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INCREASE EFFICIENCY IN MILLETS AGRARIAN AND NUTRITIONAL FOOD FROM BIO-FORTIFIED HYBRIDS: A REVIEW

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ABSTRACT

Millet is a resilient, climate-smart crop known for its nutritional richness and adaptability to marginal agro-climatic conditions. Despite their potential, their productivity and consumption have remained sub-optimal compared to major cereals. This study focuses on enhancing the agrarian efficiency and nutritional profile of millets through the development and promotion of bio-fortified hybrid varieties (RHB234 etc.). Bio-fortification, which involves breeding crops to increase their nutritional value, particularly in terms of iron, zinc, calcium, and protein content, plays a critical role in combating micronutrient deficiencies prevalent in rural and urban populations alike. The research explores the integration of high-yielding, nutrient-rich millet hybrids into existing farming systems to improve both food security and farmer income. It emphasizes precision agronomic practices, optimized input use, and post-harvest technologies to support value chain development. The deployment of these improved varieties is shown to increase productivity, resilience against pests and diseases, and market competitiveness. By aligning with national nutrition strategies and sustainable agricultural goals, bio-fortified hybrid millets present a dual advantage: enhancing farm-level efficiency and addressing malnutrition. This approach provides a sustainable, scalable pathway toward agricultural transformation and public health improvement in millet-growing regions.

Keywords: Millets, Agrarian , Nutritional Food , Bio-fortified Hybrids.

Introduction

“Dr Mahalingam Govindaraj has won the Norman E Borlaug Award for developing the world's first bio-fortified pearl millet variety called Dhanashakti, which is rich in nutrients”

Millet is a collective term referring to a number of small-seeded annual grasses that are cultivated as grain crops, primarily on marginal lands in dry areas in temperate, subtropical and tropical regions. The most important species are pearl millet, finger millet, proso millet and foxtail millet. Pearl millet accounts for almost half of global millet production. It is the most important species of millet both in terms of cropped area and contributions to food security in regions of Africa and Asia that can produce little else. Finger millet is widely produced in the cooler, higher-altitude regions of Africa and Asia both as a food crop and as a

preferred input for traditional beer. Proso millet is important for bird seed in the developed countries and for food in parts of Asia. Foxtail millet is important in parts of Asia (mainly China) and Europe. The other species (barnyard, kodo and little millets, the fonios and teff) are locally important food grains restricted to smaller regions or individual countries. The various species differ in their physical characteristics, quality attributes, soil and climatic requirements and growth duration.

Millets are better adapted to dry, infertile soils than most other crops, and are therefore often cultivated under extremely harsh conditions - for example, high temperatures, low and erratic precipitation, short growing seasons and acidic and infertile soils with poor water-holding capacity. Most millet have strong, deep rooting systems and short life

cycles, and can grow rapidly when moisture is available. As a result, they can survive and reliably produce small quantities of grain in areas where mean annual precipitation is as low as 300 mm. This compares with a minimum water requirement of 400

mm for sorghum and 500-600 mm for maize. Some species (pearl and proso millets) also appear to tolerate higher temperatures than sorghum and maize, although they do not tolerate long drought periods as well as sorghum.

Table 1: Utilizing of various millets in the food and feed for benefit of nutritional value

S. no.	Vernacular Name	Botanical Name	Agronomic Benefits	Nutritional Benefits	Health Benefits
1.	Pearl millet or Bajra Gero, arum, bulrush millet, milheto, dark millet, Bajri, cattail millet	<i>Pennisetum glaucum</i> L.	Drought & heat tolerance	It is good source of protein, starch & It also contains folate, iron, magnesium, calcium, copper, zinc, vitamins E and B-complex. Pearl millet has a high energy content compared to other millets.	No gluten and this millet is known to possess phytochemicals that lower cholesterol.
2.	Sorghum or Jowar	<i>Sorghum bicolor</i> L.	Resistant to pests and diseases	Principal source of protein, vitamins, energy & minerals and rich in potassium, phosphorus and calcium with sufficient amounts of iron, zinc and sodium.	It helps to control heart problems, obesity, arthritis, body weight and arthritis. Adding sorghum regularly in the meals of pregnant women helps them attain the dietary mineral and vitamin requirements.
3.	Foxtail millet Italian millet, German millet, Chinese millet, Hungarian millet, green millet	<i>Setaria italica</i> L.	Drought tolerance	It contains fibre, protein, calcium and vitamins and minerals such as copper and iron that keep one's body strong and immune.	No gluten and apart from controlling blood sugar and cholesterol, it increases disease resistant capacity and is recommended for people suffering from diabetes and gastric problem.
4.	Japanese Barnyard millet	<i>Echinochloa sculneta</i> L.	Early maturity, anti-fungal	It is a good source of protein, dietary fiber with good amount of soluble and insoluble fractions. Low carbohydrate content. In this millet, the major fatty acid is linoleic acid followed by palmitic and oleic acid. It also shows a high degree of retrogradation of amylase, which facilitates the formation of higher amounts of resistant starches	No gluten and highly digestible. It can be potentially recommended for patients with cardiovascular diseases and diabetes. It is most effective in reducing blood glucose and lipid levels.
5.	Indian Barnyard millet Sawa millet, Janpanese barnyard millet, Indian barnyard millet, kodisama, bhagar, burgu millet	<i>Echinochloa rumetacea</i> L.	Early maturity	It is a good source of protein, dietary fiber with good amount of soluble and insoluble fractions. Low carbohydrate content. In this millet, the major fatty acid is linoleic acid followed by palmitic and oleic acid. It also shows a high degree of retrogradation of amylase, which facilitates the formation of higher amounts of resistant starches	No gluten and highly digestible. It can be potentially recommended for patients with cardiovascular diseases and diabetes. It is most effective in reducing blood glucose and lipid levels.
6.	Kodo millet Varagu, varigalu	<i>Paspalum scrubiculatum</i>	Drought tolerance	It has high protein, low fat and very high fibre. It is also rich in	It contains no gluten and it is very easy to digest, it contains a

		L.		B vitamins, especially niacin, B6 and folic acid, as well as minerals like calcium, iron, potassium, magnesium and zinc.	high amount of lecithin and is excellent for strengthening the nervous system. Regular consumption of kodo millet is very beneficial for postmenopausal women suffering from signs of cardiovascular disease, like high blood pressure and high cholesterol levels.
7.	Little millet Samalu, samai	<i>Panicumsum atrense</i> L.	Abiotic stress tolerance	High in phytochemicals, fibre, protein, B vitamins, iron, zinc and magnesium.	It is anti-diabetic.
8.	Proso millet Broomcorn millet, common millet, broomtail millet, hog millet, white millet	<i>Panicummili aceum</i> L.	Drought tolerance, early maturity	This is rich in protein, crude fiber, minerals and calcium and has significant amounts of carbohydrate and fatty acids. It is a cheaper source of manganese.	Gluten-free and It is proven to reduce cholesterol levels and also reduces the risk of heart diseases besides preventing breast cancer among other diseases.
9.	Finger millet or Ragi African millet, red millet, caracan millet, koracan, ragi, dagusa	<i>Eleusine coracana</i> L.	Drought and salt tolerance	Finger millet contains high amount of calcium, protein with well-balanced essential amino acids composition along with Vitamin A, Vitamin B and phosphorous.	Its high fiber content also checks constipation, high blood cholesterol and intestinal cancer. It is an ideal food for diabetics as it has demonstrated the ability to control blood glucose levels and hyperglycemia.
10.	Tef	<i>Eragrostis tef</i> L.	Water- logging tolerance and storage pest tolerance	Rich in protein, fiber and minerals like calcium, iron, phosphorus, and zinc.	No gluten and it can be beneficial for celiac disease, hypertension, anemia, diabetes, and cancer condition.
11.	Fonio	<i>Digitaria exilis, D. Iberian</i> L.	Drought tolerance and storage pest tolerance	Rich in amino acids, protein, fiber and minerals like iron, copper, zinc and magnesium and good source of B vitamins, including thiamine, riboflavin, and niacin	Gluten-free and it may help moderate blood sugar level.

In Asia, millet is restricted almost exclusively to two countries, India and China, although Myanmar, Nepal and Pakistan also produce small quantities. India is the world's largest producer, harvesting nearly 40 percent of the world's output. Pearl millet, which accounts for about two-thirds of India's millet production, is grown in the drier areas of the country, mainly in the states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana. Finger millet is produced mainly in the state of Karnataka, but also in Orissa, Uttar Pradesh and Tamil Nadu. It is also the most important millet in Nepal and Bhutan. China produces millet (mainly foxtail), largely in the provinces of Hebei, Shanxi and Shandong.

Table 2 : Nutritional constituents of common millets per 100 g

Millet type	Protein (g)	Carbo- hydrates (g)	Fat (g)	Crude fiber (g)	Minerals		Mineral matter (g)	Sulfur Containing (Amino Acids)		Energy (kcal)
					Ca(mg)	Fe(mg)		Methionine	Cysteine	
Pearl millet	11.6	67.5	5.0	1.2	42	8.0	2.3	150	110	363
Finger millet	7.3	72.0	1.3	3.6	344	3.9	2.7	210	140	336
Proso millet	12.5	70.4	1.1	2.2	14	0.8	1.9	160	-	364
Foxtail millet	12.3	60.9	4.3	8.0	31	2.8	3.3	180	100	351
Kodo millet	8.3	65.9	1.4	9.0	27	0.5	2.6	-	-	353
Little millet	8.7	75.7	5.3	8.6	17	9.3	1.7	180	90	329

Barnyard millet	11.6	74.3	5.8	14.7	20	5.0	4.7	180	110	300
Sorghum	10.4	67.98	1.9	1.6	25	4.1	1.4	100	90	296
Rice	7.9	76.0	2.7	1.0	10	0.7	1.3	150	90	362
Wheat	11.6	71.0	2.0	2.0	41	5.3	1.6	90	140	348

Millet production in Africa is distributed among a much larger number of countries, notably Nigeria (over 40 percent of the regional output), Niger, Burkina Faso, Mali, Senegal and Sudan. Pearl millet is grown along the southern peripheries of the Sahara (i.e., the Sahelian countries and the northern parts of the coastal countries in Western Africa) and in the drier areas of Eastern and Southern Africa. Finger millet production is concentrated in Eastern and Southern Africa, where the leading producers are Uganda and Tanzania. As a grain crop, Tef is largely confined to Ethiopia. Small quantities of white fonio are grown throughout sub-Saharan Western Africa, most importantly in Mali. Black fonio is grown in isolated pockets in Nigeria, Togo and Benin. Guinea millet is cultivated only on the Fouta-Djallon plateau of northwestern Guinea and adjacent Sierra Leone. Foxtail and proso millets are very minor crops in Africa, but are cultivated to a

limited extent in Kenya and other upland areas in Eastern Africa. Kodo millet is commonly harvested from wild forms in Western Africa, but cultivated forms of this "ditch millet" are only found in Asia. In Latin America, millet production is confined to a small area in Argentina. Therefore, its production and productivity can be enhanced by using scientific management practices.

1. **Selection of Soil:** Millets can be grown in different soils but sandy loam and light or loam soils with proper drainage are considered as best. The field should be ploughed once or twice followed by harrowing to create fine tilth. Prepare the field by doing 1st ploughing with mould-bold plough followed by 2-3 ploughing with cultivator to pulverize the soil. Where as it does not grow well in soils prone to waterlogged conditions.

Table 3: Suitable soil for Bio-fortified variety of Various Millets Crops

S. No.	Vernacular Name	Soil Type	Recommended biofortified varieties	Recommended Areas
1.	Pearl millet	sandy, loam, and clay soils	HHB 299, AHB 1200Fe, AHB 1269Fe, ABV 04, RHB 233, RHB 234, HHB 311, HHB 67 Improved 2	Haryana, Rajasthan, Gujarat, Punjab, Delhi, Madhya Pradesh, Maharashtra and Tamil Nadu
2.	Sorghum or Jowar	Black and Alluvial Soil	Parbhani Shakti, ICSV-188 (SAMSORG 45)	Kharif sorghum growing areas of Maharashtra
3.	Little millet	Red Soil	CLMV 1	Maharashtra, Andhra Pradesh, Telangana, Tamil Nadu and Puducherry
4.	Finger millet or Ragi	Laterite and Red soil	VR 929 (Vegavathi), CFMV1 (Indravati), CFMV 2	Andhra Pradesh, Tamil Nadu, Karnataka, Chhattisgarh, Gujarat, Maharashtra, Puducherry and Odisha

2. **Important Varieties:** Most of the pearl millet area is grown with hybrids while the varieties are preferred in drought prone ecologies.

Table 4 : Bio-fortified variety of Various Millets Crops

S. no.	Vernacular Name	Varieties	Released From	Recommended Areas
1.	Pearl millet	HHB 299, HHB 311	CCS-Haryana Agricultural University, Hisar	Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu
		AHB 1200Fe, AHB 1269Fe	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani	Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu
		ABV 04	ARS, Acharya NG Ranga Agricultural University, Ananthapuramu	Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu
		Phule Mahashakti	Mahatma Phule Krishi Vidyapeeth, Dhule	Maharashtra
		RHB 233, RHB	Sri Karan Narendra Agricultural	Rajasthan, Gujarat, Haryana, Madhya

		234	University, Jobner	Pradesh, Delhi, Maharashtra and Tamil Nadu
2.	Sorghum or Jowar	Prabhani Shakti	Vasantryao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani	Kharif sorghum growing areas of Maharashtra
3.	Little millet	CLMV1	ICAR-Indian Institute of Millets Research, Hyderabad	Maharashtra, Andhra Pradesh, Telangana, Tamil Nadu and Puducherry
4.	Finger millet or Ragi	VR 929 (Vegavathi)	Acharya NG Ranga Agricultural University, Guntur	across the country
		CFMV1 (Indravati)	ARS, ANGRAU, Vizianagaram	Andhra Pradesh, Tamil Nadu, Karnataka, Puducherry and Odisha
		CFMV 2	Hill Millet Research Station, Navsari Agricultural University, Waghai	Andhra Pradesh, Chhattisgarh, Gujarat, Maharashtra and Odisha

The latest list of hybrids and varieties of pearl millet is given below. Two types of varieties remain available for sowing of Bajra commonly referred as Composite and hybrid varieties. The important composite varieties suitable for growing areas varieties are: as ICMB-155, WCC-75, ICTP-8203, Raj-171,

CZP 9802, ICMV 221, ICMV 155, Parbhani Sampada, Samrudhi, PC 612, NDFB-3, and Dhanshakti etc. Among hybrids as following RHB 234, RHB 233, Pusa-322, Pusa-23, RHB-173, HHB 67, HHB-226, GHB 905, MPMH 17, HHB 234, HHB-226 and RHB-177, etc.

Table 5 : The latest list of hybrids and varieties of pearl millet is given below.

Region/ State	Season	Recommended Hybrid	Recommended Variety
Rajasthan	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173, HHB 67	MBC 2, PC 443, JBV3, PC 383, ICMV 221, Raj 171
	Summer	Nandi 70, Nandi 72, 86M64	
	Kharif – arid parts	HHB 234, Bio 70, HHB-226, RHB-177	CZP 9802
Gujarat	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173, HHB 67	MBC 2, PC 443, JBV3, PC 383, ICMV 221, Raj 171
	Summer	Nandi 70, Nandi 72, 86M64	
	Kharif – arid parts	HHB 234, Bio 70, HHB-226, RHB-177	CZP 9802
Haryana	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173, HHB 67	MBC 2, PC 443, HC 20, JBV 3, PC 383, HC 10, ICMV 221, Raj 171
	Kharif – arid parts	HHB 234, Bio 70, HHB-226, RHB-177	CZP 9802
Punjab	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173	PCB 164, ICMV 221, Raj 171
Delhi	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173	JBV 3, PC 383, ICMV 221, Raj 171
Uttar Pradesh	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173	JBV 3, PC 383, ICMV 221, Raj 171
Madhya Pradesh	Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, 86M66, RHB-173	JBV 4, JBV 3, PC 383, ICMV 221, Raj 171
Maharashtra	Kharif	Kaveri Super Boss, Pratap, PKV Raj, Shine, MP 7792, 86M86, PAC 909, 86M64, 86M53	ABPC-4-3, PC 612, Parbhani Sampada, Samrudhi, ICMV 221, Raj 171, ICMV 155

3. **Seed Rate:** For arid-western plain of Rajasthan, Haryana and Kutch of Gujarat, pearl millet should be planted in rows 60 cm apart, maintaining low plant population of 1.00 to 1.25 lac/ha. For the area receiving rainfall more than 450 mm, the crop should be planted at the spacing of 45 x 10-15 cm keeping plant population of 1.75 to 2.0 lakhs/ha. Seed rate for the crop should be taken @ 3 to 5 kg/ha for obtaining required plant stand.

Table 6 : Seed rates per ha for Bio-fortified variety of Millets Crops

S. No.	Vernacular Name	Method	Seed Rate
1.	Pearl millet	Direct Sowing	5kg/ha
		Transplanting	3.75kg/ha
		Dibbling method	3-3.5kg/ha
		Drilling method	4-5kg/ha
2.	Sorghum or Jowar	Broadcasting	12-18kg/ha
		Drilling	8-12kg/ha
3.	Foxtail millet	Broadcasting	15kg/ha
		Line Sowing	8-10 kg/ha
4.	Indian Barnyard millet	Broadcasting	12-15kg/ha
		Line Sowing	8-10kg/ha
5.	Kodo millet	Broadcasting	15kg/ha
		Line Sowing	10kg/ha
6.	Little millet	Broadcasting	12kg/ha
		Line Sowing	8kg/ha
7.	Proso millet	Broadcasting	15kg/ha
		Line Sowing	10kg/ha
8.	Finger millet or Ragi	Broadcasting	8-10kg/ha
		Line Sowing	8kg/ha
9.	Tef	broadcasting	4.5-6kg/ha
10.	Brown top millet	Line Sowing	5kg/ha

4. **Plant population:** The recommended plant stand for pearl millet under normal conditions is 180,000 plants ha⁻¹ or 72,000 plants acre⁻¹. Under irrigation or high levels of management on highly productive soils, a population of 225,000 plants ha⁻¹ (100,000 plants acre⁻¹) is recommended. On extremely sandy, droughty soils, a population of about 90,000 plants ha⁻¹ (40,000 plants acre⁻¹) is desirable.

Table 7: Plant Population for Bio-fortified variety of Various Millets Crops

S. No.	Vernacular Name	Spacing	Plant population	Area where it is recommended
1.	Pearl millet	60 cm x 15 cm	1.0 to 1.25 lakhs/ha	Arid-western plain of Rajasthan, Haryana and Kutch of Gujarat
		45 cm x 10-15 cm	1.75-2.0 lakhs/ha	area receiving rainfall more than 450 mm
2.	Sorghum or Jowar	45 cm x 12-15 cm	72,000 plants per acre	Maharashtra, Karnataka, AP, Telangana, Rajasthan, Gujarat, MP, Tamil Nadu (rain fed) For Kharif Sowing
		45 cm x 15 cm	1.5 to 1.8 lakh/ha	Maharashtra, Karnataka, AP, Telangana, Rajasthan, Gujarat, MP, Tamil Nadu (rain fed) For Rabi Sowing
3.	Foxtail millet	25-30 cm x 8-10 cm	5 to 8 lakhs/ha	Arid/semi-arid South India; Karbi Anglong (Assam, Jhum fields)
4.	Indian Barnyard millet	25 cm x 10 cm	4-5 lakhs/ha	Minor millet across peninsular India, upland rain-fed areas
5.	Kodo millet	22.5cm x 10 cm	3-4 lakhs/ha	MP, Chhattisgarh, Maharashtra, Tamil Nadu, Karnataka; some parts of Arunachal Pradesh
6.	Little millet	22.5 cm – 8-10 cm	4.5-5 lakhs/ha	Peninsular & hill regions of South/Central India
7.	Proso millet	22.5 cm x 10 cm	5-5.25 lakhs/ha	Upland dry zones in peninsular India
8.	Finger millet or Ragi	7.5-10 cm x 22.5-30 cm	4-5lakhs/ha	Southern India (esp. Karnataka); high-altitude areas (rabi), India & Nepal
9.	Fonio Millet	15 – 20 cm Row to Row spacing	2.5-3 lakhs/ha	Not commonly cultivated in India (primarily West African origin)

5. **Sowing Time and Method:** Sowing of kharif pearl millet should be done with the onset of monsoon i.e. first fortnight of July in north and central parts of the country. For grain Bajra should be sown from July to mid-August and for fodder purpose it can be sown from last week of June to first week of July'. First fortnight of October is appropriate time for rabi season in coastal areas of India. Bajra should be sown at the depth of 4cm in lines (max.) with a spacing of 45cm. Gap filling should be done by transplanting seedlings after 2-3

weeks of sowing is recommended in dry sowing prior to first monsoon rains if scanty population exists. Summer pearl millet should be sown from 4th to 5th Standard Meteorological Week (SMW) i.e. last week of January to 1st week of February to obtain higher production of summer pearl millet in summer growing areas of millet in India. Three systems of pearl millet sowing are followed: (1) on a flat surface, or (2) using ridge and furrow system, or (3) on a broad-bed and furrow system. The seed should be sown at 2.5 cm – 3 cm depth.

Table 8: Sowing times and Methods for Bio-fortified variety of Various Millets Crops

S. No.	Vernacular Name	Sowing Time	Method of Sowing
1.	Pearl millet	(i) with the onset of monsoon for <i>Kharif</i> pearl millet i.e. first fortnight of July in north and central parts of the country (ii) First fortnight of October for rabi season in Tamilnadu	(i) on a flat surface (ii) using ridge and furrow system, (iii) on a broad-bed and furrow system
2.	Sorghum or Jowar	3rd week of June to 1st week of July with onset of monsoon	Line Sowing and Broadcasting
		2nd fortnight of September to 1st fortnight of October	Line Sowing
		June (with onset of monsoon)	Broadcasting for forage sorghum
3.	Foxtail millet	kharif irrigated crop is planted from the beginning of June to end of July and rabi crop in August to September, and summer irrigated crop in January	Line sowing and broadcasting.
4.	Indian Barnyard millet	For Kharif season, it is June to July and for Rabi season, it is September to October	Broadcasting and line sowing
5.	Kodo millet	for <i>Kharif</i> is June to July	Broadcasting or line sowing is recommended
6.	Little millet	for <i>Kharif</i> is June to July for <i>Rabi</i> September-October	Line sowing and broadcasting
7.	Proso millet	For <i>Kharif</i> is first fortnight of July For <i>Summer</i> is Feb	broadcasting and line sowing using seed drills
8.	Finger millet or Ragi	for Kharif- June to July, for Rabi- September to October	Line sowing under rainfed conditions and transplanting is done under irrigated conditions
9.	Brown top millet	from mid-April until mid-August	Line Sowing

6. **Seed treatment:** Seed treatment with biopesticides (*Trichoderma harzianum* @ 4g kg⁻¹) or thiram 75% dust @ 3 g kg⁻¹ seed will help against soilborne diseases. Seed treatment with 300-mesh sulfur powder @ 4 g kg⁻¹ seeds controls the smut disease. Seed treatment with metalaxyl (Apron 35 SD) @ 6 g kg⁻¹ seed controls downy mildew. Seeds are treated with *Azospirillum* (600 g) and *Phosphobacterium* to enhance the availability of nitrogen and phosphorus. Treat the seed with thiram or cabendazim @2-2.5gm per 1kg of seed before sowing to avoid seed borne diseases. To manage Ergot treat the seed in 20% salt solution.

7. **Fertilizer Management:** Use balance fertilizers as per the soil test basis. Generally for hybrid varieties 80-100kg nitrogen, 40-50kg phosphorous, and 40kg potash is recommended, while composite varieties needs 40-50kg nitrogen, 25kg phosphorous, and 25kg potash per hectare. Application of 40 kg N + 20 kg P₂O₅/ha for arid regions and 60 kg N/ha + 30 kg P₂O₅/ha for semi-arid regions is recommended for sole pearl millet as well as intercropping system. In light soils (sandy loams) the applied nitrogen may be lost due to leaching with heavy rains. So, only about half of the recommended nitrogen dose should be applied at seedbed preparation. The remaining half of nitrogen dose is side-dressed when the crop is 25-

30 days old. On soils which do not leach easily like black soils, all of the nitrogen may be applied during seedbed preparation. Pearl millet seeds are sensitive to fertilizer burn. Do not apply fertilizer in the furrow with the seed or very near the seed in the row after sowing. It should be applied as side dressing. Use of bio-fertilizer (*Azospirillum* and PSB) can economize the N and P fertilizer application.

In zinc deficient soils of the pearl millet growing area of the country, application of 10 kg ZnSO_4/ha is recommended. To correct the zinc deficiency in standing crop, spray of 0.2% ZnSO_4 at tillering to pre-flowering stage is recommended. Under prolonged dry spell, skip top dressing of N and spray 2% urea. Under excessive rain situation during vegetative phase, additional dose of nitrogen @ 20 kg/ha should be given

8. **Thinning and Gap filling:** It is an important operation to be done after 10-15 days of sowing. Transplant the plant from high density area to poor germination area and fill the gap to maintain crop geometry and population.
9. **Inter-cultivation and Weed Management:** Two weeding, hoeing and earthing are done manually with khurpi after 15-20 and 30-35 days of sowing it helps in proper aeration and good establishment of crop. And with the herbicidal weed control through pre-emergent application of Atrazine @1.25kg per hectare in light to medium soils within 48 hours of sowing. For very hardy weeds add pendamethylen 30EC @2.5 liters with atrazine to control weeds.
10. **Irrigation Management:** Bajra crop is highly susceptible to moisture especially at the times of flowering and grain formation, thus, if rain fails two irrigations on these stages must be provided. Under prolonged dry spells, irrigation should be applied at critical stages of crop growth i.e. tillering, flowering and grain developmental stage, if water is available. In summer, pearl millet should be irrigated at regular intervals (0.75-1.0IW/CPE with 40 mm) as per need of the crop.
11. **Harvesting:** The best stage to harvest pearl millet is when the plants reach physiological maturity determined by the black spot at the bottom of the grain in the hilar region. When the crop matures, the leaves turn yellowish and present a nearly dried up appearance. The grains are hard and firm. The usual practice of harvesting pearl millet is cutting the ear heads first and the stalks later. The stalks

(straw) are cut after a week, allowed to dry and then stacked. Grain at or below 14% moisture is considered dry. For long-term storage (more than 6 months), grain moisture content should be less than 12%.

12. **Plant Protection:** (Major Diseases): Insect pests are considered to be relatively less important in most of the pearl millet growing areas in India. The most important insect pests of pearl millet are white grub, shoot fly and grey weevil etc.

Ergot: It is a serious disease of Bajra in which sclerotia are developed in the ears and black powder is formed in grains with the eruption of slesma (honey like sticking liquid) from the affected ears. To manage this disease treat the seed before sowing with chemicals or 20% salt solution. Use Zeerum 80% WP or Zeneb 75% WP 2kg or Mencozeb 75% WP @ 2kg per hectare.

Downy mildew: Downy mildew is widely distributed in all the pearl millet growing areas in the world. Systemic symptoms as chlorosis generally appear on the second leaf and all the subsequent leaves and panicles of infected plant show symptoms. Leaf symptoms begin as chlorosis at the base of the leaf lamina and successively higher leaves show a progression of greater leaf area coverage by the symptoms. Infected chlorotic area produce massive amount of asexual spores, generally on the lower surface is giving the leave a 'downy' appearance. Systemically infected plants remain stunted either do not produce panicle or produce malformed panicles. In many affected plants 'green ear' symptoms appear on the panicles due to the transformation of floral parts into leafy structure that may be total or partial and such plants do not produce seed or produce very few seeds. The infected leaves produce sexual spores (oospores) in the necrotic leaf tissue late in the season. Currently in India about 50% of the 9 million ha under pearl millet cultivation is grown with more than 70 hybrids in which DM incidence has been highly variable, with some hybrids showing more than 90% incidence at farmer's 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%. The diseases of pearl millet can be best controlled by integrating methods of chemical or biological control, and cultural practices. Use of resistant cultivars & Rotate hybrids with variety alternately to keep soil inoculum under control. Seed treatment with Apron 35 SD @ 6g/kg seed, Seed treatment with *Bacillus pumilis* (INR7), Seed treatment with Chitosan 10g/kg seed, Foliar spray of Ridomil 25 WP (100 ppm) after

21 days of sowing if infection exceeds 2-5 %, Rogue out infected plants and bury or burn and Seed treatment with Ridomil MZ-72 @ 8g/kg seed and a foliar spray of Ridomil MZ-72 2g/l.

Bajra Smut: Smut disease is of greater importance in India especially with the adaptation of hybrids. The disease is more severe in CMS-based single-cross hybrids than in open-pollinated varieties. The infected florets produce sori that are larger than grains and appear as oval to conical, which are initially bright green but later turn brown to black. Black powder is formed in grains. The estimated grain yield loss due to smut is 5-20%. The disease occurs during the month of September/ October. Early sown crop generally escapes from the smut infection and Use of resistant cultivars, Pray with Captafol followed by Zineb on panicle at boot leaf stage which reduces infection or Remove smutted ears from the field. To manage this disease treat seed and use fungicides as recommended for ergot.

Rust: Rust symptoms first appear on lower leaves as typical pustules containing reddish brown powder (uredospores). Later, dark brown teliospores are produced. Symptoms can occur on both upper and lower surface of the leaves but mostly on upper surface and also on stem. Highly susceptible cultivars develop large pustules on leaf blades and sheaths. Rust has generally been considered as a relatively less important disease in most of the pearl millet growing areas than downy mildew, ergot and smut because of its appearance, generally after the grain-filling stage, causing little or no loss in grain yield. Worldwide this disease is probably of greater importance of multicut forage hybrids where even low rust severities can result in substantial losses of digestible dry matter yield and Use of resistant hybrids/varieties, Sow the crop with the onset of monsoon, Destruction of collateral hosts like *Ischaemum pretosum* and *Panicum maximum* on the field bunds or Dusting of fine sulphur @ 17kg/ and two sprays of 0.2% Mancozeb at 15 days intervals.

Ear Kokkle/green ear disease: In this disease the whole bajra ear converts into green leaf and de-shaped which finally looks like a broom. To control

this disease use 2 sprays of carbendazium 50% WP or Thiophanate methyl 70% WP @ 2gm per liter of water at an interval of 10 days.

Blast: The disease is known as leaf spot of pearl millet caused by *Pyricularia grisea* (Cooke) Sacc [teleomorph: *Magnaportha grisea* (Herbert) Barr.] has become a serious disease during the past few years. The disease affects both quality and production of forage and grain. The symptoms appear as distinct large, indefinite, water soaked, spindle shaped, grey centred and purple grey horizon with yellow margin, resulting in extensive chlorosis and premature drying of young leaves.

Important Insects & Pests: Termites: Use chloropyrifos 20% EC @ 2.5 liter in standing crop with irrigation water.

Nematodes: Use 10kg forate 10G before one week of sowing in soil.

Stem borer: Use Cabofuron 3G or Forate 10G @ 20kg or spray Di methoate 30%EC 1 liter or Quiolphos 25%EC 1.50 liter per hectare.

Shoot borer: Use Cabofuron 3G or Forate 10G @ 20kg or spray Di methoate 30%EC 1 liter or Quiolphos 25%EC 1.50 liter per hectare.

White Grub: A common pest in Gujarat and Rajasthan States. The grubs attack the root of the growing seedlings and cause complete withering of the plants. Patchy gaps are formed due to death of plants which result in poor or uneven plant stand. Grubs cause maximum damage during July-August. The adults emerge from May to July with the pre-monsoon/monsoon showers and feed on pearl millet flower and grains in the milky stage. The extent of damage ranged from 5- 25% in Rajasthan. Inter-cropping with Sunflower and Pigeon pea reduces the incidence of white grub, Collect and destroy the adult beetles immediately after first showers when they visit Neem/ Acacia trees mating, Mixing of Carbofuran 3 G @ 12 Kg/ha with Bajra seed and application in seed furrows at the time of sowing is effective, Spray host trees with Carbaryl 0.2 % or Chlorpyrifos 0.2% with onset of monsoon and the spraying within 2-3 days after receipt of first showers.

Table 9: Disease and insect-pest of Bio-fortified variety of Various Millets Crops

S. No.	Vernacular Name	Insect-pests	Diseases
1.	Pearl millet	White grub, Shoot fly, Grass hoppers, Termites, Grey weevil, Ear head bug, Stem borers	Downy mildew, Rust, Smut, Ergot, Blast,
2.	Sorghum or Jowar	Shoot fly, Stem borer, Fall army worm, Shoot bug, Aphids	Grain mold, Downy mildew, Charcoal rot, Stripe virus

3.	Foxtail millet	Shoot fly	Downy mildew, Rust
4.	Indian Barnyard millet	Shoot fly, Stem borer, Termites	Smut
5.	Kodo millet	Shoot fly, Termites and stem borer	Rust, Head smut
6.	Little millet	Shoot fly, Stem borer, Termites	Smut
7.	Proso millet	Shoot fly	Head smut
8.	Finger millet or Ragi	Army worms, cut worms, Leaf aphid, Stem borer, Ear head caterpillars	Blast, Brown spot
9.	Brown top Millet	Shoot fly, Army worms and grasshoppers	Rust
10.	Fonio	shoot flies, stem borer, some species of thrips, bugs, and grasshoppers	Fungal and bacterize

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