrid seed production from A line is 3000−3500 kg/ha and this is marketed. R line produces about 3500−4000 kg/ha seed.

Pearl millet hybrid seed production is concentrated in a few states with favourable agroclimatic conditions, strong institutional support and active public-private partnerships. The important states involved in producing hybrid seed of pearl millet are listed in Table 13.

ICAR-All India Coordinated Research Projects (ICAR-AICRP) coordinates research and breeder seed production of pearl millets across zones, while National Seeds Corporation (NSC), State Seeds Corporation (SSC) and State Farms Corporation of India (SFCI) handle foundation and certified seed multiplication. Private seed companies lead in hybrid development and large-scale seed production. Hybrids for grain purpose have a seed multiplication ratio of 1:200−250 while that of forage types have a ratio of 1:150−200.

TABLE 13. Major pearl millet hybrid seed-producing states in India

State	Role in seed production
Rajasthan	Largest contributor; ideal for A_1 zone hybrids; strong presence of AICRP-PM centres
Maharashtra	Active in post-rainy (rabi) season production; private sector dominates hybrid seed market
Gujarat	Summer and kharif season seed production; high-quality seed hubs
Uttar Pradesh	Significant certified seed production; cultivation in summer season gaining traction
Haryana	Important for A1 zone hybrids; strong SSC involvement
Tamil Nadu	Summer season production; advanced seed processing infrastructure
Telangana	Hybrid seed production using drip irrigation; private-public collaboration
Punjab	Limited but high-quality seed production; focus on certified seed
Madhya Pradesh	Emerging player; contributes to breeder and foundation seed multiplication

Source: Authors' own elaboration

CHAPTER 3. Sorghum

Sorghum bicolor (L) Moench

FIGURE 19. Field view of sorghum hybrid
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Sorghum is the second most important millet staple cultivated in India. Its grain is valued for food, as animal feed and in the brewing industry, while its biomass is used as fodder and is being explored for biofuel production. It is mostly grown under rainfed conditions. During 2024/25, sorghum was grown on 3.995 million hectares (Mha) producing 4.995 million tonnes (Mt) of grains. Of this, 35.06 percent was produced in the kharif season, 64.32 percent in rabi and rest in summer. Until 2008/09, the kharif season crop accounted for the major share in total sorghum production. Since then, more sorghum is produced in the rabi season. The decline in the production of sorghum in kharif season is attributed to the occurrence of the grain mould disease (in the flowering stage) under prolonged rains, making the infected grains unfit for human consumption. As they have poor price realization, farmers have lost interest in cultivating sorghum in kharif. The latest data for 2024/25 (Table 14) indicates that Rajasthan (29.94 percent) and Uttar Pradesh (25.04 percent) are the major kharif sorghum producers followed by Karnataka (12.32 percent), Tamil Nadu (11.11 percent) and Madhya Pradesh (10.54 percent).

Rabi sorghum is cultivated on clayey soils (vertisols or black cotton soil) of varying depths (less than 45 cm to more than 100 cm) relying primarily on the residual soil moisture stored from the previous monsoon. The quantity of stored moisture in the soil decides the productivity of the rabi crop. Maharashtra (53.03 percent), Karnataka (18.56 percent), Telangana (11.61percent), Andhra Pradesh (8.94 percent) and Tamil Nadu (6.81 percent) were the major rabi sorghum growing states during 2024/25 and together accounted for 99.25 percent of production (Table 15). Irrigated rabi sorghum has a very high and stable productivity (as high as 10 t/ha in the rice fallows of Andhra Pradesh). Summer production

(0.30 lakh tonnes) comes from Maharashtra. Though the area under sorghum has declined from 18.6 Mha in 1969/70 to 3.995 Mha in 2024/25, its productivity has more than doubled (from 554 kg/ha to 1240 kg/ha) during the same period. Enhanced productivity of sorghum is attributed to the spread of improved varieties (hybrids in kharif season) and adoption of associated production and protection technologies in both kharif and rabi seasons.

TABLE 14. Area, production and yield of sorghum in India (2024/25): sum of kharif, rabi and summer seasons

State	Area (Mha)	% of total area	Production (Mt)	% of total production	Yield (kg/ha)
Maharashtra	1.546	38.70	1.690	34.11	1091
Karnataka	0.648	16.22	0.815	16.45	1258
Rajasthan	0.642	16.07	0.520	10.49	811
Uttar Pradesh	0.268	6.71	0.435	8.78	1622
Tamil Nadu	0.339	8.49	0.410	8.27	1211
Andhra Pradesh	0.083	2.08	0.287	5.79	3459
Other states	0.469	11.74	0.798	16.10	1701
Country	3.995	100	4.955	100	1240

Source: UPAg: Unified Portal for Agricultural Statistics, Ministry of Agriculture and Farmers Welfare, Government of India

TABLE 15. Season-wise production of sorghum in India

State	Kharif (Mt) (2024/25)	Share (%) in total*	State	Rabi (2024/25)	Share (%) in total*
Rajasthan	0.520	29.94	Maharashtra	1.690	53.03
Uttar Pradesh	0.435	25.04	Karnataka	0.601	18.86
Karnataka	0.214	12.32	Telangana	0.370	11.61
Tamil Nadu	0.193	11.11	Andhra Pradesh	0.285	8.94
Madhya Pradesh	0.183	10.54	Tamil Nadu	0.217	6.81
Others	0.192	11.05	Others	0.024	0.75
Total	1.737	100	Total	3.187	100

Source: UPAg: Unified Portal for Agricultural Statistics, Ministry of Agriculture and Farmers Welfare, Government of India
* Calculated by authors

Despite an increase of 223.8 percent in mean sorghum yields between 1969 and 2024, the actual yields for farmers are still lower than that of research stations and their estimated potential yields which were 3210−3410 kg/ha in kharif and 1000−1360 kg/ha in rabi seasons (Murty *et al.*, 2007). This wide gap between farmers and potential yields could be attributed to various technological and socio-economic reasons. In addition, the adoption of good agricultural practices (GAP) at the farmers level is not complete. To bridge this yield gap, it is also necessary to motivate farmers to adopt GAP as a whole and not partially.

Climatic requirements

Sorghum is a warm-season crop but can thrive under a wide range of climatic conditions. It can tolerate high temperatures throughout its life cycle better than any other cereal. The minimum temperature for seed germination is 7−10 ºC while 26−30 ºC is optimum for growth. Though it can withstand temperatures up to 45 ºC, any temperature below 8 ºC, limits its cultivation on account of impaired flowering and pollination. Temperatures below 13 ºC at the blooming stage are detrimental to seed setting in the rabi season, which is why sorghum is not cultivated in winter (rabi) in north India. Sorghum is a short day C_4 plant and the time of heading is influenced by temperature as well as photoperiod. It can also tolerate drought conditions very well, because it remains dormant during moisture stress conditions and resumes growth when favourable conditions arise. It can also tolerate waterlogging conditions better than other cereals, second only to rice. It grows successfully from sea level to elevated lands, as high as 3000 metres. Thus, it can be cultivated successfully in areas having an average seasonal rainfall between 40−100 cm.

Soil

In India, sorghum is grown on a variety of soils. Alfisols (red soil) and vertisols (black soil) are most conducive to its cultivation. Red soil, derived from coarse crystalline acidic granite, is light textured and has shallow depths. These soils have a high infiltration rate (5−15 cm/hour), are neutral in pH (6.5 to 7.5), rich in non-exchangeable potassium, and low in available nitrogen and phosphorus. Surface crust formation is a serious problem in these soils. These soils are mostly found in Andhra Pradesh and Karnataka. Black soils are clayey in nature with varying depths. They contain high montmorillonite clay (2:1) and have a low infiltration rate (about 0.1 cm/hour) resulting in salt accumulation. They are generally deficient in nitrogen and phosphorus. During the kharif season vertisols with high clay content get waterlogged because they swell with water and therefore, cannot be ploughed. In general, vertisols with 90−120 mm of stored moisture per metre of soil depth can sustain a reasonably good rainfed rabi crop. However, in soils with low water-storage capacity, winter showers or supplemental irrigation is necessary; otherwise crop yield is likely to be low.

Varieties

In India, several improved grain sorghum varieties (since 1930) and hybrids (since 1964) have been developed for both kharif and rabi seasons. The first commercial sorghum hybrid ‘CSH-1’ (CK-60A × IS-84) was released during 1964. This was a major milestone in dryland agriculture, especially for sorghum cultivation in semi-arid regions. Early-released sorghum hybrids (CSH-1 to CSH-6) have exhibited 40 percent yield superiority. For low rainfall zones, CSH-17 and CSH-6 were found to be promising. Very few hybrids have been released for rabi sorghum; CSH-15R, CSH-29R and CSH-39 R are a few of them. SPH-2036 (Maldandi Supreme) is the latest hybrid released in 2025 after a gap of 12 years.

In recent years cultivars suitable for summer season are also being developed. Kharif cultivars need to be of short duration, short stature and photo insensitive to avoid grain mould disease. On the contrary, rabi (post rainy) cultivar should be tall, thermo-photo-insensitive, tolerant to terminal drought, and resistant to charcoal rot and lodging. In kharif season hybrids have predominance to varieties (60:40), whereas in rainfed rabi situations, varieties have exclusive presence; with M-35-1 being the mega variety. Coloured sorghums (yellow sorghum and red sorghums rich in anthocyanin, niacin, iron and zinc) are cultivated in kharif season. Hurda sorghums (varieties only, no hybrids as on date) are cultivated on a large scale during rabi season in Maharashtra and Gujarat. Maharashtra also cultivates hurda sorghum during the kharif season, though on a smaller scale. Hybrids are cultivated under ecologies of irrigated rabi and rice fallows. Grain sorghum varieties and hybrids suitable for kharif and rabi seasons for different states are presented in Table 16.

TABLE 16. Recommended high-yielding cultivars of grain sorghum in India

Kharif season		
State	**Hybrid**	**Variety**
Maharashtra	CSH 47, CSH 45, SPH 1635, SPH 1641, CSH 41, CSH 35, CSH 30, CSH 25, CSH 16, SPH 2024*, SPH 2021 (Mahabeej 727)*	PDKV Kalyani (AKSV-181), CSV39, CSV36, CSV 34, Palamuru jonna (CSV31), CSV 27, CSV20, CSV 60 Yellow (SPV 2620), CSV 65 Yellow (SPV 2906)
Karnataka	CSH 45, CSH 41, CSH 35, CSH 30, CSH 18, CSH 17, CSH 16, CSH 14, CSH 13, CSH 42, DSH-7 (CSH 55), DSH-6 (CSH 49)	CSV 36, CSV 34, Palamuru jonna (CSV31), CSV 27, CSV 17, CSV 15, CSV 55 (Gujarat Goti), CSV 60 Yellow (SPV 2620), CSV 65 Yellow (SPV 2906), DSV-10 (CSV-62)
Andhra Pradesh and Telangana	CSH 47, CSH 45, CSH 41, CSH 35, CSH 30, CSH 25,CSH 14, CSH 42	Palamuru jonna (CSV 31), CSV 39, CSV 36, CSV 27, CSV 23, CSV 20, CSV 17, CSV 15, CSV 60 Yellow (SPV 2620), Palem jonna-1 (PSV-512), CSV 65 Yellow (SPV 2906), DSV-10 (CSV-62)
Madhya Pradesh	CSH 47, CSH 41, CSH 25, CSH 23, CSH 18, CSH 17, CSH 16, CSH 42, SPH 2024*, SPH 2021 (Mahabeej 727)*	Raj Vijay Jowar 1862 (RVJ 1862), CSV 34, CSV 15, CSV 17, JJ 741, JJ 938, Palamuru jonna (CSV31), CSV 55 (Gujarat Goti), DSV-10 (CSV-62)
Gujarat	CSH 47, CSH 41, CSH 35, CSH 27, CSH 25, CSH 18, CSH 16, CSH 13, CSH 42	GJ42 (SR-666-1), Palamuru jonna (CSV 31), CSV 39, CSV 36, CSV 34, CSV 17, CSV 15, GJ 41, GJ 40, GJ 39, GJ 38, CSV 55 (Gujarat Goti), GJ 45 (SDAU Jowar moti), GJ 44 (Madhu), CSV 65 Yellow (SPV 2906), DSV-10 (CSV-62), SPV 2976*
Rajasthan	CSH 47, CSH 45, CSH 41, CSH 35, CSH 27, CSH 23, CSH 18, CSH 16, CSH 14, DSH-7 (CSH 55)	Palamuru jonna (CSV 31), CSV39, CSV36, CSV 23, CSV 20, CSV 17, DSV-10 (CSV-62), SPV 2976*
Tamil Nadu	CSH 41, CSH 35, CSH 27, CSH 18, CSH 17, CSH 16, CSH 14, DSH-7 (CSH 55)	K-12, Palamuru jonna (CSV 31), CSV 27, CSV 23, CSV 20, CSV 17, CO 26, CO-34
Uttar Pradesh	CSH 27, CSH 25, CSH 23, CSH 18, CSH 16, CSH 14	CSV39, CSV36, Palamuru jonna (CSV31), CSV 23, CSV 20, CSV 17, CSV 15

Rabi and summer (zaid) season			
State	**Area of adaptation**	**Hybrid**	**Variety**
Maharashtra	Rainfed areas (Medium to deep soil)	CSH 39R, CSH 19R, CSH 15R, SPH 2036 (Maldandi Supreme)*	Phule Rohini (RPASV3), Phule Suchitra (RSV 1098), CSV 216R, CSV 29R, CSV 22R, CSV 18R, Parbhani Super Moti, (SPV 2407), Phule Yashomati (RSV 1910), Phule Purva (SPV 2737), SPV 2919*
	Irrigated areas		PKV Kranti, CSV22R, Phule Vasudha

	Shallow soil	-	CSV 26R, Phule Anuradha, Phule Chitra
Karnataka	Dry zones (deep soil)	CSH 15R, SPH 2036 (Maldandi Supreme)*	BJV 44 (SPV 2034), SPV 2217, CSV 29R, M 35-1, DSV4, SPV 2919*
	Transitional zones (médium soil)		BJV 44 (SPV 2034), SPV 2217, CSV 26R, DSV5
	Irrigated zone	CSH 39R, CSH 19R, CSH 15R	BJV 44 (SPV 2034), SPV-2217, CSV 29R, CSV 22R, DSV5
Telangana	Normal rabi areas	SH 15R, SPH 2036 (Maldandi Supreme)*	CSV 29R, CSV 26R, CSV 22R, CSV 18R, Tandur jonna 55 (SVT 55), Tandur jonna 1 (SVT-68)
Tamil Nadu	Entire *rabi* area		CSV 29R, CSV 26R, CSV 18R, CSV 22R, CO-34
	Summer areas		CO 26, CO 24, COFS 29, CSV 33MF
Gujarat	Entire rabi zone		CSV 29R, CSV 26R, CSV 18R, GJ 102 (Surat Goti), SPV 2919*
Andhra Pradesh	Rice fallows	CSH 16	

Source: Authors' own elaboration
*2025 releases

*Red sorghums***:** Red sorghums are rich in phenolics and contain a unique pigment called 3-deoxy-anthocyanin which lacks a hydroxyl group in the third carbon position. The pigment has high potential to be used as a food colourant because it is more stable even under high temperature and alkaline pH. Because of the benefits in food, feed and pharmaceutical industries, red sorghum is gaining attention from stakeholders. If exploited to its full potential, especially through exports to China, this can generate substantial revenue for the farming community. CO-4, Paiyur-2 (Tamil Nadu), AKJ-1 and CSV-50R are some of the red sorghum varieties in India.

Pop varieties: Some promising varieties for popping are C 43, Pop 11 (both are breeding lines), Phule Panchami (RPOSV-3) and M-35-1.

Hurda sorghum: Hurda (*sheetani* or *belasi* in Kannada, *ponkh* in Gujarati and hurda in Marathi) is the name given to tender sweet sorghum grain (Brix greater than 15) which is rich in protein (greater than 10 percent) and is harvested at the soft dough/milky stage. Hurda sorghum cultivars are characterized by easy threshability and grain separation.

Traditionally, hurda is roasted on coal in mud pits, giving it an earthy taste. This freshly roasted hurda is then eaten with a variety of chutneys made up of sesame, groundnut, dry coconut, garlic and red chillies. Adding jaggery, *revdi*, lime, *miri* (black pepper) and *sev* (a crunchy noodle-like snack) enhances the taste and makes the dish more flavourful. In an article published in *The Guardian*, American chefs described sweet grain sorghum as the next "wonder grain". They extolled its health benefits, its versatility in cooking and its eco-friendliness. (Danovich, 2015)

'Phule Mathur', a hurda cultivar, is tolerant to shoot fly and charcoal rot while 'SMJ-1' is tolerant to shoot fly and shoot bug. Important hurda varieties are listed in Table 17.

TABLE 17. Recommended varieties of hurda sorghum

Kharif	Rabi		
PDKV Kartiki, PKV Ashwini, Malkapur Wani (Maharashtra)	Surthi, Phule Uttara, Phule Madhur (RSSGV-46), RSSGV-56, RSSGV-83, RSSGV-89, PVR SG-101, PVR SG-102, PVR SG-8-4 (Maharashtra)	Sakkari Mukkari Jola, Raosaheb, Gulbhendi Local-1, SMJ-1 (Karnataka)	Andhali Wani (Gujarat)

Source: Authors' own elaboration

Fodder sorghum

Sorghum is the most extensively cultivated (about 2.6 Mha) fodder crop in India, available in both single and multicut forage cultivars. Though it has a high biomass yield, it contains a toxic compound 'prussic acid' − also called formonitrile or hydrogen cyanide (HCN) − which is a highly volatile and extremely toxic chemical compound (formula H−C≡N). Its concentration is the highest during early growth stages of the crop and under conditions of drought stress. If consumed by animals without proper precaution, HCN can be fatal because it inhibits cellular respiration by binding to the ferric (Fe^{3+}) iron in the heme group of cytochrome c oxidase (Complex IV of the electron transport chain). Historically it was used in capital punishment and was infamously part of Zyklon B during World War II.

Some important cultivars in single cut sorghum are: HC 308, HJ 513, HJ 541, CSV 21F, GFS 5, GFS 8, CSV 30F, CSV 32F, CSV 44F, PC 1080, HJH 1513, CNFS 1 (Karnataka), CSH 40F and CSH 53F. Brown midrib sorghum (BMR) with low lignin content and high digestibility has been developed with CSV 43BMR serving as the national check. SPV 2997 and SPV 2912 are the two latest single cut BMR varieties released during 2025.

Perennial varieties such as: COFS-29, COFS-31 and CSV-33MF (selection from COFS-29) are very popular across the country. Multicut cultivars include SSG-59-3, GK-909, GK-917, CSH-20MF, CSH-24MF, CSH-43MF. CSH 24MF is the most extensively cultivated fodder sorghum hybrid of India. Sprint super gold (SPH-2018) is the latest multicut hybrid released during 2025.

Land preparation

The field is prepared by deep off-season ploughing every year in shallow-to-medium-deep soil, and once every three years in deep-to-very-deep soil. This should be done soon after harvesting the rabi crop in double-cropped regions and immediately after the cessation of the southwest monsoon in areas that grow only kharif crops. This leaves the field cloddy, exposing weed and other pest propagules to high temperatures. A cloddy field also aids in moisture conservation by decreasing runoff.

With the onset of monsoon, the field is ploughed or harrowed twice or thrice to break the clods followed by planking. In heavy soils prone to waterlogging, levelling is also done for easy drainage. In recent times, no-till/zero-till and minimum-tillage cultivation of sorghum, particularly within cropping systems, is gaining popularity. For kharif sorghum, application of farmyard manure (8−10 t/ha) or, more recently, poultry manure (2–3 t/ha) is done during the summer season and incorporated with the onset of monsoon through land preparation. In heavy soils, green manure crops such as dhaincha and sunn hemp are grown in kharif and are incorporated before sowing rabi sorghum. Furrow irrigated raised beds (FIRB) and broadbed and furrow (BBF) are made after final land preparation. Sowing is done on beds with furrows acting as water conservation points as well as drainage channels at times of excess rains during the kharif season.

For cultivation of sorghum in rabi season, kharif fallow management is essential to conserve moisture through land shaping and by keeping the field free from weeds. Compartmental bunding (3–4.5 m × 3–4.5 m depending on the slope) or the formation of check basins is beneficial for rabi sorghum. These structures are prepared before the onset of the southwest monsoon in June. Tractor drawn ‘Phule check basin’ developed in Maharashtra has made check basin formation easy and economical. Enhanced stored soil moisture (10−15 percent) with compartmental bunding was found to boost the rabi sorghum yields by 20−25 percent as compared to its control. Since these bunds are disturbed by the sowing operations of rabi crop, formation of ridge (20 cm) and furrow (45 cm) through bullock-drawn ploughs is found to be as useful as compartmental bunding for moisture conservation. In rice fallows of Andhra Pradesh rabi sorghum is sown without tillage, whereas thorough land preparation is done for the crop sown in summer (Zaid season).

Sowing windows

Sorghum is an exclusive kharif crop in northern parts of India, while in the southern parts it is grown throughout the year. Sowing of the rainfed kharif crop depends on the onset of the southwest monsoon. The last week of June to the first week of July is the ideal time for sowing. However, irrigated crop sowing before the onset of monsoons (10−15 days in advance) is desirable. Sowing too early is undesirable as the flowering may coincide with the rains, leading to incidence of grain mould. On the other hand, sowing too late may expose the crop to moisture stress. Normally, sowing is completed by July in most areas and any delay in sowing shortens the life cycle of the crop and results in poor yields.

Rabi sorghum is cultivated in about seven states. It is predominantly a rainfed crop in Maharashtra and Karnataka. The ideal sowing time is mid-September which can be extended up to the first week of October depending on the stored moisture status in the soil and its sufficiency. However, it is important to adjust sowing time to avoid shoot fly menace especially in areas where there is overlap of the kharif and rabi sorghum crops. In Andhra Pradesh, Gujarat, Tamil Nadu and Karnataka, rabi sorghum is grown under irrigation and in these regions sowing can be delayed depending on the harvest of the kharif crop (which may be soybean, mung bean, urd bean, etc.) up to the second fortnight of October. Under irrigated conditions in Dharwad (Karnataka) the second week of October is considered the optimum time for sowing. For Maghi sorghum cultivation in Andhra Pradesh (KC canal area of Kurnool district), sowing in mid-September to mid-October is ideal. The sowing time for rice fallow sorghum in Andhra Pradesh depends on the harvest of the rice crop and the creation of favourable moisture conditions (where excess moisture is dried sufficiently).
January to February is the ideal sowing time for the summer crop in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Gujarat.

Seed rate, spacing and seed treatment

A seed rate of 8−10 kg/ha is required to maintain optimal plant stand. The seeds of hybrids are 5 to 10 times more expensive than varieties, hence optimizing seed rate becomes important in curtailing costs of cultivation. Fodder sorghum has a seed rate requirement of 25−30 kg/ha.

The optimum population for grain sorghum varies from 1 35 000 plants per hectare to 1 66 666 plants per hectare. Rainfed rabi season crop has the lowest optimum population (1 35 000 plants per hectare) and early varieties/hybrids of kharif, the highest. Fodder sorghum has a population requirement of 6 60 000 plants per hectare. The above plant populations of grain sorghum are attained through a planting geometry of 45 cm × 15 cm or

60 cm × 10 cm. For fodder sorghum, a planting geometry of 30 cm × 5 cm is ideal.
Seed treatment with 14 ml of imidacloprid along with either 2 g of carbendazim or 3 ml thiamethoxam per kg seed is recommended for protection against shoot fly. Metalaxyl at 1 g a.i./kg seed is recommended for downy mildew in varieties. Hybrid seeds are marketed as pre-treated and thus may not require separate treatment at the farmers' level.

Method of sowing

A sorghum crop is predominantly established by sowing seeds. In north India, seeds are sown either by broadcast or in rows behind the plough. When sown behind the plough, seeds can be sown by kera method (seeds are dropped manually by hand into opened furrows) or pora method (seeds are dropped manually through a pipe into opened farrows). Hybrids and improved varieties are always sown in rows for realizing higher yields. Sowing in rows is common in black cotton soils. Sorghum is a tall crop and to avoid mutual shading, sowing in the direction of sunrise and sunset is desired. In moisture limiting environments a paired row planting pattern is promising. Two rows are planted at 30–45 cm distance followed by a gap of 60–90 cm between the next two rows. In the rice fallows of Andhra Pradesh, the practice of manually dibbling of seeds in holes under zero-tillage conditions, is followed.

Transplanting of nursery-grown seedlings of 15−20 days was found to reduce the incidence of shoot fly and the need to apply insecticides either through seed treatment or foliar spray. Transplantation also shortens the crop duration and aids in crop intensification. The transplanted crop gets a competitive advantage over weeds and the establishment of the seedlings is 100 percent.

Thinning and gap filling

Thinning and gap filling are important for realizing maximum yield. To maintain a plant-to-plant spacing of 15−20 cm, thinning of plants in rows is done in two stages. The first is done 10−15 days after emergence and the second, 20−25 days after sowing. All diseased and insect infested plants should be removed during the thinning process. Gap filling should be done within a week after sowing by dibbling seeds. Under favourable moisture conditions, healthy thinned plants can also be transplanted to fill the gaps.

Manure and fertilizers

Sorghum is a nutrient exhaustive crop; however, application of fertilizers is usually moderate because it is often cultivated under moisture-limiting environments. The increasing area under irrigation (from 2.98 percent in 1950/51 to 11.54 percent in 2021/22) and the use of high-yielding varieties and hybrids (during kharif season) justify liberal fertilization. In general, the requirement of fertilizers for hybrid/composites is higher than local/desi cultivars. Organic sorghum varieties also need adequate manuring, biofertilizers and permitted fertilizers (rock phosphate and potassium sulphate).

For rainfed kharif grain sorghum, the recommended application of nutrients is 10 t/ha of FYM (incorporated by ploughing 15−30 days before sowing) along with 60−40 kg/ha of N-P_2O_5 fertilizers. The entire dose of phosphorus along with 50 percent nitrogen (N) is applied at the time of sowing (basal dose). The remaining 50 percent N is top dressed at the panicle initiation stage (30−35 DAS) under optimum soil moisture conditions, preferably after weeding. Under irrigated and favourable moisture conditions, in addition to phosphorus, higher nitrogen (80−100 kg) and potassium (40 kg/ha) fertilizer application is required. Band placement of top-dressed nitrogen at 30 DAS facilitates effective nutrient utilization by the crop. Using the sorghum leaf colour chart (LCC), developed by IIMR, the leaf colour of the topmost fully opened leaf is monitored from 15 days after sowing using the 6-panel

LCC strip (3.0, 3.5, 4.0, 4.5, 5.0, 6.0). Whenever the readings fall below threshold level (less than 4.5), 23.2 kg per hectare nitrogen fertilizer is top-dressed. This ensures that nitrogen nutrition is adjusted for optimum performance (Gangaiah and Tara Satyavathi, 2024).

In Maharashtra, for kharif hurda sorghum, N-$P_2O_5K_2O$ in the proportion 80-40-40 kg/ha is the recommended dose of fertilizer (RDF). Alternatively, 75 percent of the RDF along with 5 t/ha FYM and 25 kg/ha of zinc sulphate ($ZnSO_4$) is recommended. Foliar spray of 1.0 percent ferrous sulphate ($FeSO_4$) at the flowering stage is promising for hurda sorghum production and hurda nutritional quality (Fe content).

The rabi rainfed crop is fertilized based on the storage of moisture in the soil (the function of soil texture and depth), and its availability. In shallow soils a lower fertilizer dose (40−20 kg N-P_2O_5/ha as basal) and in medium-deep vertisols a dose that is 50 percent higher (60–30 kg N-P_2O_5/ha as basal) is recommended. Top dressing of nitrogen is done under favourable soil moisture and upon receipt of light showers. Under moisture limiting conditions of rabi, foliar spray of urea or DAP (1−2 percent) is a promising substitute to conventional top dressing. With the increasing deficiency of zinc and iron (in calcareous soils), soil application of 25 kg zinc sulphate once every three years or foliar spray of 0.2 percent zinc sulphate twice (at panicle initiation and at flag leaf stage) is beneficial in zinc deficient soils. In case of iron deficiency, foliar spray (twice) of 0.1 percent ferrous sulphate is recommended. In soils deficient in boron and sulphur, fertilization with 1 kg/ha (or 0.1 percent foliar spray) of boron and10 kg/ha of sulphur (as bentonite) is done for rabi crop.

Biofertilizers

Azotobacter chroococcum or *Azospirillum lipoferum* or *A. brasilense* and phosphate solubilizing microbes (PSM) applied as seed inoculation (50 g/kg seed) was found effective in N fixation and P mobilization, thereby improving crop nutrition. Recently, carrier-based biofertilizers have been replaced by liquid formulations (4 ml/kg seed) because of their better efficacy.

Organic nutrition

For organic sorghum cultivation, application of FYM to supply the recommended dose of N and the use of biofertilizers (NP) is required. Studies at Dharwad (Karnataka) on organic rabi sorghum cultivation have indicated that seed treatment with *Trichoderma, Rhizobium* and PSM combined with manure application (comprising a mixture of enriched compost, vermicompost and *Gliricidi*a leaf manure to supply a third of the recommended nitrogen) along with 10 percent cow urine and a 5 percent vermiwash spray, effectively fulfils the nutrient needs of the crop (Kudari and Babalad, 2021). In the kharif season, including a legume such as green gram in the cropping system, followed by rabi sorghum cultivation was found to reduce the manuring requirements of the rabi crop.

Studies under the Network Project on Organic Farming (NPOF) by ICAR-Indian Institute of Farming Systems Research (IIFSR), Modipuram, Uttar Pradesh have reported a 5−20 percent higher yield in organic sorghum. Organic groundnut–sorghum rotation at Dharwad (Karnataka) has recorded 20 percent higher net returns compared to that of an inorganically grown one. In Tamil Nadu, a model integrated organic farming system for sorghum as staple was developed. The system included: sequencing green manure–cotton–sorghum; incorporating desmanthus; adding a livestock component (one each of milch cow, heifer and bull calf); preparing vermicompost; and establishing boundary plantations (*Gliricidia*, coconut). For organic hurda sorghum cultivation in Akola (Maharashtra), a vermicompost application equivalent to 150 percent of the recommended dose of nitrogen (120 kg/ha) is recommended. Organic sorghum cultivation is currently practised in Arunachal Pradesh, Karnataka and Maharashtra.

Weed management

Under rainfed conditions in kharif season weeds germinate alongside the crop and if not managed efficiently, they can substantially reduce productivity (20−60 percent loss in yield). In sorghum, the initial 30−45 days after sowing is the most critical period for crop-weed competition. Manual weeding and hoeing in rabi and zaid (summer) seasons are effective in creating weed-free conditions. However, in kharif, intermittent rains may not permit timely manual weeding and hoeing. Both grassy and broadleaved weeds and sedges grow along with sorghum in a kharif crop. Weeds should be removed with the help of *khurpi* or hand hoe when the crop is about three weeks old. The declining number of draught animals and the increasing labour costs are pushing farmers towards use of herbicides in weed management.

Herbicides

*Sole sorghum***:** Pre-emergence application of 0.75 kg a.i/ha of atrazine in 500 litres of water within three days of sowing manages most weeds in sole sorghum crop. Yet, some grasses may not be completely controlled. In such cases, mixing 0.75 kg a.i./ha each of atrazine and pendimethalin, or 0.50 kg a.i/ha of metolachlor is recommended. Adequate moisture in the soil at the time of spraying is essential for proper activation of atrazine. Spraying metolachlor at 1.0 kg a.i./ha is as effective as using atrazine as a pre-emergence herbicide. Integrating this treatment with one hand-weeding at 20–25 days after sowing, or hoeing at 35–40 days, provides good weed control. Atrazine at 0.75 kg a.i./ha applied at 10 days after sowing (early post-emergence), or 2,4-D sodium salt at 1.0 kg a.i./ha at 4–6 weeks after sowing (particularly when broadleaved weeds and striga are present), can manage weeds throughout the sorghum crop cycle. Striga, a root parasitic weed, is a serious problem in Maharashtra, Karnataka and Andhra Pradesh. Effective management includes manual removal of striga plants and practising crop rotation with non-host crops.

Intercropped sorghum: For sorghum intercropped with legumes, pre-emergence atrazine and post-emergence 2,4-D Na salt applications are not suitable. Pendimethalin (0.75−1.0 kg a.i./ha) or metolachlor (1.0−1.5 kg a.i./ha) is recommended for effective management of grassy weeds.

Effective land preparation and the rain-free conditions of rabi/zaid season result in lesser weed pressure than kharif season sorghum. As a result, the same herbicides from the kharif season will give effective weed management in the rabi and summer crop as well.

Effective weed management is an important and integral component of moisture conservation in rainfed conditions under both kharif and rabi seasons. It also arrests the loss of nutrients to weeds under favourable moisture and irrigated conditions.

Water management

Sorghum is predominantly grown as a rainfed crop in the kharif season (31 percent of total production) and as a rainfed, residual-moisture crop in the rabi season (67 percent of total production). In rice fallows, sorghum receives protective irrigations (2 to 4 times), while during the summer season it receives only need-based irrigation. During 2021/22, 11.54 percent of sorghum acreage (3.80 Mha) was under irrigation in the country. The states with higher than (national) average irrigated area were Haryana (100 percent), Telangana (65.22 percent), Andhra Pradesh (59.74 percent), Gujarat (41.51 percent) and Karnataka (16.08 percent).

The water requirement for sorghum varies from 300−500 mm (kharif and rabi) to 600−700 mm (summer). Depending upon the availability of water resources for irrigation, sorghum is provided with protective irrigation in kharif and rabi seasons. The water requirement for irrigating summer sorghum is the highest (500−700 mm) followed by rabi (240−350 mm) and the least in kharif (120−250 mm). Similarly, deep soils (vertisols) require less water for irrigation than light soils (sandy, red soils).

Sorghum has four critical stages of growth for irrigation: flower primordial initiation (25−30 DAS), flag leaf stage (50−55 DAS), flowering (60−70 DAS) and the grain filling stage (80−90 DAS). The optimum time for scheduling irrigation for sorghum is at 75 percent depletion of available soil moisture (DASM) in the plough layer during kharif, and at 50 percent DASM in rabi and summer. When using IW/CPE ratio (irrigation water/cumulative pan evaporation) to schedule irrigation, an IW/CPE of 0.4 in kharif, and between 0.8−1.0 in rabi and summer seasons is considered optimum.

Under adequate water supply conditions, for rabi and summer crops, irrigation should be given at all the four critical growth stages. If water is available for only two irrigations, it should be supplied at the seedling and flower primordial initiation stages. If water is adequate for three and four irrigations, then the flowering and grain filling stage should also receive irrigation (in that order). In a rainfed kharif crop, with prolonged dry spells, irrigation should be given at all the four critical growth stages. In the canal (*ayacut*) irrigated areas in Kurnool (Andhra Pradesh), one or two irrigations are commonly given to Maghi jowar for higher yields.

Sorghum is usually flood irrigated using check basin or border methods. With the implementation of the 'more crop per drop' (MCPD) programme, pressurized irrigation systems (drip and sprinkler irrigation) are increasingly being adopted (2-3 percent sorghum total area of India mainly in the states of Tamil Nadu, Maharashtra and Gujarat).

Moisture management / conservation

Moisture conservation is extremely important in rainfed kharif and rabi sorghum crops. Land shaping techniques are crucial in moisture conservation. In vertisols, broadbed and furrow (BBF) and check basin formation during rabi season, and furrow irrigated raised bed (FIRB) formation during kharif season are effective for moisture conservation. Moisture conserved in furrows under FIRB in sorghum during kharif season of 2025 at IIMR, Hyderabad can be seen in Figure 20. The tractor-drawn 'Phule check basin former' is a welcome development in in-situ moisture conservation for rabi sorghum. Sowing in ridge and furrow or flat sowing followed by ridging at 30−35 DAS has been found effective in moisture conservation during kharif season. The furrows serve as moisture reservoirs during periods of moisture stress and as drainage ways during waterlogging. Organic mulching with crop residues or removed weeds and vertical mulching, by digging trenches that are 30−40 cm deep and 15−20 cm wide, are other effective methods of in-situ moisture conservation practices recommended for successful sorghum cultivation. Soil mulching by filling deep cracks of vertisols is useful in for moisture conservation in rabi sorghum.

FIGURE 20. Furrow irrigated raised bed (FIRB) – storing rainwater in furrows
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Cropping systems

Mixed cropping and/or intercropping of sorghum with soybean, pigeon pea, mung bean, urd bean and cowpea (in the ratio of 2:1 or 2:2) during the kharif season has proven profitable in north India. In Telangana, Maharashtra, Madhya Pradesh, Karnataka, Gujarat, Rajasthan, Haryana, and Tamil Nadu, pigeon pea is the most widely intercropped legume with sorghum (1:2). Cotton is strip cropped with sorghum in 6−8:2 pattern. This practice has declined and is being replaced by cultivation of Bt cotton exclusively. High density cotton planting systems have further reduced the scope for strip cropping. However, to produce both food and fibre, strip cropping is desired. The sorghum hybrid 'CSH-6' has been identified as more suitable for mixed cropping while short-to-medium duration hybrids (CSH 16, CSH 17 and CSH 18, etc.) are suited for intercropping. Mixed cropping limits the use of animal-drawn implements. Both intercropping and mixed cropping systems limit the choice of herbicide, though pre-emergence herbicides such as pendimethalin/metolachlor can still be applied.

Intercropping of rabi sorghum with safflower (in the ratio of 4:2 or 6:3) and chickpea/lentil (in the ratio of 1:4) is recommended in deep black cotton soils. At Bijapur (Karnataka), intercropping rabi sorghum with senna in 1:3 proportion was more profitable than cultivating only senna. For enhancing and diversifying millet production in the country, intercropping systems of tall growing sorghum with all other millets (except finger millet) have also been developed.

Traditionally, cotton is rotated with sorghum (biennial rotation) under rainfed conditions in Madhya Pradesh, Gujarat and Maharashtra. However, declining prices of sorghum have forced farmers to shift to monocropping of Bt cotton from biennial rotations with sorghum. In Tamil Nadu, crop rotation systems of cotton–sorghum and cotton–pulse–sorghum were found promising to cotton-fallow system. Soybean–rabi sorghum sequence cropping was profitable for irrigated conditions. Important crop rotations involving sorghum are given below. Most of the high-varieties and hybrids mature in about 90−120 days, and thus sorghum fits well in many crop rotations. Important crop rotations are listed in Table 18.

TABLE 18. Sorghum-based crop rotations in India

North India	South/Central/Western and Coastal India
Sorghum–potato/rapeseed–wheat/tobacco	Sorghum–cotton–groundnut
Sorghum–wheat–cowpea/pearl millet	Sorghum–ragi–groundnut
Sorghum–wheat–green gram	Sorghum–cotton
Sorghum–pea/oat/berseem	Groundnut–sorghum (rabi)
Sorghum–gram/barley	Urd bean/mung bean–sorghum
Sorghum–lentil/chickpea	Sorghum–tobacco
Sorghum–safflower/mustard	Sorghum–urd bean/mung bean
Sorghum + pigeon pea–chickpea	Sorghum–sorghum (rabi)

Source: Authors' own elaboration
Note: + is intercropping; – is rotation

Agroforestry systems: In Haryana, Himachal Pradesh and Uttarakhand, intercropping sorghum–wheat with poplar is prominent. In Mizoram sorghum is cultivated as an intercrop in *Melia dubia* plantations, and in Karnataka and Maharashtra with teak (*Tectona grandis*).

Insect-pest management

Shoot fly (*Atherigona soccata*)

Shoot flies are seedling pests and typically appear from the first to the fourth week after germination. The maggots feed on the growing tips causing wilting of leaves and central leaf giving a typical appearance of thedead heart symptom. If the infestation occurs a l ittle later, damaged plants produce side tillers, but these also become infested leading to a rapid build-up of pest population. To schedule chemical control, shoot fly infestation can be monitored by checking for eggs on the lower surface of the seedling leaves prior to the formation of dead hearts (Figure 21).

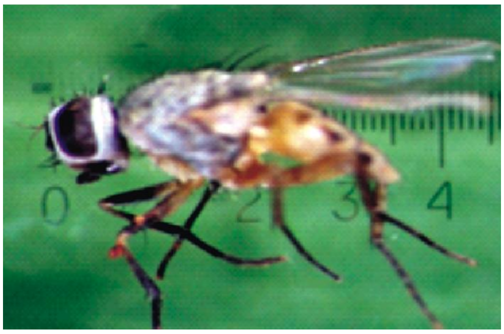

FIGURE 21. Dead heart formation in sorghum **FIGURE 22.** Adult shoot fly

Management

Shoot fly management in sorghum can be achieved through a combination of cultural, chemical and varietal practices. Adjusting the sowing time so that the vulnerable stage of the crop does not coincide with peak shoot fly activity is important. Sowing within 7–10 days of the onset of rains helps in kharif, while for the rabi crop, planting by the end of September or the first week of October reduces damage. Destroying seedlings with dead heart symptoms, after they have been removed, prevents further spread. Using a higher seed rate, about 1.5 times the recommended rate, ensures an optimum plant stand in kharif. Seed treatment with thiomethoxam 30 FS at 10 ml per kg seed along with neem oil at 2 percent per kg seed, protects seedlings up to four weeks of age. Seed treatment with imidacloprid 70 WS at 2 g per kg seed is also effective. Application of carbofuran 3G at 20 kg per hectare at sowing provides good control. Intercropping sorghum with pigeon pea in a 2:2 proportion further reduces shoot fly incidence. Using resistant cultivars such as Phule Anuradha and Parbhani Moti for kharif, and Giddi Maldandi for rabi, can be a reliable strategy for managing shoot fly.

Stem borer [*Chilo partellus* (Swinhoe, 1885)**]**

This pest attacks the crop from about two weeks after germination and continues until crop harvest.Initially, the larvae feed on the upper surface of whorl leaves leaving the lower surface intact creating transparent windows. Irregular-shaped holes appear on the leaves as the early instar larvae feed in the whorl.

As the severity increases, ablend of punctures and scratches of epidermal feeding is prominent. Drying of central shoot gives the characteristic dead heart appearance. After the emergence of the panicle, the larvae tunnel into the peduncle causing it to break or resulting in complete or partial chaffy panicles.

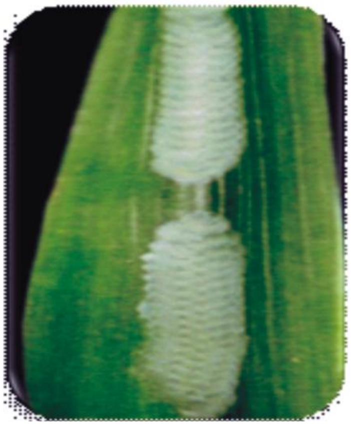

FIGURE 23a. Shoot fly egg on of sorghum leaf

FIGURE 23b. Damage caused by shoot fly larvae on leaves

FIGURE 23c. Close view shoot fly larvae

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FIGURE 24. Spotted stem borer adult

FIGURE 25. Stem borer tunnelling in stem

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Management

Stem borer management in sorghum requires a combination of preventive and chemical measures. Uprooting and burning stubbles, along with chopping of stems from the previous crop, helps prevent carryover of the pest. Carbofuran 3G can be applied at 8–12 kg/ha inside the whorls of leaf-injured plants at 20 days and 35 days after emergence, depending on the need. Intercropping sorghum with cowpea also reduces pest incidence. Carbofuran 3G at 10–12 kg/ha applied in the whorl at 30–35 days after germination is effective. When the damage is severe and indicated by more than 10 percent dead hearts, spraying chlorantraniliprole at 0.3 ml per litre of water is recommended. Uprooting and burning of stubbles and chopping of stems of the earlier crop is recommended to prevent its carryover.

Shoot bug (*Peregrinus maidis*)

Being a sporadic pest, under favourable conditions, it produces several generations and can cause heavy damage to sorghum. However, heavy infestation is seen on the rabi crop, when rain occurs at seedling stage. Both the adult type (Branchypterous and Macropterous) and nymphs suck the plant sap causing reduced plant vigour and yellowing. In severe cases, the younger leaves start drying and damage gradually extends to lower leaves. Sometimes, complete plant death occurs. Heavy infestation at vegetative stage may twist the top leaves and prevent either the formation or emergence of panicles (Figure 26).

FIGURE 26. Shoot bug damage on sorghum

FIGURE 27. Adult shoot bug

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Management

Shoot bug management in sorghum can be achieved through a combination of cultural, biological and chemical practices. Integrating several cultural methods helps to reduce the build-up of insect populations. Removing alternate host grasses prevents shoot bug from multiplying. Releasing natural enemies such as the ladybird beetle (*Coccinella septempunctata*), the predatory bug (*Geocoris tricolor*) and egg parasitoids like *Paranagrus optabilis* is beneficial in reducing pest population. Infested plant parts should be collected and destroyed and yellow sticky traps (10–156 per hectare) can be used to catch adult insects. Crop rotation with non-hosts; timely sowing to avoid peak pest periods; and removal of weeds and crop residues, further reduces pest pressure. Chemical control by foliar sprays of 2.5 ml dimethoate 30 percent EC and 1.5 g acephate 75 percent WP, each diluted in a litre of water, is also effective in managing shoot bugs.

Aphids (*Melanaphis sorghi*) & (*Melanaphis sacchari* Zehntner)

Aphids occasionally cause damage to sorghum seedlings. Attack during boot stage may result in poor panicle exertion. However, after panicle emergence, their population rapidly declines.

Bigger plants in boot and later stages generally tolerate larger populations without any significant damage. Both the adults and nymphs suck the sap (phloem feeders). Heavily infested leaves show yellowish blotches and necrosis may occur on the leaf edges. Aphids produce abundant honeydew which predisposes the plant to sooty and other sporadic fungal pathogens. The honeydew excretion hinders the harvesting process and leads in poor quality grain. Severe damage can occur under moisture stress conditions resulting in drying of leaves. Dried leaves with hindered plant photosynthesis may lead to perishing of the plant. Unlike the corn leaf aphid, sugarcane aphid predominantly is a serious pest in the rabi crop and prefers to feed on older leaves and also infest younger leaves including panicle at the flowering stage. Adults are yellow to bluff coloured. Both adults and nymphs suck the plant sap and cause stunted growth. Under field conditions, the occurrence of 40 aphids per leaf have been determined as the economic threshold level (Figure 28 and Figure 29).

FIGURE 28. An aphid infested sorghum leaf

FIGURE 29. A single aphid on sorghum leaf

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Management

Aphid management in sorghum involves both preventive and chemical approaches. Destroying wild host plants before planting, especially johnsongrass (*Sorghum halepense* L.), helps reduce the risk of aphid migration into fields. Seed treatments with thiamethoxam, clothianidin, or imidacloprid can effectively suppress aphid infestations for 4–6 weeks after planting. Spraying Oxydemeton-methyl 25 EC at 1 litre per hectare in 500 litres of water also provides good control. Applications of dimethoate at 0.56 kg a.i/ha and chlorpyriphos at 1.12 kg a.i/ha are used for aphid management, though chlorpyriphos is harmful to beneficial insects and both the chemicals may occasionally trigger aphid outbreaks. Newer options such as sulfoxaflor at 23 g a.i/ha (Corteva Agriscience, United States of America) and flupyradifurone at 0.29–0.51 litres per hectare (Bayer Crop Science, Germany) have been found effective in controlling aphids.

Sorghum midge

Midge (*Contarinia sorghicola*) is a tiny yet devastating pest that attacks sorghum in tropical and subtropical regions. Maggots feed on the developing ovary, preventing grain formation. The life cycle is completed in approximately 15–17 days allowing the pest to produce up to 10 to 12 generations per season. The larvae overwinter in the spikelets during December–January, resuming activity when conditions become favourable. Infested panicles become sticky as a result of larval feeding and frass, and despite flowering, no grain formation (empty panicles) is seen and the panicles dry prematurely.

FIGURE 30. Midge-affected sorghum panicles **FIGURE 31**. Adult midge

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Fall armyworm (FAW)

Fall armyworm (FAW), *Spodoptera frugiperda*, is a major invasive pest threatening sorghum production across tropical and subtropical regions.

After maize, sorghum is the second-most affected crop by this pest. The crop is susceptible to FAW from the seedling stage up to the V6 stage. This pest can cause complete defoliation and seedling death. During the vegetative stage, windowing and shot-hole damage on leaves are seen. During the reproductive phase, larvae feed on panicles and developing grain (Figure 32 to Figure 35).

Biological management through *Trichogramma spp.*, *Telenomus remus* egg parasitism along with spraying of neem-based formulations is effective against early-stage larvae.

FIGURE 32. FAW egg mass **FIGURE 33.** Fully-grown FAW larvae

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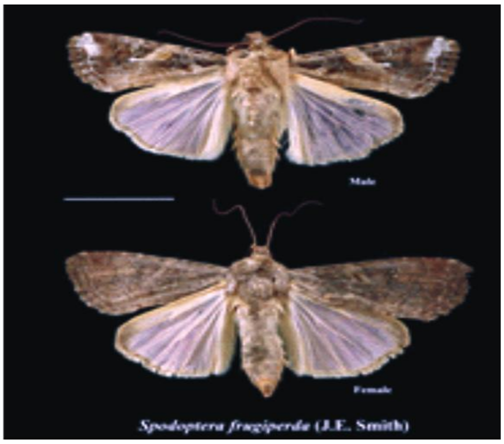

FIGURE 34. Sorghum plant damaged by FAW **FIGURE 35.** Adult FAW

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Nematode

The nematode *Heterodera sorghi* has been reported in sorghum in Andhra Pradesh, but the yield losses were minimum (Sharma and Sharma, 1988).

Disease management

Anthracnose

Anthracnose is a fungal disease in sorghum caused by *Colletotrichum graminicola*. The first symptoms of anthracnose are visible as dark lesions on the leaves, often accompanied by red or orange pigmentation. These lesions later expand into necrotic patches and reduce photosynthesis (Figure 36). The infected stems may develop soft rot, weakening the plant's structure and causing panicle collapse, which adversely affects grain development. In severe cases, anthracnose significantly reduces grain quality by causing premature grain deterioration and mould formation. The conditions that favour the development of this disease are high humidity, temperatures between 28–30°C and continuous rainfall or irrigation stress.

Management

Anthracnose in sorghum can be managed through a combination of chemical, cultural and varietal practices. Treating seeds with at 3 g/kg of seed and applying foliar sprays of mancozeb at 0.25 percent or carbendazim at 0.1 percent, provides effective control. Destroying infected plant debris and collateral hosts helps to reduce the source of infection. Crop rotation with non-host crops further minimizes disease pressure. Additionally, growing resistant varieties such as SPV 162 and CSV 17 has been explored and found to be a dependable approach to managing the disease.

FIGURE 36. Anthracnose leaf symptoms

FIGURE 37. Leaf blight symptoms in sorghum

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Leaf blight

Leaf blight of sorghum caused by *Exserohilum turcicum* (Pass.) Leonard and Suggs. (Syn. *Helminthosporium turcicum*), is a destructive polycyclic foliar disease that significantly reduces photosynthetic area, especially under humid conditions. Initial symptoms appear as small, narrow, elongated spots that expand along leaf veins. They become long, elliptical necrotic patches with straw-coloured centres and dark margins. In advanced stages, lesions coalesce, giving leaves a scorched or “burnt” appearance (Figure 37). It also causes seed rot and seedling blight, reducing stand establishment. The primary source of inoculum for the disease is infected crop debris or the soil.

Leaf blight in sorghum can be effectively managed through a combination of chemical, cultural, and biological practices. Treating seeds with thiram at 4 g/kg seed, or applying mancozeb at 1.25 kg/ha helps control the disease. Using disease-free seeds, removing infected crop residues, rotating sorghum with non-host crops and maintaining optimal plant densities contribute to lowering disease pressure. Biological control is also effective. Applying *Trichoderma harzianum* at 2×10^8 cfu/g at 0.4 percent prior to fungicidal sprays has been shown to lower disease intensity.

Grain mould

Grain mould is a complex fungal disease caused by *Fusarium moniliforme*, *Curvularia lunata*, *Alternaria alternata* and *Phoma sorghina*.

Grain moulds are severe during the years of prolonged rainfall at the time of grain maturity. Moderate temperature (25−35 °C) and high relative humidity (greater than 90 percent) favour infection and subsequent disease development. The pathogen can be soil-borne, air-borne, or carried on plant residues. Grain mould results in discoloration of grain.

Severe infection reduces grain weight and size leading to considerable yields losses (25−100 percent) and a reduction in the market price by 30−40 percent. Infected grains have reduced germination and nutritive value (Figure 38 and Figure 39). The toxins produced in moulded grains render them toxic to animals and poultry birds when included in their feed.

FIGURE 38. Sorghum panicle infested by grain mould
© Das I. K, ICAR-IIMR, Hyderabad

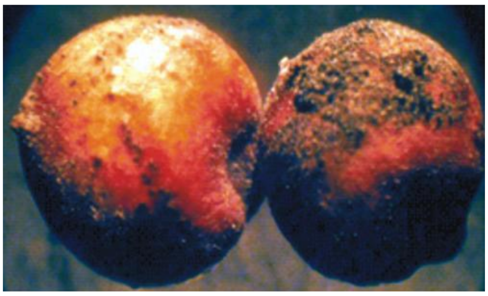

FIGURE 39. A sample of sorghum grain infected with sorghum mould fungi
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Management

Grain mould can be minimized by avoiding cultivars that mature during the rainy season. By using longer-duration, photoperiod-sensitive cultivars the grain is not exposed to high humidity at maturity. Harvesting genotypes at physiological maturity and drying them promptly reduces mould incidence; delayed harvest should be avoided. Growing mould-tolerant cultivars such as hybrids CSH16, CSH27, CSH30, and varieties such as CSV20 and PVK801, is recommended. Seed treatment with *Trichoderma viride*, *T. harzianum*, and *Pseudomonas fluorescens* has been effective in checking fungal growth. Effective management can also be achieved by spraying the earhead three times with aureofungin (200 ppm) and 0.2 percent captan at 10-day intervals starting from flowering. Alternatively, three sprays of captan (0.3 percent) combined with mancozeb (0.3 percent) or propiconazole (0.2 percent) at 10-day intervals from flowering can also control grain mould.

Charcoal rot (*Macrophomina phaseolina* (Tassi.)

In infected sorghum plants the roots and lower stems exhibit water-soaked lesions that slowly turn brown or black and the pith of the infected stalk disintegrates across several nodes. Symptoms such as stunted growth, smaller stalks than normal, loss of quality and quantity of fodder are seen (Figure 40 to Figure 42). In rabi sorghum, the disease can cause 21−64 percent loss in grain yield, primarily because of reduced seed size.

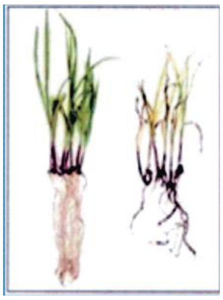

FIGURE 40. Seedling radicle rot

FIGURE 41. Charcoal rot-affected stem
© Pandhare, 2014

FIGURE 42. Premature lodging of stem

Management

Charcoal rot can be managed through several indirect practices. Using minimal dose of nitrogen fertilizer and maintaining low plant densities helps reduce the disease. Mixed cropping and crop rotation are also effective in lowering its incidence. Moisture conservation practices, such as applying wheat straw mulch, provide an advantage in suppressing symptoms of the disease. Growing varieties and hybrids that are resistant to stress conditions is considered more economical. Soil treatment with thiram at 4.5 kg/ha during sowing can reduce charcoal rot by about 15 percent. Similarly, seed treatment with a talc-based formulation of *Pseudomonas chlororaphis* at 10 g/kg of seed lowers disease incidence. Cultivating tolerant cultivars such as CSV19R, CSV216R, and DSV6 is also an effective strategy to manage charcoal rot.

Smut

Sorghum is affected by several smut diseases – grain smut/covered smut *(Sporisorium sorghi*), loose smut (*Sporisorium cruenta*), long smut (*Tolyposporium ehrenbergii*) and head smut (*Sporisorium reilianum*). Amongst these, the most destructive form is grain smut, also known as kernel smut or short smut. The disease is prevalent in Tamil Nadu, Andhra Pradesh, Uttar Pradesh, Madhya Pradesh and Maharashtra.

Individual grains on the ear are replaced by smut sori, which occur usually when ovaries get infected. The ovary is replaced by an oval or conical dirty-grey sac, which is surrounded by the unaltered glumes at the base. Most of the infected grains of earhead are replaced by the sori covered with a membrane-like fungal structure (Figure 43).

Formulations based in the systemic fungicide metalaxyl and thiram-based formulations also provide better control of smut diseases. Smut can be managed effectively with seed treatment fungicides. Metalaxyl and thiram proved particularly effective against covered kernel smut.

FIGURE 43. Smut-infested sorghum panicle
© Das I. K, ICAR-IIMR, Hyderabad

FIGURE 44. Maize stripe virus symptoms in sorghum
© Basvaraj Raigond, ICAR-IIMR, Solapur

Viral diseases of sorghum

With the use of high-yielding varieties under intensive cultivation and changing climate, an increasing incidence of viral diseases in sorghum have been reported. This is more prevalent in rabi sorghum grown under protective irrigation. In India, sorghum is infected by several viral diseases. These include sugarcane mosaic virus (SCMV), maize dwarf mosaic virus (MDMV), johnsongrass mosaic virus (JGMV), sorghum mosaic virus (SrMV) and sorghum red stripe virus-India isolate (SRSC-Ind), all belonging to the genus *Potyvirus*. Maize stripe virus (MStV) belonging to the genus *Tenuivirus* and maize mosaic virus (MMV) belonging to *Rhabdovirus* also affect sorghum. In addition, sugarcane streak mosaic virus (SStMV) causing mosaic symptoms was reported in Andhra Pradesh (Srinivas et al., 2010) while sugarcane streak mosaic virus (SCSMV) and sugarcane yellow leaf virus (ScYLV) were reported in Tamil Nadu (Viswanathan et al., 2023)

Stripe virus

The occurrence of maize stripe virus sorghum strain (MStV-S) was first reported in India during the 1990s with more prevalence in peninsular India. An incidence of 10–20 percent was recorded in rabi sorghum with a grain yield loss of five percent and fodder yield loss of 10 percent in the crop. The appearance of continuous chlorotic stripes/bands between the veins of the infected leaf, progresses from the base towards the tip of the leaves and subsequently the leaves appear as yellow stripes (Figure 44). Disease incidence was observed during both kharif and rabi seasons, ranging from 10 percent to 30 percent. Affected plants exhibit stunted growth. Early infected plants die sooner before the emergence of earheads. Plants infected at later stages appear dwarfed with short internodes. They show partial earhead exertion with few or no seed formations.

Plant hoppers (*Peregrinus maidis*) are known vectors in the transmission of MStV-S. Nymphs and the macropterous females are more efficient transmitters of MStV than the males. The infection significantly reduces grain yield and the quality of forage (protein content and soluble solids).

Management

No direct methods are available to control viral diseases, therefore, indirect practices are employed to minimize yield losses. Delayed sowing in October instead of September helps reduce the incidence of stripe virus disease because the pressure from insect vectors gets reduced. Removing weed hosts, cutting down ratoons and eliminating plants that show symptoms also help in managing the disease. In addition, spraying oxydementon methyl or methyl-S-demeton 35EC at 5 ml for 10 litres of water every 15 days, beginning from 20 days after emergence, can control insect vectors and limit the spread of the disease.

Sorghum red stripe virus (SRSV)

In India, sorghum red stripe virus (SRSV) was first reported in Maharashtra in 1977. The virus has been reported to infect several grain sorghum cultivars in the Parbhani and Marathwada regions in the state.

The virus initially manifests as a mosaic pattern on the leaves, followed by the development of red stripes that later turn necrotic depending on the temperature. Finally the entire leaf turns red and becomes necrotic. A major outbreak of this disease was reported in Solapur and adjoining regions of Maharashtra in the year 2010. The symptoms of red stripes on leaves can be seen in Figure 45.

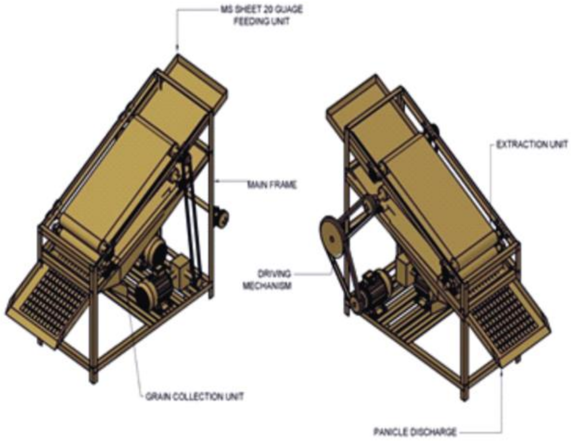

FIG 45. Red stripe virus symptoms in sorghum
© Basvaraj Raigond, ICAR-IIMR, Solapur

FIG 46. Isometric view of sorghum grain (hurda) thresher
© Dr Panjabrao Deshmukh Krishi Vidyapeet, Akola

Zonate leaf spot (*Gloeocercospora sorghi* Bain and Edgerton)

This is an important disease in sorghum crops. The disease appears as small lesions on lower leaves that become circular, turn into large purple-red or dark-brown lesions with 2–8 rings. Semi-oval shaped lesions occur along the leaf margin or near the midrib. In the advanced stages, dark-red to blackish-purple or brown lesions on leaves and leaf sheaths coalesce and the entire area gets blighted. Some zonate lesions do not have a target appearance and the size is variable. Severely infected seeds are red, red-brown, or dark brown with black oval spots on the seed surface.

Crop rotations, removal of crop residues, field sanitation, biopriming seeds with *Trichoderma harzianum* followed by two foliar sprays is effective in disease management. Seed treatment with carbendazim along with one or two foliar sprays is most effective in reducing the severity of this disease.

Grey leaf spot (*Cercospora sorghi* Ellis & Everh)

Grey leaf spot is a late-appearing disease, usually observed at crop maturity stage, and is of moderate importance in southern parts of India.

Crop rotation, use of healthy resistant cultivar seeds, field sanitation, removal of infected plant and seed treatment with thiram or captan at 4 g/kg seed is useful in disease management.

Harvesting

The grain crop should be harvested at physiological maturity (95−115 days). There is no need to wait for stalks and leaves to dry as hybrid sorghum plants appear green even at physiological maturity. Continuous rainfall keeps plants green despite grain maturity, particularly so in stay-green cultivars during the kharif season. However, in rabi season, rainfed crop shows uniform drying/yellowing of leaves. The optimal time to harvest for grain purposes is when the seeds become hard and contain less than 25 percent moisture.

Generally two methods of harvesting are adopted – stalk cutting and earhead cutting with sickles. In India, combine harvesters for sorghum are gaining popularity, particularly in Maharashtra, Karnataka and Telangana where large-scale cultivation of sorghum is common. However, mechanical harvesting of sorghum is more challenging compared to crops like wheat or rice because of its tough stalks, variable panicle height and the risk of grain shattering. Use of quality seeds may ensure uniform crop maturity and panicle height. Several combine harvesters from various manufacturers are available in India for harvesting sorghum. In case of the stalk cut method, plants are cut close to the ground level. The stalks are tied into bundles of convenient sizes and stacked on the threshing floor. After 2–3 days, the earheads are removed from the plants. In the earhead cutting method, instead of the entire stalk only the earheads are removed from the standing crop and collected at the threshing floor, where they are sun dried for 3–4 days before threshing.

Hurda crop is harvested at the soft dough stage of grains, 15–20 days prior to physiological maturity of the crop. A power-operated hurda sorghum grain extractor with a capacity of 180 kg/hour, consisting of extraction unit and cleaning unit, was designed and developed at Dr Panjabrao Deshmukh Krishi Vidyapeet (PDKV) in Akola (Maharashtra). The extractor is an economical tool for separation of hurda grain (Figure 46).

For fodder purposes, sorghum is harvested at 50 percent flowering stage (approximately 60−65 DAS). In north India, because of delayed flowering, harvesting single-cut cultivars at 80 DAS is recommended irrespective of flowering. Multicut sorghums in north India are grown under irrigated conditions in summer by sowing in April. The first harvest is done at 60 DAS followed by two subsequent cuts at 45-day intervals.

Threshing of earheads is done either by beating them with sticks or by using bullocks to trample them. The later method is quicker and adopted by majority of the farmers. Threshing is also done with the help of threshers. The threshed grain should be cleaned and sun dried for 6−7 days to reduce the moisture content down to 13–15 percent, which is optimum for safe storage. Bagging of the grains is done in plastic or gunny bags for immediate sale.

Yield

Grain yield

A kharif sorghum crop can yield grains up to 1.0 t/ha in harsh environments. However, up to 5.0 t/ha yields were realized in Madhya Pradesh and Uttar Pradesh because of favourable soil moisture and high external input use. A rainfed rabi crop, depending on soil depth, produces grain yields ranging from 0.5 t/ha in shallow soils (depth less than 45 cm) to 1.5 t/ha in deep soils (depth greater than 90 cm). An irrigated crop can yield up to 3 t/ha depending on management practices. Stover forms an important by-product because it supports livestock feeding requirements. Stover yield ranges from 3–8 t/ha.

Hurda sorghum can produce 2−3 t/ha of grain and 12−15 t/ha of nutritious green fodder which is superior in quality to stover. In Maharashtra, an agrotourism industry revolving around the consumption and cultivation of hurda sorghum is gaining popularity.

Stover yield

A large quantity of stover is produced from the grain sorghum crop because of its low harvest index. However, thick stems prevent their complete utilization as feed for small ruminates. The rainfed rabi sorghum crop serves a dual purpose – that of stover production as well as grain production – as both are equally important. Stover production ranges from 3–12 t/ha. The use of stover in the manufacture of cardboards and production of biofuel is gaining prominence.

Fodder production

Sorghum crops produce a large quantity of green fodder. Single-cut cultivars provide up to 50 t/ha, while multicut sorghums yield 100−120 t/ha.

Utilization pattern

Sorghum is mainly cultivated in India for consumption as food. According to FAO (2023), the total grain produced was 4.42 Mt (2018–2020). Of this 90.7 percent is utilized for food, 1.4 percent for animal feed, 3.3 percent for other purposes (non-food, seed and processing) and 4.6 percent accounts for grain losses.

Export

During 2022, 43 620 tonnes of sorghum valued at USD 18.64 million were exported. These exports included sorghum intended for use as seed as well as for staple food purposes.

Support price

Sorghum is the second millet crop in India to have a minimum support price (MSP). For 2025/26 season, the MSP of sorghum grain is INR 36 690 per tonne of sorghum (hybrid) and INR 37 490 per tonne of sorghum (Maldandi).

Seed production

Sorghum is often cross-pollinated and for certified seed production, an isolation distance of 200 metres is recommended. Open pollinated varieties (OPV) have a seed multiplication ratio of 160.

Hybrid seed production

Hybrid seed production is an important economic activity, and private companies are entering into contracts with farmers and undertaking the production of certified hybrid seeds. For efficient hybrid seed production, temperatures of 27–32 °C during the flowering stage is ideal. At night temperature below 11 °C for a prolonged period is not suitable. Flowering and seed development stages should not coincide with rainfall, as rains cause pollen loss and grain mould incidence leading to deteriorated seed quality. Sorghum seed production is mostly undertaken during kharif season in Maharashtra, Madhya Pradesh, Rajasthan and Gujarat, while in the other sorghum growing areas, it is taken up during rabi or summer seasons. Seeds produced in seasons other than kharif have good germination and vigour. Seed production in rabi is predominantly concentrated in Andhra Pradesh and in the adjoining regions of Karnataka because of favourable ecological conditions.

Certified seed production involves plating of A:R lines in the ratio of 5:2 with four rows of R-line around the plot to ensure adequate pollen supply. A-line (female line) is planted at 60 cm × 20 cm spacing (8 kg/ha seed) while R-line (restorer line, male parent) is planted in solid rows at a spacing of 60 cm (4 kg/ha seed).

Synchronization of flowering is important for effective seed set and requires a fair understanding of the flowering time of parents at the seed production site. The use of growth regulators such as MH 500 ppm (delays flowering in early parent) and CCC 300 ppm, along with an additional dose of 50 kg N/ha (used to synchronize lagging parents) and a spray of one percent urea (boosts flowering in delayed parents) aids in synchronization. Selective irrigation of one parent is also practised to bring synchronised flowering to both parents. The problem of disparity of heights in parents can be overcome to some extent by planting the short parent on the raised ridges and the taller parent in the furrows. It is also advised to spray two percent borax to improve the pollen production and dispersal. For pollen dispersal, tapping the male plant or blowing air through an empty duster over the male heads is recommended.

Isolation of seed plots from other sorghum fields is essential for hybrid seed production. An isolation distance of 200 m for certified seed production (300 m for foundation seed) and

400 m for johnsongrass is maintained. Rogueing, involving the removal of off-types, pollen shedders and diseased plants on a daily basis during flowering, is an important activity in hybrid seed production. Harvesting and threshing should be done separately; male rows first, then female (hybrid seed). Harvested seeds are treated with captan or thiram at 2 g/kg and a halogen mix, for storage protection. Hybrid seed production from A line can reach up to 3000 kg/ha under optimal conditions.
In India, the hybrid seed production of sorghum is concentrated in states with favourable agroclimatic conditions, strong institutional framework and active public-private partnerships. The key players of hybrid seed production are listed in Table 19.

TABLE 19. Major sorghum hybrid seed-producing states

State	Role and highlights
Madhya Pradesh	Large-scale certified seed production; ideal for both kharif and rabi hybrids
Andhra Pradesh	Strong private sector involvement; active MoUs with ICAR-IIMR for hybrid seed production
Karnataka	Major contributor to forage and grain sorghum hybrids; suitable agroclimatic zones
Tamil Nadu	Advanced seed processing infrastructure; active in multicut forage hybrid production
Telangana	Home to ICAR-IIMR, Hyderabad; central hub for sorghum breeding and seed coordination
Maharashtra	Dominates post-rainy season sorghum seed systems; strong public-private seed networks
Uttar Pradesh	Focuses on forage sorghum hybrids; centre at Pantnagar contributes breeder and certified seed
Rajasthan	Emerging player in kharif sorghum hybrid seed production; suitable for dryland hybrids

Source: Authors' own elaboration

ICAR–IIMR coordinates hybrid development and seed dissemination. AICRP–Sorghum centres, located across 10 states, support region-specific hybrid trials and seed production. State agricultural universities play a key role in breeder and foundation seed multiplication. In Andhra Pradesh, Maharashtra and Telangana, private seed companies are actively involved with IIMR to produce seeds under MoUs (memorandum of understanding).

Hybrids for grain purpose have a seed multiplication ratio of 100−120 while forage types have a seed multiplication ratio of 100.

CHAPTER 4: Finger millet

Eleusine coracana (L) Gaertn

FIGURE 47. Field view of finger millet

© ICAR-IIMR, Hyderabad

Finger millet is often considered "a crop for the poor" or "a famine crop" because it gives good yields even with low inputs. FAO has also included it in its list of "future smart foods" (FSF). It is the third most important millet in India, after pearl millet and sorghum, yet it records the highest average grain productivity. Finger millet is nutrient-rich, uses water efficiently, withstands climate stress and stores well, making it a reliable staple in semi-arid regions. It is the richest source of calcium among cereals (364 ± 58 mg/100 g), containing three times more calcium than milk. It also has high dietary fibre (10–18 percent), balanced protein (6–13 percent), minerals (2.5–3.5 percent), phytates (0.48 percent), tannins (0.61 percent) and phenolic compounds (0.3–3 percent). The grains are especially good for people with diabetes. Because of its high nutritional value and health benefits, finger millet has long been a staple food in Karnataka, Uttarakhand, Odisha and many hilly regions of India. Finger millet is primarily cultivated for its grain throughout the year in different parts of India. The residual stalks are used as fodder and the green plants can also be conserved as silage.

In 2024/25, finger millet was grown on 1.248 Mha, producing 1.977 Mt. The major finger millet producing states in India are Karnataka, Tamil Nadu, Uttarakhand, Maharashtra, Odisha, Andhra Pradesh and Arunachal Pradesh (Table 20).

Climatic requirements

Finger millet grows well in tropical and subtropical regions and can be cultivated from sea level up to an altitude of 2400 metres on hill slopes. It prefers moist climates, with rainfall of about 100 cm, and can be grown throughout the year if there is sufficient moisture and if the temperatures remain above 15 °C. In areas with higher rainfall or those under irrigation, it is often raised as a transplanted crop. In India, finger millet is mainly grown as a kharif crop during the monsoon period, but it can also be cultivated as a summer crop and as a rabi crop in south India. The crop requires a minimum temperature of 8–10 °C for germination, with the optimum growth occurring at 26–29 °C. Yields decline when temperatures fall below

20 °C. The crop is highly sensitive to frost. Finger millet shows good tolerance to drought, however, its inability to withstand frost limits its cultivation in winter season in northern parts of India.

TABLE 20. Area, production and yield of finger millet in India (2024/25)

State	Area (Mha)	% of total	Production (Mt)	% of total	Yield (kg/ha)
Karnataka	0.879	70.43	1.359	68.74	1546
Tamil Nadu	0.064	5.13	0.242	12.24	3765
Uttarakhand	0.065	5.21	0.103	5.21	1583
Maharashtra	0.069	5.53	0.096	4.86	1397
Odisha	0.053	4.25	0.046	2.33	872
Andhra Pradesh	0.023	1.84	0.033	1.67	1456
Arunachal Pradesh	0.028	2.24	0.029	1.47	1038
Rest of the states	0.067	5.37	0.069	3.49	1030
Country	1.248	100	1.977	100	1584

Source: Directorate of Economics and Statistics, DAC&FW.
States arranged in descending order of their percent share of production

Soil

Finger millet is a versatile crop, and while it can grow on many types of soils with varying fertility levels, it favours porous and well-drained soils. Among cereals, finger millet has the highest tolerance to salinity. The most suitable soils are alluvial and loamy soils while deep black cotton soil and rocky soil are less suitable, because of poor drainage in black cotton soil and low fertility in rocky soil. The crop can still perform reasonably well on marginal lands with low fertility and in soils with a pH between 4.5 and 7.5. In the semi-arid tropics, where finger millet is commonly grown, soils are often deficient in both major and micronutrients and thus have low yields. Yields are further reduced because of continuous cropping, low and imbalanced use of fertilizers, non-existent recycling of crop residue and minimal application of organic manure.

Land preparation

Finger millet seeds are small, so the field must be prepared to a fine tilth. This is usually done by deep ploughing with a mould board plough, followed by harrowing with a cultivator, and finally levelling the field. In hilly regions such as Uttarakhand, where frequent ploughing is challenging, the soil should be thoroughly dug and turned, perennial weeds removed and the land should be smoothened. An inward slope with a shallow drain should also be provided to remove excess rainwater.

Varieties

Since 1969 more than 150 finger millet varieties have been developed using native and exotic germplasm under the All India Coordinated Millets Improvement Project (AICMIP). The work was strengthened with the creation of the Small Millets Improvement Project (AICSMIP) in 1986, which was initially based in Bengaluru and later shifted to IIMR, Hyderabad in 2023. Most varieties were developed through pure line selection (72) and recurrent selection (66), while mutation breeding (9) and somaclonal selections (GN 4 and Daploi-2) also contributed varietal development in a small scale. The primary focus of the finger millet improvement programme has been to produce high-yielding varieties that are resistant to drought and blast disease. More recently, biofortification in finger millet has focussed on improving its nutritional quality, especially by increasing the levels of essential micronutrients such as iron, zinc and protein. Finger millet varieties are classified into three groups based on crop duration: early maturing types that take 90–100 days, medium duration types that take 100–110 days and late maturing types that take more than 110 days. The important finger varieties recommended for cultivation in different states are given in Table 20.

TABLE 21. Recommended finger millet varieties for different states in India

State	Varieties
Karnataka	DHFM-78-3, Vakula (PPR 2700), Arjuna (OEB-526), VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), GPU 67, GPU 66, GPU 48, GPU 45, GPU 28, PR 202, MR 1, MR 6, Indaf 7, ML-365, KMR 340, KMR 301, KMR 204, KMR-630, CFMV-1 (Indrāvathi), Vegavathi (VR-929), Hagari ragi (HR-13), Siri (KMR-316), ML-322
Tamil Nadu	VL Mandua 376 (VL 376), Arjuna (OEB-526), GPU 28, CO-15, TNAU 946 (CO 14), Vegavathi (VR-929), CO 13, CO 12, CO 9, ATL-1 (TNEc 1285), CFMV-3 (Ekvijay), CFMV-1 (Indrāvathi), OUAT Kalinga Finger Millet-2 (Shreeprava /CFMV 7), ATL-2 (TNEC 1294)
Andhra Pradesh & Telangana	VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), VR 847, PR 202, VR 708, VR762, VR 900, VR 936 (Hima), Vakula (PPR-2700), Vegavathi (VR-929), VL-988, CFMV-1 (Indrāvathi), Tirumala (PPR-1012) CFMV-2 (Gira), CFMV-3 (Ekvijay), Gouthami (PR-10-45), Palem Ragi –38 (PRS 38), Gosthnai (VR 1099)
Jharkhand	VL Mandua 379 (VL 379), VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), A 404, BM 2, BM-3
Odisha	VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), Arjuna (OEB-526), OEB 10, OUAT 2, BM 9-1, OEB 526, OEB 532, CFMV-1 (Indrāvathi), CFMV-2 (Gira), Shree ratna (OUAT Kalinga Finger millet-1)
Uttarakhand	VL 379, VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), VL 348, VL 324, VL315, VL 149, VL 146, PES 400, PRM 1, PRM 2, VL-378, VL-382, Chhattisgarh ragi-3 (BR-14-3), VL Mandua 400 (CFMV-5), VL Mandua 402, VL Mandua 409, VL Mandua 408 (CFMV 6), VL Mandua 410 (CFMV 8)
Chhattisgarh	Chhattisgarh Ragi-2 (BR-336), Arjuna (OEB-526), VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), VL 324, VL 315, VL 149, Indira Ragi-1, Chhattisgarh ragi-3 (BR-14-3), BR7, GPU 28, PR 202, VR 708 and OEB-526, OEB-532, CFMV-2 (Gira), OUAT Kalinga Finger Millet-2 (Shreeprava /CFMV 7)
Maharashtra	VL Mandua 376 (VL 376), Phule Nachani 1 (KOPN 235), KOPLM 83, Dapoli 1, Dapoli 2 (SCN-6), Phule Kasari (KOPN 942), Dapoli -3, CFMV-2 (Gira), CFMV-3 (Ekvijay), OUAT Kalinga Finger Millet-2 (Shreeprava /CFMV 7)
Gujarat	VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), GNN7, GNN 6, GN 5, GN 4, GN-8, CFMV-2 (Gira), CFMV-3 (Ekvijay)
Bihar	VL Mandua 379 (VL 379), Arjuna (OEB-526), VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), RAU 8, VL379, OEB 526, OEB 532, Chhattisgarh ragi-3 (BR-14-3), VL Mandua 410 (CFMV 8), Rajendra Mandua-1 (RAUF-17)
Madhya Pradesh	VL Mandua 379 (VL 379), VL Mandua 376 (VL 376), VL Mandua 352 (VL 352), GPU 28, PR 202, Chhattisgarh ragi-3 (BR-14-3), VL Mandua 408 (CFMV 6)
Assam	VL Mandua 410 (CFMV 8)
All of India	Vegavathi (VR-929)

Source: Authors' own elaboration

In India, several finger millet varieties have been developed with special traits. For salinity tolerance, an important cultivar is CO-11 (EC 4849). This cultivar is high-yielding (3.5–4.0 t/ha), drought and salinity tolerant, photoperiod-insensitive and early maturing (in about 110 days). Another significant salinity-tolerant variety is Nirmal**,** which is blast resistant and suitable for saline soils with a short duration of 110 days. Some others are: ML 365, GPU 28, GPU 67 and Trichy-1**.** For high protein content, varieties such as CO-9 (9.6 percent protein), Hamsa and PRM-2 (more than 9 percent protein) have been developed. These cultivars combine yield potential with nutritional and stress-resilient traits, making them valuable for farmers.

Sowing/planting windows

Finger millet can be grown either by direct seeding under rainfed and irrigated conditions or by transplanting under irrigation. The optimum sowing time depends on the region. As a rainfed crop sowing usually begins with the onset of the southwest monsoon, from June in south India to August in north India. In Karnataka sowing may start as early as April or May for the early kharif season. Under irrigation, sowing time is more flexible and can be done during the rabi season from October to March, and in some areas it can be done even in summer from January to May. In Uttarakhand sowing is done in May–June in the mid- and high hills, and in June–July in valleys. In Bihar, Jharkhand, Maharashtra and Odisha, sowing is carried out in May–June. As an irrigated rabi crop in Karnataka, Tamil Nadu, and Andhra Pradesh, sowing is done in September–October, with late rabi sowing in Andhra Pradesh extending to November. In Karnataka, summer sowing is done in January, while in Tamil Nadu irrigated finger millet can be sown from April to December.

Seed rate and sowing / planting

Finger millet can be cultivated by broadcasting seeds, by line sowing or by transplanting nursery-raised seedlings. In the Konkan region of Maharashtra, farmers often use the *avatni* method, where uprooted seedlings are broadcast in the field to save labour. Amongst all these established methods, transplanting yields the highest grain production, while broadcasting yields the least. For good productivity, an optimum plant population of 0.4–0.5 million plants per hectare is needed. Line sowing using seed drills that maintain 22.5–30 cm spacing between rows is preferred. Since finger millet seeds are very small (about 400 seeds per gram), the recommended seed rate for drill sowing is 10 kg/ha, which provides about 4 million seeds. Even with seed drills, thinning within rows is necessary to maintain a distance of 7.5–10 cm between plants. For transplanting, 4–5 kg of seed is sufficient to raise the required seedlings per hectare, with a nursery area of about 150 square metres needed for each hectare of transplanting.

Nursery raising and transplanting

Finger millet nurseries are prepared on raised seed beds about 1.2 m wide, 7.5 m long and 10 cm high. Each bed is enriched with 50 kg of well-decomposed farmyard manure along with 1.0 kg single super phosphate, 0.5 kg muriate of potash and 0.75 kg of zinc sulphate. About 4–5 kg of seed is sown per hectare of nursery by opening rows at 7.5 cm spacing, usually during May–June. Seeds are covered with soil and a top dressing of 0.5 kg urea per bed is applied when seedlings are two weeks old. Seedlings aged 21–25 days are ideal for transplanting, though in the System of Ragi Intensification (SRgI), younger seedlings of 10–12 days are used. In the main field, one or two seedlings are transplanted per hill at a spacing of 20–25 cm × 8–10 cm. Because nursery raising and transplanting require substantial labour, farmers in the Konkan region of Maharashtra often practise the '*avatni'* method of cultivation. In some areas seedlings are placed in furrows, opened with a desi plough, and the next pass of the plough covers the roots with soil. In SRgI, single seedlings are transplanted in a square pattern at 30–60 cm spacing. Seedlings should be set 2–3 cm deep and the field should be irrigated on the third day after transplanting. Transplanted crops remain stable and do not lodge during rains.

System of Ragi Intensification (SRgI)

The system of ragi intensification (SRgI), also known as the *Guli* or *Guni* or *Netti* method and sometimes referred to as the system of finger millet intensification (SMFI), was developed by farmers in Haveri district (Karnataka) over the past 40 years to achieve higher grain yield. Although based on transplanting, it differs from the traditional transplanting method. In SRgI, young seedlings of 10–12 days old are transplanted at wider spacing in a square pattern (45–60 cm between rows and plants) with reliance on the use of organic manures for plant nutrition. Frequent inter-cultivation is carried out with a cono-weeder to improve root aeration, control weeds and to leave uprooted weeds as mulch on the soil surface. Fifteen to twenty days after transplanting, a light wooden plank or log (*koradu*) is dragged across the field in different directions to gently bend the plants. This practice removes the apical dominance, encourages more tiller formation and strengthens root growth, leading to better crop performance. Because of increased tillering, SRgI produces nearly double the yield compared to conventional transplanting, with grain yields reaching 2–2.5 t/ha.

FIGURE 48. Koradu/wooden log/plank

FIGURE 49. Passing of a koradu/wooden log/plank over ragi crop

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The SRgI has been successfully validated and scaled up through the efforts of several NGOs and agencies. These include Professional Assistance for Development Action (PRADHAN) in Jharkhand**,** Pragati in Odisha**,** People's Science Institute (PSI) in Uttarakhand **and the** Agricultural Technology Management Agency (ATMA) in Chhattisgarh**.** Their involvement has helped demonstrate the effectiveness of SRgI and promote its wider adoption among farmers.

Manure and fertilizers

Finger millet responds well to fertilizer application under both rainfed and irrigated conditions, though the recommended dose differs. For rainfed crops, applying 5 t/ha of FYM along with 40-20-20 kg/ha of N-P_2O_5-K_2O is advised. In Odisha, farmers also use 2.5–5.0 t/ha of *Gliricidia* green leaf manure, which provides nutrients while helping with weed control and moisture conservation. Integrated nitrogen management, where 25 percent of N comes from FYM, 25 percent from *Gliricidia* and the remaining 50 percent from urea, has shown better results than using urea alone. Similarly, applying 75 percent of the recommended N combined with 5 t/ha FYM and *Azospirillum* seed treatment has performed as well as full N fertilizer application. For irrigated finger millet crops, the recommended fertilizer dose is 100-50-50 kg/ha of N-P_2O_5-K_2O, although the crop can respond positively to nitrogen levels as high as 150 kg/ha. In acidic soils additional application of 50 kg magnesium and 16.8 kg calcium has been found beneficial.

The Leaf Colour Chart (LCC) for finger millet was developed by IIMR to guide nitrogen (N) top dressing. Beginning from 20 days after sowing or 15 days after transplanting, the colour of the topmost fully opened leaf is compared against a six-panel LCC strip. When the leaf colour reading falls below the threshold level (4.0), 20 kg/ha nitrogen fertilizer is applied as a top dressing for rainfed and irrigated line sown crop while 40 kg/ha is applied for the transplanted crop. This practice helps adjust N application according to crop need, ensuring optimum growth and yield while avoiding excess or insufficient fertilizer use (Gangaiah and Tara Satyavathi, 2024).

For rainfed finger millet, all fertilizers should be applied as a basal dose at sowing, placed 8–10 cm deep in the soil. When rainfall is favourable, 50 percent of the nitrogen is applied as a basal dose and the remaining 50 percent is top-dressed in two equal splits at four and six weeks after sowing. Research by AICSMIP at Bangalore, Mandya, Ranchi and Vizianagaram during the 2021 and 2022 kharif seasons showed that applying 75 percent of the recommended fertilizer dose (RDF) along with 2 percent foliar spray of 19-19-19 NPK fertilizer at panicle initiation, flowering and grain development stages resulted in 23.2 percent higher grain yield (3091 kg/ha) compared to when 100 percent RDF alone was applied. This highlights the benefit of combining reduced basal fertilizer with targeted foliar nutrition for better yield efficiency. Fertilizer recommendation for finger millet (rainfed and irrigated) in different states is given in Table 22.

TABLE 22. Recommended fertilizers for finger millet across different states in India

State	Fertilizers (N-P_2O_5-K_2O kg/ha)	
	Rainfed	Irrigated
Andhra Pradesh	40-20-20	60-30-30
Bihar	40-20-20	40-20-20
Jharkhand	40-20-20	40-20-20
Gujarat	40-20-10	–
Himachal Pradesh	40-20-00	–
Karnataka	50-40-25	100-50-50
Maharashtra	25-20-00	50-25-0
Chhattisgarh	60-30-20	–
Madhya Pradesh	40-40-00	–
Odisha	40-20-20	60-20-20
Tamil Nadu and Uttarakhand	40–60-20–30-20	90-45-45

Source: Authors’ own elaboration

Biofertilizers

Treating finger millet seeds with *Azospirillum brasilense* (a nitrogen-fixing bacterium) and *Aspergillus awamori* (a phosphorus-solubilizing fungus) at the rate of 25 g/kg of seed enhances crop establishment. Using the liquid form of NP biofertilizers at 4 ml/kg of seed has shown superior results compared to carrier-based formulations. When seed-dressing chemicals such as thiram (2.5 g/kg of seed) are required, the seeds should first be treated with the chemical and then with biofertilizers at the time of sowing. This sequence ensures both protection against seed-borne diseases and effective microbial inoculation for improved nutrient uptake.

Organic finger millet nutrition

In organic finger millet farming, inputs like *Glyricidia* green leaf manure, farmyard manure (FYM), and NP biofertilizers have proven effective. A promising practice in Tamil Nadu involves applying 6.5 t/ha of FYM as a basal dose**,** incorporating sunn hemp green manure at 45 days after sowing (DAS)**,** and spraying 3 percent Panchakavya on the crop. For rainfed organic systems in Uttarakhand, special varieties such as VL-378 and VL-382 have been developed to suit local conditions. These approaches combine nutrient recycling, organic amendments and varietal selection to improve yields and sustainability under organic management.

Weed management

Weeds are a serious threat to finger millet productivity, although the crop has some inherent ability to suppress weed growth. In irrigated transplanted finger millet, the first 4–6 weeks after planting are critical for crop-weed competition, while in rainfed seeded finger millet, the first five weeks are critical. Uncontrolled weeds can smother the crop and reduce yield by 5–75 percent, with grasses being more competitive than sedges or broadleaved weeds. Wild relatives such as *Eleusine indica* and *E. africana* are noxious weeds that closely resemble cultivated finger millet and can only be distinguished at the flowering stage. More than eighty weed species are associated with finger millet in India, and *Striga asiatica*, a hemi-parasitic annual weed, parasitizes the crop and causes serious problems.

Two rounds of manual weeding or hoeing at 15-day intervals beginning from 20–25 days after sowing are recommended. Pre-emergence spray of oxyflurofen (0.1 kg /ha (in irrigated areas) effectively weeds for 25–30 days after application. Other pre-emergence options include: bensulfuron-methyl 0.6 percent G and pretilachlor 6 percent G (0.75 kg/ha; ready mix), butachlor (0.75 kg/ha), oxadiargyl (150–200 g/ha) or pretilachlor (0.5 kg/ha) applied at 3 DAS/DAT. Applying pre-emergence herbicide followed by one hand-weeding at 30–35 DAS/DAP provides the most effective weed control in both transplanted and direct-seeded crops.

In irrigated and assured rainfall conditions, post-emergence application of 2,4-D Na salt (0.75 kg/ha) at 20–25 DAS controls broadleaved weeds including striga. Bispyribac sodium (15 g/ha) and penoxsulam (20 g/ha) are also recommended for post-emergence spray at 15–20 DAS/DAP. Metolachlor (2.2 kg/ha) inhibits striga attachment to host roots by up to 80 percent. Post-emergence application of chlorosulfuron and dicamba is also effective in managing striga.

Water management and moisture conservation

Finger millet is predominantly a rainfed kharif crop, with nearly 89 percent of the area cultivated without irrigation, dependent solely on rain water. Irrigation at tillering and flowering stages helps increase yield when there are long dry spells. Flowering is the most critical stage for moisture. Studies at Bengaluru, Hagari, Jagdalpur and Karaikal in 2021 and 2022 showed that crop residue mulch at 5.0 t/ha with hydrogel at 7.5 kg/ha conserved moisture and improved grain and straw yields. Drought-tolerant cultivars such as K 1, Dibya Sinha and KM-65 are useful in reducing drought effects. These varieties have traits such as stay-green, strong roots, purple pigmentation, early flowering and early maturity. Other drought-tolerant varieties include PR 202, Udaya, KMR 340 and ML 365. In rabi and summer seasons, finger millet is grown with protective irrigation. During rabi the crop needs 2–3 irrigations at tillering, flowering and grain filling stages. Transplanted crops need extra irrigation three days after planting to ensure uniform establishment. After seedlings are established, water is withheld for two weeks to promote healthy growth. The total water requirement of finger millet is about 350 mm. In kharif season good drainage is important during periods of heavy rainfall.

Cropping systems

Finger millet is widely grown as part of mixed cropping, intercropping, crop rotations and agroforestry systems. Mixed cropping with niger, amaranthus or soybean is practised in different regions. Intercropping with legumes such as pigeon pea, soybean, green gram, horse gram, common bean and groundnut is common, as legumes improve finger millet performance through biological nitrogen fixation and phosphorus solubilization. Nitrogen fixation is more effective under low nitrogen application. However, finger millet being a cereal, requires high nitrogen fertilizer. Therefore, a system of transplanting finger millet after the legume is established, can be beneficial. Application of NPK at 60:13.3:25 kg/ha has been found to maximize the performance of finger millet with grain legume systems such as pigeon pea and groundnut. Intercropping finger millet with early-duration pigeon pea at a row ratio of 2:4 gives higher productivity and economic returns compared to systems with medium-duration varieties. Intercropping with the green manure legume desmodium increases finger millet yield compared to monocropping, mainly by controlling pests such as *Striga hermonthica* and cereal stem borer. Similarly, intercropping with mung bean reduces diseases like *Cercospora* leaf spot and leaf curl. In Kolhapur (Maharashtra), finger millet is relay intercropped with sugarcane. Intercropping systems practised in different states are given in Table 23.

TABLE 23. Intercropping systems in finger millet

State	Intercropping system
Karnataka, Tamil Nadu and Andhra Pradesh	finger millet + pigeon pea (8–10:2)
	finger millet + field bean (8:1)
	finger millet + soybean (4:1)
Bihar	finger millet + pigeon pea (6:2)
Uttarakhand	finger millet and soybean seed mixed together in 90:10 proportion on weight basis; finger millet + french bean (1:3)
Hilly areas in north India	finger millet + soybean
Maharashtra (Kolhapur)	finger millet + black gram/moong bean (6–8:1) (submountain regions); finger millet + moth bean (8:2); finger millet + okra (4:2); finger millet + sugarcane relay intercropping

Source: Authors' own elaboration
Note: + is intercropping

Finger millet is often grown in crop rotation or relay cropping systems such as maize–millet, potato–millet and groundnut–millet. Including legumes in rotation with finger millet helps reduce the need for nitrogen fertilizer because the nitrogen fixed by legumes becomes available to the succeeding finger millet crop. This benefit, however, is not observed in intercropping or mixed cropping systems. In the rice–sunn hemp–finger millet rotation, studies have shown that 25 percent savings in NPK fertilizers is possible. Important crop rotations of finger millet are given in Table 24.

Finger millet is integrated into several agroforestry systems across India. It is cultivated under bamboo in Maharashtra, under gliricidia (*Gliricidia sepium*) in Karnataka, and under bhimal (*Grewia oppositifolia*) in Uttarakhand. It is also grown under malabar neem (*Melia dubia*) in Andhra Pradesh, Karnataka and Telangana in the initial four years of planting. Other promising agroforestry combinations include custard apple (*Annona squamosa*) with finger millet and amla (*Emblica officinalis*) with finger millet.

TABLE 24. Finger millet-based crop rotations in India

State	Crop rotation
North India	Finger millet–green gram/black gram/rice bean/soybean Finger millet–mustard /barley/linseed/tobacco/chickpea finger millet + soybean–oats (Uttarakhand)
North Bihar	Potato–paddy–finger millet for garden lands
South India	Finger millet–horse gram/pigeon pea/groundnut finger millet–potato–maize/finger millet; finger millet–sugarcane and finger millet–tobacco, rice–sunn hemp–finger millet
Deccan plateau (south Karnataka)	Finger millet–potato–maize or finger millet–onion–finger millet
Assured rainfall areas	Cowpea/green gram/sesame – early duration finger millet (direct sown or transplanted)

Source: Authors' own elaboration
Note: + is intercropping; – is rotation

Insect-pest management

Finger millet is attacked by many pests. The most important ones are armyworm, cutworm, stem borer, leaf aphid, grasshoppers, grey weevil, shoot fly and ear caterpillars.

Armyworms and cutworms

These pests appear during the early stages of finger millet and continue until harvest. Their occurrence is cyclic in nature. In the early stage, caterpillars cut seedlings at the base, giving them an appearance like they have been grazed by domestic animals. They are active at night and hide under stones and soil clods during the day. At later stages of crop growth, they act as defoliators by feeding on leaves.

Management

Dusting of quinalphos 1.5 percent at 24 kg/ha can be used when pest symptoms are noticed. Poison baits can also be prepared by mixing 10 kg rice bran, 1 kg jaggery, and 1 litre quinalphos (25 percent EC). The mixture is made into small balls and broadcast in the field, preferably in the evening.

Leaf / shoot aphid (*Hysteroneura setariae*)

Leaf aphid infestation occurs throughout the growing period of the crop and can attack all graminaceous plants and grasses including finger millet. Both nymphs and adults suck sap from tender leaves and stems, resulting in reduced plant vigour and stunted growth, especially during August–September. They can cause severe damage in the seedling stage up to 30 days, and in advanced stages, even the earheads may become fully covered with aphids.

Spraying dimethoate (0.05 percent) or quinalphos (0.05 percent) at 1.7 ml/litre of water effectively controls leaf aphids.

Root aphid (*Tetraneura nigriabdominalis* [Sasaki])

Root aphid infestation is endemic to the finger millet growing areas of Karnataka. Infected roots cause plants to show wilting, excess tillering, stunted growth, early maturity and drying of roots. The presence of black ants around the root zone indicates aphid infestation. Aphids also transmit viral diseases, which further increase crop losses.

Spraying dimethoate (0.05 percent) or quinalphos (0.05 percent) at 1.7 ml/litre of water effectively controls root aphids. Predators such as *Coccinellidae* (ladybird beetles) and Syrphidae (*Paragus auritus*) help in managing root aphids. These natural enemies feed on aphids and reduce their population, thereby minimizing crop damage.

Pink stem borer (*Sesamia inferens* Walker**)**

Pink stem borer is a polyphagous pest that attacks several crops including sugarcane, sorghum, rice, wheat and maize. It prefers irrigated finger millet grown during the rabi and summer seasons compared to the rainfed kharif crop. In contrast, white stem borer (*Saluria inficita* Walker) is specific to finger millet and is monophagous. Both borers are widely distributed in states where finger millet is cultivated, such as Karnataka, Tamil Nadu, Odisha and Andhra Pradesh. The insects lay eggs in clusters between the leaf sheath and the whorl. After hatching, larvae feed by scraping leaves, resulting in small pinholes in newly opened leaves. By the third instar stage, the larvae move to the base of the plant and bore inside, leading to drying of the central shoot and death, known as dead heart. In mature plants, larvae create tunnels while feeding on internal tissues.

Management

Ploughing the stubbles of the previous crop helps prevent the carryover of inoculum. Earthing up of established seedlings reduces borer infestation. Foliar spraying of *Bacillus thuringiensis* (Bt) at 2 g/L around 30 DAS lowers larval damage. Botanicals such as neem oil, neem leaf extract, and NSKE deter stem borer adults from laying eggs. Spraying dimethoate or Oxydemeton-methyl (0.07 percent) helps control borer populations. Application of cartap hydrochloride (4 percent GR) at 20 kg/ha to the soil at 30 DAS has proven most effective for managing pink stem borer in the rabi season, as it is systemic and has minimal adverse effects on natural enemies. Using resistant cultivars like PRM 9002, KOPN 933, OEB 28, RAU 8 and Champabati also helps in reducing infestation and minimizing yield losses.

Earhead eaterpillars

Several species of lepidopteran earhead caterpillars attack finger millet and sometimes become serious pests. Important species include *Cryptoblabes angustipennella* Hamps, *C. gnidiella* (Mill), *Eublemma (Autoba) silicula* Swinh, *Helicoverpa armigera* (Hub.), *Cacoecia epicyrta* Meur, *Stathmopoda theoris* Meyr, *Archips micaceanus* (Wlk.) and *Sitotroga cerealella* (Oliv.).

Earhead caterpillars attack finger millet at the dough stage and remain until harvest. They bite the maturing seeds and form fine webs using their castings and half-eaten grains, which further attract saprophytic fungi. For management, dusting with quinalphos 1.5 percent at 24 kg/ha is effective. Other control measures include spraying thiodicarb 76 WP (1.0 g/l), acephate 75 SP (1.5 g/l), profenphos 50 EC (2.0 ml/l), lambda cyhalothrin 5 EC (0.6 ml/l), novaluron 10 EC (1.5 ml/l), fenvalerate 0.4 D, chlorpyriphos 1.5D at 25 kg/ha, and chlorpyriphos 20 EC (2.0 ml/l). These treatments have been found effective in reducing different species of earhead caterpillars.

Grasshopper

Finger millet is also attacked by grasshoppers. Previously recommended chemicals are now banned for use. The new recommendation is awaited.

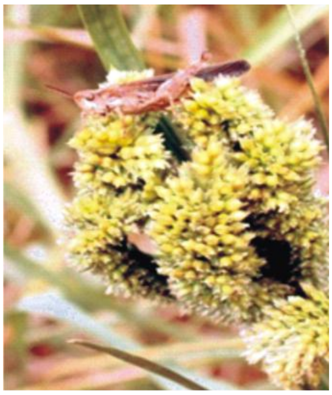

FIGURE 50. Grasshopper damage in finger millet

Nematode

Finger millet is affected by several nematodes, among which *Rotylenchulus reniformis* is particularly important. This nematode also attacks barnyard millet. According to studies (Krishnappa, Ravichandra and Reddy, 2002), 4.8 percent of the finger millet area in Karnataka is affected by *Rotylenchulus reniformis*. Typical symptoms include general stunting, brown to black discoloration of roots, reduced plant height, fewer tillers, fewer fingers, lower earheads and straw weight.

Management practices include green manuring (Krishnappa, Ravichandra and Reddy, 2002) and soil application of carbofuran 3G at 1 kg a.i./ha (Jothi and Sunderbabu, 1998). Seedling root dip in *Pseudomonas fluorescens* at 2.5 g/l of water for 30 minutes combined with soil application at 2.5 kg/ha at 30 days after planting, and soil application of *Trichoderma viride* at 4 g/m², suppresses *R. reniformis* menace (Rajendran and Cannayane, 2000).

Disease management

Among the various diseases affecting finger millet, the most prominent are blast, seedling blight, wilt, downy mildew, smut, damping-off and cercospora leaf spot. These diseases can cause severe damage and economic loss.

Blast (*Pyricularia grisea*) (Perfect Stage: *Magnaporthe grisea*)

Blast disease affects finger millet at all stages of growth, from seedling to grain formation. The symptoms can be seen on the seedling, leaf, peduncle and finger. The conditions that favour the disease are a minimum temperature of 15–25 °C, relative humidity above 85 percent, and intermittent rains.

Leaf blast is characterized by water-soaked lesions with a chlorotic ring along with elliptical or diamond-shaped spots having grey centres. Under favourable conditions, these spots enlarge, merge and give the leaf blades a blasted appearance (Figure 51).

Neck blast appears as elongated black lesions one to two inches below the ear leading to severe yield losses, reduced grain weight and increased spikelet sterility. This stage is considered the most dangerous form of the disease. Finger blast symptoms begin at the tip of the finger and progress downward, with the base turning brownish (Figure 52). Unlike other crops, blast in finger millet specifically affects the neck and finger portions, showing a peculiar host range. The life cycle of blast in a finger millet crop is illustrated in Figure 53.

FIGURE 51. Leaf blast in finger millet

FIGURE 52. Neck blast in finger millet

Management

Effective management includes cultivating resistant varieties such as GPU 26, GPU 28, GPU 48 (Ratna), GPU 66, PRM-2, VL 380, VL 386, VL 399, VL 400, CFMV-1 and CFMV-2, which are highly resistant to neck and finger blast. Seed treatment with carbendazim at 2 g/kg or *Trichoderma harzianum* helps reduce initial inoculum. While foliar sprays of 0.3 percent *Pseudomonas fluorescens*, carbendazim at 0.1 percent, or tricyclazole at 0.06 percent (any one of the options) applied at flowering and again 10 days later suppress blast development and ensure better yield stability.

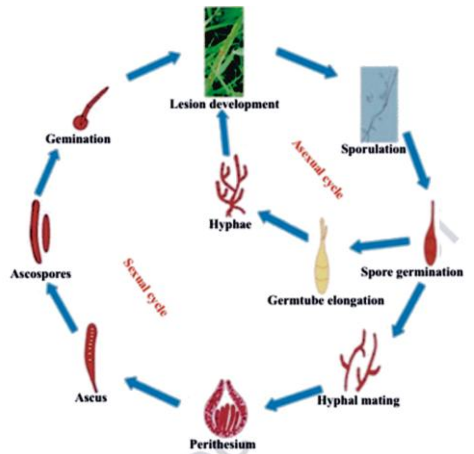

FIGURE 53. Life cycle of blast in finger millet

FIGURE 54. Brown spot disease in finger millet

Brown Spot (*Drechslera nodulosum*) (Leaf Blight or Seedling Blight)

This disease manifests as brown to dark brown dots on the leaf lamina or sheath, particularly in older plants. The infection can spread to the fingers and neck and under severe infestation, the neck may break or hang from the plant. Affected panicles become chaffy and grains show discolouration. Crops under drought stress or nutrient deficiency are more vulnerable to the disease. The optimum temperature for infection is around 30–32 °C. High relative humidity combined with intermittent rains during ear emergence and before grain formation create highly favourable conditions for heavy ear infection, resulting in significant yield reduction (Figure 54).

Management

The disease can be effectively managed through proper nutrition and water management. Seed treatment with carbendazim 50 WP or thiram 40 FS at 2–3 g/kg of seed provides complete control of pre-emergence damping-off seedling blight, since the disease is primarily seed-borne. Secondary infection can be minimized by spraying mancozeb 75 WP at 2 g/l or by spraying a combination of carbendazim 12 percent along with mancozeb 63 percent WP at 1 g/l.

Downy bildew (*Sclerophthora macrospora*) **(Green Ear or Crazy Top Disease)**

In finger millet plants that are affected by downy mildew the internodes are shortened, resulting in stunted growth along with profuse tillering. The plants take on a bouncy, bushy appearance, and pale-yellow translucent spots often appear on the leaves. At the time of grain formation, the disease manifests as the "green ear" symptom, where the earheads are completely transformed into narrow, green, leafy structures, leading to complete sterility. The entire ear assumes a bush-like appearance, which is a characteristic feature of the green ear symptom.

Management

Providing good drainage in lowlands, adopting crop rotations and rogueing of infected plants are effective cultural practices to reduce disease incidence. Additionally, seed treatment with organomercurials such as metalaxyl 35 percent SD at 2 g/kg of seed helps in suppressing the pathogen and minimizing early infection, thereby lowering the overall pressure of the disease in finger millet.

Finger millet maize streak virus (Transmitted by- *Cicadulina chinai*) and **Ragi mottle streak virus** (Transmitted by- *Cicadulina bipunctella, C. chinai*)

Ragi mottle streak virus infection typically appears when finger millet plants are 4–6 weeks old. The disease is characterized by regular dark-green patches along the leaf veins, accompanied by frequent leaf streaks and chlorosis. On the lower leaves, the symptoms manifest as white mottle-type spots. Infected plants show stunted growth and produce small, underdeveloped ears leading to significant yield loss. The virus is transmitted by cicadellid leafhoppers which act as vectors and spread the infection within and across the fields.

Management

Viral diseases in finger millet cannot be controlled directly, but their losses can be managed through indirect measures. Avoiding cultivation of finger millet in proximity to maize or sorghum helps reduce the risk of cross-infection. Managing vectors such as leafhoppers with neem-based sprays or insecticides is effective in limiting transmission. Timely sowing, adoption of crop rotation and rogueing of infected plants further reduce the spread of the disease and safeguard yield.

Cercospora leaf spot (*Cercospora eleusinis*)

Cercospora leaf spot, an important foliar disease in finger millet in the Himalayan region, occurs under conditions of low temperatures (below 20 °C) and heavy rainfall. Early sown crops are more vulnerable, with peak infestation is observed in June. The infection begins on older leaves and gradually spreads to younger ones. Initial symptoms appear as reddish-brown specks surrounded by a yellow halo which later enlarge into bigger lesions, giving the leaves a burnt appearance (Figure 55). Effective management involves maintaining field sanitation and spraying carbendazim at 0.05 percent concentration at 15-day intervals. This helps to suppress the disease and protect crop yield.

FIGURE 55. Cercospora leaf spot in finger millet
© Palanna K.B, University of Agricultural Sciences, Bengaluru

Harvesting

The crop matures in about 95 to 110 days for early varieties and 115 to 125 days for varieties of medium-to-late duration depending on the tract and the variety. The earheads are harvested with ordinary sickles and straw is cut close to the ground. At some places under rainfed conditions, the whole plant along with the earhead is cut, heaped and then threshed.

For economical and speedy harvesting of finger millet, combines and reaper harvesters are used. Studies conducted by AICSMIP at Bengaluru and Mandya (both in Karnataka) during kharif 2022 indicated that using combine harvesters reduced labour requirement by 85 percent and using reaper harvesters reduced labour by 70 percent as compared to manual harvesting.

Yield

In direct seeded finger millet crops, grain yield of 2.5−3.0 t/ha and fodder yield of 6.0−7.0 t/ha is achievable. Under SRgI grain yields can reach up to 5.0 t/ha. The straw of finger millet serves as nutritious fodder for livestock.

Export

During the year 2022, 21 160 tonnes of finger millet worth USD 6.53 million were exported from India.

Support price

Finger millet is the third millet crop in India to have a minimum support price (MSP). For 2025/26 season, MSP of finger millet grain is INR 48 860 per tonne of grain.

Seed production

Finger millet is a self-pollinated crop and for certified seed production an isolation distance of five metres is sufficient. This helps maintain genetic purity. Finger millet has a seed multiplication rate of 1:80.

CHAPTER 5: Foxtail millet

[*Setaria italica* (L.) Beauv]

FIGURE 56. Field view of foxtail millet
© ICAR-IIMR, Hyderabad

Foxtail millet, also known as Italian millet and German millet, is predominantly grown as a rainfed crop in the semi-arid regions of India because of its tolerance to drought. China is largest producer of foxtail millet in the world with a production of 1.74 Mt in 2014 (Zhang *et al.,* 2022) followed by India with a production of 0.056 Mt (Mundhe *et al.,*2025). In India the area under cultivation declined sharply during the 1990s because of the introduction of more remunerative crops. At present foxtail millet is cultivated on a limited area in Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, Rajasthan, Madhya Pradesh, Uttar Pradesh and some northeastern states. Some of the major districts where foxtail millet is cultivated are Kurnool, Kadapa and Anantapur (Andhra Pradesh); Mahbubnagar and Rangareddy (Telangana); Bellary, Koppal, Chitradurga, Belgaum, Gadag, Davangere, Dharwad (Karnataka); East Siang, Siang, Upper Siang, Lower Dibang Valley, Tirap, Longding, Changlang, Namsai, Shiyomi (Arunachal Pradesh); and West Garo Hills (Meghalaya).

Foxtail millet is a rich source of carbohydrates, proteins, dietary fibres, vitamins and minerals. It contains both nutritional and anti-nutritional components (phytic acid, tannins and total phenolic compounds). Various phytochemicals are known to contribute to several health benefits including stimulation of the immune system, reduction in the division rate of tumour cells and increase in natural insulin levels. The consumption of foxtail millet can lower the risk of type 2 diabetes and suppresses the level of high glycaemic index. Polyphenols in foxtail millet can improve gut microbiota disorders caused by colitis-associated carcinogenesis.

Climatic requirements

Foxtail can be grown in tropics as well as in temperate regions under both low and moderate rainfall (50−75 cm). It can be grown even at an altitude of 2000 m. Although it grows better in temperatures between 16 °C and 26 °C, it can tolerate temperatures up to 35 °C.

Soil

Foxtail millet can grow well on sandy to heavy clay soils (except saline soils) provided they are well drained, but it requires fairly fertile soils for good yields. Light soils including red loams, alluvial and black cotton soil are suitable for its cultivation. However, it cannot tolerate waterlogged soils or extreme drought. Soil with neutral pH is ideal and it can be grown within a pH range of 5.5−7.5.

Land preparation

Foxtail millet requires minimal field preparation. Before the onset of the monsoon, the field should be ploughed once with mould board plough. When the monsoon arrives, in north India the field is harrowed or ploughed twice with local ploughs and in the southern parts it is worked with blade harrows.

Sowing windows

The optimum sowing period for a rainfed foxtail millet crop varies by state. It is from August–September in Tamil Nadu, July–August in Karnataka, the first fortnight of July in Andhra Pradesh, and the second and third week of July in Maharashtra. In Tamil Nadu, kharif irrigated crop is sown from early June to late July and the summer irrigated crop is sown in January. For plains of Uttar Pradesh and Bihar, mid-June is the optimum sowing time.

Foxtail millet can be sown both by line sowing and broadcast methods though line sowing is preferred because of its advantages in weed management through interculture.

Seed rate and spacing

A planting geometry of 25–30 cm × 8–10 cm (row × plant) is standardized and a plant population of 4−4.5 lakh/ha is considered optimum. A seed rate of 8–10 kg/ha is adequate for line sowing, while a rate of 15 kg/ha is adequate for broadcast sowing. Seed treatment with metalaxyl or carbendazim (2 g/kg seed) is promising for good crop establishment.

Varieties

Several state-specific varieties of foxtail millet with potential for high yield have been released in India (Table 25).

TABLE 25. Recommended varieties of foxtail millet across different states in India

State	Varieties
Andhra Pradesh and Telangana	Renadu (SiA3223), Garuda (SiA 3222), Suryanandi (SiA 3088), SiA 3156, SiA 3085, Lepakshi, SiA 326 (Prasad), PS 4, Narasimharaya (SiA 2662), Krishnadevaraya (SiA 2593), CFXMV-1 (IIMR FxM 7), CFXMV -3 (GPUF-16)
Bihar	RAU-2 (Rajendra Kauni 1), Suryanandi (SiA 3088), SiA 3156, SiA 3085, PS 4, CFXMV -3 (GPUF-16)
Karnataka	DHFt 109-3, HMT 100-1 (high tillering and stay green type), SiA 3156, Suryanandi (SiA 3088), SiA 3085, SiA 326 (Prasad), PS 4, Narasimharaya (SiA 2662), Hagari Navane-46, CFXMV-1 (IIMR FxM 7), CFXMV-2 (FXV 647), CFXMV -3 (GPUF-16)
Maharashtra, Madhya Pradesh, Jharkhand and Chhattisgarh	SIA 326 (Prasad), PS 4, CFXMV-2 (FXV 647)
Tamil Nadu	CO-7 (rust resistant, high protein: 14%), TNAU 43, TNAU-186, TNAU 196, CO 1, CO 2, CO 4, CO 5, K2, K3, Suryanandi (SiA 3088), SiA 3156, SiA 3085, PS 4, ATL-1 (TNSi 331)

Uttar Pradesh	PRK 1, PS 4, SiA 3088, 3085, Sreelaxmi, Narasimharaya (SiA 2662), SiA 326 (Prasad), S-114
Uttarakhand	PS 4, PRK 1, Sreelaxmi, SiA 326, SiA 3156, SiA 3085, VL Mandua 410 (CFMV 8)
Rajasthan	Prathap Kangani-1 (SR 51), SR 11, SR 16 (Meera), SiA 3085, SiA 3156, PS 4 (a mutant cultivar from SiA 326 with high seed yield and profuse tillering)
Assam	AAU-GSG-Cawn 1 (Gossaigaon Cawn; Yellow Seeded), VL Mandua 410 (CFMV 8)

Source: Authors' own elaboration

Manure and fertilizers

Manuring is the most common method of providing nutrition to foxtail millet. However, application of adequate fertilizer results in better yields. Application of 5 tonnes/ha FYM or compost is done 2–3 weeks before sowing. In addition to manure, application of 20 to 40-20 kg/ha N-P_2O_5 is recommended. Although there is no formal recommendation for potassium fertilizers, studies indicate that producing one quintal of foxtail millet grain requires 3.61 kg of K_2O under inorganic nutrient management approach and 4.19 kg of K_2O under integrated nutrition approach.

Potassium plays a crucial role in foxtail millet cultivation by enhancing grain yield, photosynthetic efficiency and carbohydrate metabolism. Recent field studies have provided detailed insights into optimal application rates and physiological responses, especially in regions with potassium-deficient soils like alfisols. In alfisols of Tirupati (Andhra Pradesh) with low to medium native K, response to application of 30 kg/ha K_2O was seen. On the other hand, in vertisols of Nandyal (Andhra Pradesh) with high native K, no response to K fertilization was seen. For irrigated foxtail millet of Tamil Nadu, application of 22 kg/ha K_2O was promising. Where soil application is not feasible, foliar sprays of potassium sulphate (1 percent) is an effective alternative. Though all fertilizers are generally applied as basal dose, top dressing of 20 kg N under favourable moisture conditions and after weeding, results in better crop performance. State-wise recommendations for fertilizer application are given in Table 26.

TABLE 26. Recommended dose of fertilizers for foxtail millet

State	Fertilizer dose (N:P_2O_5 kg/ha)
Andhra Pradesh	40:30
Jharkhand and Tamil Nadu	40:20
Karnataka	30:15
Maharashtra and other states	20:20

Source: Authors' own elaboration

Organic nutrition of foxtail millet

Application of 5–10 t/ha of FYM, seed treatment with *beejamrut*, NP biofertilizers, and foliar spray of 3 percent *panchagavy*a (at 20 days after sowing) were found adequate in meeting the nutritional requirements of organically grown foxtail millet.

Weed management

Weed flora associated with foxtail millet is highly diversified and varies depending upon the season, agro-ecological conditions and the level of management. Foxtail millet has a slow growing canopy during the initial growth and this makes it susceptible to weed competition. The initial 4−6 weeks after emergence of seedling is considered a critical period for removal of weeds. Reports indicate a grain yield loss of 50 percent in foxtail millet because of the presence of weeds throughout the crop season. Therefore, there is scope for increasing productivity by minimizing weed-associated yield losses.

Two inter-cultivations and a single hand-weeding in a foxtail millet crop that is line-sown, and hand-weeding twice in crop that is broadcast, is necessary for effective weed management. Hand-weeding twice at 20 and 40 DAS was found effective at Anantapur (Andhra Pradesh). Pre-emergence application of 70 g/ha oxadiargyl, 0.75 kg/ha pretilachlor or 15 g/ha pyrazosulfuron-ethyl followed by inter-cultivation at 20 DAS is recommended for weed management in foxtail millet. Application of 1.0 kg/ha 2, 4-D sodium salt at 20–25 DAS aids in effective management of broadleaved weeds.

Water management

Foxtail millet is basically a rainfed kharif season crop and is seldom irrigated. It exhibits remarkable drought tolerance and high water-use efficiency. However, under prolonged dry spells, providing two irrigations – first at 25–30 DAS and then at 40–45 DAS – supports successful crop culture and results in higher yields.

Drought stress in early growth stages (before heading) is particularly more harmful to foxtail millet. Studies reported a significant reduction in shoot length in drought-affected foxtail millet, accompanied by an increase in root length. Selection of drought-tolerant cultivars like Prasad (SiA 326) and TNAU-186 are useful in areas prone to drought. Early duration cultivars Suryanandi, (suited for the entire country) and Pratap Kangni 1, (suited for Rajasthan) are also effective in overcoming the adverse impact of drought on yields.

Cropping systems

Intercropping of foxtail millet with groundnut (in 2:1 ratio) or foxtail millet with pigeon pea/cotton (in 5:1 ratio) is popular in Andhra Pradesh. Intercropping foxtail millet with castor (in 7:1 ratio) is also promising for Andhra Pradesh. If monsoon arrives early and the conditions are favourable, in Andhra Pradesh foxtail millet is sown at 45 cm row spacing and rabi sorghum is introduced as a relay crop at the time when foxtail millet is nearing maturity. In Karnataka, intercropping systems of foxtail millet with soybean (ratio of 1:2 or 2:4) or with groundnut (ratio of 1:6) or with field bean/horse gram (ratio of 4:2) were found promising. In the western zone of Tamil Nadu, intercropping foxtail millet with vegetable cowpea in a ratio of 3:1 under irrigated conditions proved to be both highly productive and profitable. Intercropping finger millet with foxtail millet (in the ratio of 4:2 or 6:2) is also practised in India.

In medium deep black soils of Andhra Pradesh, cultivating two crops such as foxtail millet with mustard/green gram/sunflower/pigeon pea is more profitable than cultivating foxtail millet alone. In Karnataka, foxtail millet–safflower rotation is followed. In the black cotton soils of Nandyal (Andhra Pradesh), early rotation of foxtail millet with chickpea was found more promising than the fallow-chickpea system. The productivity of foxtail millet–chickpea system was higher with in situ soil moisture preservation than without moisture conservation practices.

Foxtail millet is an important component of many agroforestry systems. It is cultivated under malabar neem (*Melia dubia* Cav). in Karnataka and pride of India or Indian lilac (*Melia azedarach* L.) in Gujarat, Madhya Pradesh and Rajasthan.

Insect-pest management

Shoot fly is one of the major pests in foxtail millet crop. Other pests that can appear occasionally, but can affect severely, are armyworm, cutworm and leaf scrapping.

Shoot fly (*Atherigona atripalpis* Wiedemann.)

Shoot fly infestation in foxtail millet results in the formation of dead hearts leading to yield loss. Shoot fly damages the crop from the time of sowing to about six weeks after emergence. The pest feeds on the crop and soon the central shoots start drying and show typical symptoms of dead heart in the early stage. In the later stages there is profuse tillering but the tillers are also affected. Damaged tillers may produce earheads devoid of grains (white ear). Maximum incidence occurs during late July to early August (Figure 57).

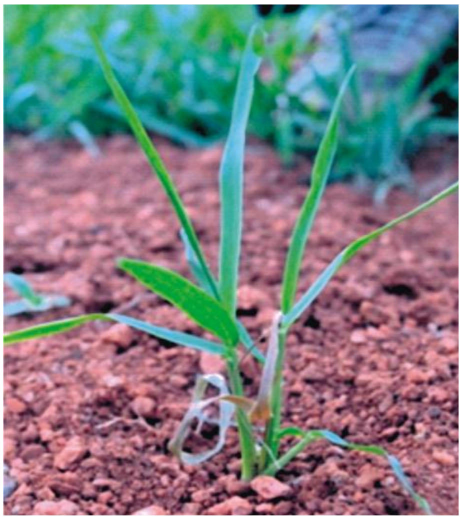

FIGURE 57. Dead heart symptoms in foxtail millet

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FIGURE 58. Blast millet

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Management

Early sowing of the crop using a higher seed rate (1.5 times the recommended rate) just as the monsoon sets in, helps to manage seedling mortality. Seed treatment with thiomethoxam 30FS (10 ml/kg seed) is very effective in managing shoot fly. Additionally, application of carbofuran 3 percent granules (30 kg/ha) in furrows at the time of field preparation is recommended to manage shoot fly.

Disease management

Blast, smut, leaf spot and downy mildew are major diseases that affect foxtail millet. Sheath blight (*Rhizoctonia solani*), bacterial leaf blight (*Pseudomonas avenae*), rust (*Uromyces setariae*-italiae) and udabatta (*Ephelis* sp.) are the minor diseases that affect the crop.

Blast (*Pyricularia setariae*)

Blast is a serious disease in foxtail millet and it can cause yield loss up to 60 percent. The disease appears as spindle shaped spots that enlarge under favourable conditions and coalesce, and leaf blades dry from tip towards the base giving a blasted appearance (Figure 58).

Blast disease in foxtail millet can be managed by spraying mancozeb (0.2 percent) or carbendazim (0.05 percent) at 50 percent flowering followed by a second spray 10 days later. Cultivating resistant varieties such as SR 118, SR 102, JNSc 33, RS 179 and ST 5307 also help in reducing the incidence of this disease. Split application of N, with top-dressing of N dose applied after fungicide spraying, is recommended to reduce disease incidence.

Smut (*Ustilago crameri* Koem)

This disease manifests itself at the time of ear formation. Pale greyish to dark brown sori appear in the flowers initially and later the sori turn black. The fungus is known to affect most of the grains in the ear but sometimes the terminal portion of the spike may remain unaffected. When this occurs, sori are produced in the flowers and basal parts of the palea. After the rupture of sori, dark black powdery mass of spores can easily be seen on the infected earheads.

For smut management, seed treatment with carbendazim (2 g/kg seed) applied 24 hours before sowing is recommended. Seed treatment with thiram (3 g/kg seed) is also effective. Hot water treatment of seeds at 52 °C for 10 minutes can kill surface-borne spores.

Downy mildew (*Sclerospora graminicola*)

In India, this soil-borne disease is prevalent in Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Bihar and Kashmir. In certain years, yield loss of up to 50 percent was recorded because of downy mildew. The diseased plants become dwarfed with excessive development of tillers and exhibit lengthwise yellow-green streaks on the leaves. The floral sections transform in leafy structures that become pale. Under severe infestation, no panicle is produced.

Management

Spraying metalaxyl at 3 g per litre of water in the field helps in controlling the disease. Additionally, seed treatment with biocontrol agents like *Trichoderma harzianum* (20 g/kg seed) *Pseudomonas fluorescens* or *Bacillus* spp. (10 g/kg seed) are also useful. The collection and removal of the debris of infected plants helps in reducing the inoculum levels in the field. Delayed sowing can also lower the incidence of the disease. Cultivation of downy mildew resistant varieties such as SiA 3085 (recommended for cultivation across India) and Meera (SR 16) (released for Rajasthan) reduce susceptibility to the disease.

Leaf spot (*Cochliobolus setariae*)

Fungus typically causes leaf spots that can reduce photosynthetic efficiency and yield, particularly under humid conditions. The fungus has both a sexual stage (teleomorph) and an asexual stage (anamorph, often classified under *Bipolaris*). The conidia are typically fusiform and multicellular, facilitating rapid spread under favourable conditions.

Seed treatment with carbendazim (3 g/kg seed) or foliar spray carbendazim 50 WP (one gram per litre of water) is effective in leaf spot management. Selection of brown spot resistant cultivars like GPUS 27, SiA 3039, SiA 3059, SiA 3066, SiA 3088, TNAU 213 and TNAU 235 can reduce the incidence of the disease.

Udbatta disease (*Ephelis oryzae*)

Udbatta disease, commonly affecting rice, has also been reported in foxtail millet under conditions of high humidity, high plant density and the use of infected seeds.

Panicles appear as black, straight, cigar-shaped structures resembling incense sticks (hence the name). The entire panicle is replaced by fungal mycelium and spores and this results in complete failure to form seeds.

Seed treatment with carbendazim or thiram (2 g/kg seed) or hot water treatment of seeds at 52 °C for 10 minutes is effective in managing the disease.

Harvesting

The crop matures in 80–100 days and can be harvested when the earheads are dry. The crop is usually harvested during kharif season (September–October) and rabi season (January–February) either by cutting the whole plant by sickle or cutting the earheads separately. Alternatively, a reaper can be used to harvest foxtail millet crop. Lodging is another important factor that can reduce both yield and quality depending on the environmental conditions. Threshing is carried out using an all-crop thresher to separate the grain from the panicles. Proper grading of the produce aids in better price realization.

Yield

Grain yield of foxtail millet ranges from 1.5−1.8 t/ha and straw yield ranges from 2.0−4.0 t/ha.

Seed production

Foxtail millet is a self-pollinated crop and for certified seed production, an isolation distance of five metres is sufficient. This helps maintain genetic purity. It has a seed multiplication rate of 1:80−100.

CHAPTER 6: Little millet

Panicum sumatrense (Roth ex Roem. & Schult).

FIGURE 59. Field view of little millet
© ICAR-IIMR, Hyderabad

FIGURE 60. Formation of panicle in little millet
© ICAR-IIMR, Hyderabad

In India little millet is known as *chama* in Malayalam, *same* in Kannada, s*amai* in Tamil, *sama* in Telugu and *kutki* in Hindi. It is an annual herbaceous plant which grows upright, or with folded blades, reaching a height of 30–100 cm. The leaves are linear, with occasionally hairy laminae and membranous hairy ligules. The panicles measure 4–15 cm in length with awns that are 2–3.5 mm long. The grain is round and smooth and about 1.8–1.9 mm long.

Little millet is a very nutritious millet suitable for people of all age groups. Its high fibre content helps to prevent constipation and heals problems related to the stomach. The fibre also helps to reduce fat deposits in the body. It is found beneficial in improving semen count in men and regulating irregular periods in women. Every 100 g of little millet contains 8.7 g of protein, 75.7 g of carbohydrate, 5.3 g of fat and 1.7 g of mineral.

Little millet grain is recommended as a substitute for rice in patients with diabetes. As a result of its high dietary fibre content, it acts as a hypoglycaemic agent. The higher lecithin content in this millet encourages simple digestion making it suitable for consumption by both humans and animals. Because of its cooling properties, it is a good food option in summers. Recent cultivation details are not available. However, as per 2015/16 data, it is cultivated on 2 34 000 ha with a grain production of 1 27 000 tonnes (Hariprasanna, 2023).

Climatic requirements

Little millet is grown throughout India especially in the states of Karnataka, Tamil Nadu, Odisha, Madhya Pradesh, Chhattisgarh, Jharkhand, Andhra Pradesh, Uttarakhand, Maharashtra and Gujarat. It can withstand both drought and waterlogging situations. It can be cultivated up to an elevation of 2000 m above sea level.

Soil

Little millet can be grown on a wide range of soils including waterlogged soils. Deep, loamy, fertile soils rich in organic matter are ideal. It can withstand both salinity and alkalinity to some extent. In India it is often cultivated on marginal lands by the tribal populace of the country.

Land preparation

Effective soil management for little millet is crucial for boosting productivity, enhancing nutrient-use efficiency and maintaining long-term soil health, especially under rainfed and marginal conditions in India. Conventional tillage using a disc plough followed by a cultivator or rotovator helps to improve soil aeration, moisture retention, root penetration, microbial activity, and nutrient availability. Ploughing also aids in the incorporation of manure into the soil.

Varieties

There are two races of little millet i.e. nana and robusta. 'Nana' races have small inflorescence (14–15 cm) are upright, open, and heavily branched, with branches that droop at maturity. Plants in the race 'robusta' are tall (120–190 cm) with long inflorescences (20–45 cm) that open compactly and are extremely branching. The 'nana' race of little millet has higher Fe, Zn and protein content than the robusta race. The list of improved and popular little millet varieties recommended for different states is given in Table 27.

TABLE 27. Recommended varieties of little millet across different states in India

State	Varieties
Odisha	OLM-203, OLM-208, OLM-217 (Kalinga Saun 217), BL-6, DHLM-36-3, DHLM-14-1
Madhya Pradesh	JK-4, JK 8, JK 36, JK-137, BL-6, DHLM-36-3, CLMV 3 (LMV 539)
Andhra Pradesh	OLM-203, JK-8, BL-6, DHLM-36-3, CLMV-1 (JAICAR Sama-1)
Tamil Nadu	Paiyur-2, TNAU-63, CO-3, CO-4, K-1, OLM-203 (Tarini), OLM-20, BL-6, DHLM-36-3, DHLM-14-1, CLMV-1
Chhattisgarh	JK-8, BL-6, JK-137, BL-4, JK-36, DHLM-36-3, BL-41-3 (Chhattisgarh Sonkutki), CLMV-3 (LMV 539)
Karnataka	OLM-203, JK-8, BL-6, DHLM-36-3, DHLM-14-1, CLMV-1
Gujarat	GV-1, GV-2, GNV-3, GV-4, OLM-203, JK-8, BL-6, DHLM-36-3, DHLM-14-1, CLMV-1
Maharashtra	Phule Ekadashi (KOPLM-83), JK-8, OLM- 203, BL-6, DHLM-36-3, DHLM-14-1, CLMV-1
Himachal Pradesh	CO-2, BAU-3

Source: Authors' own elaboration

Sowing windows

Little millet is cultivated during both kharif and rabi seasons. In the kharif season, little millet is sown in June in Tamil Nadu, mid-June in Odisha and from the end June to the first week of July in Madhya Pradesh and Karnataka. In Tamil Nadu the sowing window for little millet in the rabi season is September–October.

Seed rate and spacing

Little millet is sown by broadcasting or in lines. Resource-poor farmers in drylands resort to broadcast sowing and thus have a higher seed requirement (12 kg/ha). In contrast, line sown crop requires 8 kg seed/ha. Line sowing is preferred for ease of intercultural operations and higher productivity. Sowing in rows 22.5 cm apart with a plant-to-plant spacing of 8−10 cm is recommended, with the sowing depth not exceeding 5 cm.

Manure and fertilizers

Little millet is a crop with low fertilizer requirements; however, high-yielding varieties require adequate fertilization, especially in poorly fertile soils. An application of 5–10 t/ha FYM one month before sowing during summer ploughing aids in better crop nutrition and moisture conservation. In addition, application of 40-20-20 kg/ha N-P_2O_5- K_2O is desirable. Studies conducted as part of the All India Coordinated Research Project on Small Millets (AICRP-SM) at Kolhapur (Maharashtra), Nandyal (Andhra Pradesh) and Waghai (Gujarat) during 2021 indicated that 50 percent RDF application as basal and 19-19-19 N-P-K fertilizer foliar spray (2 percent) at panicle initiation and flowering stages, was promising. This is more so under drought conditions. The fertilizer recommendations for different states are given in Table 28.

TABLE 28. Recommended dose of fertilizers for little millet across different states in India

States	Fertilizer dose (N:P_2O_5:K_2O kg /ha)
Andhra Pradesh	20:20:0
Bihar and Orissa	20:10:0
Tamil Nadu	40:20:0
Other states	20:20:0

Source: Authors' own elaboration

Biofertilizers

Seed inoculation with *Agrobacterium radiobacter* and *Aspergillus awamori* biofertilizers is practised to enhance crop nutrition and thereby improve seed yield. Seed treatment with *Agrobacterium radiobacter* and *Aspergillums awamori* in liquid form (4–5 ml/kg seed) followed by soil application of liquid biofertilizers in furrows (6–7.5 litres mixed with 500 kg FYM/ha) was found promising in studies conducted by AICRP-SM during 2021 at Jagdalpur (Chhattisgarh), Mandya (Karnataka) and Vizianagaram (Andhra Pradesh).

Weed management

Two inter-cultivations and a single hand-weeding in a little millet crop that is line-sown, and hand-weeding twice in crop that is broadcast, is necessary for effective weed management. Post-emergence application of 2, 4-D sodium salt (1.0 kg/ha) at 20−25 DAS is effective in managing broadleaved weeds.

Water and moisture management

Little millet is a rainfed crop that makes soil moisture conservation inevitable for stable yields. Cultivation of drought tolerant variety 'OLM 20' in Odisha, Madhya Pradesh, Chhattisgarh and early maturing (55−60 days) 'Birsa Gundli-1' in Bihar plateau and Jharkhand, is recommended for coping moisture stress. Irrigation at critical stages enhances crop performance and increases the likelihood of achieving higher yields. Two irrigations, the first at 25−30 DAS and the second at 45−50 DAS is recommended for higher yields.

Cropping systems

Little millet is integrated into many mixed, intercropping systems and crop rotations. In Karnataka and Odisha little millet is intercropped with black gram (4:2 row ratio). In Karnataka it is also relay intercropped with horse gram. In Madhya Pradesh it is intercropped with sesame/soybean/pigeon pea (2:1 row ratio). Intercropping little millet with pigeon pea

(2:1 row ratio) is also practised in south Bihar. In Tamil Nadu, little millet intercropping with groundnut (1:6) has shown promising results. Among the crop rotations, little millet rotation with niger and little millet with mustard are prominent. Multilocation experimental studies by AICRP-SM demonstrated the profitability of little millet rotation with safflower, cowpea or lentil.

Insect-Pest Management

Many insect pests are reported in little millet, with varying levels of economic losses.

Shoot fly (*Atherigona pulla* Wiedemann**)**

Shoot fly is the most common insect pest of little millet causing substantial yield loss. During the early vegetative stages, it causes significant damage by targeting the central growing shoot, leading to dead hearts (Figure 61) and poor tillering. If infestation continues into the panicle initiation stage, it leads to the formation of "white ears".

Early sowing with the onset of monsoon is an effective and economical method of control. Other recommendations for management of shoot fly in little millet include: the cultivation of shoot fly tolerant varieties (BL-4, JK-4, JK-36, OLM-208 and OLM-217); spraying of 1500 ppm neem / azadiractin on the seventh day after sowing; seed treatment with chlorpyriphos 2 EC at 2.5 ml/kg seed or imidacloprid 600FS at 5 ml/kg seed (Kumar and Channaveerswami, 2015). Intercropping little millet with onion or garlic was found effective in reducing oviposition and lowering the formation of dead hearts, resulting in enhanced grain and fodder yields (Sathish Manjunatha and Rajashekarappa, 2017).

FIGURE 61. Dead heart symptoms in little millet
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Stem borer

During the vegetative stage, the larva bore into the stem and feed on growing shoot. This causes drying of the central shoot, also known as dead heart. Stem tunnelling weakens the plant and subsequently leads to lodging. Affected plants show poor panicle emergence and grain filling.

Early sowing helps to reduce borer infestation. **S**eed treatment with **b**iocontrol agents like *Trichogramma chilonis* (egg parasitoid), *Beauveria bassiana* or *Metarhizium anisopliae* (entomo-pathogenic fungi) will effectively reduce infestation. Seed treatment with imidacloprid *or* thiamethoxam (5 g/kg seed) is also beneficial.

Termites

Termites are emerging as a serious threat to little millet cultivation in dryland systems where application of organic residues and moisture stress conditions coexist.

Affected crops show wilting or drying of seedlings, patchy crop stands (especially in light soil) and these symptoms are often mistaken for drought or nutrient stress.

Disease management

Blast, banded leaf and sheath blight (*Rhizoctonia solani*), grain smut, rust, foot rot, udabatta (*Ephelis oryzae*) and viral diseases are reported in little millet. Among these grain smut is the most important and often problematic disease.

Smut (*Macalpinomyces sharmae* K.Vanky)

The disease is ovaricolous (ovary-borne) and its symptoms appear at the grain formation stage. The affected ovary is converted into a smut sorus but does not enlarge beyond the size of the normal grain. Some of the late-developing grains remain greenish and become slightly larger than normal grains. When these greenish, healthy-appearing grains are pressed, they release spores.

Management

Seed treatment with carbendazim or carboxin (2 g/kg seed) as well as *Trichoderma viride* is effective in smut management. Little millet varieties like OLM2-17, DHLM-14-1 and OLM-203 have exhibited strong resistance to grain smut.

Rust (*Uromyces linearis* Berk. & Broome)

The disease can affect the crop at all growth stages, however, the damage is severe only when infection begins before flowering. Use of rust-resistant varieties like OLM-217, DHLM-14-1 and OLM-123 and spraying mancozeb 75 WP (0.2 percent) help in managing rust to a certain extent.

Harvesting

The kharif season crop is harvested between September and October, while the rabi crop is harvested between January to February.

Yield

The grain yield of little millet ranges from 1.2−1.5 t/ha and straw yield ranges from 2.0−2.5 t/ha.

Exports

No separate data on export of little millet is available.

Seed production

Little millet is a self-pollinated crop and for certified seed production, an isolation distance of five metres is sufficient. This helps maintain genetic purity. It has a seed multiplication rate of 1: 80–100.

CHAPTER 7: Proso millet

(*Panicum miliaceum* L.)

Figure 62. Field view of proso millet

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Proso millet is also known as *panivaragu* (Tamil and Malayalam), *barre* (Hindi), *baragu* (Kannada), *varigulu/varagalu* (Telugu), *vari* (Marathi), *cheno* (Gujarati) and *cheena* (Bengali and Punjabi). It is an important minor millet grown in India. Owing to its quick maturity, this crop is able to evade drought. It is a shallow-rooted and short duration crop (60–90 days) with relatively low water requirement, and therefore, it offers better prospects for intensive cultivation in dry lands. Proso millet is grown as a rainfed crop during the kharif season, but under irrigation it can be grown as a summer catch crop in high-intensity rotations.

Among the small millets, proso millet has the highest protein content (13.21 percent). Its protein has higher proportion of leucine, phenylalanine and methionine, but relatively low lysine. Proso millet is a good source of carbohydrate (74 g carbohydrates in 100 g) and crude fibre (5.5 g in 100 g flour). It is believed to have originated in India and later spread to other parts of the world. It may have evolved from *Panicum psilopodium*, a wild species found in Myanmar, India and Malaysia.

In India, proso millet is extensively cultivated in Madhya Pradesh, eastern Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra, Telangana, Andhra Pradesh and Karnataka. In 2015/16, it was cultivated over an area of 40 000 hectares with a grain production of 22 000 tonnes (Hariprasanna, 2023).

Climatic requirements

Proso millet is primarily a self-pollinated short-day plant, suited to warm climates. It is highly drought resistant and can be grown in areas where there is scanty rainfall. It displays remarkable drought tolerance and can grow in dry, semi-arid areas, producing seeds under an annual precipitation as low as 330–350 mm. Proso millet has very high water use efficiency, resulting in the lowest water requirement among all cereal crops. It has a very short growing duration (60–100 days) and can withstand water stagnation to some extent. It can be cultivated at altitudes ranging from 1200 m to 5000 m above sea level. The optimum temperature for proso millet cultivation is 20–30 °C. When temperatures go above 30 °C, vegetative growth and flowering slow down. The main stems become short in stature, making them drought tolerant.

Soil

Proso millet can be cultivated on a wide range of soils, from heavy soils to comparatively poor soils; with variable texture, ranging from sandy loams to clays of black cotton soils. Coarse sands are not suited for proso millet cultivation. Well drained loam or sandy loam soils free from *kankar* (hard nodules or layers of calcium carbonate) and enriched with organic matter are ideal for proso millet cultivation. It grows best in soils with a pH of 5.5–6.5 and can tolerate soil salinity in the range of 1.5–9.5 dS/m (deci-siemens per metre). Saline tolerant accessions/cultivars of proso millet were found to possess higher chlorophyll-a content suggesting an association between chlorophyll-a and salt tolerance. Proso millet also shows high tolerance to alkalinity. It has very low nutrient requirements.

Land preparation

Soon after harvesting the preceding crop, the field is ploughed to expose the soil to sunlight and enhance its moisture retention. With the onset of monsoon, the land is harrowed two or three times and then levelled. When proso millet is being cultivated as a summer crop, one irrigation is given prior to land preparations. Once the soil reaches a workable condition, the seedbed is prepared by ploughing thrice followed by harrowing and then by planking. Proso millet needs a firm and clean seedbed but does not respond to deep ploughing.

Varieties

Several improved varieties of proso millet have been developed beginning with the first pure line variety 'Ram Cheena' in 1960. Among the known races of proso millet, 'ovatum' has been found to have significantly higher iron, zinc, calcium and protein content compared to other races (miliaceum, patentissimum, contractum, compactum and nutans). The list of improved and popular varieties recommended for different states is given in Table 29.

TABLE 29. Recommended varieties of proso millet across different states in India

State / Union territory	Varieties
Tamil Nadu and Puducherry	Co.5 (TNAU-143), TNAU-151, TNAU-164, TNAU-145, TNAU-202, Co-4, K-1, K-2, Co-3, Co-2, GPUP-21, GPUP-8 , GPUP-25 (PMV-42), ATL-1 (TNPm-230), DHPM-8-3 (CPRMV-2), PMV-480 (VP-021)*
Uttarakhand	PRC-1, TNAU-145, TNAU-151, TNAU-164, GPUP-25, ATL-1 (TNPm-230)
Karnataka	GPUP-8, GPUP-21, GPUP-25, TNAU-145, TNAU-151, TNAU-164, TNAU-202, ATL-1 (TNPm-230), DHPM-2769, PMV-442, DHPM-8-3 (CPRMV-2),
Bihar	BR-7, TNAU-164, TNAU-145, PR-18, TNAU-202, TNPm-230, ATL-1 (TNPm-230), PMV-480 (VP-021)*
Andhra Pradesh	Sagar, Nagarjuna, Co 4, Co 3, TNAU-151, TNAU-164, TNAU-202, GPUP 25, ATL-1 (TNPm-230), DHPM-8-3 (CPRMV-2), PMV-480 (VP-021)*
Uttar Pradesh	Bhawna, PRC-1, TNAU-145, TNAU-164, TNAU-151, GPUP-25, ATL-1 (TNPm-230)

Source: Authors' own elaboration
*2025 release

Sowing windows

Proso millet is cultivated throughout the year. As a kharif crop, it is sown with the onset of monsoon. As an irrigated rabi crop, it is sown in September–October in Tamil Nadu and Andhra Pradesh. In Bihar and Uttar Pradesh it is sown as a catch crop during summer in the second fortnight of March and May. During summer, it is advisable to sow proso millet immediately after harvesting the rabi crop.

Seed rate and spacing

The seed rate depends on the method of sowing with broadcast crops needing 30–50 percent higher seed than line sown ones (10 kg/ha). It is important to use high-quality seeds for good germination and disease-free crops. Proso millet is sown in lines that are 25 cm apart with a plant-to-plant spacing of 10 cm. Shallow sowing (1.5 cm to 2 cm) is done under favourable soil moisture conditions in high rainfall and irrigated areas. Deep sowing (3 cm to 4 cm) is done under rainfed and low rainfall conditions. Proso millet is sown by broadcast method and by line sowing. Line sowing ensures better germination, cuts down seed requirement and facilitates intercultural operations compared to broadcasting.

Manure and fertilizers

Being a short duration crop, proso millet requires relatively less nutrients compared to other cereals. Under irrigated conditions, the general fertilizer recommendation is 50-30-20 kg/ha of N-P_2O_5-K_2O. The entire dose of phosphorous and potassium along with half the dose of nitrogen is applied as a basal dose at the time of sowing. The remaining nitrogen is top dressed at the time of the first irrigation. Under rainfed conditions, a fertilizer dose of 25-15-10 kg/ha of N-P_2O_5-K_2O is sufficient. If organic manure is available, it may be added to the soil a month prior to sowing at the rate of 4–10 t/ha. The fertilizer required specific to different states is given in Table 30.

TABLE 30. Fertilizer recommendations for proso millet

States	Fertilizer dose (N-P_2O_5 kg/ha)
Andhra Pradesh and other states	20-20
Bihar and Tamil Nadu	20-10
Uttar Pradesh	40-20

Source: Authors' own elaboration

Weed management

The productivity of proso millet is adversely affected by weeds, more so during the kharif season. To achieve higher yields, the field should be kept weed-free during the first 4–5 weeks after sowing.

For weed management in line sown crop, two inter-cultivations and/or one hand-weeding along with pre-emergence spray of atrazine (0.56 kg/ha) is recommended. In crops sown by broadcasting, one hand-weeding along with post-emergence application of 2,4-D sodium salt (1.0 kg/ha) at 20−25 DAS is recommended. Pre-emergence application of pendimethalin (1.0 kg/ha) or atrazine (0.56 kg/ha) followed by a mechanical weeding at 20 days after transplanting offers integrated weed management benefits. Mulching with organic material like straw, hay or dried leaves suppresses weeds.

Water management

Proso millet sown during the kharif season generally does not require any irrigation. Its water requirement is very low (200–500 mm) and over 90 percent of this is met through rainfall. When limited water is available for irrigation, the ear emergence stage is the most critical period. Hence, if dry spells prevail for longer period, then one irrigation must be given at tillering stage to boost yields. A summer crop, however, would require two to four irrigations depending upon the soil type and climatic conditions. The first irrigation must be given at 25−30 DAS and the second irrigation at about 40–45 DAS. Because the crop has a shallow root system, heavy irrigation is not advisable. In proso millet, the yield increases substantially with irrigation when compared to other cereals (32.57 kg/ha for every cm of irrigation).

For rainfed cultivation, short duration early varieties such as TNPm-230, DHPM-2769, Nagarjuna, Bhawna, CO-3, CO-5 and TNAU-202 are recommended. Mulching the soil with organic material like straw, hay or dried leaves aids in the conservation of soil moisture.

Cropping systems

Owing to its short duration (60–75 days), proso millet can fit well into many intercropping and crop rotation systems. Its intercropping with green gram in 2:1 proportion is important in Bihar and Uttar Pradesh. Proso millet is also included in crop rotations such as: millet–wheat / barley; proso millet–chickpea; maize–potato–proso millet or maize–wheat–proso millet. In western regions of Bihar, proso millet rotation with potato is particularly prominent. In Maharashtra, proso millet is cultivated alongside bamboo as part of an agroforestry approach.

Insect-pest management

Shoot fly is the major insect pest of proso millet. Fall armyworm infestation has also been reported in recent years.

Shoot fly (*Atherigona pulla*)

Shoot fly is the most serious pest of proso millet capable of causing significant yield losses of up to 80 percent or sometimes even total loss of crop. Adult flies lay eggs on the central shoot of seedlings. Larvae bore into the stem and feed on the growing point, that leads to the droning of the central shoot (dead heart) within 2–6 weeks after sowing. Dead heart symptoms in proso millet crop can be seen in Figure 63.

FIGURE 63. Dead heart symptoms in proso millet

FIGURE 64. Fall armyworm in panicles of proso millet

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Management

Early sowing with the onset of monsoon is an effective and economical method for managing shoot fly. Using a higher seed rate and thinning and destroying of seedlings that show symptoms of dead hearts also help reduce infestation. Application of carbofuran 3 percent granules (30 kg/ha) in furrows or as broadcast before sowing is recommended to control the pest. In shoot fly prone areas, tolerant cultivars such as GPUP-21, GPUP-8, BR-7, TNAU-145, TNAU-151, TNAU-164 and CO-4, is desired.

Fall armyworm

Incidences of fall armyworm damage in proso millet have also been reported (Figure 64).

Nematode

Proso millet has been known to be infested mainly with the seed-borne nematode *Aphelenchoides besseyi*. The nematodes were found localized underneath the glumes in an anhydrobiotic state. Up to 16 nematodes with an average of 1.8 per seed were recorded. The larvae feed on the central growing shoots of crops.

Complete eradication of the nematode can be achieved by pre-soaking the seeds in one percent hydrogen peroxide (H_2O_2) for 3 hours followed by hot water treatment at 48 °C for 15 minutes. Alternatively, hot water treatment at 50 °C for 15 minutes can be given directly in case of seeds not pre-soaked in H_2O_2 (Gokte and Mathur, 1993).

Disease management

Head smut and grain smut (*Sphacelotheca sorghi /Ustilago crameri*) and leaf spot are major diseases affecting a proso millet crop. Blast, banded leaf and sheath blight, downy mildew (*Sclerospora graminicola* (Sacc.) J. Schröt.), Udabatta (*Ephelis oryzae* Syd.) and melanosis are other minor and emerging diseases affecting the crop.

Head Smut (*Sorosporium paspali-thunbergii*)

The fungus modifies the entire inflorescence into a sorus enclosed by a greyish-white false membrane. The membrane ruptures as the plants mature, exposing the dark-brown spore mass and the vascular tissues of the smutted panicle. The pathogen survives in soil and is transmitted as externally seed-borne teliospores. High humidity and high temperature are conducive conditions for the spread of this fungus.

Management

Treating seeds with organo-mercurial compounds such as carboxin (1.5–1.875 g/kg seed) or hot water treatment by soaking the seeds in hot water at 55 °C for 7–12 minutes, is useful in managing the disease.

Cultivation of smut resistant cultivars such as TNAU-145, TNAU-151, TNAU-218, TNAU-164, DHPRMV-2769, TNAU-148 and CO-5 is recommended.

Rust (*Uromyces linearis* Berk. and Broome)

The symptoms of rust appear as small, raised yellow to white spots on both sides of the leaf. As the disease progresses, spots enlarge and merge, forming reddish-orange pustules. Pustules often have yellow margins. The pustules darken, turning brown or black and the leaves dry prematurely, reducing photosynthetic area. If infection occurs before flowering, the plant may collapse. Yield losses are highest when rust strikes early in the crop cycle. Warm, humid weather, dense crop stands with poor air circulation and late sowing often increases rust incidence.

Early sowing helps avoid peak infection periods. Cultivation of rust resistant cultivars such as TNAU-164, TNAU-145, TNAU-204, TNAU-218, TNAU-220 and CO-5 is recommended. Spraying of *Trichoderma viride* or neem-based formulations (azadirachtin 0.15 percent) or seed treatment with mancozeb or propiconazole were found effective in rust management. Crop rotation is also helpful in reducing inoculum build-up in the fields.

Bacterial stripe disease / bacterial leaf blight (*Acidovorax avenae* subsp. *Avenae*)

The disease is more severe in the years following floods making it an important concern for climate change. In younger plants, the pathogen results in stunting and death of seedlings (Figure 65). In the hilly areas of Uttarakhand, it is recommended to use a leaf blight resistant cultivars such as PRC-1.

FIGURE 65. Leaf blight in proso millet crop

FIGURE 66. Leaf spot in panicles of proso millet

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Grain smut (*Sphacelotheca sorghi /Ustilago crameri* Korn)

This disease, also known as covered smut/kernel smut, is characterised by the transformation of grains into white greyish sacs (smut sori). The sori are filled with chlamydospores appearing as black powder which is responsible for the spread of disease as an externally seed-borne pathogen. The cultivar CO-5 (TNAU-143) is resistant to grain smut.

Leaf spot (*Bipolaris panici-miliacei* (Syn. *Helminthosporium panici-miliacei*)

Leaf spot is one of the serious diseases of proso millet. It is seed-transmitted and appears as brown rectangular spots over infected leaves. Seed rotting, coleoptile spot and seedling blight are the common symptoms of seed infection (Figure 66).

Cultivating leaf spot resistant varieties such as 'PRC-1', GPUP-8, CO-5 and RAUM-7 is recommended. Seed treatment with 2–3 g/kg of carbendazim (50 percent WP) or foliar spraying of carbendazim (0.05 percent) at the time of flowering has been recommended to prevent secondary infections.

Downy mildew: Downy mildew was also reported in proso millet (Figure 67).

FIGURE 67. Downy mildew symptoms in panicles of proso millet
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Harvesting and threshing

In most varieties, proso millet is ready for harvesting 65–75 days after sowing. The crop should be harvested when it is about to mature. Lodging and shattering are problems in proso millet, particularly in post-rainy and summer season crops. The seeds at the tip of the upper heads ripen and shatter before the lower seeds and the panicles mature later. Therefore, the crop should be harvested when about two thirds of the seeds are ripe. Cultivation of non-lodging and non-shattering varieties such as K-2 is useful. The crop is threshed manually or using bullocks.

Yield

Under better management, it is possible to harvest 2.0–2.5 tonnes of grain and 5.0–6.0 tonnes of straw per hectare.

Exports

According to Volza's India Export data, India is the top exporter of organic proso millet. Most of the organic proso millet exports from India go to the United States of America, United Arab Emirates and Hong Kong. Globally, India is the top exporters of organic proso millet. (Source: Volza export trade data)

Seed production

Proso millet is a self-pollinated crop and for certified seed production, an isolation distance of five metres is sufficient. This helps maintain genetic purity. It has a seed multiplication rate of 1:80–100.

CHAPTER 8: Kodo millet

Paspalum scrobiculatum (L).

FIGURE 68. Field view of kodo millet
©ICAR-IIMR, Hyderabad

Kodo millet is a highly drought-resistant crop and is considered the coarsest of all food grains. It is known by the names cow grass, rice grass, ditch millet, native paspalum or Indian crown grass. Originally from tropical Africa, kodo millet is believed to have been domesticated in India 3000 years ago. The grains are enclosed in a hardy seed coat which should be removed before cooking. Nutritionally each grain of kodo millet contains 8.3 percent protein, 1.4 percent fat, 65.6 percent carbohydrates and 2.9 percent ash. The grain is recommended as a substitute for rice in patients suffering from diabetes.

India is a major producer of kodo millet. It is cultivated in many states including Madhya Pradesh, Uttar Pradesh, West Bengal, Andhra Pradesh, Tamil Nadu and Rajasthan. Though recent cultivation details are unavailable, as per the data available for 2015/16, it is cultivated on 1 96 000 ha (Hariprasanna, 2023) with a grain production of 94 000 tonnes of which 50 000 tonnes were produced in Madhya Pradesh, 17 000 tonnes in Chhattisgarh, 12 000 tonnes in Tamil Nadu, 7000 tonnes each in Gujarat and Uttar Pradesh and the remaining in other states. Dindori and Mandla (Madhya Pradesh) are the two districts which have highest area and production of kodo millet.

Climatic requirements

Kodo millet is cultivated predominantly in warm and dry climate. It performs best at temperatures between 25–35 °C, with germination and early growth most vigorous at around 30–35 °C. At temperatures below 20 °C, kodo millet has slow germinates and low seedling vigour while temperatures above 40 °C result in reduced growth, leaf scorching and yield losses up to 30 percent. Being highly drought tolerant it can be cultivated in areas where rainfall is scanty and erratic. It thrives well in areas receiving only 40 to 50 cm annual rainfall and is highly sensitive to waterlogging.

Soil

Kodo millet is grown on a variety of soils, from gravelly and stony types to loamy soils. Deep, loamy, fertile soils, rich in organic matter are ideal for optimum growth. Well-drained soils with adequate moisture supply are required for uninterrupted growth of this crop. Kodo millet has the highest level of heavy metal tolerance (copper and zinc) during the seedling stage.

Varieties

The list of improved and popular varieties recommended for different states is given in Table 31.

TABLE 31. Recommended varieties of kodo millet across different states in India

State	Varieties
Madhya Pradesh	JK 439, RBK 155, JK 13, JK 65 and JK 48, JK 137, RK 390-25, JK 106, GPUK 3, JK-98, DSP-9-1, TNAU-86, CKMV 1 (ATL-2), Dahod Kodo (CKMV 2), Chhattisgarh Kodo-03 (BK-36), CKMV 4(ATL-3), TNPSc 328 (KMV 528)*
Tamil Nadu	KMV 20 (Bamban), CO 3, TNAU 86, GPUK 3, RK 390-25, ATL1 (TNPsc 176), CKMV 1 (ATL-2), Chhattisgarh Kodo-03 (BK-36), Dahod Kodo (CKMV 2), CKMV 4 (ATL-3)
Gujarat	GK 1 and GK 2, GPUK 3, JK-13, JK-65, RK 390-25, Gujarat Anand Kodra-3 (GAK-3), Gujarat Kodo millet 4 (Dahod Kodra-4), CKMV 1 (ATL-2), Dahod Kodo (CKMV 2), CKMV 4(ATL-3), CKMV 5(ATL-4), TNPSc 328 (KMV 528)*
Chhattisgarh	RBK 155 and JK 439, Indira Kodo-1 (BK-1), Indira Kodo-48, GPUK 3, JK-65, JK-98, Chhattisgarh Kodo-2, Chhattisgarh Kodo-03 (BK-36), RK 390-25, TNAU-86, CKMV 1 (ATL-2), Dahod Kodo (CKMV 2), CKMV 4(ATL3), CKMV 5(ATL-4), TNPSc 328 (KMV 528)*
Karnataka	GPUK 3, RBK 155, RK 390-25, TNAU-86, CKMV 1 (ATL-2), Chhattisgarh Kodo-03 (BK-36), Dahod Kodo (CKMV 2)
Jharkhand	CKMV 4 (ATL-3), TNPSc 328 (KMV 528)*
Andhra Pradesh	CKMV 4(ATL-3), CKMV 5(ATL-4)

Source: Authors' own elaboration

* 2025 release

Sowing windows

The optimum sowing time for kodo millet in India varies across regions and seasons, but it's generally aligned with the onset of the monsoon. Under rainfed conditions the crop is sown when the monsoon arrives, and depending on the state, sowing time varies from mid-June to the end of July. In Madhya Pradesh and Chhattisgarh the last week of June to the first week of July is ideal for sowing. Under irrigated conditions, sowing can begin as early as mid-May, especially in Tamil Nadu and parts of Andhra Pradesh. The rabi crop in Andhra Pradesh and Tamil Nadu is sown from September to October.

Seed rate and spacing

Line sowing performs better than broadcasting as it facilitates inter-cultivation and weed management and thus requires less seed rate (10 kg/ha) than a broadcast one (15 kg/ha). A spacing of 22.5 cm × 10 cm is optimum and sowing should be done shallow, at a depth of 3−4 cm. Seed treatment with carbendazim or carboxin at 2 g/kg is recommended to avoid grain smut and other fungal infections.

Manure and fertilizers

Addition of organic manures is always beneficial since it helps to improve the water retention capacity of soil in addition to providing essential nutrients to the crop. Application of 5−10 t/ha of FYM is done about a month before sowing. A fertilizer dose of 40-20-20 kg/ha N-P_2O_5-K_2O is recommended. All fertilizers should be applied in furrows at the time of sowing. In high rainfall areas of Madhya Pradesh and Chhattisgarh, and in crops under irrigation, split application of nitrogen (half basal and the other half at 35−40 days after sowing) has shown promising results.

Biofertilizers

Treating seeds (25 g inoculant/kg seed) with *Azospirillum brasilense* (N fixing bacterium) and *Aspergillus awamori* (phosphate solubilizing fungus) is beneficial.

Weed management

Effective weed control during the initial stages of plant growth is essential as weeds were found to reduce kodo millet yields by 30−60 percent. Typically, two rounds of weeding at an interval of 15 days are adequate. In line sown crops, weeding may be done with hand hoe or wheel hoe. Two rounds of hand-weeding at around 20 days and 35 days after sowing combined with 2 or 3 inter-cultivations provide better weed management. In regions of Madhya Pradesh with reliable rainfall, pre-emergence application of pendimethalin (0.75 kg /ha) has been effective in weed management. Pendimethalin integration with one inter-cultivation at 20 DAS and one hand-weeding at 40 DAS ensures weed control for the entire season.

Application of 2, 4-D sodium salt (1.0 kg /ha) at 20−25 DAS is effective in managing broadleaved weeds. Pre-emergence application of bensulfuron-methyl (0.06 kg/ha) with pretilachlor (0.495 kg/ha) effectively manages both broadleaved and grassy weeds in sole kodo millet. When integrated with one inter-cultivation at 25–30 DAS this combination provides weed management for the entire season. Similarly, post-emergence application of bispyribac-sodium (20 g/ha) at 20 DAS was found effective in broad spectrum weed management in sole kodo millet. When integrated with one inter-cultivation at 30–35 DAS, bispyribac-sodium provides weed management for the entire season.

Striga management

Kodo millet is susceptible to attack by *Striga asiatica* and *S. densiflora*. Depending on cultivars and infestation levels, yield losses varying from 42.4 percent to 65.8 percent have been reported in kodo millet because of *Striga densiflora*. The use of organic fertilizers containing high amount of nitrogen can help suppress striga infestation by reducing stimulant exudation from the host roots. High amount of nitrogen is said to have the effect of reducing strigolactone production from the host plant and also inhibiting the germination of striga seeds. Soil application of FYM and vermicompost enriched with *Trichoderma* spp., *Azospirillum* spp. and *Glomus intraradices* is also effective in managing *Striga asiatica* in kodo millet. Twenty-nine kodo millet cultivars were identified as resistant to striga menace. They are: GPUK 1, GPUK 3, GPUK 5, JK 41, JK 13, JK 65, RBK 155, RPS 517, RPS 530, RPS 531, RPS 541, RPS 594, RPS 606, RPS 687, RPS 697, RPS 743, RPS 744, RPS 745, RPS 971, DPS 36, DPS 54, TNAU 86, TNAU 96, TNAU 141, BK 3, BK 21, KOPN 8, KOPN 21 and KOPN 22.

Irrigation management

During periods of moisture stress, irrigation is required every 4–7 days depending on the severity of the moisture stress and the type of soil. Two irrigations, the first at 25–30 DAS and the second at 40–45 DAS, was found promising. Draining out the excessive rainwater from fields during heavy and continuous rains is also essential.

Cropping systems

Kodo millet is a component of many mixed intercropping systems and crop rotations. Among intercropping systems, two rows of kodo millet with one row of pigeon pea/green gram/black gram/soybean is profitable in Madhya Pradesh. Four rows of kodo millet with two rows of horse gram is another promising intercropping system.

Among crop rotations, kodo millet–niger–kodo millet is the most sustainable one in Madhya Pradesh. Studies at Dindori (Madhya Pradesh) for 9 years (2011–2020) indicated that niger–soybean–kodo millet and kodo millet–soybean–kodo millet were the most remunerative crop rotations in recent years.

Insect-pest management

Shoot fly (*Atherigona simplex*)

Shoot fly is the only major pest in kodo millet and can cause significant yield losses (39–49 percent in years with serious incidence of the pest). The pest appears 10 days after sowing resulting in dead hearts (Figure 69). Application of carbofuran-3G (30 kg/ha) in furrows or as broadcast before sowing is recommended to manage this pest. Since delayed sowing increases the incidence of shoot fly, sowing with the onset of monsoon is beneficial. Sowing the crop before the second fortnight of July has given promising results. The use of higher seed rate (1.5 times the recommended seed rate) also helps in coping with shoot fly menace. Cultivation of shoot fly-resistant cultivars such as JK13, RPS 515, 584, 810, 834, 842, 846, 871, 872, 938, 974, IQS 147-1 is helpful.

FIGURE 69. Dead heart symptoms in kodo millet

FIGURE 70. Smut infected kodo millet panicle

FIGURE 71. Kodo millet infected by banded sheath and leaf blight

Termite and stem borer

Previously recommended chemicals for control of termite and stem borer are now banned for use. A new recommendation is awaited.

Disease management

Rust (*Puccinia substriata* Ellis and Barthol)

Brown pustules are seen on leaves hindering photosynthesis and causing considerable loss in yield. The collection and destruction of the grass hosts is partly useful in the management of the disease. Foliar spraying of mancozeb 75 WP (0.2 percent) effectively suppresses the disease.

Head smut (*Sorosporium paspali-thunbergii* (Henn.) S. Ito)

This seed-borne disease was first reported in Bihar and Andhra Pradesh and has since become an endemic in India. The disease was more prevalent in black soil than red gravel and red soils. The diagnostic symptoms of the disease appear from the flowering stage to the dough stage of the crop. Diseased plants have stunted growth. Almost all the panicles in the infected plants are converted into a long smut sorus that varies from 2.1 cm to 14.6 cm in length and 0.1 cm to 0.6 cm in breadth. Initially, the developing smut sorus remains covered by a creamy membrane. At maturity the membrane is ruptured, exposing the black mass of teliospores (Figure 70).

Management

An integrated stem borer management module is followed for optimum results. Soaking seeds in hot water at 55 °C for 7−12 minutes is effective. Growing resistant varieties (KMV 8, KMV 20, JK 41, JK 62, JK 65, JK 106, GPUK-3 and JK 13) is the cheapest way and most effective way of managing head smut disease. Varieties such as GPLM-78, 96, 176, 322, 364, 621, 641, 679 and 720 and RK-31, 65-18, 87-9, 106, 162, ICK769 and DPS-486, 516, 542, 672, 700, 727 are resistant to smut and can therefore be used in breeding programmes. Seed treatment with fungicides (2 g/kg) such as carbendazim, mancozeb, carboxin, chlorothalonil, thiram and tebuconazole (1.5 g/kg seed) is also effective in managing the disease. Shallow sowing resulting in early emergence of seedlings, reduces the incidence of head smut.

Sheath rot (*Sarocladium oryzae* (Sawada) W. Gams and D. Hawksworth)

This disease is widespread in Tamil Nadu, especially in the Vrundhachalam region. In regions where kodo millet is grown as a rabi or summer crop after paddy, the infected mycelium is carried by the rice crop residue which serves as a primary disease inoculum. This disease affects the emergence of panicle and leads to a reduction in grain yield. The topmost leaf sheath which encloses the young panicle shows the symptoms in the form of lesions. The grains get discoloured and this affects the seed quality.

Udbatta disease (*Ephelis oryzae* Syd)

Balansia oryzae-sativae H. is the perfect stage of this pathogen. It occurs in kodo millet in addition to little millet, *Pennisetum* and *Cynodon dactylon*. In 2008, it was first reported in GKVK farm, Bengaluru (Karnataka). This sporadic disease of kodo millet shows the highest incidence in the variety RBK 155. The disease is commonly called udbatta because the panicle looks like an *udbatha* or *agarbatti* (incense stick). The symptoms of this disease are visible in the panicle initiation stage.

Ergot or sugary disease (*Claviceps paspali* Stevens and Hall**)**

The disease occurs in both cultivated as well as wild forms of kodo millet. Infected flowers exude a sweet and sticky liquid and hence the name honeydew or sugary disease.

The exudate eventually hardens into a brown-coloured substance. With maturity, ergot develops in the kernels of the panicle. Matured sclerotia are toxic and can cause paralysis and even death in animals that consume them.

Leaf blight

This disease is caused by *Alternaria alternata* (Fr.) Keissl and is considered a minor emerging threat to kodo millet (Figure 71).

Harvesting

In north India, kodo millet which is cultivated in the kharif season becomes ready for harvesting in the month of September or October, while rabi crops are harvested from January to February. Lodging is a common and major problem in all kodo millet cultivars. To minimize lodging, crop management practices such as the use of early maturing varieties (JK 76), adjusting the date of sowing, increasing the intra-row space, or lowering the number of plants in a row, can be practised.

Yield

Under better management, it is possible to obtain a yield of 1.5–1.8 tonnes of grain and 3.0–4.0 tonnes of straw per hectare.

Exports

According to Volza's India Export data, India exported 800 shipments of Kodo Millet between June 2024 to May 2025 TTM (till the month/trailing twelve months). These exports were made by 165 Indian exporters to 284 buyers. Globally, the top three exporters of Kodo Millet are India, Sri Lanka and Egypt. Most of the kodo millet exports from India go to the United States of America, United Arab Emirates and Canada. (Source: Volza export trade data)

Kodo millet poisoning

Kodo millet poisoning was reported from parts of north India, especially Uttar Pradesh and Madhya Pradesh. These incidents occurred when maturing and harvesting of kodo millet coincided with rainfall, resulting in fungal infection of the grains. The contaminated kodo millet, locally known as *matawna* kodoo or *matona* kodo, caused toxicity upon consumption.

Studies have indicated that the toxicity was because of the contamination of seeds with mycotoxin producing fungi belonging to *Aspergillus* and *Penicillium* genus that produce mycotoxin and cyclopiazonic acid (CPA). Kodo poisoning was first identified during the mid-80s.

Pre-harvest management of kodo toxicity includes 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 pests and diseases through appropriate pest management practices; harvesting the crop at right maturity (18−20 percent moisture in the grains); and avoiding over maturity of the crop.

Post-harvest grain management practices to minimize the risk of production of mycotoxins and thus kodo toxicity include proper drying (quick drying of grain to 10−13 percent moisture); storage (at a relative humidity of 70 percent or less and grain moisture content of 12 percent or less); and processing (milling of grains to remove lemma and palea).

Seed production

Kodo millet is often a cross-pollinated crop and for certified seed production, an isolation distance of 200 metres is recommended to maintain genetic purity. The crop has a seed multiplication rate of 1:80–100.

CHAPTER 9: Barnyard millet

Echinochloa frumentacae (Link)

FIGURE 72. Field view of barnyard millet

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Barnyard millet (known as shyamak or samak in Hindi) is essentially a weed in paddy fields that has been transformed into a staple in India. It is known by different names in different regions: *sanwa* (Uttar Pradesh, Bihar and Delhi), *jhangora* (Uttarakhand) *bhagar* or *sawa* (Maharashtra), *moriyo* or *samo* (Gujarati), *samai* (Tamil Nadu) and *oodalu* or *samalu* (Andhra Pradesh and Telangana). It is also cultivated for fodder. With a protein content of about 12 percent, barnyard millet presents a highly digestible protein source that is also relatively low in calories. What distinguishes barnyard millet further is its carbohydrate profile, with an average content ranging between 51.5 percent and 62 percent. Barnyard millet varieties contain exceptionally high total dietary fibre content (7 percent) which can meet 100 percent of the fibre requirement of the body if 100 g of millet were to be consumed per day (ICMR, 2020). The crop is particularly popular in hilly and tribal areas, especially the Himalayas, and forms an important part of the staple diet in the region. Though on a lesser scale, it is also grown in Bihar, Tamil Nadu, Maharashtra and Madhya Pradesh.

Barnyard millet is an ancient crop grown in warm and temperate regions across the world. Among the many cultivated and wild species of barnyard millet, two of the most popular species are *Echinochloa frumentacea* (Indian barnyard millet) and *E. esculenta* (Japanese barnyard millet). It is widely cultivated in Asia, particularly India, China, Japan and Korea. It is the fourth most produced small millet, providing food security to many economically challenged people across the world. Globally, India is the biggest producer of barnyard millet, both in terms of area and production. Barnyard millet was cultivated on 96 000 hectares with a grain production of 73 000 tonnes during 2015/16 in India (Hariprasanna, 2023). In Uttarakhand, barnyard millet contributed to 11.5 percent of the total fodder consumption by livestock, indicating its prominence. Tamil Nadu, Maharashtra, Madhya Pradesh, Karnataka and northeastern states are other regions where barnyard millet is cultivated.

Barnyard millet is a short duration crop capable of growing in adverse environmental conditions with minimal inputs and can withstand a wide range of biotic and abiotic stresses.

It is a tall erect crop growing up to 50–95 cm in height. The stem as well as the leaves are green in colour. Its leaves are flat, glabrous or slightly hairy without ligule. The grain is caryopsis and white or yellow in colour.

Climatic requirements

Barnyard millet is highly adaptable. During the summer season, it can be cultivated at altitudes up to 2000 metres above mean sea level. Temperature plays a major role in the growth of both species (*E. frumentacea* and *E. esculenta*) of barnyard millet. Low temperatures (15 °C in the day and 10 °C at night) restrict growth and affect the plant development, particularly leaf area and dry weight. For proper growth of *E. frumentacea*, the optimum day temperature should be 27−33 °C and night temperature should be 15−22 °C. In comparison, *E. esculenta* demonstrates better tolerance to low temperature and shows very little reduction in relative growth rate. Barnyard millet can grow and reproduce in a range of photoperiods, short days (8–13 hours) and long days (16 hours). Under short-day conditions, plants are small and the flowering is quick, yet abundant; under long-day conditions, the plants are more robust with a large seed output. Salinity impacts productivity in barnyard millet. Some barnyard millet cultivars that are salinity tolerant are: CO (KV) 2, MDU-1, PRJ1, TNEf 301, TNEf 204, TNEf 361, TNEf 364 and VL 29. Freshly harvested barnyard millet seeds have an innate seed dormancy that varies from 4 to 48 months depending on the genotype, seed coat thickness, composition (lignin, cuticular waxes), abscisic acid content of the seed, environmental conditions during seed growth (seed developed under drought have long dormancy periods), etc.

Soil

Barnyard millet can grow well in soils with low moisture-holding ability and climates with low humidity. Hence, sandy loam soils and red laterite soils are most suitable for cultivating barnyard millet.

Varieties

Important varieties recommended for different states is presented in Table 32.

TABLE 32. Recommended varieties of barnyard millet across different states in India

State	Varieties
Uttarakhand	VL 172, VL Madira 207, PRJ 1, VL 29, PRS 1, DHBM-93-3, DHBM-23-3
Uttar Pradesh	VL 172 and VL 207, Anurag, VL 29, DHBM-93-3, Kanchan, DHBM-23-3
Tamil Nadu	CO 1, CO 2 (TNAU-43), VL 181, VL 29, DHBM-93-3, DHBM-23-3, MDU-1 (high Fe:16 mg/g), CBYMV-1 (BMV 611)
Karnataka	VL 172, RAU 11, VL 181, DHBM-93-3, DHB-93-2, DHBM-23-3, CBYMV-1 (BMV 611)
Gujarat	Gujarat Banti-1, DHBM-93-3, VL-172, DHBM -23-3, GB-2 (Sabari)*
Bihar	VL Madira181
Maharashtra	Phule Barti-1 (KOPBM 46), DHBM-23-3
Rajasthan	ER 64 (Pratap Sawan 1)
Andhra Pradesh, Madhya Pradesh and Telangana	CBYMV-1 (BMV 611)

Source: Authors' own elaboration
*2025 release

Sowing windows

Barnyard millet can be cultivated throughout the year. As a kharif rainfed crop, it is sown with the onset of monsoons during June–July. Dry seeding before the onset of monsoon (during April–May) is practised in the hills of Uttarakhand and northeast India. In mid- and high hill areas of Uttarakhand, the crop is sown during April–May, while in the valleys it is sown during May–June. In Tamil Nadu, as a rabi rainfed crop, it is sown during September–October and in February–March as an irrigated crop.

Seed rate and spacing

A barnyard millet crop can be sown by both broadcast and line sown methods. Line sowing facilitates inter-cultivation, better weed management and consequently results in superior yields compared to broadcasting. Additionally, the seed requirement is low for a line sown crop (8–10 kg/ha) when compared to a broadcast one (15 kg/ha). A transplanted crop has the least seed requirement (5–6 kg/ha). The transplanting method is followed under delayed monsoon conditions in terrace farming systems of Uttarakhand, and in intercropping systems, where precise row spacing needs to be maintained between component crops. Nursery raised seedlings with 3–4 leaves and a healthy root system are transplanted in the main fields when they are 15–20 days old. A spacing of 25 cm × 10 cm is optimum and shallow sowing is done at a depth of 3–4 cm.

Seed treatment enhances germination, improves seedling vigour and protects against diseases. Seed treatment with thiram (2–3 g/kg seed), provides protection against seed-borne diseases like grain smut and head smut.

Manure and fertilizers

The application of well decomposed FYM (5–10 t/ha), about a month before sowing, along with fertilizer application of 20–40 kg/ha of N with 20 kg/ha P_2O_5 has been promising. The recommended nitrogen dose is higher in Uttar Pradesh, Bihar and Tamil Nadu (40 kg/ha) than that in Andhra Pradesh and other states (20 kg/ha). Under irrigated conditions and under favourable moisture conditions for a rainfed crop, nitrogen application in two equal parts is recommended (50 percent each as basal and 25 DAS). A transplanted crop requires a higher nitrogen dose, up to 60 kg/ha. A balanced fertilization that includes 20 kg K_2O/ha application (besides nitrogen and phosphorous nutrients) is particularly recommended under favourable moisture, irrigation and transplanted conditions.

Biofertilizers

Traditionally, seed treatment with powdered biofertilizers such as phospho-bacteria along with *Azospirillum* at 20 g/kg seed has been recommended. However, seed treatment with a liquid biofertilizer consortium containing *Azospirillum lipoferum* (N-fixer), *Bacillus megaterium* (P solubilizing bacteria) and *Frateuria aurantia* (K solubilizing bacteria) at the rate of 4–5 ml/kg seed is more effective. In addition, soil application (6.25 l of liquid biofertilizer mixed with 500 kg of FYM incubated overnight) at the time of sowing in seed furrows, along with the recommended dose of fertilizers was found promising for realizing higher yields of barnyard millet as compared to seed or soil application of the liquid biofertilizer consortium alone (Sowmyalatha *et al.*, 2023).

Weed management

Weeds are major biotic pressures of barnyard millet, especially in broadcast sown crop where yield reduction of up to 60 percent has been reported. Effective weed management is a pre-requisite to achieve higher grain yields. Two inter-cultivations and one hand-weeding help in effective weed management in a line sown crop. For a crop sown by broadcasting, two hand-weeding are usually sufficient. The transplanted crop has an advantage over weeds, as the seedlings are already 15–20 days old when they are transplanted. The use of herbicides has increased because of escalating manual labour costs and declining availability of animal draft power.

In sole barnyard millet, pre-emergence application of bensulfuron-methyl (0.06 kg/ha) and pretilachlor (0.495 kg/ha) was found effective in managing grassy, broadleaved and sedge type weeds. Use of drones for pre-emergence application of pretilachlor (500 g/ha) with a spray fluid of 40 l/ha has been standardized for weed management in transplanted barnyard millet at Tiruchirappalli (Tamil Nadu). Post-emergence application of 2, 4-D Na salt (1.0 kg/ha) at 20–25 DAS effectively manages broadleaved weeds.

Water management

Barnyard millet crops generally do not require irrigation. However, if dry spells prevail for a longer period, irrigation at 25–30 DAS and at panicle initiation stage (45–50 DAS) gives stable yields. Excess water after heavy rains is drained out from the field to avoid waterlogging.

Cropping systems

Mixed cropping of barnyard millet with cotton, pigeon pea, or short duration pulse crops is practised. Sowing of seed mixtures (by weight) of barnyard millet (90 percent) and soybean / *Amaranthus* (10 percent) is practised in Uttarakhand. Intercropping of barnyard millet and *Amaranthus* (row ratio of 4:1) and intercropping of barnyard millet with rice bean or with niger in a row ration of 4:1 was found promising in Uttarakhand. In Haryana, intercropping of barnyard millet with green gram in 1:5 or 2:4 row ratio were found promising in terms of productivity, profitability and land use efficiency when compared to sole barnyard millet cultivation (Jat *et al.*, 2024).

In Uttarkhand, barnyard millet is grown in the agroforestry mode with *Grewia oppositifolia* Buch.-Ham. ex DC. (known as *bhimal*). This is a shrub/small tree whose timber is used for firewood, and for items such as bows, oars, poles and tool handles. Its leaves are valued as fodder for livestock in winter, especially when no other source of fodder is available.

Insect-Pest Management

The major insect pests of barnyard millet are the pink stem borer and the shoot fly.

Shoot fly (*Atherigona falcata*)

Shoot fly (Figure 73) is a serious pest that can cause significant yield loss. Infestation usually begins during the seedling stage (1–5 leaf stage). Actual damage occurs at one to four weeks after emergence of seedlings. Maggots upon hatching from the eggs bore into the central shoots of the seedlings and kill the active growing point, producing dead hearts (Figure 74). They feed on the decaying core of the shoots and subsequently cause death of the central shoot. Affected plants give out tillers, giving a bushy appearance. In severe cases, the seedlings may die.

FIGURE 73. Shoot fly in barnyard millet

FIGURE 74. Dead heart symptoms

Management

Early sowing with the onset of monsoon is the most effective and economical method to manage shoot fly. Seed treatment with imidacloprid 600 FS (5 ml/kg seed) or thiamethoxam 70 WS (2 g/kg seed) is effective in managing shoot fly in Uttarakhand. Spraying with neem oil (5 ml/l) also provides moderate shoot fly management. These seed treatment practices curb laying of eggs by the shoot fly.

Avoiding early sowing in the kharif season, especially during peak shoot fly activity, together with synchronized sowing across fields, minimizes build-up of the pest. Intercropping with legumes has been reported to disrupt pest cycle.

Cultivation of shoot fly tolerant cultivars such as: VL 207, VL 172, TNAU 151, TNAU 155, KOPBM-46, TNEF-204 and DHBM 996 help to reduce loss because of pest infestation.

Pink stem borer (*Sesamia inferens* Walker)

The pink stem borer damages the barnyard millet crop by boring into the stem and peduncle region causing dead heart and “white ear” symptoms. This ultimately results in substantial economic loss.

Management

A foliar spray of neem oil at 3 percent applied at 35 days and 50 days after sowing was found effective in managing pink stem borer at Madurai (Tamil Nadu). Barnyard millet cultivars ‘TNEF-204’ and ‘DHBM 996’ have shown resistance to stem borer and their cultivation reduces incidence of infestation. Early sowing in the kharif season also helps to avoid peak stem borer incidence. Use of biocontrol agents, such as *Trichogramma* egg parasitoids, are beneficial in reducing the pest infestation.

Termites

Termites attack young seedlings by tunnelling into roots and stems. Infested plants wilt, dry up, or die in patches, often mistaken for moisture stress. Damage is higher in light soils with low organic matter, and under delayed sowing.

Soil should be mixed with 35 kg/ha chlorpyriphos 5 D at the time of sowing. When the incidence of pest is noticed in standing crops one litre of chlorpyriphos 20 EC can be diluted with five litres of water and mixed with 50 kg of soil. This can be broadcast evenly in a hectare of land followed by light irrigation.

Disease Management

Grain smut is a major disease affecting barnyard millet. Anthracnose, head smut *(Ustilago crusgalli), Cercospora* leaf spot (*Cercospora fusimaculans*), leaf blight (*Helminthosporium crusgalli*) and sheath blight (*Rhizoctonia solani*) are the other diseases of minor importance.

Grain smut (*Ustilago panici-frumentacei*)

In barnyard millet, grain smut is an externally seed-borne fungal disease that significantly reduces grain quality and yield (up to 61 percent), especially in humid hill regions of Uttarakhand.

The disease appears during the grain formation stage, typically when temperatures range between 20–25 °C. The fungus infects ovaries directly, replacing the seed with smut spores. Only a few grains per ear are affected, not the entire panicle. Infected grains become 2–3 times larger than normal. The surface of the affected grains turns hairy or fuzzy, often greyish-black. Smut-affected grains may appear as round sacs filled with spores (Figure 75). Figure 76 shows the image of a barnyard millet panicle infected by head smut.

FIGURE 75. Barnyard millet panicle infected by grain smut

FIGURE 76. Barnyard millet panicle infected by head smut

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Management

Seed treatment with thiram or carbendazim (2.5 g/kg seed) or soaking seeds in hot water at 55 °C for 7–12 minutes is useful in managing grain smut. Hot water seed treatment is useful for organically grown barnyard millet.

Cultivation of smut resistant (PRJ-1, URJ-4, VL29, VL172, VL 207, K1, ER 64, TNAU 143, TNAU 25, TNAU 63, VL 10, PRB 903, DHBMV 56-6, DHBMV93-3, RBM 82, RBM 45, RBM 78, RBM 85) is helpful in managing the disease. Rogueing of infected plants from the field is useful in reducing the spread of the disease. Crop rotation is also an effective practice in managing the disease.

Leaf spot or blight (*Helminthosporium crusgalli*)

Leaf spot is a foliar fungal disease affecting barnyard millet under humid conditions. The disease is seed-borne, and the use of contaminated seeds proliferates this disease severely. It can cause premature leaf senescence and a reduced photosynthetic area, impacting grain yield and quality.

This disease app.rs as minute, oval-to-oblong, light brown spots on young leaves that enlarge with time and turn dark brown with a yellow halo. Multiple spots merge to form large necrotic patches. Severely infected leaves dry up and die prematurely giving the appearance of blight (Figure 77). In advanced stages, there is discoloration and weakening of the neck tissue, causing earheads to droop or break.

FIGURE 77. Barnyard millet crop devasted by banded leaf and sheath blight
© Palanna K.B, University of Agricultural Sciences, Bengaluru

Management

To manage this seed-borne disease, seed treatment with systemic fungicides such as thiram (4 g/kg seed) and foliar spray of copper oxychloride (0.2 percent) or mancozeb (1.25 kg/ha) is beneficial.

Harvesting

The crop should be harvested when it is ripe. It is cut from the ground level with the help of sickles and stacked in the field for about a week. This is followed by threshing which is done by trampling under the feet of bullocks.

Yield

A grain yield of 1.2–1.5 t/ha along with a straw yield of 2.0–2.5 t/ha can be achieved by following improved production technologies. Transplanted crops are reported to have a grain yield as high as 2.8 t/ha.

Processing

Barnyard millet requires dehulling before the grains are suitable for human consumption. Dehulling is conventionally done by repeated pounding in mortar. This is time consuming as well as labour intensive as the grain is firmly encased in the lemma and palea. The drudgery involved in manual processing is an important factor contributing to the reduction in the consumption of millets. Their small seed size also makes processing of barnyard millet difficult.

Exports

It is estimated that every year under 1000 tonnes of barnyard millet, often bundled with other millets, is exported from India as whole grain, flour, flakes or ready-to-eat mixes. United Arab Emirates, Saudi Arabia, Nepal, United States of America, Germany and Japan are major importers.

Seed production

Barnyard millet is often a cross-pollinated crop and for certified seed production, an isolation distance of 200 metres is sufficient. This helps maintain genetic purity. It has a seed multiplication rate of 1:80–100.

CHAPTER 10: Browntop millet

(*Brachiaria ramosa* (L.)

FIGURE 78. Field view of browntop millet
© ICAR-IIMR, Hyderabad

Browntop millet (*korale* in Kannada and *andakorra* in Telugu) is cultivated for both grain and green fodder purposes. It is gluten-free and rich in fibre, iron, calcium, magnesium and other minerals. It has a low glycaemic index (GI) making it beneficial for reducing cholesterol. During the Neolithic age, browntop millet was cultivated as a subsistence crop in India. Evidence shows that it was cultivated alongside other crops in south India from as early as the third millennium BCE when it was part of the millet-legume mixed cropping agropastoral systems of the Neolithic times (Fuller, 2006). During the second millennium BCE it spread from Deccan and reached Tamil Nadu and Gujarat, and in scattered sites in Odisha and the Gangetic plains. It was present in Paithan (currently Chhatrapati Sambhajinagar district) in Maharashtra until the seventh century CE. In modern India, it is present as a common weed in little millet. It is cultivated and consumed in limited quantities in Bundelkhand region and on a large scale in the rainfed regions of Karnataka (Tumakuru, Chitradurga and Chikkaballapura) and Andhra Pradesh (Anantapur). Since 2017/18 it has been included under AICRP–SM (All India Coordinated Research Project–Small Millets), which has standardized its production technology.

Globally, India is the largest producer of browntop millet, both in terms of area and production. There are two types of browntop millet which are cultivated in south India – the branched type and the round panicle. In Kannada they are known as *chaduru-korale* and *dundu-korale*, respectively. The round panicle browntop millet is characterized by its higher yield, while branched browntop millet is characterized by its susceptibility to pests and diseases.

Browntop millet contains moisture (11.9 percent), fat (1.89 percent), fibre (8.20 percent), protein (8.89 percent), carbohydrate (71.32 percent) and provides 338 Kcal of energy per 100 grams. It is rich in micronutrients and every 100 grams of browntop millet contains iron (7.72 mg), calcium (28 mg), phosphorus (276 mg), potassium (60 mg), manganese (1.99 mg), magnesium (94.5 mg), copper (1.23 mg), sodium (7.6 mg) and zinc (2.5 mg). Browntop (a darker millet) contains higher levels of phenolic compounds than millets of white varieties.

Browntop millet is an annual/perennial warm-season grass belonging to the Poaceae family. At maturity the plant grows to a height of 90 cm. The nodes of browntop millet are minutely hairy with lance shaped and hairless leaf blades measuring 2–25 cm in length and 4–14 mm in width. The flowers are indeterminate in nature and borne on stalks. The inflorescence is open and spreading, with a simple axis. They arise from the central axis and are 1–8 cm long. The number of inflorescences ranges from 3 to 15. The flowers are white and the seeds are ellipsoid and tan in colour. The fibrous roots of browntop millet can penetrate a depth of up to 60 cm. The duration of the crop is approximately 60–75 days. The crop is valuable from the perspective of plant protection because it suppresses root-knot nematode populations in crops such as tomato and pepper.

Climatic requirements

Browntop millet has the unique quality of growing under partial shade making it a good choice for cultivation even in fruit orchards. It can grow in altitudes of up to 2500 m above mean sea level. It cannot survive in temperatures below 11°C. Moisture stress is a major constraint to its cultivation and it grows in areas with rainfall of 75–125 cm.

Soil

Browntop millet prefers sandy loam soils with a pH of 5 to 6.5 under full sunlight, although it grows in the partial shade as well. It can grow in rocky, shallow soils from sea level to elevations of up to 2450 m. It is adaptable to almost all upland soils. The crop has the capacity to accumulate lead and zinc in plant tissues and is considered a good option for remediation of contaminated soils. Production is adversely affected by poor soil fertility, soil salinity and inadequate drainage. Pot culture studies conducted at Coimbatore (Tamil Nadu) in 2023 have confirmed that browntop millet shows adaptability and good performance in acidic and moderate saline soil conditions (Abhigna *et al.*, 2024).

Varieties

The list of improved and popular varieties recommended for different states is listed in Table 33.

TABLE 33. Recommended varieties of browntop millet across different states in India

State	Varieties
Uttarakhand	GPUBT-6, HBr-2
Karnataka	BTV 30 (DHBT 11-5) and BTV 31 (DHBTM 13-7), GPUBT-2, AK1, AK2
Andhra Pradesh	VZM-1, BTV 31 (DHBTM 13-7),
Tamil Nadu and Maharashtra	BTV 31 (DHBTM 13-7)

Source: Authors' own elaboration

Sowing windows

When cultivated as a kharif crop, the onset of monsoon (June–July) is the ideal sowing time for browntop millet in Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Odisha and Chhattisgarh. When cultivated as an irrigated crop, sowing time can be advanced to May in Tamil Nadu. Studies at Bengaluru (Karnataka) have indicated that the second fortnight of October is the ideal time for sowing during the rabi season and the second fortnight of January is the ideal for summer sowing. In Tamil Nadu, during the rabi season, sowing in

September is recommended. In Bihar and Uttar Pradesh browntop millet is sown from May to September as a catch crop.

Seed rate and spacing

The seed rate varies with the method of sowing, from 10–12 kg/ha under line sowing to 25–30 kg/ha when broadcast. Line sowing shows superior results in yield compared to broadcast sowing.

Studies conducted by AICRP at Bengaluru (Karnataka), Jagdalpur (Chhattisgarh), Kolhapur (Maharashtra) and Vizianagaram (Andhra Pradesh) in 2019 have indicated that a spacing of 30 cm × 10 cm is optimal for this crop. Under highly fertile soils and favourable moisture regimes, a wider spacing of 45 cm × 10 cm shows promising results.

Manure and fertilizers

Application of 10 t/ha of FYM about a month before sowing is recommended. AICRP studies at Bengaluru, Jagdalpur, Kolhapur, and Vizianagaram during 2019 have indicated that application of N-P_2O_5 at 40-20 kg/ha is optimum. Further, AICRP studies at Athiyandal (Tamil Nadu) and Bengaluru during 2020 have indicated that application of 20 kg/ha K_2O besides N, P fertilizers is useful in enhancing grain and stover yields. Studies at Agricultural Research Station, Baljigapade (Chikkaballapur district, Karnataka – Eastern Dry Zone) indicated that application of 6.25 t/ha of FYM along with 30-20-10 kg/ha N-P_2O_5-K_2O proved effective for improving yield and grain quality.

Biofertilizers

AICRP studies at Athiyandal, Bengaluru and Kolhapur during 2020 indicated that seed treatment with liquid biofertilizer (4–5 ml/kg seed) or their furrow application (6−7.5 litres liquid biofertilizer mixed with 500 kg FYM /ha at the time sowing) is promising in realizing higher yields over the recommended dose of fertilizers. Biofertilizer application recorded higher grain yield of 1846 kg/ha and higher straw yield of 8261 kg/ha as compared to the recommended fertilizer practice (1503 kg/ha grain yield and 6662 kg/ha stover yield). Inoculation of seeds with bacterial endophytes *Methylobacterium* sp. and *Bacillus amyloliquefaciens* was found to produce auxin, solubilize phosphate and inhibit *Fusarium*, a fungal pathogen infection, and thus promote seedling growth.

Weed management

In the early stages of crop establishment, browntop millet faces severe competition from weeds, especially grasses, as they cannot be distinguished from the crop easily. As it is a rainfed crop, there is competition for moisture. Weeds also compete for sunlight and nutrients under favourable moisture and irrigated conditions, and this lowers the grain productivity. Studies have indicated that 15–42 days after sowing (2–6 weeks after sowing) is the critical period of crop-weed competition and can reduce barnyard millet yields by 15–97 percent (Giri *et al.*, 2024). In addition to grasses, sedges, broadleaved weeds, the parasitic weed striga also imposes threat to browntop millet.

Line sowing the crop on a well-tilled field and intercultural activity reduces major weed pressure. Two hand-weedings at the critical stages of crop growth, which are 20–25 DAS and 40–45 DAS, are effective in managing weeds in the browntop millet crop. Use of wheel hoe or cycle weeder or power weeder is recommended to reduce labour requirements and the cost of weeding operations. Chemical weed control options are limited.

Water management

Although browntop millet is a drought-tolerant crop, it benefits from regular watering, especially during dry periods. Excessive water can lead to root rot, so it's important to keep the soil well-drained. Applying mulch can help retain soil moisture by suppressing weed growth and moderating soil temperatures.

Cropping systems

As a result of its short growth period and ability to tolerate shade, it can be cultivated as a catch, cover and nurse crop. Browntop millet is compatible to grow as an intercrop or strip crop along with other crops such as sunflower, maize, sorghum, soybean and pulses. Studies at Dharwad (Karnataka) demonstrated that intercropping of browntop millet with groundnut/soybean (in rows of 4:2 or 2:1) was economically more rewarding than sole browntop millet cultivation.

Navadhanya is a traditional mixed cropping system practised by farmers of the rainfed Rayalaseema region of Andhra Pradesh (Anantapuram, Chittoor, Kadapa and Kurnool districts). In this system browntop millet is cultivated along with groundnut, sorghum, pearl millet, pigeon pea, cowpea, field bean, green bean, kenaf, castor, etc. The cultivation of browntop millet as an intercrop between tamarind trees is also common in the dryland regions of southern India.

Insect-pest management

In general, browntop millet has very few pests compared to other grains.

Shoot fly (*Atherigona* sp. Rond)

Shoot fly is the major insect pest of browntop millet and can cause significant yield losses. Symptoms appear from the time of sowing until the crop is about six weeks old. The central shoot begins to dry and shows typical symptoms of a dead heart in the early stage, and profuse tillering in the later stages (Figure 79).

FIGURE 79. Dead heart

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FIGURE 80. Banded leaf and sheath blight symptoms

FIGURE 81. Banded leaf blight

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Management

Early sowing with the onset of monsoon is not only effective but also the most economical method of control. Cultivation of the shoot fly resistant cultivar 'GPUBT-5' also aids in reducing the incidence of shoot fly.

Disease management

Leaf blight/brown spot, leaf blast and rust are the major reported diseases in browntop millet.

Banded blight (*Rhizoctonia solani*)

Banded blight is an emerging seed-borne disease reported in browntop millet. Soil application of FYM/vermicompost enriched with a combination of *Pseudomonas fluorescence*, *Trichoderma viride* and *Bacillus subtilis* or only *T. viride* (2 kg /t of manure) is very effective. Seed treatment with validamycin or hexaconazole (2 ml/l water) along with a foliar spray is also effective in controlling the disease. The variety 'HBr 2 showed resistance to banded blight and its cultivation has shown promising results.

Leaf blight (*Bipolaris setariae* Shoemaker**)**

Leaf blight on browntop millet was first reported in 2018 at Bengaluru (Karnataka) and the disease was known to infect up to 75 percent of the crop. In the early stages of the disease, small brown spots with a yellow halo emerge on both sides of the leaves. As the infection advances, these spots enlarge and merge, leading to a blighted aspect (Figure 80 and Figure 81). The symptoms closely resemble those of maize leaf spot induced by *B. setariae*.

Seed treatment with carbendazim (1 g/kg seed) and one foliar spray of mancozeb (0.2 percent) is recommended. Removal of crop residues helps in reducing inoculum. Seed treatment with Arka microbial consortia (10 g/kg seed) combined with spraying of azoxystrobin 23 percent SC or propiconazole 25 percent EC (1ml/l) at 35–40 DAS is the best practice for leaf blight management.

Blast (*Pyricularia grisea* (Cke.)

Blast infection becomes severe during the wet season. Numerous little brown flecks that grow into brown spindle-shaped dots on the leaves are its key characteristics. As the disease progresses, the patches become larger and merge to form a blasted appearance. They also have ash-grey centres with brown edges. Culm nodes can lodge and turn black. At the base of the panicles, brown to black patches enlarge and frequently girdle the neck beneath the panicles. In damp conditions nodes and necks develop an abundance of conidia and conidiophores. Panicles fail to appear when the neck blast is severe. The spikelet develops an infection and turns black. Early neck infection prevents the grains from filling and keeps the panicles upright. As it progresses, the infection causes partly-filled panicles to lodge.

Blast disease can be prevented by wide spacing while planting and controlling the amount of nitrogen fertilizer. A wide range of chemicals are frequently employed to manage blast in the absence of resistant varieties.

Rust

Uromyces sp. causes rust disease in browntop millet. The symptoms include numerous tiny brown rust pustules that are rectangular and often occur in linear rows on both sides of the leaf. Under favourable conditions pustules also develop on leaf sheaths, culms and stems, affecting the crop at all growth phases. Severe infection also causes the leaves to dry out too soon (Figure 82).

The use of resistant varieties and the removal of alternate and collateral hosts reduces rust incidence. Early sowing enables the crop to reduce rust incidence. Foliar sprays of chlorothalonil (0.1 percent) or mancozeb (0.2 percent) or hexaconazole (0.1 percent) or (0.1 percent) or propiconazole (0.1 percent) is effective for rust management. Cultivars 'GPUBT 6' and 'DHBT-11-5' (BTV 30) have demonstrated moderate resistance to rust and hence their cultivation may be useful to manage rust in browntop millet crops.

FIGURE 82. Rust symptoms in browntop millet leaves
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Downy mildew or "green ear disease" (*Sclerospora graminicola* (Sacc.)**)**

The disease becomes most severe under moist conditions. Plants are dwarfed with excessive tillering from the crown and the development of axillary buds along the culm. Flower parts develop leaflike structures with no kernel development. A downy greyish growth, which is the conidia and conidiophores, develop on infected tissue during wet or humid weather. As plants approach maturity, leaves become brown, necrotic and split or shred.

Seed treatment with fungicides and adopting effective fertilizer management practices reduce occurrence of the disease.

Harvesting

The crop should be harvested at full maturity. The appropriate stage of physiological maturity (PM) and harvestable maturity (HM) for browntop millet cultivar AK-1 AK-2 and GPUBT-6 are 51 days, 50 days and 48 days after anthesis respectively. Shattering is a major problem. Early morning harvesting is ideal to minimize grain loss caused by the cracking of panicles. For fodder production, a first cut at 50–60 DAS and a second cut 30 days later, is recommended.

Yield

Typically, the grain yield of browntop millet is 1.0–1.5 t/ha and the stover yield is 5–6 t/ha.

Exports

Exports of browntop millet are meagre, estimated under 500 tonnes a year, mostly bundled with other minor millets. It is exported in the form of whole grain, flour, flakes and ready-to-eat mixes.

Seed production

Browntop millet is a self-pollinated crop (occasional cross-pollination occurs with wind and insects). Hence for certified seed production an isolation distance of typically five metres is sufficient. This helps maintain genetic purity. Browntop millet has a seed multiplication rate of 1:300–500.

CHAPTER 11: Fonio

Digitaria sanguinalis (L.) Scop

FIGURE 83. Woman (on the left) holding sikiya (Madhya Pradesh)

Fonio is also known as crabgrass or finger grass. In Madhya Pradesh it is known as sikiya and in the Khasi hills of Meghalaya, it is known as raishan. Within the genus *Digitaria* Haller (Panicoideae: Poaceae), four species have been incredibly important to traditional agriculture systems and for use as staples – white fonio (*D. exilis*), black fonio (*D. iburua*), raishan (*D. compacta* (Roth) Veldkamp), and Polish millet (*D. sanguinalis* (L.) Scop.).

White fonio (*D. exilis*) or *fundi, findi, acha* or "hungry rice" is the most commonly cultivated *Digitaria* grown in West Africa, where it is especially important for both subsistence agriculture in rural areas and as an increasingly popular export crop. Black fonio (*Digitaria iburua*) or *iburu*, is restricted to small areas of Benin, Togo, and Nigeria (just below the Sahel region). It is relatively less popular than white fonio as it is reportedly even more difficult to dehusk. In Togo it is used to brew a traditional beer called "tchapalo". A third *Digitaria* food crop, raishan (*Digitaria compacta* Syononym: *Digitaria cruciata* var. esculenta Bor.) is a millet cultivated in the Khasi hills near Shillong (Meghalaya, India), a wet highland environment to which this crop is endemic. Hooker (1857) describes the cultivation of what was earlier named as *Paspalum sanguinale* var. *commutatum* (auct. non Hook.f. in nearby Assam and the Khasi Hills. The French agronomist Roland Portères records that in the 1950s it was still under cultivation on about 100 acres of land in Assam (Portères, 1957). It has overlapping occurrence to wild *D. cruciata* across central and southeastern Asia.

Raishan, sown as a rainfed crop in April–May, develops tufted growth producing 20–30 shoots by August. By September the terminal portion of each shoot bears a spike (20 cm long). The crop is harvested in October after the main crops such as maize, soybean and rice bean are harvested. The plant attains a height of 1.00−1.25 metres (Singh and Arora, 1972).

Sikiya is traditionally grown by the Baiga tribal community in Dindori (Madhya Pradesh). Also called *ghas ki roti*, this particular millet is not known outside the Baiga community. It is a wild perennial grass species that grows naturally in *bewar* plots, a form of shifting cultivation practised by the Baigas. The millet is known for its small grains, resembling wild ragi (finger millet). It is considered nutritious and gives prolonged satiety. Its seeds are light yellow in colour (smaller than those of little millet) and contain about 12 percent protein. Locally, people find it more filling than rice and use it to make porridge. A serving of 250 g of porridge is said to take care of a person's food requirement for the entire day.

Polish millet (*Digitaria sanguinalis*) is believed to have been cultivated during the 1500s to the 1600s in eastern Europe. It was first intentionally cultivated in a monastery garden in Croatia or Albania, before spreading north towards Germany, Hungary, and later to Poland and Ukraine. The 2018 participatory mapping exercise conducted by NESFAS (North East Slow Food & Agrobiodiversity Society) in Khapmaw and Rasong (villages in Mawkynrew Block, east Khasi Hills) reports four millet species – *Digitaria sanguinalis* (commonly known as crabgrass, finger grass or fonio), finger millet, foxtail millet and job's tears *(Coix lacryma-jobi*) being grown by the local community (Pohtam, 2024). These millets are traditionally used for brewing in northeast India. Fonio seeds were reported to contain 8.7 percent protein, 8 percent crude and 3.8 percent ash (mineral matter).

Climatic requirements

Raishan uniquely adapts to the rainfed uplands with warm temperate zones (altitudes of about 1500 metres). Its cultural significance among Khasi tribes make it a promising candidate for conservation and niche market development. Its tufted growth and nodal rooting contribute to stabilizing soil and preventing erosion on hills.

Sikiya thrives in warm tropical conditions (20–30 °C) and is sensitive to frost; hence it is cultivated only in the frost-free monsoon months in Madhya Pradesh. It tolerates short dry spells because of resilience, but prolonged drought reduces yield. The crop performs best under 600–1000 mm of well-distributed annual rainfall.

Soil

Raishan grows well in Khasi hills of Meghalaya on well drained loamy soils with acidic pH levels of 5.5–6.5. Under the bewar system of shifting cultivation, sikiya is cultivated in soils that are often shallow, coarse-textured (sandy loam and light clay soils), and low in fertility.

Sowing windows

Raishan is sown as a rainfed crop during April–May in Khasi hills and is harvested during September–October. Sikiya is sown with the onset of the southwest monsoon in June–July by the Baiga community (Madhya Pradesh) in the bewar system of shifting cultivation.

Seed rate and spacing

Raishan is a niche millet, cultivated in Meghalaya's Khasi Hills, with limited formal agronomic data. However, based on field observations and data from analogous *Digitaria* species like fonio and small millet with extremely small seeds, a seed rate of 8–10 kg/ha is required for broadcasting and 6–8 kg/ha is required for line sowing. Using fresh, untreated seeds with a germination rate of 80 percent and more, ensures establishment of optimal plant population. As raishan is often grown with maize or legumes, the seed rate is reduced by about 20 percent to avoid competition. In line sown conditions, 20–25 cm between rows and 10–15 cm between plants is optimum. Soaking seeds in warm water for 4–6 hours enhances germination.

Sikiya seeds are scattered (broadcast) on lightly prepared soil in forest clearings (bewar plots) often mixed with other crops like kodo millet, kutki (little millet) and pulses.

Land preparation

In settled plots, 2–3 shallow ploughings followed by light harrowing to create a fine tilth, especially for line-sown raishan, improves seed–soil contact and germination. Sikiya is grown with minimal land preparation, where the soil is loosened using simple tools in Madhya Pradesh under bewar system.

Varieties

Formal improvement programmes for raishan are yet to be initiated in the country. In Raishan, two distinct forms are recognized – wild types and cultivated types. Wild types are found in mountainous tracts of northeast India that have shorter plants with smaller grains. The cultivated types (by Khasi tribals) have taller plants, longer spikes and bolder grains. Cultivated types are maintained through traditional seed saving and exchange, rather than formal seed systems.

Manure and fertilizers

Raishan is traditionally grown in Meghalaya's uplands with minimal external inputs, yet for optimized yields and soil health, a balanced nutrition is essential. Organic manure such as FYM (5–10 t/ha) is used in Khasi hills to improve soil structure, microbial activity and long-term fertility. Incorporation of *Sesbania* or sunn hemp as green manure at 45 days before sowing boosts nitrogen supplies to raishan crop. Application of neem or castor de-oiled cakes (200–300 kg/ha) not only releases nitrogen slowly but also aids in pest suppression. A fertilizer dose of 20–30 kg N (through urea), 15–20 kg P_2O_5 (through single super phosphate (SSP) or bone meal) and 10–15 kg K_2O (through muriate of potash (KCl) or wood ash) is recommended for higher yields. The entire phosphorous and potassium fertilizer along with half the dose of nitrogen is applied as basal dose. Top dressing with the remaining half of nitrogen at 25–30 DAS, ideally after light rain or irrigation, is recommended. Use of biofertilizers like *Azospirillum* and phosphate solubilizing bacteria (PSB) can further support crop nutrition through N fixation and P mobilization.

No fertilizers are applied to sikiya in Dindori (Madhya Pradesh). The crop survives on residual fertility and organic matter present in forest soils. Ash from burnt vegetation in bewar plots also provides some nutrients.

Weed management

Raishan faces stiff competition from fast-growing annual weeds, particularly during its early growth stages. The period between 15 to 35 DAS is the most critical stage for weed competition. Weed control during this phase can prevent yield loss and ensure a healthy crop establishment.

Hand-weeding twice at 20–25 DAS and at 40 DAS is possible in both broadcast and line sown crop. In line sown crop, inter-row hoeing with the use of a light hoe or finger weeder between rows can be practised. No herbicide usage is reported till date. Since sikiya is traditionally grown in bewar systems of shifting cultivation, weed pressure is naturally moderated by biodiversity.

Moisture management

Raishan is typically grown in the upland rainfed systems of Meghalaya. However, supplemental irrigation can significantly improve germination, tillering and grain filling, especially under erratic rainfall conditions. The panicle initiation stage is the most critical one for moisture stress. A single irrigation at this stage can enhance crop establishment and improve crop yield. Sikiya is strictly cultivated as a rainfed crop by the Baiga community.

Cropping systems

Raishan thrives when it is cultivated as a mixed crop with maize or legumes (soybean and rice bean). Raishan seeds are broadcast into maize, soybean and rice bean crops. Pairing sikiya with legumes like pigeon pea or cowpea can improve nitrogen availability naturally in Baiga farming systems of Madhya Pradesh and Chhattisgarh. In bewar cultivation, crops such as bade kutki, kang, katki and sikiya are sown by broadcasting without ploughing, across the whole field or a part of the field.

Harvesting

A grain yield of 0.8 t/ha was reported in raishan. The grain is dehusked manually using mortar and pestle and consumed like rice or porridge. The straw is useful as winter fodder for cattle at high elevation regions (1500 m and above) where frost is common. Occasionally the straw is dumped on muddy cow-dung floors in piggeries, where trampling by pigs accelerates further decomposition. This mixture is subsequently utilized as compost in the next sowing cycle.

Yield

An yield of 300 kg of sikiya from 2–3 hectares under Baiga cultivation was reported by farmers from the community (Niyogi, 2018). Sikiya grains are sun-dried and stored in mud *kothis* (traditional containers), which can preserve them for up to 20 years. Because of the grain’s hard outer husk, dehusking of sikiya is done using a *musar*, a heavy wooden pestle.

Exports

No exports of raishan/sikiya were reported as their production levels is meagre.

Seed production

Organized seed production systems are yet to evolve in the country. Based on the experience in African counties, an isolation distance of 200–300 metres from other *Digitaria* species is required for ensued seed purity.

CHAPTER 12: Teff

(*Eragrostis tef* (Zucc.) Trotter)

FIGURE 84a. Teff harvest in Gadag (Karnataka)

FIGURE 84b. Cleaning of teff at a farm in Gadag

© Shree Padre, Gadag (Karnataka)

Teff, known as "Williams love grass", "teffa", and "annual bunch grass" in different parts of the world, is native to Ethiopia and Eritrea, where it is the staple grain used to prepare *injera*. *Injera* is a traditional Ethiopian and Eritrean flatbread made from fermented teff flour, characterized by its spongy texture and slightly sour taste. It serves both as food and as an edible plate, used to scoop up stews and vegetables. In Ethiopia grains of teff are also used in brewing.

A drought-resistant C_4 crop, teff was introduced in India as a potential superfood by Central Food Technological Research Institute (CFTRI), Mysore. It was included in the small millets group in India during the First Small Millets Workshop held in Bangalore in 1986. Since then, it has been cultivated in small pockets in Mysore, Sirsi (Uttar Kannada), Haveri, Gadag, and Raichur districts of Karnataka. CFTRI Mysore and Kadamba Foundation at Sirsi are the premier organizations promoting its cultivation in north and south Karnataka, respectively. Teff cultivation spread from research trials and farmer-led experiments in Gadag (Karnataka) and extended southeast towards Penukonda (Andhra Pradesh).

In Ethiopia, three major types can be identified: white (nech), red (quey), and mixed (sergegna). White teff is generally preferred over red (brown) teff by consumers from high-income groups. Studies conducted on nine varieties of teff indicated that white and brown teff are most suitable for growing under Indian conditions.

Teff grains are gluten free. Studies (Sharma, Akansha and Chauhan, 2018) showed that 100 g of teff grains contain protein (11.0 percent), fat (2.5 percent), carbohydrate (70.2 percent), fibre (3 percent), moisture (10.5 percent), ash (2.8 percent), calcium (165.2 mg), iron (15.7 mg), copper (2.6 mg), magnesium (181 mg), manganese (3.8 mg), phosphorous (425.4 mg), potassium (380 mg), sodium (15.9 mg) and zinc (4.8 mg).

Teff straw is a very course source of livestock feed. Teff hay is a rich source of crude protein (9–14 percent), acid detergent fibre (32–38 percent), neutral detergent fibre (53–65 percent), total digestible nutrients (55–64 percent) and a higher relative feed value (80–120 percent) as compared to straw of other minor millets.

Climatic requirements

Teff can grow under varied climatic conditions, performing well in areas with annual rainfall of 450−550 mm and a daily temperature of 15−27 °C. It is sensitive to frost and requires frost-free conditions throughout its growing period. Although teff is harmed by waterlogging, it thrives in moist but well-drained soils. Traditionally, teff is cultivated in Ethiopian highlands at an altitude of 1000–2000 metres above sea level.

Soil

Teff grows on a wide range of soils – from sandy loam to clay – but prefers light, fertile soils. It is cultivated on neutral pH soils, though it can tolerate acidity up to pH 5. Its deep root system allows survival in semi-arid conditions.

Land preparation

Teff requires a fine seedbed especially for broadcast or row planted crops. Rolling the soil after sowing can improve seed-to-soil contact and enhance germination.

Sowing windows

As a monsoon crop, its sowing coincides with the onset of monsoon in June–July. Sowing can be done during August–October for late kharif and early rabi sown crops that use residual soil moisture or supplemental irrigation. Under irrigated conditions, sowing is done from October to December.

Seed rate and spacing

A teff crop can be grown both by broadcast sowing and transplanting. The recommended seed rate for teff is 10 kg/ha. As the seeds are very small, deep sowing should be avoided and sowing at 0.5–0.75 cm depth is desired. Studies at Haveri (Karnataka) during 2019 indicate that transplanting outperformed line sowing. Further studies at Bengaluru and Raichur (both in Karnataka) during 2021 indicate that transplanting of 21-day-old seedlings at a spacing of 30 cm × 10 cm was optimal.

Manure and fertilizers

Teff requires balanced fertilizer application to ensure healthy growth and high yields. Studies at Bengaluru and Raichur during 2021 identified 20–30 kg N and 20-20 kg/ha P_2O_5-K_2O along with 6 t/ha FYM as the best integrated nutrition for higher teff yields. Teff is highly responsive to nitrogen, but excessive doses of nitrogen increase the risk of lodging and should be avoided.

Weed management

Teff is prone to weeds in initial stages of establishment and exerts pressure on weeds through allelopathy on weeds like rye grass and radish. Proper land preparation helps reduce weed pressure on the growing crop. Even a single hand-weeding in local teff varieties, that are sown after single ploughing, sufficiently increases yield when compared to no weeding. Herbicide recommendations are yet to be made for teff in India. Studies elsewhere suggest that broadleaf weed management is possible with 2,4-D amine spray at 5–7 leaf stage of the crop. Delayed application at tillering stage proves toxic to teff, as the narrow stems and delicate tillers of teff are highly sensitive to auxin herbicides once tillering begins.

Water management

Teff can grow well under extreme moisture regimes, tolerating both drought and waterlogged conditions. It copes well with water logging stress by enhancing the activity of nitrogen reductase in the shoots. For this reason, teff is often cultivated in poorly drained soils where cultivation of other crops, such as maize and wheat, is not possible. However, teff responds well to irrigation and the yields are higher in irrigated crops compared to water-stressed ones. The grain-filling stage is more sensitive to moisture stress, and irrigation at this stage is desired. Detailed information on irrigation in India is yet to be worked out.

Cropping systems

No formal studies on teff-based cropping systems have been carried out in India. However, literature suggests that mixed cropping of teff with sunflower is popular as a subsistence farming practice, while mixed cropping with faba bean yields higher economic returns as a commercial farming practice. Teff is intercropped with *Brassaica carinata*, safflower, sunflower and wheat at varied space patterns and as a relay crop in maize and sorghum.

Insect-pest management

Teff is relatively resistant to pests. Shoot fly (*Atherigona hyalinipennis*) is the most significant insect pest. Regular monitoring for aphids and armyworms is recommended.

Disease management

In high humidity areas (not India), head smut (*Tilletia baldratii*) and rust (*Uromyces eragrostidis*) have been known to affect teff.

Harvesting

Studies conducted in Bengaluru show that teff is ready for harvest in approximately 110 days. Lodging is a major challenge in teff due to its weak stems. Studies in Bengaluru showed 30–75 percent lodging in the crop which increases with higher fertilizer dose. High rainfall, winds and nitrogen fertilizers were found to accelerate lodging in teff. Line sowing reduces lodging when compared to broadcast sowing. In Ethiopia application of paclobutrazol (1 kg/ha) between the jointing and tillering stages was effective in reducing plant height and lodging stress in teff. In Ethiopia, a lodging-tolerant cultivar “Kegne” was developed by mutation of the alpha-tubulin-1 gene in teff using EMS (ethyl methane-sulfonate). As teff grains are very small, manual cleaning is very labour intensive and cumbersome. In addition, heavy rainfall during the harvest may cause the grains to fall to the ground and be lost in the rain.

Yield

Teff produces 10–12 ears per plant with an ear weight of about 0.3 grams. The grains have a test weight of 0.31 grams. In Bengaluru, a grain yield of 2.2 t/ha and stover yield of 3.5 t/ha were obtained. Storage of seeds does not require any maintenance as teff is not susceptible to weevils and other storage pests.

Teff hay makes nutritious fodder for livestock. The crop produces up to 5 t/ha stover, irrespective of grain yield.

Processing

Teff does not require milling, but manual cleaning is a major challenge. Limited consumer and trader awareness is another challenge in local markets, and this restricts its acceptance.

Exports

Teff fetches a very high price in international markets (5–6 USD/kg). However, exports from India are meagre (≈100 tonnes) and are mostly pilot shipments.

Seed production

As teff is still an experimental crop, no technology has been developed for seed production in India. Information from Ethiopia indicates that an isolation distance of at least 200–300 m from other teff varieties or related grasses is required for quality seed production.

CHAPTER 13: Job’s tear

(*Coix lacryma-jobi*)

FIGURE 85. Job’s tear crop at Pasighat, Arunachal Pradesh

FIGURE 86. Job’s tear crop at Pasighat, Arunachal Pradesh

Job's tear is known by various regional names – *jagradi* (Sanskrit), *sankru* (Hindi), *gurgur* (Bengali), *megaru* (Garo), *sohriew* (Khasi), *kunch* (Tripuri) and *adlay* (Assamese). It is an annual, erect, tall (height of 1–2 metres), branched grass typically producing 7–8 tillers. It has spongy internal tissues with maize-like brace roots emerging from the lower nodes. The grass is monoecious, having separate male and female flowers on different parts of the plant.

Leaves of job’s tear are long, broad and flat with linear leaf blade (lanceolate, acuminate and cordate). Inflorescence appears in the axils of upper leaves on 3–6 cm peduncle. The female flowers produce yellow, purple or brown seeds; often tear shaped (hence the name) and shattering easily. This is a quantitative short-day plant – it undergoes accelerated flowering under short-day conditions but can flower under long-day conditions as well – that requires high temperatures, abundant rainfall and reasonably fertile soils. It shows non-synchronous flowering and has a 100-seed weight of 16–17 g. This crop takes 150–160 days to reach maturity.

Nutrient composition: Every 100 grams edible portion of the husked job’s tear grain contains: water (10.1–15.0 g), protein (9.1–23.0 g), fat (0.5–6.1 g), carbohydrates (58.3–77.2 g), fibre (0.3–8.4 g) and ash (0.7–2.6 g). The amount of starch in the grain is very high, about 58 percent. The energy value is about 1500 kJ/100 g. Job's tear forage at early vegetative growth has dry matter (29.9 percent), crude protein (8.5 percent), crude fibre (27.9 percent), ash (8.96 percent), ether extract (2.7 percent) and nitrogen-free extract (51.9 percent).

Utility: Job’s tear is an underutilized, multipurpose crop with both nutritional and cultural significance. Its utility varies with its botanical variants which are: the soft-shelled *Coix lacryma-jobi* var. ma-yuen and the hard-shelled *Coix lacryma-jobi* var. lacryma-jobi. Soft shelled grains are very nutritive and are traditionally cooked with rice and pulses. The flour when blended with water makes for a refreshing, cooling drink. Grains are used by Garo, Naga and Karbi tribes for brewing a local liquor. Its roots are used as medicine. The grains are used by the Naga farmers as pig and chicken feed. As a locally sourced animal feed, Job's tears can be fed either broken, ground, or as a whole grain to animals.

Hard-shelled types are used for making beads and ornaments. Green leaves are used as fodder, and dried plants as thatching material. Therapeutically, grains are considered useful in the treatment of kidney and gall bladder stones, menstrual disorders, catarrhal infection, and the brew of its roots is used as a vermifuge. The kernel is considered a richer source of protein and carbohydrates than rice, wheat and maize and has lower phytosterol content than maize. The cultivated types of job's tear have stiffening roots that are very durable and can be processed into twine or binding material.

Two additional variants, *Coix lacryma-jobi* var. stenocarpa (characterized by cylindrical involucres; used ornamentally) and *Coix lacryma-jobi* var. monilifer (characterized by bead-like seeds; often used in tribal jewellery and crafts) have been cultivated for centuries by tribal communities in Meghalaya, Nagaland, Manipur, Mizoram and Arunachal Pradesh.

This multipurpose crop, which is used for food, fodder and medicine, is grown particularly in the northeastern states, parts of Bihar and West Bengal. In Garo hills of Meghalaya, job’s tear is known as *mairukku*/*megaru* and is widely cultivated. In Arunachal Pradesh, job’s tear is known as *anyat*/*tanyet*/*fompalling* and is cultivated in several towns and districts including Upper Siang, Shiyomi, East Siang, Siang, West Siang, Lepa-Rada, Roing, Tezu, Anjaw, Namsai, Daporijo, Lower Siang, Papum Pare and Kamle. Apart from the northeastern states, job’s tear has also been reported in the Dang district in Gujarat. Despite its utility, the cultivation of this millet is gradually declining owing to a shift in food habits and the adoption of remunerative cash crops by the farming community in the northeast.

Climatic requirements

In the tropics, job’s tear is present in plains and on hills up to an altitude of 2000 m above mean sea level. The crop prefers mild and humid climate. It has low tolerance to cold and is intolerant to drought but grows well under flooded conditions. It thrives in areas with high rainfall, moderate temperature and low relative humidity. An annual temperature of 9.6–27.8 ºC (optimum: 21.5 ºC) is considered ideal for cultivation of job’s tear. A dry period is needed during seed setting phase. Black-shelled types of job’s tear are suitable for planting in areas at higher altitudes while dwarf types are suitable for planting in low altitudes. Planting can begin when the ground temperature is above 12 °C.

Soil

Job’s tear is generally grown in fertile, well-drained fields with sandy loam soils with a pH of 4.5–8.4, the optimum pH being 6.2. It is a resilient crop and can be productive in waterlogged, acidic and lateritic soils, and even on degraded and sloping lands.

Land preparation

Job’s tear requires moist soil for optimal germination, growth and development. The land should be prepared through deep ploughing, followed by 2–3 harrowing, and then levelling by a plank.

Sowing windows

Except in winter, the crop can be grown throughout the year. June is the most ideal time for sowing. As the seeds have a hard seed coat, the seeds need to be soaked in water for at least a day before sowing, to facilitate germination, Seeds are usually sown at a depth of 5–7 cm. Transplanting seedlings that are 30–35 days old in low lying areas gives better establishment.

Seed rate and spacing

A seed rate of 30–40 kg/ha is adequate for sowing in lines at a spacing of 40 cm ×15 cm. For broadcast sowing, a higher seed rate (40–50 kg/ha) is used. In low lying areas, where seedlings that are 30–35 days old are to be transplanted, a lower seed rate of 20–30 kg/ha is sufficient. Crop can be established by dibbling seeds about 5 cm deep into prepared fields at the beginning of the rainy season. Propagation by cuttings is possible, particularly when it is being produced for fodder.

Varieties

Suitable for grain

Only a few varieties of job's tear have been released in India so far, as there is no breeding programme. Land races are cultivated in northeastern states (Meghalaya, Arunachal Pradesh, Manipur, Mizoram and Nagaland). The National Bureau of Plant Genetic Resources (NBPGR), Regional Station, Umiam (Barapani), Meghalaya has collected over 50 accessions of job's tears from the northeastern states between 1986 and 2004. Notable high-yielding genotypes include IC-012703 (grain yield of 3.18 t/ha), IC-089391 (grain yield of 3.00 t/ha) and IC-521338 (grain yield of 2.90 t/ha). The evaluation of 37 germplasm lines from northeast at NBPGR Regional Station, Bhowali, Nainital (Uttarakhand), found accessions IC-0332644, IC-0416831 and IC-054017 to be promising. Evaluation of 10 germplasm lines of job's tear (JBN-1, JBN-2, JBN-3, JBN-4, JBN-5, JBN-6, JBN-7, JBN-8, JBN-9 and JBN-10) collected from the farmers' fields across different districts (Kohima, Wokha, Zunheboto, Longleng and Jalukie town in Parent) in Nagaland indicated that JBN-10 is the best for grain yield as compared to other lines (Kumar *et al.*, 2017).

Suitable for fodder

Job's tear biomass is palatable to animals and is highly nutritious. Studies indicate that job's tear flour can replace maize flour in poultry feed. Some varieties released in India that are suitable of fodder are:

- KCA-3**:** This variety was developed at Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani (West Bengal) in 2004 and is suitable for cultivation in Assam, Odisha, Jharkhand, West Bengal, Meghalaya and Bihar. It is characterised by high fodder yield and soft-shelled grains.
- KCA-4: This variety was also developed at BCKV, Kalyani in 2005 and is suitable for cultivation in the same states as KCA-3. It shows improved grain quality and greater adaptability compared to KCA-3.
- Bidhan Coix-1: This is a fodder variety, suitable for cultivation in West Bengal, Orissa, Assam and north Bihar. It has a green fodder yield of 34.6 t/ha and dry fodder yield of 6.9 t/ha.

Manure and fertilizers

This crop responds well to application of nutrients. The recommended dose is 10–12 t/ha of FYM or compost along with 80-40-40 kg/ha N-P_2O_5-K_2O. Half the N dose to be applied with the entire dose of P and K at basal and the remaining half of the N dose to be applied after cutting the crop for fodder.

Use of biofertilizers (*Azospirillum* and *Phosphobacteria*; 2 kg/ha each), mixed with FYM is recommended. Incorporation of *Sesbania* or *Crotalaria* green manure biomass at 30–40 days before sowing is desired. In acidic soils of northeast India, application of 1–2 t/ha lime or dolomite once every three years is desirable.

Weed management

One hand-weeding at 20–25 DAS is sufficient for weed management in job's tear. However, in marshy areas, aquatic weeds compete with the crop. To eliminate this two cycles of hand-weeding at 20–25 DAS and 40–45 DAS is required. Loosening of the soil during weeding, promotes crop growth, development of roots and initiation of tillering. At present, no herbicide recommendations are available for this crop in India.

Water management

During the rains, job's tear does not require any irrigation if the rainfall is well distributed. However, adequate soil moisture is essential for uniform crop germination. Post rains and during the summer season, irrigation becomes necessary. After germination, tillering (20–30 DAS) is the next critical stage for irrigation, as moisture stress at this stage reduces plant stand and biomass. Flowering and grain filling (45–70 DAS) are the most sensitive stages for irrigation and water deficiency can drastically reduce yield. Generally, 3–4 irrigations (at sowing, tillering, flowering, and grain filling) are sufficient for the crop. Job's tear does not tolerate prolonged waterlogging, therefore proper draining of the field is important.

Cropping systems

A job's tear crop is often grown alone or in mixed cropping systems along with rice or rice bean. In Nagaland, an alder-based shifting cultivation is practised. During the pollarding period of alder (*Alnus nepalensis*), field crops like job's tear, maize and rice are cultivated, followed by sequential crops including cowpea, finger millet, perilla (*Perilla frutescens*; Lamiacaee), potato, soybean, taro and other vegetables. Under the shifting cultivation system, grain yields of 1.12 t/ha were reported in Nagaland

Insect-pest management

Job's tear does not suffer major losses from pests and diseases, making its cultivation easy. Insect pests affecting this crop include stem borer (*Sesamia inferens* and *Ostrinia furnacalis*), rice skipper (*Pelopidas mathias*) leaf feeder, thrip (*Chaetanaphothrips orchidii*), aphid (*Rhopalosiphum maidis*) and woolly aphid (*Ceratovacuna lanigera*).

Disease management

Job's tear is susceptible to leaf blight (*Fusarium* spp., *Rhizoctonia solani),* leaf spot (*Helminthosporium* spp.), leaf rust and smut disease. The seeds are also damaged by rats and parrots.

Smut

Job's tear is affected by two types of smut fungus – *Ustilago coicis* and *Ustilago lacrymae-Jobi*. *Ustilago coicis* affects and destroys all the ovaries while *Ustilago lacrymae-Jobi*, affects only a few ovaries. The male flower is unaffected by smut. Seed treatment with carbendizim (2 g/kg seed) reduces the incidence of the disease.

Rust (*Puccinia coicis*)

Upon fungus infection, minute straw coloured rust pustules are formed on both the surfaces of the leaf. Seed treatment with dithane-M-45 (2 g/kg seed) effectively manages rust disease.

Harvesting

When nearly 80 percent of the grains turn brown, the panicle is harvested by cutting the stems from three nodes above the ground. The harvested panicles are threshed by hand and the seeds are sun dried. Job's tear seeds differ in colour; the more soft-shelled seeds are light brown and the hard-shelled forms have a dark red pericarp.

The crop is cut fresh for fodder purpose at 30 cm above the ground and 2–3 cuttings can be taken per year with the first cutting taken at 45–80 DAS depending on the growth of crop and the need. This can be followed by subsequent cuts at intervals of 30–45 days. It is possible to obtain a green fodder yield of 60–70 t/ha.

Yield

Typically, job's tear produces a yield of 2–4 tonnes of husked grain per acre. The grain has a hulling percentage of 30–50, which means that only 30–50 percent of grains remain after husking. Soft-shelled types (eg., var. ma-yuen) are easier to process while hard types are used for beads. Lack of customized machinery for small-scale de-husking and grading is a major bottleneck. Some Farmers Producers Organizations (FPOs) in Meghalaya and Nagaland are experimenting with modified rice mills.

Exports

Job’s tear is slowly emerging as a niche commodity in regional and international trade, especially in the context of functional foods, nutraceuticals and tribal livelihood systems. Often traded under HS Code: 1008.90 (other cereals) or 1211 (medicinal plants), job’s tear commands a price of US$ 2–4 per kg in bulk exports. Every year India exports approximately 1000 metric tonnes of job’s tear in forms such as: whole grain, polished grain, flour, roasted snacks and herbal supplements. Meghalaya, Nagaland, Manipur, Jharkhand and Odisha contribute significantly to the exports. Japan, South Korea, United States of America, European Union (for health food and gluten-free markets) are the key importers.

Seed production

Job’s tear is a highly cross-pollinated crop, primarily pollinated by wind. Therefore, for certified seed production, an isolation distance of 300 metres from other varieties or wild types is required to maintain genetic purity. This distance aligns with general standards for cross-pollinated cereals and is crucial for preventing contamination from off-types, wild relatives or non-certified fields. Job’s tear has a seed multiplication rate of 1:50–80. Structured seed production systems are yet to evolve in India for this crop.

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