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17. Bio Fortification of Millets

Doppalapudi Vijaya Rani

Ph. D. Research Scholar (ICAR),
Department of Agronomy,
Sardar Vallabhbhai Patel University of Agriculture & Technology,
Meerut, Uttar Pradesh.

Kaila Tara Meghana

Erasmus Mundus Scholar, IMSOGLO,
International Masters in Soil and Global Change,
University of Ghent,
Belgium, Austria, Germany.

Pemula Priyanka

Ph.D Scholar,
Department of Agronomy,
Junagadh Agriculture University,
Gujarat.

Sushmita Moi

Erasmus Mundus Scholar, IMSOGLO,
International Masters in Soil and Global Change,
University of Ghent,
Belgium, Austria, Germany.

Himanshu Thakur

J.R.F,
Department of Entomology,
CSK Himachal Pradesh Krishi Viswavidyalaya,
Himachal Pradesh.

Abstract:

In today's world, nutritional security is a crucial issue, particularly for millions of people who rely on a cereal-based diet that is deficient in micronutrients. Millets have emerged as a significant source of energy in the semi-arid regions and drought-prone areas of Asia and Africa, second only to cereals. Millets are recognized for their exceptional nutritional value, as they consist of high levels of proteins, vital amino acids, vitamins, and minerals. The HarvestPlus group recognized the significance of biofortification for millets and has released conventionally bred high-iron pearl millet in India to address iron deficiency. This approach has demonstrated the economic feasibility of biofortification as an effective tool to combat malnutrition caused by micronutrient deficiencies. Biofortification is a process *for improving the nutritional quality of crops through conventional breeding or genetic engineering. Millets have been biofortified to increase their iron, zinc, and vitamin A content, which can help alleviate micronutrient deficiencies. However, biofortification poses several challenges, including genetic uniformity, safety concerns, consumer acceptance, and cost. Therefore, future research and dissemination efforts should focus on addressing these challenges and promoting the sustainable production and distribution of biofortified millets.*

Keywords:

Biofortification, Millets, Micro nutrients, Nutrition security.

17.1 Introduction:

Biofortification: Biofortification or biological fortification refers to nutritionally enhanced food crops with increased bioavailability to the human population that are developed and grown using modern bio-technology techniques, conventional plant breeding, and agronomic practices.

From a broader perspective, biofortification aims to address malnutrition and hidden hunger, particularly for people who have limited access to a diverse and nutritious diet. Biofortification is a sustainable strategy for improving the nutritional quality of staple food crops, as no additional resources are required to apply this method. Hence biofortification is an innovative, sustainable, and cost-effective solution to address micronutrient deficiencies and malnutrition globally. By increasing the level of essential micronutrients in staple food crops, biofortification helps to enhance the nutritional status of populations, particularly those in low-income settings, ultimately contributing to a healthier and sustainable future.

History & Origin of Biofortification:

The term "biofortification" was first coined in 2001 by the HarvestPlus program, which is a global alliance of researchers and development partners that work together to improve the nutritional quality of staple food crops in developing countries. The HarvestPlus program was founded by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI) in consultation with the Consultative Group on International Agricultural Research (CGIAR).

By creating and promoting biofortified crops, the HarvestPlus program aims to address the problem of hidden hunger or micronutrient deficiency that affects more than two billion people worldwide. The program uses conventional plant breeding techniques to enhance the nutritional content of staple food crops such as maize, rice, wheat, beans, and sweet potatoes to provide more essential micronutrients such as iron, zinc, and Vitamin A.

Since their inception, the HarvestPlus program has collaborated with various national and international research organizations, universities, NGOs, policymakers, and farmers to scale up biofortification programs and promote the concept of biofortification globally.

Today, biofortification has become an established nutrition intervention strategy and a promising solution to reduce micronutrient malnutrition and improve the health and well-being of populations, particularly in low-income settings.

Millets: Millets are a group of small-seeded grasses that are widely grown and consumed in many parts of the world. They are known for their drought resistance, short growing season, and versatility in different culinary preparations. In recent years, there has been a renewed interest in millets due to their high nutritional content and health benefits.

Millets are an excellent source of dietary fiber, vitamins, minerals, and essential amino acids. They are also gluten-free, making them an ideal choice for people with gluten intolerance or celiac disease. In many parts of the world, millets have been an important staple food for centuries, particularly in regions where other grains such as wheat and rice cannot grow.

Millets are highly nutritious and are an excellent source of several essential nutrients such as: 1. Carbohydrates 2. Fiber, 3. Vitamins (vitamin B-complex, folate, and Vitamin E), 4. Minerals (Iron, phosphorus, magnesium, zinc, and calcium), 5. Protein Millets are rich in proteins and are especially high in methionine and cysteine, which are usually lacking in cereal grains, and 6. Antioxidant.

Figure 17.1: Types of millets

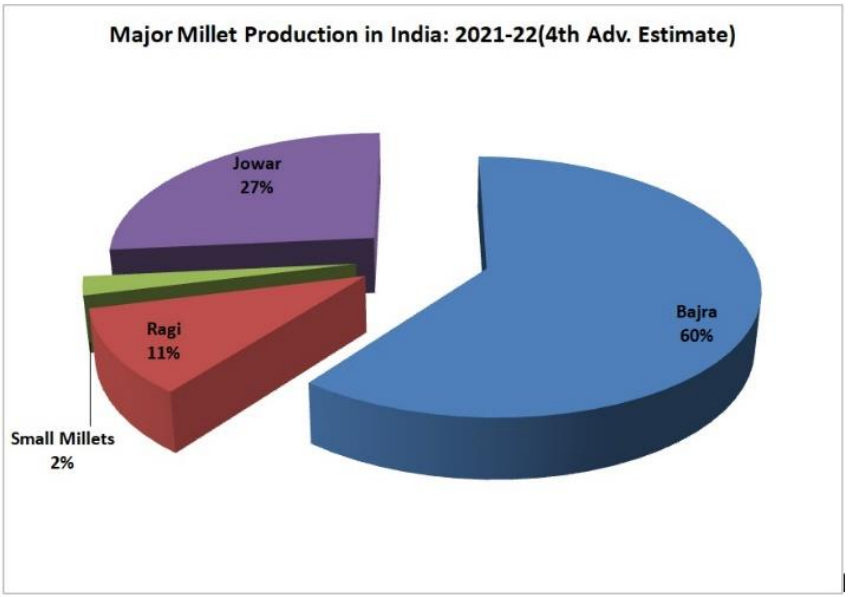

Figure 17.2: Major millet production in

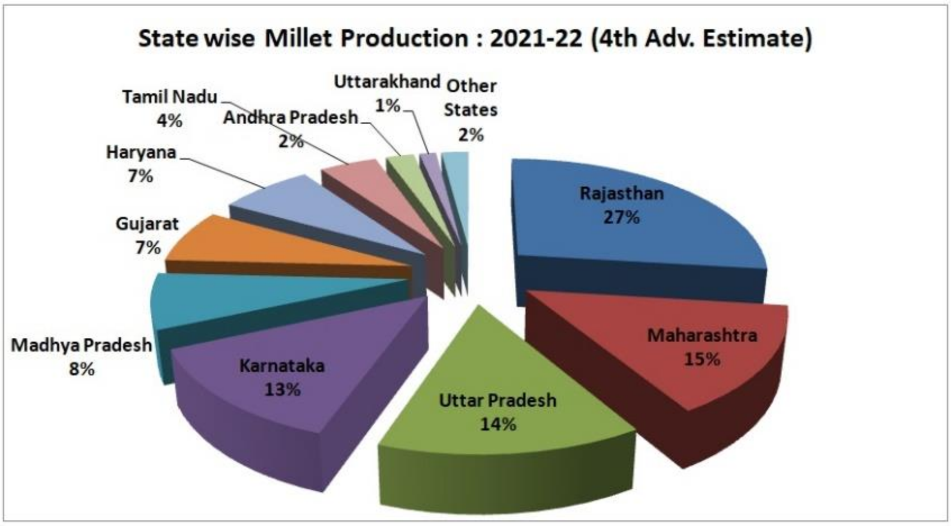

Figure 17.3: State Wise Millets Production

How does problem of micronutrients deficiency overcome by biofortification in millets ??

Micronutrient deficiencies, also referred to as hidden hunger, is a severe health problem that affects a large number of people globally, particularly in developing countries. Micronutrients, such as iron, zinc, and Vitamin A, are vital for good health and well-being, and their deficiency can lead to various health problems, including anemia, blindness, and stunted growth.

One solution to address micronutrient deficiencies is the concept of biofortification. Biofortification involves the breeding of crops to have higher levels of essential micronutrients, thus improving their nutritional quality. Biofortification has emerged as a cost-effective, sustainable, and viable solution to address hidden hunger, and it can significantly improve the nutritional quality of staple crops and improve the health and well-being of millions of people worldwide.

List of micronutrients that are commonly deficient in millets:

Micronutrient	Function	Deficiency symptoms
Iron	Formation of red blood cells, immune system support	Anemia, fatigue, weakness, impaired cognitive function
Zinc	Immune system support	Decreased growth and development, impaired immune function
Vitamin A	Eye health support	Vision impairment, impaired immune function
Vitamin B-complex	Energy production, immune system support	Weakness, fatigue, headaches, irritability, impaired cognitive function
Calcium	Bone and teeth health	Osteoporosis, weakened bones
Magnesium	Muscle and nerve’s function	Weakness, muscle cramps, twitching

It is important to note that the specific micronutrient content in millets can vary depending on the variety, and biofortification efforts are aimed at enhancing the micronutrient content.

17.2 Methods of Biofortification in Millets:

Several methods of biofortification in millets to have higher levels of micronutrients, including:

a. Conventional breeding: This method involves classical plant breeding techniques, such as crossbreeding, to select the best varieties of millets that have higher levels of micronutrients. Crossbreeding involves crossing plants that are rich in essential micronutrients with local, conventional varieties of millets to develop improved varieties that have higher levels of the desired micronutrients.
b. Marker-assisted selection: Marker-assisted selection is a breeding technique that involves the use of molecular markers to identify and select millet plants that have desired traits such as high levels of essential micronutrients.
c. Genetic engineering: Genetic engineering involves introducing specific genes that produce essential micronutrients into the millet genome. This method is still experimental, and its implementation is subject to rigorous testing and regulation.
d. Agronomic approaches: Agronomic approaches focus on improving soil fertility and crop management practices to increase the uptake and availability of essential micronutrients in the soil to improve the millet crop's nutritional quality.

e. Post-harvest interventions: Post-harvest interventions include processing techniques that improve the bioavailability of essential micronutrients in the millet crop. For example, fermentation can increase the availability of iron in millet and other cereals, thus improving their overall nutritional quality.

How does the above mentioned processes works to increase higher levels of micronutrients?

A. Conventional breeding process of biofortification works in by introducing or selecting genes that encode enzymes responsible for micronutrient synthesis or transport. For example, in millets, breeders can introduce or select genes that are responsible for the synthesis of phytase and phytase-like enzymes. These enzymes help to release essential micronutrients such as phosphorus, iron, and zinc in the digestive tract, making them more bioavailable for the body to absorb.

Using genetic markers and targeted breeding techniques, breeders can then isolate and propagate the millet plants, which have the desired properties, leading to a population with higher levels of the essential micronutrient.

Once the genetically improved crop has been developed, it can be propagated and planted in the same way as the original variety, providing farmers with improved, nutritionally rich crops.

Biofortified crops must undergo rigorous testing and regulation processes to ensure that they are safe for human consumption and that they retain the crop's desirable traits. Once the biofortified crop is approved, it is released to farmers, who can then grow the crop and sell it to markets.

B. Marker-assisted selection (MAS) is a process of selecting plants that have desirable traits, such as higher levels of essential micronutrients, using molecular markers. It is a type of genetic selection that enables breeders to select plants that have the desired traits without the need for lengthy and expensive phenotypic evaluations. Here is how marker-assisted selection works in the context of biofortification in millets.

The process of marker-assisted selection to have higher levels of micronutrients involves identifying and mapping the genes that are responsible for micronutrient levels in millets and selecting the plants that have these genes using DNA markers. Once the markers have been identified, breeders can use them to track the presence of the micronutrient genes throughout the breeding process.

Here is a step by step guide to how the process of marker-assisted selection works:

a. Identify molecular markers: The first step in marker-assisted selection is to identify molecular markers that are specific to the genes associated with the desired micronutrient, such as iron, zinc, and Vitamin A, in millet.
b. Develop breeding populations: Breeders then develop breeding populations that contain a large number of millet plants with diverse genetic backgrounds.

c. Genotyping: Using the molecular markers, breeders genotype the breeding population to determine the genetic makeup of each individual plant at the target gene's specific location.
d. Select plants: selecting the plants that have desirable genes that result in higher levels of micronutrients. The plants with favorable genotypes can then be selected for further breeding.
e. Breeding: The selected millet plants can now be crossed with other high-quality elite varieties to develop new varieties with high levels of the desired micronutrient.
f. Test new varieties: The newly developed millet varieties with higher levels of essential micronutrients can be tested in a field trial to confirm their nutritional values and performance.
g. Release biofortified millets: Once the new variety of biofortified millet has been successfully tested, it can be released to farmers and other stakeholders for cultivation and consumption.

C. Genetic engineering is a method of breeding crops to have higher levels of essential micronutrients, such as iron, zinc, and Vitamin A. The process of genetic engineering involves introducing or modifying specific genes into the crop genome to enhance the synthesis and accumulation of a particular micronutrient. Here is how the process of genetic engineering to have higher levels of micronutrients works:

a. Identifying specific genes: The first step is to identify specific genes responsible for the biosynthesis or accumulation of the desired micronutrient. This involves an understanding of the pathway of micronutrient synthesis and metabolism in the crop plant.
b. Isolation of genes: Once the specific genes have been identified, they are isolated from the donor organism. The source of these genes could be from the same or different plant species or even from other organisms such as bacteria.
c. Construction of a transformation vector: The isolated genes are then inserted into a transformation vector such as a plasmid, which is then introduced into the plant cells.
d. Transformation: Genetic transformation involves introducing the transformation vector carrying the desired genes into the plant cell using various techniques such as electroporation, biolistic bombardment, and Agrobacterium-mediated transformation.
e. Selection of transgenic plants: After genetic transformation, the plant cells are selected for successful integration of the desired genes. This selection is achieved by using antibiotic or herbicide resistance markers inserted into the transformation vector along with the desired transgenes.
f. Tissue culture and regeneration: Transformed plant cells are usually grown under tissue culture conditions to regenerate into whole plants.
g. Field testing: Genetically modified plants are then field tested to evaluate their micronutrient content and other agronomic traits.
h. Regulatory approvals: Once the field testing is completed, the genetically modified crop must be approved by the regulatory authorities and undergo rigorous safety and environmental impact assessments.

D. Agronomic biofortification through fertilizers works by adding specific fertilizers to the soil to increase the availability of essential micronutrients to the crops. Here's how it works:

a. Soil analysis: Soil analysis is conducted to determine the nutrient content, pH level, and any possible deficiencies that could affect the uptake of micronutrients by crops.
b. Identification of deficiency: Based on the soil analysis, the micronutrient that is deficient in the soil is identified.
c. Selection of fertilizers: Specific fertilizers containing the deficient micronutrient are then selected. For example, zinc and iron containing fertilizers are selected to address the deficiency of these micronutrients in the soil.
d. Application of fertilizers: The selected fertilizers are then applied to the soil at appropriate rates and times to ensure that the crops have sufficient access to the essential micronutrients.
e. Monitoring: Crops are monitored to ensure that they are absorbing the applied fertilizers properly and that the biochemical needs of the crop are met.
f. Harvesting: After the harvesting process, crops are checked for the presence and amount of the micronutrients specific to the fertilizer applied.

E. Post-harvest interventions refer to the processing and storage techniques that can be used to increase the bioavailability and concentration of essential micronutrients in millets after they have been harvested. Here are some of the post-harvest interventions that can be used to increase the micronutrient content in millets:

a. Fermentation: Fermentation is a process that can increase the bioavailability of micronutrients in millets. The fermentation process enhances the enzymatic activity, which increases the levels of micronutrients such as zinc and iron, making them more easily absorbed by the body.
b. Germination: Germination is another process that can increase the bioavailability of micronutrients in millets. During germination, enzymes become activated, which increases the bioavailable amounts of vitamins and minerals such as Vitamin A and iron.
c. Dehusking: Removing the hull or outer layer of the millet grain can increase the bioavailability of micronutrients. The hull is known to contain anti-nutritional factors that can reduce the bioavailability of nutrients in the millet grain.
d. Fortification: Fortification is a process where premixed powders containing vitamins and minerals, including essential micronutrients, are added to milled millet during processing to increase the nutrient content in the final product. The fortification process ensures that the micronutrients are present in the food in significant amounts, making them more accessible to the population.

17.3 Millets as Biofortified Crops:

Here is a list of millets and their nutritional content.

Please note that the figures below are approximate and may vary depending on the variety and cultivation methods:

A. Pearl Millet:

- Carbohydrates: 65g

- Protein: 11g
- Fat: 4g
- Fiber: 1g
- Vitamins: Thiamin (0.27mg), Niacin (2mg), Vitamin B6 (0.37mg), Folate (80mcg)
- Minerals: Calcium (37mg), Iron (2.8mg), Magnesium (114mg), Phosphorus (248mg), Potassium (280mg), Zinc (1.7mg)

B. Finger Millet:

- Carbohydrates: 72g
- Protein: 7g
- Fat: 1g
- Fiber: 3g
- Vitamins: Thiamin (0.33mg), Niacin (1.3mg), Vitamin B6 (0.13mg), Folate (44mcg)
- Minerals: Calcium (350mg), Iron (3.9mg), Magnesium (137mg), Phosphorus (287mg), Potassium (408mg), Zinc (2.2mg)

C. Foxtail millet:

- Carbohydrates: 60g
- Protein: 4g
- Fat: 1g
- Fiber: 2g
- Vitamins: Thiamin (0.19mg), Niacin (2.3mg), Vitamin B6 (0.08mg), Folate (19mcg)
- Minerals: Calcium (31mg), Iron (2.8mg), Magnesium (29mg), Phosphorus (216mg), Potassium (116mg), Zinc (0.9mg)

D. Barnyard Millet:

- Carbohydrates: 67g
- Protein: 10g
- Fat: 2g
- Fiber: 1g
- Vitamins: Thiamin (0.24mg), Niacin (5.2mg), Vitamin B6 (0.13mg), Folate (81mcg)
- Minerals: Calcium (11mg), Iron (6.3mg), Magnesium (99mg), Phosphorus (293mg), Potassium (195mg), Zinc (2.6mg)

E. Kodo Millet:

- Carbohydrates: 65g
- Protein: 8.3g
- Fat: 1.4g
- Fiber: 9.7g
- Vitamins: Thiamin (0.37mg), Niacin (1.8mg), Vitamin B6 (0.21mg), Folate (25mcg)
- Minerals: Calcium (35mg), Iron (1.7mg), Magnesium (37mg), Phosphorus (276mg), Potassium (143mg), Zinc (1.2mg)

F. Proso Millet:

- Carbohydrates: 77g
- Protein: 12g
- Fat: 2g
- Fiber: 7g
- Vitamins: Thiamin (0.33mg), Niacin (3mg), Vitamin B6 (0.35mg), Folate (23mcg)
- Minerals: Calcium (14mg), Iron (4.7mg), Magnesium (205mg), Phosphorus (333mg).

G. Little Millet:

Little Millet, also known as kutki, is a small-grained cereal that is similar in size to foxtail millet. It is a good source of dietary fiber, protein, and various essential minerals. Here are the approximate nutritional contents of little millet:

- Carbohydrates: 68g
- Protein: 7g
- Fat: 2g
- Fiber: 7g
- Vitamins: Thiamin (0.3mg), Niacin (2.3mg), Vitamin B6 (0.2mg), Folate (85mcg)
- Minerals: Calcium (17mg), Iron (9.3mg), Magnesium (116mg), Phosphorus (210mg), Potassium (207mg), Zinc (1.2mg)

H. Sorghum:

Carbohydrates: 75g

- Protein: 11g
- Fat: 3g
- Fiber: 3g
- Vitamins: Thiamin (0.4 mg), Niacin (2.5 mg), Vitamin B6 (0.4 mg), Folate (28 mcg), and Vitamin E (0.5 mg).
- Minerals: Calcium (28mg), Iron (4.2mg), Magnesium (127mg), Phosphorus (287mg), Potassium (350mg), and Zinc (2.7mg).

Sorghum is an excellent source of protein and carbohydrates, and it is also a rich source of essential minerals, especially iron, magnesium, and potassium, which are essential for vital organ functions. Additionally, sorghum is a good source of dietary fiber, which is important for maintaining digestive health and reducing the risk of heart disease and other chronic conditions.

17.4 Examples of Biofortified Millets:

a. Iron-biofortified Pearl Millet: This Pearl millet has been selectively bred to have higher levels of bioavailable iron. The iron-biofortified pearl millet was developed by ICRISAT and HarvestPlus, a public research program that aims to improve the nutritional content of staple crops. Iron-biofortified Pearl Millet has been shown to help combat iron-deficiency anemia, especially among women and children.

b. Zinc-biofortified Finger Millet: Finger Millet has been genetically modified to have higher levels of bioavailable zinc. The zinc-biofortified finger millet was developed by ICRISAT and HarvestPlus. Finger Millet is rich in calcium, iron, and fiber, and the biofortified version provides increased zinc intake, which is essential for optimal immune function, enhancing memory and learning capabilities, and for preventing diseases like diarrhea.

c. Provitamin A-biofortified Little Millet: Little Millet has been selectively bred to have higher levels of provitamin A carotenoids, which are important for vision and immune health. The provitamin A-b

Crop	Variety	Salient features
Pearl millet	HHB 299	Rich in Fe (73.0ppm), Zn (41.0 ppm)
	AHB 1200	Rich in Fe (73.0ppm)
	AHB 1269 Fe	Rich in Fe (91.0ppm), Zn (43.0 ppm)
	ABV 04	Rich in Fe (70.0ppm), Zn (63.0 ppm)
	RHB 233 (MH 2173)	High Fe (83ppm), Zn (46ppm)
	RHB 234 (MH 2174)	High Fe (84ppm), Zn (41 ppm)
	HHB 311 (MH 2179)	High Fe (83 ppm)
	Phule Mahashakti	Rich in Fe (87.0 ppm), Zn (41.0ppm)
Finger millet	Vegavathi (VR 929)	High content of Zn in grain (199.1%), high in Fe, Ca, Protein, dietary fibre & low in tannin content
	CFMV 1 (Indravathi)	Rich in Ca (428 mg/100g), Fe (58mg/kg) and Zn (44mg/kg)
	CFMV 2	Rich in protein (6.41%), Ca (654 mg/100g), Fe (39 mg/kg) and Zn (25 mg/kg)
Little millet	CLMV 1	Rich in protein (14.4%), Fe (59 mg/kg) and Zn (35 mg/kg)

Source: *www.icar.org* released on 16th October, 2020, New Delhi.

17.5 Challenges of Biofortification:

There are several potential challenges that could arise as a result of biofortification. Some of these challenges include:

- Genetic Uniformity: The development of biofortified millet varieties could lead to a loss of genetic diversity within the crop overall, which could threaten the long-term resilience of the crop to environmental changes.
- Safety Concerns: There is a possibility of unintended effects of the changed nutrient profile in the biofortified variety. Therefore, it is critical to ensure the safety of biofortified products before promoting their widespread adoption.

- Acceptance by Consumers: Different communities have different cultural preferences when it comes to food choices, and biofortification may not be accepted universally or be adopted by all communities. Hence it is essential to create awareness and generate demand through social marketing and promotion programs for biofortified food products.
- Cost: The costs of biofortification program implementation could be significant, including breeding, testing, and scaling-up of production, distribution, and marketing. This could make the biofortified millets more expensive and difficult for low-income and marginalized populations to access.

Assessment, monitoring, and evaluation are critical requirements to ensure the safety of bio-fortified products as well as the overall efficacy of implementing biofortification programs. It is also necessary to test for any potential negative impacts before launch, and evaluate the impacts of biofortification after launch.

To promote the adoption of biofortified millets, it is important to raise awareness among farmers and consumers by educating them on the nutritional benefits of these biofortified crops.

17.6 Summary & Conclusion:

Biofortification is a strategy that has proven to be effective in improving the nutritional content of food crops, and has been extended to improve the nutritional value of millets. Biofortification has resulted in new millet varieties with higher levels of iron, zinc, and vitamin A, which have proven effective in improving health outcomes in vulnerable populations. Biofortification of millets has the potential to address the triple burden of malnutrition, including undernutrition, obesity, and micronutrient deficiencies.

Future research and dissemination efforts should focus on addressing the challenges associated with biofortification, improving access and awareness among farmers and consumers, and promoting the sustainable production and distribution of biofortified millets.

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