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2. Biofertilizers Application on Millet Production

Abstract:

The book chapter delves into the multifaceted aspects of millet production, focusing on the application of bio fertilizers, the impact of processing on millet grains' antioxidant activity, and the intricacies of fertilizer and nutrient management to optimize yield. Millets exhibit a positive response to fertilizer application, particularly to nitrogen and phosphorous. The judicious utilization of organic and inorganic manures enhances fertilizer efficiency. The chapter emphasizes the need for applying the entire P_2O_5 and K_2O at sowing, while nitrogen is best applied in 2 or 3 split doses.

Additionally, it explores the potential of treating millet seeds with bio fertilizers to further augment yield. An essential aspect covered is the detailed procedure for inoculating millet seeds with bio fertilizers. The recommended approach involves using a culture specifically tailored for the crop at a rate of 25g/kg of seed. To ensure effective seed inoculation, a sticker solution is deemed necessary. This solution is prepared by dissolving 25g of jaggery or sugar in 250ml of water, followed by boiling for 5 minutes and subsequent cooling. The seeds are meticulously smeared with the sticker solution, and the culture is then added and thoroughly mixed to achieve a fine coating on the seed. To prevent clumping, the culture-coated seeds are dried in shade. The chapter concludes by advocating for the use of these inoculated seeds for sowing, offering practical insights into enhancing millet production through bio fertilizers application and proper seed treatment techniques.

Keywords:

Bio fertilizers, Antioxidant activity, Nutrient Management, Organic and Inorganic Manures.

2.1 Introduction:

Bio fertilizers are products that contain living or dormant microorganisms, such as bacteria, fungi, *actinomycetes*, and algae. They help fix atmospheric nitrogen, solubilize and/or mobilize complex compounds in soil, and secrete substances that promote plant growth. Even though bio fertilizer is used as a term that refers to various types of materials such as composts, agro-waste, and some liquid cultures containing unidentified microorganisms, specifically works by colonizing the rhizosphere or the interior of the plant, which promotes growth by improving the supply or availability of primary nutrients to the host plant. It stimulates plant growth and development by enhancing the rate of nutrient release into the soil. It has been widely known that although plant growth-promoting rhizobacteria (PGPR) enhance plant growth and development by producing phytohormones, they are not all bio fertilizers (Basu *et al*., 2021). However, some PGPR can promote growth by acting as both a bio fertilizer and a bio enhancer. Bio fertilizers should be also taken into consideration as modernized forms of organic fertilizers that contain organic compounds such as green manure, manure, intercrop, or organic-supplemented chemical fertilizer.

Bio fertilizers are environmentally friendly and excessive use does not cause pollution, unlike inorganic fertilizers that can run off into water resources and cause eutrophication. Bio fertilizers act as a soil conditioner that adds organic matter to the soil, which helps to bind soil particles together. This, in turn, prevents soil erosion, desertification, and soil eruption, and increases the water retention capacity of the soil. Cultures of specific microorganisms are selected *in vitro* for bio fertilizer production to fulfill specific plant nutrient requirements. For this purpose, many bacterial genera such as *Azotobacter*, *Bacillus*, *Klebsiella*, *Enterobacter*, *Arthrobacter*, *Burkholderia*, *Pseudomonas*, *Rhizobium*, *and Serratia* are mostly used. In bio fertilizer applications, microbial formulations can be made according to the problem in the soil and the properties of bacterial and/or fungal species.

Bio fertilizers generally include nitrogen-fixing bacteria (*Rhizobium*, *Azotobacter*, *Azospirillum*, *Clostridium*, and *Acetobacter*) and photosynthetic. Besides phosphorus solubilizing and/or mobilizing bio fertilizers include phosphate-solubilizing bacteria (PSB) such as *Bacillus*, *Pseudomonas*, and *Aspergillus*. Mycorrhizae are nutrient-mobilizing fungi, also known as vesicular-carbuncular mycorrhiza (VAM), and direct phosphorus, zinc, and sulfur into the plant root system (Mitra *et al*., 2023). Moreover, bio fertilizers also include PGPR which either serve as bio-protectants, bio-fertilizers, or bio-stimulants.

They do not provide nutrients however they increase plant growth and performance. Involved microorganisms also function in long duration causing improvement of the soil fertility. This technique can boost crop yield by 20-30% while decreasing the need for chemical fertilizers (Shah and Wu, 2019). It also promotes plant growth and maintains the natural soil habitat. Additionally, it can protect against drought and certain soil-borne diseases, leading to more sustainable farming practices. Millets are annual warm-weather crops that belong to the Poaceae (Gramineae) family. With a rising population, there is an ever-growing demand and a search for alternative food grains. It is generally known that *Azotobacter* bio fertilizer increases yields of wheat, maize, cotton, and mustard by up to 30% and reduces the required chemical fertilizer amount for maize and millet by 50% without reducing yield.

Inoculating nitrogen-fixing (*Pseudomonas fluorescens*, *Azotobacter chroococcum*, *Azospirillum lipoferum*, *Acetobacter diazotrophicus*, *Trichoderma viride*) and phosphate solubilizing microorganisms (*Bacillus megaterium*), separately or in combination; improves the plant height, dry weight, grain quality, nitrogen uptake, and phosphorus uptake significantly in pearl millet (Gite *et al*., 2021). Besides, pearl millet and sorghum inoculated with *Azotobacter* or *Azospirillum* showed an increase of 11-12% in yield.

The effects of bio fertilizers containing *Azotobacter vinelandi* and *Rhizobium phaseoli* on the germination of Dansalka and Bahaushe millet (*Pennisetum glaucum* L. Br.) varieties (Aamir *et al*., 2020). Three working concentrations of 10, 15, and 20ml/l were obtained from each bio fertilizer. The highest germination rate was recorded after 2 days in 20ml/l treatment resulting in 63% for Dansalka and 53% for Bahaushe in *Azotobacter*, and 67% for Dansalka and 57% for Bahaushe in *Rhizobium*. There was no germination in control after 2 days. After 6 days 100% germination was observed in all concentrations of *Azotobacter* while control was 87%. Although the germination was 93% and 90% in 10ml/l for Bahausheand Dansalkain *Rhizobium*, respectively, the germination rate was 100% in 15 and 20 ml/l. The control had 87% final germination inboth bio fertilizers.

Figure 2.1: A Sustainable Technology for Recycling Nutrients and Promoting Environmental Friendliness.

2.2 Impact of Processing on Millet Grains' Antioxidant Activity:

The quantity and activity of the antioxidants in millet grains were also discovered to be impacted by processing techniques such as malting, decortication, soaking, and boiling. In one study, finger millet was malted for 96 hours, and the antioxidant capacity of the fraction carrying free phenolic acids rose (2-fold), while the antioxidant capacity of the fraction holding bound phenolic acids was decreased (Sunil *et al*., 2024). In another study, a growth-promoting medium was created to increase the production of a water-soluble protein from germinated millet that is inhibitory of hydroxyl radicals. The single-factor test showed that H_2O_2 is essential for inhibitory activity. Additionally, the effects of the sprouting conditions (temperature, duration, and pH of stress media) on the hydroxyl radical inhibition were examined in order to further boost the yield of the water-soluble protein that inhibits hydroxyl radicals from stress-germinated millet. The ideal parameters were found to be pH 7.5 in the stress medium, a culture duration of 54 hours, and a temperature of 28◦C. The maximum inhibition (60.38%) was attained under ideal circumstances. Additionally, 3 days of foxtail millet germination allowed researchers to produce flour with a strong DPPH-scavenging activity. Millet-derived bioactive compounds found in millet, such as antioxidants, fibers, and micronutrients, contribute to the potential health benefits associated with the consumption of millet-based products (Samtiya *et al*., 2023). The exploration of millet-derived bio actives holds promise for applications in nutrition, functional foods, and pharmaceuticals, showcasing the diverse health-enhancing properties of this resilient and nutritious grain in Figure 2.2.

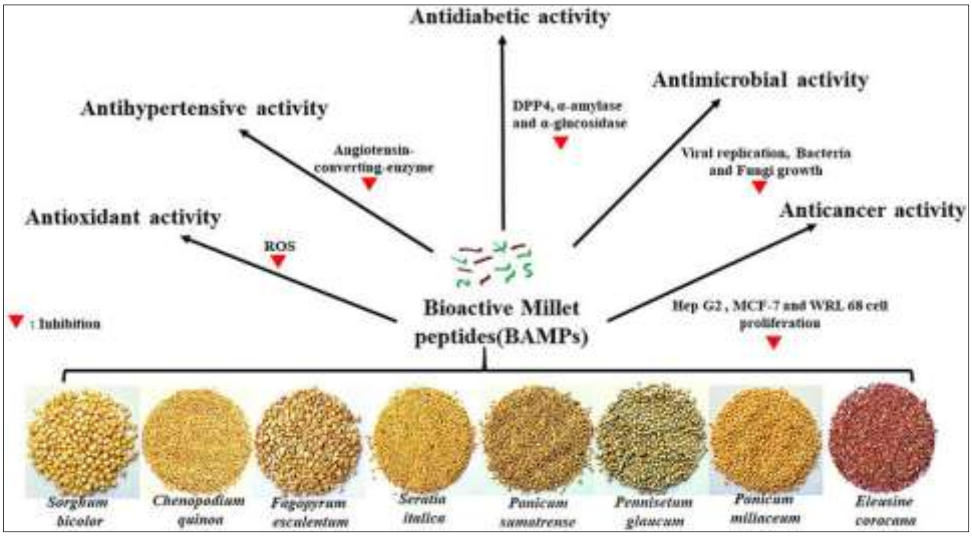

Figure 2.2: Bioactive Millets Peptides and Its Different Properties in Heath. (Source: Majid and Priyadarshini, 2020).

The antioxidant activity of Kodo or finger millet decreased after roasting or boiling. Kodo millet's DPPH quenching activity was likewise reduced by fractionating it into husk and endosperm, and the phytochemicals appeared to work synergistically with one another (Singh *et al*., 2023). The impact of germination, steaming, and roasting on the antioxidant qualities of little millet was also examined. The outcomes revealed that the total phenolic, flavonoid, and tannin levels of little millet increased by 21.2, 25.5, and 18.9 mg/100 g, respectively, over the original sample. Dehulling and hydrothermal treatments, however, were discovered to have an impact on the phenolic content and antioxidant potential of pearl millet grains (Snehal and Neena, 2018). Due to oxidation and degradation of chemicals that occur during heat treatments like cooking, boiling, and roasting, antioxidant levels and activity have decreased. However, the removal of the pericarp layer from the grains, which is known to be high in polyphenol and antioxidant chemicals, can be blamed for the decline that resulted from dehulling. As a result, millet grains, their fractions, and food products must be processed under ideal circumstances to preserve their quality and possible health advantages.

This is a result of the absence of cutting-edge millet processing technologies that can produce safe, easy-to-handle, ready-to-cook or ready-to-eat goods and meals on a big scale that can be utilized to feed numerous people in metropolitan areas. Nevertheless, as the world's population grows, so do the demands for food, fuel, and other basic necessities. As a result, society will be under pressure to either change its current crop consumption habits or increase agricultural production. Along with increased yields, crop diversification must also be promoted at the national and household levels. One crucial element of therapeutic dietary modification and encouraging consumption of minor-grain foods is the provision of more traditional and nutritious whole-grain and multigrain alternatives for refined carbohydrates. The role of gluten protein in generating high-quality, manageable baked goods and other grain-based dishes that demand elastic and extensible dough is well established.

2.3 Policy Recommendations:

India is the largest producer of millets in the world. The area and production of millets in India grew with compound annual growth rates (CAGR) of (-) 1.87% and (-) 0.13%, respectively in the period 1960- 61 to 2021-22. Instability in area, production and yield of millets has been computed using coefficients of variation. Maximum variability is observed in the case of yield (47.85%) for bajra followed by area (31.48%) and production (13.54%) of millets in the study period (Sajeev and Kundapura, 2023). While millets are gaining popularity among consumers, the actual consumption is not increasing (12.6 kg/capita availability in 2021-22), and supply can't match it if large sections start consuming millets. Hence, we need two-pronged strategies to manage supply and demand-side issues. A few important suggestions culled out from the Conclave on Millet Challenge and other sources have been presented below:

A. Promoting Consumption:

- Awareness campaigns involving celebrities and on the lines of those used for eggs in 1980s- 'Sunday Ho Ya Monday Roz Khao Ande
- Serving millet-based food and snacks on flights and premium trains
- Include millets in flagship schemes of the B. Improving the Production and Promoting Value Chains

B. Improving the Production and Promoting Value Chains:

- Enhancing the production base of millets.
- Varietal improvement to enhance yield and profitability.
- Government should introduce millets flour in the rations to soldiers and as well as officers because millets have the benefit of being a good source of protein, micro nutrients and phyto-chemicals thus boosting the nutritional profile of a soldier's diet.

C. Other General Suggestions:

There is a need for concerted efforts to sensitize farmers to shift towards more remunerative but less water guzzling crops, especially millets

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D. Fertilizer/Nutrient Management:

- Millets respond well to fertilizer application especially to nitrogen and phosphorous.
- Judicious use of organic and inorganic manures enhances the fertilizer efficiency.

- Entire $P_2O_5$and K_2O should be applied at sowing, whereas nitrogen should be applied in 2 or 3 split doses.
- Along with fertilizers seeds of the millets can also be treated with bio-fertilizers to enhance yield.

Millets vary with respect to the recommended fertilizers and the required information is provided in Table 2.1.

Table 2.1: Recommended Fertilizer Dose and Bio-Fertilizer Strain for Different Millets

Millet	Dose of Nutrients (N: P: K) (Kg ha^{-1})	Fertilizer (kg/ ha)				Bio-fertilizer strain
		As Basal dose			Top Dress	
		Urea	DAP	Potash	Urea	
Pearl millet	40:20:0	26.5	43.4	0.0	*43.4*	*Azospirillum* and PSB
Sorghum	60:30:20	39.7	65.1	33.4	65.1	--
Finger millet	40:20:20	26.5	43.4	33.4	*43.4*	*Azospirillum brasilense Aspergillus awamori*
Foxtail millet	20:20:0	4.8	43.4	0.0	21.7	-
Barnyard millet	20:20:0	4.8	43.4	0.0	21.7	*Agrobacterium radio-bacter*and *Aspergillus awamori*
Little millet	20:20:0	4.8	43.4	0.0	21.7	*Agrobacterium radio-bacter* and *Aspergillus awamori*
Proso millet	20:20:0	4.8	43.4	0.0	21.7	-
Kodo millet	40:20:20	26.5	43.4	33.4	*43.4*	-
Brown top millet	20:20:0	4.8	43.4	0.0	21.7	-

E. Procedure for Inoculating Seeds with Bio-Fertilizers:

Bio-fertilizer culture-specific to the crop is to be used @ 25g/kg of seed. Sticker solution is necessary for effective seed inoculation (Chapke *et al*., 2018). This can be prepared by dissolving 25 g jaggery or sugar in 250 ml water and boiling for 5 minutes.

The solution thus, prepared is cooled. Smear the seeds well using the required quantity of sticker solution. Then add culture to the seeds and mix thoroughly so as to get a fine coating of culture on the seed.

F. Irrigation Management/Water Management:

Millets are grown as rain fed crop and do not require any irrigation. However, based on the availability of water one life saving irrigation at critical stages of growth i.e. tillering, flowering and grain development stage needs to be given. Summer crop requires 2–5 irrigations depending upon soil type and climatic conditions. Nitrogen in a standard fertilizer was replaced with organic fertilizer at application levels of 0, 25, 50, 75, and 100%, with effects on crop yield, quality (appearance, taste, and nutritional value), and soil microbiome, assessed using field cultivation experiments. Our results indicate that partial replacement of conventional fertilizers with organic fertilizers improved both yield and quality. Specifically, the 75% replacement significantly improved the appearance (yellow pigment content and grain diameter) and taste (amylose content and soluble sugar content) of foxtail millet, while the 50% replacement significantly improved the taste (gel consistency) and nutritional qualities (crude protein content and seven amino acids' content) in figure 2.3. The 50% replacement of organic fertilizer regulated amino acid content more significantly than starch content (Gao *et al*., 2020). Increased ratios of organic fertilizer significantly reduced the soil pH by 0.03–0.36 and increased the relative abundance of Chloroflexi as well as that of Basidiomycota and Cercozoa in the soil microbiome (Han *et al*., 2023).

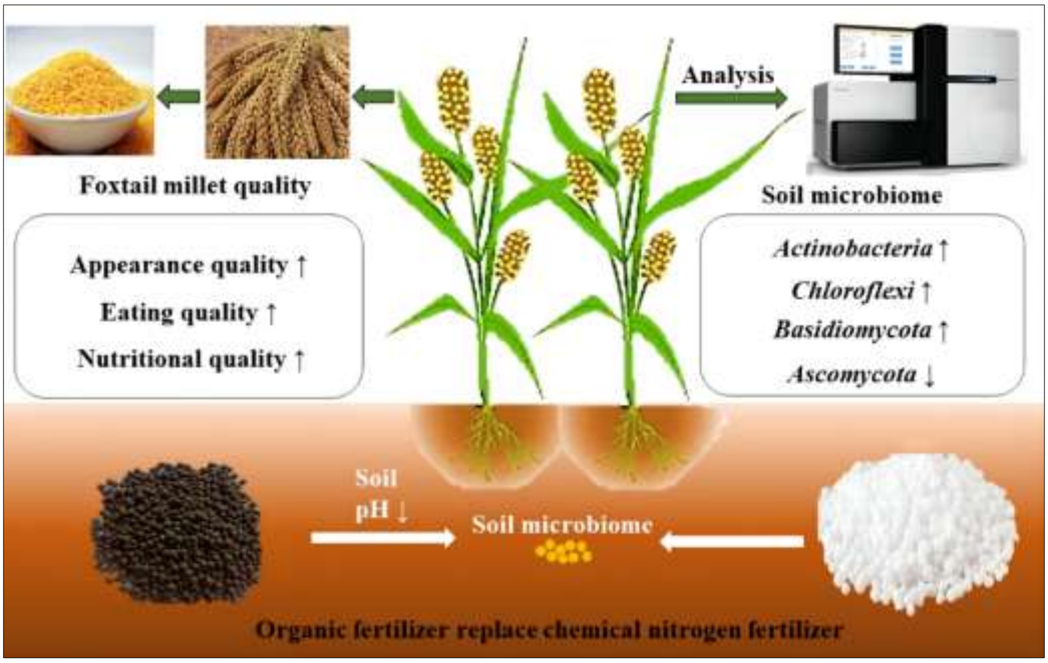

Figure 2.3: Soil Microbiome after Replacing Chemical Nitrogen Fertilizers with Organic Fertilizers

2.4 Cropping Systems:

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

- Millet + Black gram/green gram/cowpea
- Millet + Sesamum/soybean/pigeon pea
- Millet + pigeon pea
- Millet - Oats
- Millets - Wheat

Harvesting and Threshing: Harvesting at appropriate time is necessary to avoid shattering and post-harvest losses. In general, most of the millets are ready for harvest in 70–150 days after sowing depending on the crop and variety (Table 2.2).

Table 2.2: Harvesting and Yield for Millets

Millet	Harvestings	Yield (q/ha)
Pearl millet	The best stage to harvest pearl millet is when a black spot at the bottom of the grain is observed.	Grain-23-35 q/ha, Fodder-100-120 q/ha, Under Irrigated condition. Grain-12-15 q/ha, Fodder-70-75 q/ha, under rain fed condition.
Sorghum	*Kharif* sorghum should be harvested immediately after it reaches normal maturity. The panicles are harvested first and remaining plants later.	35-40 q/ha(grain) and 110-120q/ha (green fodder)
Finger millet	The crop matures in about 95 to 110 days in case of early varieties and 115 to 125 days in case of medium to late duration varieties.	25-30q/ha (grain) and 60-70 q/ha(fodder)
Foxtail millet	The crop matures in 80-100 days depending on the variety. The crop is harvested when the ear-heads are dry, either by cutting the whole plant by sickle or the ears separately.	20-25q/ha (grain) and 30-40q/ha (Straw).
Barnyard millet	The crop should be harvested when the panicle dries. It is cut from the ground level with the help of sickles and stacked in the field for about a week.	Grain yield of 12-15 q/ha and Straw: 20-25 q/ha can be obtained
Little millet	September-Oct	Grain yield is 15-20 q/ha and Straw 20-25 q/ha.
Proso millet	The crop should be harvested when about two thirds of seeds are matured. Crop is threshed with hand or bullocks.	10-15 q/ha grain and 30-40 q/ha of fresh straw per ha under rain fed condition

Millet	Harvestings	Yield (q/ha)
Kodo millet	Ready to harvest in September to October	15-18 q/ha grain and 30-40 q/ha straw per ha.
Brown top millet	The crop should be harvested when about two-thirds of seeds are matured. Crop is threshed with hand or bullocks	17 to 20 q/ha grain yield and 40-42 q/ha fodder yield

2.5 Conclusion:

Millets were shown to offer a significant potential to improve food and nutritional security. Millets should therefore be added to the list of staple foods together with wheat and rice. Millets may grow well in adverse conditions like drought, and some wild varieties can even thrive in wetlands and populated areas. These contain gluten-free protein, low glycemic index carbohydrates, an abundance of minerals (such as calcium, iron, copper, magnesium, and others), B vitamins, and antioxidants. These exceptional qualities make them nutrient-dense and resistant to climate change crops. These can benefit the health of the community as a whole in addition to providing farmers with an additional source of revenue. As a result, research and development initiatives as well as the creation of policies are needed; some actions have already been done globally, particularly in India and some are required to be taken. Minor millets have received very little attention in the scientific community despite their great nutritional qualities and easy production method. They are frequently disregarded, leading to the term "orphan cereals" being used by scientists to describe them. However, in order to increase the micronutrients' bioavailability and raise the caliber of millet diets, new processing and preparation techniques are required. The bioavailability, metabolism, and health benefits of millet grains and their many components in humans require further study. The current nutrient deficiencies of protein, calcium, and iron in poor nations will be addressed by the inclusion of millet based foods in international, national, and state-level feeding programme.

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