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5. Pearl Millet

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Abstract:

Pearl millet (Pennisetum glaucum L.) is a vital cereal crop, predominantly cultivated in the arid and semi-arid regions of Africa and Asia, valued for its exceptional drought tolerance and adaptability to poor soil conditions. This chapter explores pearl millet's role in ensuring food security and nutritional health in marginal environments. With its rich content of protein, fiber, vitamins, and minerals, pearl millet contributes significantly to dietary needs, combating malnutrition. The crop's rapid growth, minimal water requirements, and resistance to pests and diseases underscore its agronomic advantages. Additionally, pearl millet's versatility in culinary applications, from traditional porridges and flatbreads to innovative health foods, highlights its cultural and economic importance. Emerging research also points to its potential in managing lifestyle diseases like diabetes and cardiovascular conditions. The chapter underscores the increasing recognition of pearl millet as a sustainable solution for global food security and nutrition in the face of climate change.

5.1 Introduction:

Millets are a vital crop, especially in regions with dryland or semi-arid climates, such as parts of Africa and Asia. These small seeded cereals that have been cultivated for thousands of years, and are known for their resilience to harsh growing conditions, including drought and poor soil quality. In India, millets have a long history as a crucial staple food, providing essential nutrients and sustaining many communities (NAAS, 2013).

Millets such as Bajra, ragi, Kangni and Jowar have been cultivated for centuries in various parts of the country. These grains are well adapted to thrive in harsh conditions with minimal water, making them a reliable food source even during periods of drought or erratic rainfall. They are not only nutritious, but also having significant role in widely consumed traditional dishes. The Green Revolution during 1960 introduced high yielding varieties of rice and wheat, along with modern agricultural practices for boosting food production and achieving food security goal. As a result, there was a significant shift towards the practice of cultivate and habit of consumption of rice and wheat, makes them dominant staple crop in India instead of millets.

Millets, which were once staple food for many communities, gradually lost their performance. Further, with respect to the nutritional advantages of millets, interest has been revived in millet cultivation and consumption (Kane-Potaka *et al.,* 2021). After recognizing the importance of millets, Indian government has launched several development initiatives to promote millets as "Shree-Anna". After a long time, near about 60 years, during 2018-19, Indian government again takes initiatives to promote millets as "Nutri-cereals" and launched "National Mission on Nutri-Cereals" to increase their cultivation and consumption. Apart from the central government, different state governments also take responsibilities of promoting millets as Indian assets among world population. Despite such developmental and promotional programme initiatives, the habits of consumption their staple foods (rice and wheat) still not change. Consumption of their own staple food is till now relatively low in comparison to food grain staples like rice as well wheat. But the young generation growing their interest on consumption of millets through various delicious and nutritious dishes as a pathway of healthy and sustainable diet and an alternative to calorific cereals. The year 2023 has been declared the 'International Year of Millets' by the United Nations General Assembly. The declaration was done to increase awareness of the different benefits of millets in terms of food security, nutritional security and long-term production against climate change to maintain sustainable agriculture.

India is the maximum producer of millets in the world. Two different types of millets namely Bajra and Jowar together contribute approximately 90% of Indian millet production. Pearl millet (*Pennisetum glaucum*; *Pennisetum typhoides*; *Pennisetum americanum*) is one of the major coarse grain crops and most popularly cultivated types of millet. It is considered to be a poor man's food. Large stem leaves, and heads characterize this summer cereal grass. It's grown primarily in Africa and the Indian subcontinent, but also cultivated in other parts in the world. Compared to other millet, pearl millet is the most significant species of millet, utilizes moisture more effectively, condensed panicles (spiked) measuring 10 to 150 cm in length, support the grain. Pearl millet is known for its resilience in hot and dry climates, making it a staple crop in regions with challenging growing conditions. It's valued for its nutritional content and versatility in various culinary uses, from porridge to flatbreads. Pearl millet can be beneficial in the process of weight loss as it has high in fiber content and also give satiety as it takes a longer time to pass through the stomach to the intestine. Due to high fiber content in pearl millet, consumption of this lowers the possibility of occurrence of gall stone. Rich source of phosphorus and calcium also helps to attain peak bone density.

Table 5.1: Area of Pearl Millet in India

State Wise Area of Pearl Millet (Bajra) – Lakh Hectare				
Sr. No.	**State**	**2021-22**	**2022-23**	**2023-24**
1.	Rajasthan	37.36	45.71	42.65
2.	Uttar Pradesh	9.05	9.47	10.10
3.	Haryana	4.83	5.26	5.43
4.	Gujarat	4.46	5.02	2.03
5.	Madhya Pradesh	3.43	3.63	3.88

State Wise Area of Pearl Millet (Bajra) – Lakh Hectare				
Sr. No.	**State**	**2021-22**	**2022-23**	**2023-24**
6.	Maharashtra	6.67	4.34	3.67
7.	Karnataka	1.48	1.28	1.27
8.	Tamil Nadu	0.60	0.45	0.46
9.	Andhra Pradesh	0.31	0.25	0.24
10.	Jammu and Kashmir	0.09	0.18	0.00
11.	Other states	0.13	0.13	0.14
	Total	**68.41**	**75.72**	**69.87**
Source: Ministry of Agriculture & Farmers Welfare (MoA&FW)				

Table 5.2: Production Scenario of Pearl Millet in India

State Wise Production of Pearl Millet (Bajra) – Lakh Tonnes				
Sr. No.	**State**	**2021-22**	**2022-23**	**2023-24**
1.	Rajasthan	37.40	51.05	42.81
2.	Uttar Pradesh	19.51	20.46	21.95
3.	Haryana	11.20	12.00	11.69
4.	Gujarat	10.90	12.94	3.63
5.	Madhya Pradesh	8.69	9.43	9.58
6.	Maharashtra	6.69	4.68	2.01
7.	Karnataka	1.71	1.77	1.56
8.	Tamil Nadu	1.46	1..13	1.19
9.	Andhra Pradesh	0.55	0.51	0.54
10.	Jammu and Kashmir	0.05	0.10	0.00
11.	Other states	0.13	0.23	0.34
	Total	**97.79**	**114.30**	**95.30**
Source: Ministry of Agriculture & Farmers Welfare (MoA&FW)				

Table 5.3: Pearl Millet Nutrient Per 100g

Nutrient per 100g	
Energy (Kcal)	378
Protein	10.96 grams
Carbohydrate	61.78 grams
Fat	5.43 grams
Crude fiber	11.49 grams
Calcium	38 milligrams

Nutrient per 100g	
Iron	8.0 milligrams
Calcium	38 milligrams
Magnesium	114 milligrams
Zinc	1.7 milligrams
Thiamine	0.38 milligrams
Niacin	1.8 milligrams
Folate	85 micrograms
Carotene	132 micrograms

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)

Figure 5.1: Pearl Millet Crop in The Field

5.2 What is Pearl Millet?

This extraordinary grain, multipurpose cereal crop (Figure 6.1), belongs to the family Poaceae, known by various names such as Bajra, Bajri, Sajje, Kambu, or Cumbu, has graced the culinary traditions of Africa and Asia for centuries. Millets are sa critical staple food for millions, particularly in the Sahelian region of Africa and northwestern India (Srivastava *et al.*, 2020b) and extensively grown on 30 million ha worldwide, with the majority of the crop grown in Africa (>18 million ha) and Asia (>10 million ha) (Raheem *et al.*, 2021) in the arid and semi-arid tropical regions of Asia and Africa. Food and Agricultural Organization (FAO) showed that millet production covers between 29 and 38 million hectares between 2003 and 2013, and the world millet production was 29.8 million tons in 2013 while 15 million tons (50.3%) were produced in Africa, followed by Asia with 13.7 million (45.9%) and other countries shared 1.1 million (3.7%) (Miller, 2020). It is also consumed by livestock as feed and accounts for almost half of the global millet production (Srivastava *et al.*, 2020a). Pearl millet is a significant crop in various countries mainly India, China, Nigeria, Pakistan, Sudan, Egypt, Arabia and Russia. In India pearl millet is grown over an area of 6.98 million hectares (Table 6.1) with total production of 9.53 million tons (Table 6.2). Pearl millet is grown almost everywhere except in high rainfall areas like Assam, West Bengal and Odisha. States of Rajasthan, Uttar Pradesh, Haryana, Gujarat and Madhya Pradesh account for 92% of the total area (Table 6.1). About 90% of the production comes from Rajasthan, Uttar Pradesh, Haryana and Gujarat (Table 6.2).

It stands as a resilient crop, thriving in the face of the most challenging climates. It has a greater ceiling temperature for grain yield and is an underutilized crop with huge nutritional potential, which needs to be utilized fully (Krishnan and Meera, 2018).

Scientifically labeled as *Pennisetum glaucum*, boasting a chromosome number of 7, pearl millet goes beyond mere toughness; it emerges as a nutritional powerhouse, a rich source of vitamins such as riboflavin, niacin and thiamine and minerals such as potassium, phosphorus, magnesium, iron, zinc, copper and manganese (Weckwerth *et al.,* 2020) (Table 6.3), pearl millet is even more nutrient-dense than rice and wheat (Kumar *et al.*, 2022).

Pearl millet's gluten free nature and alkaline properties make it particularly beneficial for individuals with gluten allergies or sensitivities. Pearl millet's high content of slowly digestible starch (SDS) and resistant starch (RS) contributes to its low glycemic index (GI), making it an excellent choice in modern dietary trends and food industry innovations (Satyavathi *et al.,* 2020). Moreover, it plays gently with blood sugar levels, a welcomed attribute for those navigating the intricacies of diabetes management.

From heartening porridge to the versatility of bread, roti, dosa, idli, and imaginative salads and soups, pearl millet imparts its nutty, earthy charm to a diverse array of dishes. Yet, the culinary journey doesn't conclude there! Indulge in delectable desserts like kheer, halwa, laddu, and cookies, all crafted with finesse thanks to the culinary prowess of pearl millet. Simple to cook, easy to store, and brimming with flavor, this grain stands as a culinary delight that also champions your nutritional well-being. A natural superhero for both your body and mind, pearl millet encapsulates all the goodness you yearn for.

Figure 5.2: Pearl Millet Grain

5.3 Health Benefits of Pearl Millet:

Pearl millet, a nutritious grain (Figure 6.2), offers various health benefits. Rich in fiber, it aids digestion and promotes a healthy gut. Packed with essential nutrients, pearl millet supports heart health, regulates blood sugar, and boosts overall well-being. Include this versatile grain in your diet for a nutritional boost! Here are some of the benefits of Pearl millet you must know;

1. Maintains Cholesterol Level:

Pearl millet is your heart's best friend. Packed with fiber, it swoops in, grabs those pesky bile acids, and keeps them from causing trouble. Say goodbye to excess cholesterol and plaque buildup! Plus, it's a pro at boosting your good cholesterol while kicking the bad ones to the curb.

2. Maintains Stress Levels:

Say goodbye to inflammation and oxidative stress – the villains of healthy blood vessels. Pearl millet swoops in to save the day, keeping your BP in check and lowering the risk of heart troubles.

3. Stabilize Blood Sugar Levels:

This grain's got your back, especially if you're keeping an eye on those blood sugar levels! With a low glycemic index, it won't send your levels on a rollercoaster ride after you munch on it.

4. Boosts Immunity:

This grain packs a punch with iron, zinc, and vitamin B6 – the dream team for your immune cells. It's like having your squad, ready to defend and conquer you at any given moment.

5. Improve Digestion:

Packed with fiber, it keeps things moving smoothly and says goodbye to troubles like constipation or surprise visits from diarrhea. Plus, it's like a gourmet feast for your gut buddies, ensuring they're in tip-top shape to help you absorb all those nutrients. So, not only does pearl millet keep your digestive system happy, but it also gives colon cancer the cold shoulder!

6. Improve Metabolism:

Pearl Millet has the protein punch to help your muscles and tissues stay strong and snazzy. Plus, it's like a little cheerleader for your thyroid, giving your metabolism a boost and helping you burn those calories and fat like a champ.

7. Boost Brain Function:

Packed with niacin, folate, and thiamine, it's like a VIP pass to brain boost! Plus, it's a traffic controller for your blood flow, making sure those neurons get all the oxygen and goodies they need. And guess what? It's got a knack for playing with your neurotransmitters, which means better mood, memory, and thinking skills. Pearl millet is like a brain boot camp, keeping you sharp and reducing the chances of Alzheimer's and Parkinson's.

Delicious and Value-Added Food Products from Pearl Millet:

5.4 Side Effects of Pearl Millet:

You have learned how pearl millet can nourish your body and mind with its nutrients. But you also need to know that pearl millet can have some drawbacks if you eat too much or not properly. It can cause some problems for your health and well-being.

Here are some of the sides effects of pearl millet can cause:

1. Allergen Alert:

Pearl millet can also have other allergens, like proteins, lectins, or enzymes that can make you itch, swell, and have trouble breathing.

To prevent this, you should buy pearl millet from reliable sources and check the labels for any gluten or allergen warnings. You should also start eating this millet slowly and watch for any bad reactions. If you have any signs of allergy, you should stop eating pearl millet and see your doctor right away.

2. Thyroid Issue:

Pearl millet has these little things called goitrogens, which can mess with your thyroid hormones. It can lead to feeling like a sluggish sloth, gaining unwanted weight.

5.5 Botanical Description of Pearl Millet:

Pearl millet (*Pennisetum glaucum* L.) is recognized for its efficient photosynthetic pathway, known as C_4 photosynthesis, which is advantageous in hot and dry conditions; perfect to pearl millet's native environment.

Thus, being a C_4 plant, pearl millet can account for 30% of global terrestrial carbon fixation along with other C_4 plants such as maize and sorghum (Choudhary *et al.*, 2020). It holds significant agricultural importance as both a cereal and forage crop, particularly in the arid and semi-arid regions of the Indian sub-continent and various parts of Africa somehow due to food security, adaptability to harsh environments, nutritional value etc.

Pearl millet's versatility in soil adaptation makes it a valuable crop in regions characterized by marginal lands and challenging agricultural conditions. Pearl millet exhibits various growth and development features throughout its life cycle, spanning from germination to seed formation.

The growth phases of pearl millet – vegetative, reproductive, and grain filling – play crucial roles in its development and yield potential. (Figure 5.3, Table 5.4).

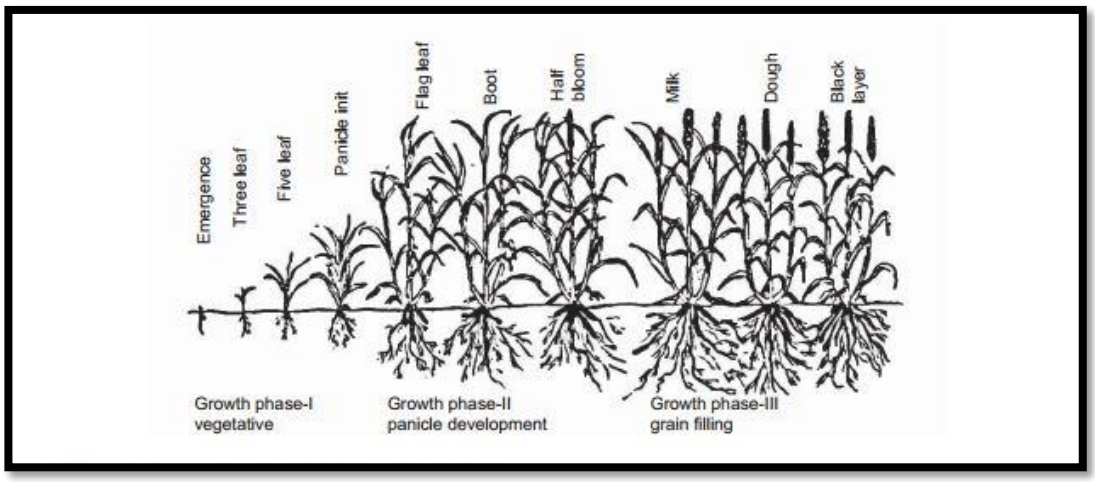

Figure 5.3: Major Growth and Morphologically Distinct Stages of Pearl Millet

Table 5.4: Three Major Growth Phases and Morphologically Distinct Development Stages of Pearl Millet

Growth Phases	Identifying Characteristics	Approximate Days After Emergence*
GP I	**Vegetative phase**	**0-21**
	Emergence stage	2-3
	Three leaf stage	3-7
	Five leaf stage	7-14
	Panicle initiation stage	14-21
GP II	**Reproductive/Panicle development phase**	**21-42**
	Flag leaf stage	21-28

Growth Phases	Identifying Characteristics	Approximate Days After Emergence*
	Boot stage	28-35
	Half bloom stage	35-42
GP III	**Grain filling phase**	**42-77**
	Milk stage	42-49
	Dough stage	49-56
	Black layer formation or physiological maturity	56-77

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)

*May vary with environmental conditions, locations and varieties

- **Root System:** Pearl millet possesses a typical monocotyledonous root system characterized by several distinct types of roots such as seminal or primary roots, adventitious roots, and crown or collar roots.
- **Stem:** Pearl millet grows upright and completes its life cycle within one year having a robust tillering habit with multiple shoots from base. The main stem of pearl millet typically reaches a height of 2 to 4 meters with 0.5-to-1.5-centimeter diameter. The stem is generally round to oval in cross-section. Nodes along the stem of pearl millet are slightly swollen, may have a pubescent (hairy) texture. At the base of each node, there is a ring of adventitious root primordia, which are potential sites for adventitious root to emerge. Internodes (the segment between nodes) of pearl millet are typically smooth and glaborous (without hairs), contributing to its streamlined appearance.
- **Leaves:** The leaves of pearl millet exhibit specific characteristics that are important for its growth, photosynthesis, and overall adaptation to various environmental conditions. The leaves are linear, 20-100 cm long and 0.5-5.0 cm wide, usually sparse to densely hairy or glabrous. The leaf consists of a leaf sheath and lamina or blade.
- **Inflorescence:** The inflorescence of pearl millet is a distinctive feature of the plant's reproductive structure, known as a panicle. Its length generally varies between 20-25 cm with a circumference of 7-9 cm.
- Pearl millet exhibits unique reproductive characteristics that's facilitates its cross pollination. Wind is supposed to be the primary agent for pollen transfer. However, insects such as bees and beetles can also contribute to cross pollination. Pearl millet exhibit protogyny (Female stigma becomes ready to receive pollen before the release of male anthers dehiscence of the same plant) and the time lag between stigma emergence and anther dehiscence favor cross pollination, but asynchronous flowering of pearl millet can limit the full realization of cross pollination. The protogyny in pearl millet is exploited for controlled cross pollination without resorting to emasculation.
- **Grain:** Pearl millet seeds, known as caryopsis, show several distinctive characteristics and its shape, ranging from globular to conical shape. The seed color varies from ivory to purplish black, with light to deep gray being the most common seed color. A small embryo is present on the depressed or flat surface at the tapering end of the seed. The size of the grain depends on its position in the panicle, being largest at the

base, medium in the middle, and smallest at the apex. Variations exist in grain size among varieties generally ranging from 4-12 g per 1000 grains.

5.6 Different Varieties of Pearl Millet:

- 1st hybrid of Bajra was HB 1 (Hybrid Bajra 1) released from Ludhiana in 1965 by crossing Tift 23A × Bil 3B through CMS system of hybridization.

Table 5.5: Different Varieties of Pearl Millet

Season	Recommended hybrids	Recommended varieties
Kharif	KBH 108, GHB 905, 86M89, MPMH 17, Kaveri Super Boss, Bio 448, MP 7872, MP 7792, 86M86, RHB 173, HHB 67	MBC 2, PC 443, JBV 3, 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

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)

Climate and Soil:

- Pearl millet is crop of warm climate, grown in an arid and semi-arid climate of tropical and sub-tropical regions.
- Moist weather with light-medium rainfall is required for its vegetative stage and clear & dry weather with no rainfall is required for its flowering and grain-filling stage.
- Rainfall during grain maturity period results in infection of diseases like ergot.
- The optimum temperature for vegetative phase is 27-30^{o}C. Below this temperature, increase ergot infection while high temperature force in early flowering.
- Loamy sand to the loamy soil is best for pearl millet.

5.7 Recommended Package of Practice of Pearl Millet:

5.7.1 Preparation of Land:

Pearl millet exhibits adaptability to various soil types, including sandy, loamy, and clayey soils. It does not thrive in waterlogged conditions. Excessive moisture can stunt growth and lead to various diseases in pearl millet crops. To ensure optimal growth, preparing the soil is crucial. Ploughing the field once or twice, followed by harrowing, helps in breaking up the soil, removing weeds, and creating a fine tilt. This preparation allows for better seedbed conditions, promotes root development, and facilitates nutrient uptake for the growing plants.

Additionally, it enhances soil aeration and drainage, which is particularly important to prevent water logging issue.

Overall, proper soil preparation, including ploughing and harrowing, sets the stage for successful pearl millet cultivation by providing favorable conditions for germination, growth, and ultimately, a healthy yield.

5.7.2 Selection of High Yielding Hybrids and Varieties:

Hybrids are commonly favored in areas with favorable growing conditions and where high yields are desired. These hybrids are developed through cross breeding and are often selected for traits such as high yield potential, disease resistance, and uniformity. They tend to perform well in regions with adequate rainfall and fertile soils.

On the other hand, in drought-prone areas or region with limited water availability, traditional varieties of pearl millet are preferred. These varieties are often more resilient to drought and can better withstand harsh environmental conditions. They may have characteristics such as deep root systems, efficient water use, and tolerance to heat and drought stress.

By selecting the appropriate cultivars based on the specific growing conditions and environmental challenges of each region, farmers can optimize pearl millet production and ensure a more reliable harvest.

5.7.3 Method of Sowing:

Pearl millet sowing methods typically involve three main systems:

1. **Flat Surface:** Seeds are sown directly onto a flat surface of the field. This method is straight forward and suitable for areas with relatively even terrain.
2. **Ridge and Furrow System:** In this method, raised ridges are formed along the length of the field with furrows in between. Seeds are sown along the ridges. This system helps in better moisture retention, especially in areas with high rainfall or where irrigation is used, and also facilitates drainage.
3. **Broad-bed and Furrow System:** Here, the field is divided into broad beds with furrows in between. Seeds are sown on the broad beds. This system is particularly beneficial for improving water management, soil aeration, and overall crop health.

Regardless of the sowing method used, it's crucial to sow pearl millet seeds at a depth of around 2.5cm to 3cm. This depth ensures adequate soil coverage for germination while still allowing the emerging seedlings to reach the surface easily. Adjusting sowing depth according to soil moisture and texture can help optimize germination and stand establishment.

5.7.4 Time of Sowing:

1. ***Kharif* Season (North and Central Parts of India):** Sowing of pearl millet should commence with the onset of the monsoon, typically during the first fortnight of July. This timing ensures that the crop receives sufficient moisture for germination and initial growth.

2. ***Rabi* Season (Tamil Nadu):** In Tamil Nadu, appropriate time for sowing pearl millet in the *rabi* season is during the first fortnight of October. This timing aligns with the climatic conditions of the region, optimizing crop growth and development.
3. **Gap Filling:** If there is a sparse population of pearl millet plants after initial sowing, gap filling can be done by transplanting seedlings. This should be carried out approximately 2-3 weeks after the initial sowing to ensure uniform plant density and maximize yield potential.
4. **Marathwada Area of Maharashtra:** In this region, dry sowing of pearl millet prior to the onset of the first monsoon rains is recommended. This strategy takes advantage of residual soil moisture and ensures that the crop establishes well when the rains arrive.
5. **Summer Season:** For summer pearl millet cultivation, sowing should be carried out from the 4^{th} to 5^{th} Standard Meteorological Week (SMW), which corresponds to the last week of January to the first week of February. This timing is conductive to obtain higher production levels of summer pearl millet in this specific zone.

Planting should be done as soon as rains are established; early planting is recommended to escape disease and insect attacks and the seeds should be planted when the soil is moist enough to enable the seed to germinate (Azare *et al.*, 2020). Following these recommended sowing timings ensures that pearl millet crops are planted under optimal conditions, maximizing their growth potential and ultimately leading to higher yields.

5.7.5 Seed Treatment:

1. **Biopesticides (*Trichoderma harzianum*):** Application of *Trichoderma harzianum* at a rate of 4g per kg of seed helps in controlling soil borne diseases. *Trichoderma harzianum* is a beneficial fungus known for its antagonistic activity against various soil borne pathogens.
2. **Thiram 75% Dust:** Thiram, applied at a rate of 3g per kg of seed, serves as protective fungicide against soil borne diseases. It helps in preventing fungal infections during the early stages of seed germination and seedling growth.
3. **Sulphur Powder:** Sulphur powder, applied at a rate of 4g per kg of seeds, is effective in controlling smut disease, a fungal infection caused by *Ustilago* species. Sulphur has fungicidal properties that inhibit the growth and spread of the smut fungus.
4. **Salt Solution:** Ergot affected seeds are soaked in a 10% salt solution to remove ergot contamination. Ergot is a fungal disease caused by *Claviceps* species, and soaking seeds in a salt solution helps in separating and removing the ergot-infected seeds from the healthy ones.
5. **Metalaxyl (Apron 35 SD):** Metalaxyl applied at a rate of 6g per kg of seed, is effective against downy mildew, a common fungal disease in pearl millet. Metalaxyl is a systemic fungicide that penetrates plant tissues and provides protection against downy mildew infection.
6. **Azospirillum and Phosphobacterium:** Treatment with Azospirillum and Phosphobacterium enhances nitrogen and phosphorus availability in the soil, respectively. These beneficial bacteria form symbiotic relationships with pearl millet roots, promoting nutrient uptake and improving plant growth and yield.

By implementing these seed treatment methods, farmers can effectively manage diseases and improve nutrient availability, ultimately enhancing the health and productivity of pearl millet crops.

Seed Rate, Spacing and Plant Population:

Seed Rate: 3 kg/ha.

Spacing: In arid-western plains like Rajasthan, Haryana, and Kutch of Gujarat, the recommendation is to plant pearl millet in rows 60cm apart with a low plant population of 1.00 to 1.25 lakhs per hectare.

For areas receiving more than 450 mm of rainfall, the crop should be planted at a closer spacing of 45 x 10-15cm, maintaining a higher plant population of 1.75 to 2.00 lakhs per hectare. The suggested seed rate for pearl millet is 3 to 4 kg per hectare to achieve the desired plant stand. These guidelines aim to optimize pearl millet cultivation according to the specific agro-climatic conditions of different regions.

Plant Population:

1. Under normal conditions, 1, 80,000 plants per hectare or 72,000 plants per acre are recommended.
2. Under irrigation or high levels of management on highly productive soils, a higher population of 2, 25,000 plants per hectare (equivalent to 1, 00,000 plants per acre) is suggested.
3. On extremely sandy, droughty soils (such as in Rajasthan), a lower population of about 90,000 plants per hectare (equivalent to 40,000 plants per acre) is desirable to account for the challenging growing conditions.

These guidelines reflect the adaptability of pearl millet cultivation to varying soil types, moisture levels, and management practices.

5.7.6 Nutrient Management:

The fertilization guidelines offer tailored recommendations based on the specific needs and characteristics of the soil and the crop.

1. Recommended Application Rates:

- For arid regions: 40 kg N + 20 kg P_2O_5 per hectare
- For semi-arid regions: 60 kg N + 30 kg P_2O_5 per hectare.

2. Nitrogen Application Strategy:

- In light soils prone to leaching (like sandy loams), only half of the recommended nitrogen dose should be applied at seedbed preparation to mitigate potential losses due to leaching. The remaining nitrogen should be band placed when the crop is 25 days old.

- On soils with less leaching tendency (like black soils), the entire nitrogen dose can be applied during the time of seedbed preparation.

3. **Precautions Against Fertilizer Burn:**

- Pearl millet seeds can be sensitive to fertilizer burn. Therefore, it's advised not to apply fertilizer directly in the furrow along the seed or very close to the seed in the row after sowing. Instead, fertilizer should be applied as side dressing to prevent damage to the seeds.

4. **Use of Biofertilizers:**

- The use of biofertilizers such as Azospirillum and PSB (Phosphate Solubilizing Bacteria) can help economize nitrogen and phosphorus fertilizer application. These biofertilizers enhance nutrient availability to the plants, reducing the need for synthetic fertilizers while promoting soil health.

5. **For Zinc-Deficient Soils:**

- Application of 10 kg $ZnSO_4$ per hectare is recommended to address zinc deficiency in the soil.

6. **To Correct Zinc Deficiency in Standing Crop:**

- A spray of 0.2% $ZnSO_4$ solution is recommended from tillering to the pre-flowering stage of the crop. This foliar application helps ensure that the growing plants receive sufficient zinc for healthy growth and development.

7. **Under Prolonged Dry Spells:**

- If there is a prolonged dry spell, it is advised to skip the top dressing of nitrogen. Instead, a spray of 2% urea can be applied to provide nitrogen to the crop. This helps maintain adequate nutrient levels despite limited moisture availability.

8. **Under Excessive Rain Situations During the Vegetative Phase:**

- If there is excessive rainfall during the vegetative phase of the crop, an additional dose of nitrogen at a rate of 20 kg per hectare should be given. This compensates for the potential loss of nitrogen due to leaching caused by heavy rains, ensuring that the crop's nitrogen needs are met.

These recommendations aim to address nutrient deficiencies, optimize nutrient management, and mitigate the impact of adverse weather conditions on pearl millet cultivation, ultimately supporting healthy crop growth and yield.

5.7.7 Inter-Cultivation and Weed Control:

Two rounds of hoeing and weeding at 15 and 30 days after sowing are sufficient to control weeds effectively. This method is being compared to using atrazine herbicide at a rate of 0.5 kg/ha applied pre-emergently, combined with one round of hand weeding. Second hand weeding is also helps to conserve soil moisture.

5.7.8 Pearl Millet Based Cropping Systems:

Rotating cultivars is a recommended practice in agriculture to mitigate the risk of diseases like downy mildew. This approach helps break the disease cycle by interrupting the

buildup of pathogens specific to certain crop varieties. By alternating between bajra hybrids and open-pollinated varieties, farmers can reduce the likelihood of disease outbreaks and maintain soil health. This rotation strategy not only helps manage diseases but also promotes biodiversity and reduces the pressure on specific plant traits, which could lead to resistance development in pathogens. Furthermore, rotating cultivars can also have other agronomic benefits such as better nutrient utilization and improved soil structure. It's essential for farmers to implement diverse crop rotation plans and consult with agronomic experts to tailor the strategy to their specific farming conditions and goals.

Table 5.6: Pearl Millet Based Cropping Systems

Rajasthan	Bajra + cluster bean/cowpea/green gram/moth bean/sesame
Haryana	Bajra + Green gram/sesame/cluster bean/cowpea
Gujarat	Bajra + Green gram/sesame/cowpea
Uttar Pradesh	Bajra + Green gram/sesame/cowpea
Madhya Pradesh	Bajra + Black gram/soybean/Pigeon pea/cowpea
Delhi	Bajra + Pigeon pea/groundnut/castor
Punjab	Bajra + Chick pea/fodder sorghum/wheat
Maharashtra	Bajra + Moth bean/Pigeon pea/soybean/black gram, green gram/cowpea/ sunflower
Karnataka	Bajra + Pigeon pea/green gram/sunflower/soybean
Tamil Nadu	Bajra + Pigeon pea/green gram/sunflower/soybean/cowpea
Andhra Pradesh	Bajra + Pigeon pea/green gram/sunflower/soybean/groundnut

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)s

5.7.9 Irrigation:

Applying irrigation at moisture sensitive stages of crop growth, such as tillering, flowering, and grain development, can help mitigate the negative effects of prolonged dry spell on crop yields. Pearl millet, particularly during the summer season, is often sensitive to moisture stress, making timely irrigation crucial for optimal growth and yield. The recommended irrigation intervals and amounts (0.75-1.0 IW/CPE with 40 mm) seem to reflect the water requirements of bajra during its growth stages.

Irrigation scheduling based on crop water needs helps ensure efficient water use while preventing both water stress and excessive moisture, which can lead to diseases or nutrient leaching. It's essential for farmers to monitor soil moisture levels regularly and adjust irrigation practices accordingly, taking into account factors such as soil type, weather conditions, and crop development stage.

By providing adequate and timely irrigation during critical growth stages, farmers can optimize pearl millet yields even under challenging environmental conditions like prolonged dry spells.

5.7.10 Harvesting:

Harvesting at the optimal stage of physiological maturity is essential for maximizing seed yield and quality. The presence of a black spot at the bottom of the seed in the hilar region is a reliable indicator of physiological maturity. Additionally, the yellowing and drying up of leaves, along with hard and firm grains, further confirm maturity. The typical harvesting practice involves cutting the ear heads first, followed by the stalks after about a week.

This allows for efficient handling and processing of the crop. After cutting, the straw is left to dry before stacking, which facilitates further drying and minimizes the risk of mold or spoilage. Moisture content within the seed is a critical factor in determining storage stability. Grain with moisture content at or below 14% is considered dry and suitable for short-term storage. However, for long-term storage, such as storage exceeding six months, it's recommended to reduce the grain moisture content to less than 12%. This lower moisture content helps prevent mold growth and maintains grain quality during storage. By following these harvesting and storage practices, farmers can ensure optimal yield, quality, and storability of pearl millet grain, thereby maximizing the returns on their harvest.

5.8 Contingency Planning:

Deep ploughing during the summer season is a crucial agricultural practice for conserving in-situ rainwater, especially in regions with heavy soils of Maharashtra, Tamil Nadu, Andhra Pradesh, Karnataka, and Eastern Rajasthan. In regions receiving less than 400 mm of annual rainfall, implementing wider row spacing is a crucial agricultural practice, especially a row spacing of 60 cm can be beneficial.

In regions with late onset of monsoon and low annual rainfall, adopting suitable intercropping system and selecting early maturing hybrids or composite varieties of pearl millet can optimize crop yields and resource use. Make the crop weed free by timely weeding. Commencement of dry spell just after sowing result to re-sowing bajra in between the existing row or practice relay cropping with short duration oilseed or pulse crops. Continued dry spell during the grand growth phase result to reduce number of plants per unit area to the extent of 25 to 40% and spray 2% urea instead of top-dressing.

Providing complementary irrigation during critical growth stages, especially if drought condition prevail, can significantly impact crop survival and yield. For pearl millet and other crops, this approach can be particularly crucial during the pre-flowering to grain setting stage. Under conditions of excessive rain during the vegetative phase of crop growth, applying a supplemental dose of 20 kg N/ha can help mitigate potential nitrogen leaching and support optimal plant development.

5.9 Disease Management:

Table 5.7: Disease Management

Disease	Infection	Symptoms	Management
Downy mildew or green ear disease (*Sclerospora graminicola)*	Transfer by oospores on seed or mycelium of seed embryo	Downy growth on lower leaf surface, wrinkled and split leaves, profuse tillering, ears either not produced or abnormal ear which transferred into twisted leafy structure	Use of hybrid and composite varieties, seed treatment with Apron 35D @ 8 g/kg seed
Ergot (*Claviceps fusiformis*)	Sclerotia produce ascospores which become air-borne and infect floret, secondary infection through rain/insect. More infection in high humidity and at 20-25^{o}C temperature	Small droplets of pinkish or light honey-like fluid exuding from infected spikelet of ear, which later dried and become hard	Use of 10% salt solution to remove sclerotia. Use a mixture of ziram 2 g/litre (0.1%) + benlate (0.1%)
Smut (*Tolyposporium penicillariae*)	Primary infection through chlamydospores	Grains are replaced by powdery material, initially, these are green later become dark black that causes secondary infection	Spray Vitavax or lantavax 0.25% on panicle at booting stage
Rust (*Puccinia penniseti*)	Alternate host - brinjal	Appears on both side of leaves, uredinial & telial stages on pearl millet while spermagonial & aecial stage on brinjal occurs, orange-colored spores which later turns black	Zineb 0.2% or mancozeb 75 WP spray. Remove alternate host

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)

5.10 Insect Management:

Table 5.8: Insect Management

Insect	Description	Management
Shoot fly (*Atherigona approximate*)	Pest of North India, attack up to 3-week plant, lays eggs singly on either lower side of leaf or base of plant, cut the apical point results in 'dead heart', cut off panicles	Early planting. Two dusting of 5% malathion @ 25 kg/ha at 10 & 20 DAS
White grub (*Holotrachia* sp.)	Feed on roots of young seedling results in wilting-like appearance, maximum damage in July-August	Intercropping with legumes. Seed treatment with chlorpyriphos 20 EC @ 12.5 ml/kg seed. Soil treatment with phorate 10 G 12 kg/ha
Grain midge (*Geromyia penniseti*)	Attack on developing grains, lays egg in flower, grain-less glumes with white purple case on the tip of spikelet	Spray metacid 250 cc orthiodan 625 cc
Termite (*Odontotermis obesus*)	Serious in dry areas, feed on roots and lower stem portion	Irrigation, use well-decomposed FYM

Source: AICRP on Pearl millet (http://www.aicpmip.res.in as on 25-02-2016)

Yield:

With improved cultural practices it is possible to harvest nearly 30-35 quintals of grain and about 100 quintals of dry Stover from a hectare of crop under irrigated conditions and about 12-15 quintals of grain and 70-75 quintals of dry Stover from a rainfed crop.

5.11 Reference:

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