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ENHANCING PULSE AGRO-BIODIVERSITY FOR IMPROVING FOOD SECURITY, NUTRITIONAL SECURITY AND ECONOMIC SUSTAINABILITY AMIDST CHANGING CLIMATE SCENARIO

Abstract

Pulses, as the world's largest producer in India's agriculture, significantly shape the nation's dietary patterns, serving as a primary protein source in predominantly vegetarian meals. With double the protein of wheat and triple that of rice, pulses contribute 20 to 25 percent protein content by weight. They serve various agricultural purposes, functioning as cover crops, components in cropping systems, and contributors to soil health and microbial diversity. Abundant in protein, dietary fiber, complex carbohydrates, vitamins, and essential minerals, pulses provide crucial nutrients for various bodily functions. In addition to being gluten-free with a low glycemic index, pulses address dietary restrictions and assist in weight management. However, global population growth, shifting dietary trends, technological advances, cultural shifts, and increased nutrition awareness amplify the complexity of providing balanced and nutritious diets. The rising demand for wholesome food raises concerns about sustainable solutions that preserve the planet's resources. Pulses emerge as a strategic solution, offering diverse phytochemicals with health-promoting properties. Moreover, pulses play a crucial role in mitigating climate change's impacts on agriculture. The promotion of agro-biodiversity, particularly with pulses, is identified as a viable strategy to enhance food security and economic stability amid these challenges. Recognizing pulse crops' vulnerability to environmental factors, the chapter explores

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potential harms posed by climate change and advocates for sustainable farming methods and climate-resilient agricultural practices, emphasizing the necessity for improved and biofortified pulse varieties.

Keywords: Pulse, Agro-Biodiversity, Food Security, Nutritional Security, Economic Sustainability, Climate Change.

I. INTRODUCTION

The word "pulse" has its origin in Latin. It comes from the Latin word "puls," which referred to a thick porridge or gruel made from various legumes or grains that were cooked and mashed. This Latin term was then borrowed into old French as "poulse" and eventually evolved into the English word "pulse." In culinary terms, "pulse" specifically refers that seeds/grains should be edible and belongs to leguminous family *viz.,* lentils, chickpeas, peas and involving all beans. These seeds/grains have been considered to be a significant and major source of multi -faceted nutrition for human and animals both. Moreover, they have been used in many preparations and served in ceremonies, which has historical and ancient evidence, because it has cheap source of high protein and it also comprises essential minerals and vitamins. Due to high protein content, pulses are a major food crop globally and locally, belonging to the family Fabaceae, the members of this family are also known as legumes, which are distinguished by their capacity to fix elemental atmospheric nitrogen into the soil. This indicates that they work in tandem with specific bacteria to convert atmospheric nitrogen into a form that plants can utilize. Leguminous plants produce edible seeds/ grains called pulses. In India, a number of important pulses, such as chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), green gram (*Vigna radiata*), black gram (*Vigna mungo*), lentil (*Lens esculenta*), pea (*Pisum sativum*), chikling pea/ khesari (*Lathyrus latifolius*), horse gram (*Macrotyloma uniflorum*), cowpea (*Vigna unguiculata*) and different types of beans are cultivated across various seasons and regions within our country (Table1), these legumes have a significant impact and contribution in fulfilling the nutritional requirements of the growing population.

Table 1: Pulses and their Growing Seasons

Growing Seasons	Pulses
Kharif	Pigeon pea, green gram, black gram, cowpea and horse gram
Rabi	Chickpea, lentil, pea, chikling pea and cowpea.
Summer	Green gram and black gram

The largest producer of pulses in the world is currently India, these are a vital group of crops in our nation that make up a sizable portion of exports and have a significant economic impact on the nation. These legumes are the chief sources of protein in the Indian diet, and they are crucial in primarily compensating Indian vegetarian carbohydrate-rich meals with the necessary protein. Pulses provide twice the protein of wheat and thrice times that of rice, with a protein content of 20 to 25 percent by weight. Numerous agricultural applications, including cover crops, component crop in cropping system, green manuring, thus restoring soil health and crop & microbial diversification are major contribution of legume crops in crop production system. Pulses are a superior plant-based source of protein, high in dietary fiber, a source of complex carbohydrates, a good source of a number of vitamins and they also contains essential minerals such as iron, magnesium, potassium, phosphorus and zinc. Magnesium and potassium are necessary for the proper operation of the muscles and nerves, while iron is crucial for the blood's ability to transport oxygen. Antioxidants found in it, such as flavonoids and polyphenols, help the body combat harmful free radicals and oxidative stress. Pulses are suitable for people with celiac disease or gluten sensitivity because they are naturally gluten-free. Generally speaking, it has a low glycemic index. Pulses can aid in promoting feelings of fullness and satiety because they are high in protein and fiber, which may also help with weight management

The challenge of feeding a growing global population with nutritious food is getting more difficult and demanding due to changing dietary habits, food preferences, technological developments in food processing, shifting cultural norms, and growing nutrition awareness (Changan *et al*., 2017). Finding sustainable solutions to meet the escalating demand for wholesome food in the future without depleting the planet's resources is the main issue at hand (Langyan *et al*., 2022). Due to the world's population shows rapid growth, it is becoming increasingly difficult to provide people with balanced diets with the necessary nutrients. The addition of pulses to the human diet is one way to address these issues while delivering crucial nutritional and physiological advantages. Pulses contain a diverse range of beneficial phytochemicals, such as phenolics, flavonoids, phytates, tannins, lectins, oxalates, peptides, saponins, phytosterols, and enzyme inhibitors, all of which contribute to the health-promoting properties. These phytochemicals have anti-inflammatory, ulcerative, anti-microbial, and anti-cancerous properties, among others.

The effects of climate change have been more pronounced over the past few years, affecting many facets of society, especially agriculture, which is particularly vulnerable. Conventional farming practices are facing significant difficulties as a result of increasing global temperatures, an increase in extreme weather events, and changing rainfall patterns. There has been an increase in interest in promoting diversity among pulse crops to combat the detrimental effects of climate change on food security and economic stability.

Agro-biodiversity with a pulse has been identified as a potential tactic to address the problems caused by climate change. Beans, lentils, chickpeas, and other pulse crops have special qualities that make them valuable in sustainable agriculture. Their nutritional value as well as their ability to adapt to various agro-ecological conditions makes them important in reducing the effects of climate change and promoting agricultural sustainability. Given how it has impacted agricultural systems around the world, climate change has in fact posed significant challenges to the quality and production of pulses. Due to their sensitivity to temperature, water availability, mineral content, pest disease incidence, and other environmental factors, pulses are particularly susceptible to the effects of climate change. Here are a few ways that pulses could be harmed by climate change. To overcome the challenges that climate change poses to pulse production, it is necessary to adopt sustainable farming methods, create improved pulse varieties that are more tolerant of temperature and water stress, and adopt climate-resilient agricultural practices. To ensure food security and sustainable agriculture, policymakers and governments must also put into action strategies to reduce ill effect of climate change and aid farmers in adapting to it.

The importance of pulses in global food systems and diets is emphasized in this chapter. Pulses are a powerhouse of health and vitality, and bio-fortification for major pulses is being investigated as a means of improving nutrition for global health. We explore the importance of pulse-specific food composition databases, consider how different processing methods affect the nutritional value of pulses, and present a number of strategies to enhance their overall nutritional profile.

II. IMPORTANCE OF PULSES IN GLOBAL FOOD SYSTEMS AND DIETS

Pulses can be a key component of our diets, which can be crucial in addressing the current food-related issues. Utilizing these nutrient-dense sources can help us make better food decisions and work towards a more sustainable food future. According to the United Nations World Population Division, 2017, the world's population has increased by two billion people over the past 25 years, and predictions indicate that it will continue to rise to 8.5 billion by 2030 and 9.8 billion by 2050. According to projections, India's population is expected to reach 1.515 billion by 2030 and further increase to 1.668 billion by 2050 (Outlook, 2023). In order to meet the growing demand for pulses and the dietary needs of both the Indian and global populations, it is necessary to increase food grain production. The total area devoted to pulses increased slightly between 2013–14 and 2021–22. However, 2016–17 saw the highest growth rates in both area and production, with an impressive 18% increase in area and a significant 42% increase in production over the previous year (2015-16). The highest area of 31.24 million hectares and the highest production of 27.75 million metric tons during 2021–22 (based on the 3rd Advanced Estimate) reflect the consistency of this positive trend. Additionally, this production level represented the highest figures for area and production in the previous eight years. Additionally, an impressive 888 kg ha^{-1} of productivity during 2021–22 was noted. The productivity of pulses has significantly increased over time, going from 764 kg ha^{-1} (2013–2014) to 888 kg ha^{-1} (2021–2022) illustrated in table 2.

Table 2: Contribution of Pulses to Food Grains Basket
{Area- Million ha, Production- Million Tons, Yield- kg ha^{-1}}

Year	Pulses			Food grains			Pulses share food grain production (%)	
	Area	Production	Yield	Area	Production	Yield	Area	Production
2013-14	25.22	19.26	764.00	125.05	265.05	2120.00	20	7
2014-15	23.55	17.15	728.00	124.30	252.03	2028.00	19	7
2015-16	24.91	16.32	655.00	123.22	251.54	2041.00	20	6
2016-17	29.45	23.13	786.00	129.23	275.11	2129.00	23	8
2017-18	29.81	25.42	853.00	127.01	285.01	2235.00	23	9
2018-19	29.16	22.08	757.00	124.78	285.21	2286.00	23	8
2019-20	27.99	23.03	823.00	126.99	297.50	2343.00	22	8
2020-21	28.78	25.46	885.00	129.80	310.74	2394.00	22	8

Source: DES, Ministry of Agri. &FW (DA&FW), Govt. of India.

The total area planted with pulses increased gradually and slightly between the agricultural years 2013–14 and 2021–22. However, the year 2016–17 saw the highest growth rates in both area and production, with a remarkable 18% increase in area and a significant 42% increase in production over the year before, 2015–16. This upward trend has been consistently maintained, and in 2021–22, both area and production will reach new highs.

With a staggering productivity of 888 kg ha^{-1}, the highest area of 31.24 million hectares and production of 27.75 million tons were accomplished. This marks the highest recorded figures for both area and production in the past 8 years shown in table 3.

Over the period from 2013-14 to 2021-22, there were variations in yearly growth rates for area, production, and productivity in the agricultural sector. Notably, the year 2016-17 saw substantial growth in all three aspects, with the area expanding by 18%, production increasing by 42%, and productivity rising by 20%. Conversely, some years experienced negative growth rates, like 2014-15, which witnessed a decrease of 7% in area, 11% in production, and 5% in productivity. Despite these fluctuations, the agricultural sector displayed resilience, as demonstrated by positive growth in various years, including a notable increase of 9% in both area and production in 2021-22. However, productivity growth was more subdued during this period, with a modest increase of 0.40% in the same year, illustrated in figure 1 and table3.

Table 3: Yearly Growth Rate of Total Pulse

(Area-Million ha, Production- Million tones, yield-kg ha^{-1}, Growth Rate -%)

Year	Area	Yearly growth rate	Production	Yearly growth rate	Yield	Yearly growth rate
2013-14	25.21		19.25		764.00	
2014-15	23.54	-7.00	17.51	-11.00	728.00	-5.00
2015-16	24.91	6.00	16.32	-5.00	655.00	-10.00
2016-17	29.44	18.00	23.12	42.00	785.00	20.00
2017-18	29.81	1.00	25.41	10.00	852.00	9.00
2018-19	29.15	-2.00	22.07	-13.00	757.00	-11.00
2019-20	27.98	-4.00	23.02	4.00	823.00	9.00
2020-21	28.78	3.00	25.46	11.00	885.00	8.00
2021-22	31.24	9.00	27.75	9.00	888.00	0.40
CAGR	0.03		0.05		0.02	

Source: *DES, Min. of Agri. & FW, GOI, (DA&FW). 2021-22* - II^rd^ Adv. Estimates.*

Note: *YGR – Yearly Growth Rate over the Previous Year; CAGR- Compound Annual Growth Rate.*

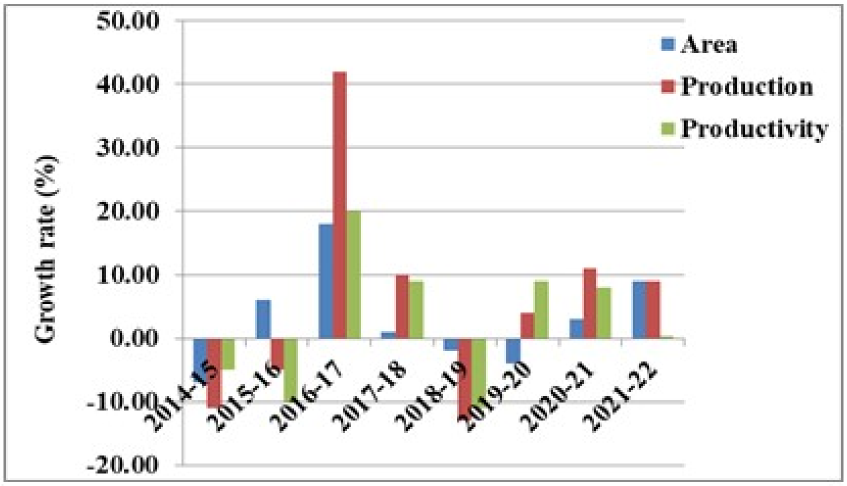

Figure 1: Yearly Growth Rate of Area Production Productivity of Pulse Crops

Since methodologies and assumptions have varied across studies, estimates for the demand for pulses in India have been inconsistent. For instance, Narayanmoorthy (2000) predicted that by 2030, there would be a total demand for 27.45 million tons of pulses. The Indian Institute of Pulses Research (IIPR) in Kanpur, on the other hand, predicted that the nation's pulse demand would reach 39 million tons by 2050 (table 4), necessitating a 2.2% annual growth rate in production (IIPR, 2015). It is crucial to implement more efficient crop-production technologies in order to meet this expanding demand and keep domestic production competitive. Additionally, encouraging policies and market support are essential in encouraging farmers to plant more pulses. By implementing these steps, the nation can successfully meet the rising demand for pulses and provide for the nutritional security of its population, particularly those who follow vegetarian diets (Ahlawat *et al.,* 2016).

Table 4: Projected Demand of Pulses in India by Different Studies

Reported by	Year of Projections	Demand (Million Tonnes)
Narayanmoorthy (2000)	2030	27.45
Mittal (2008)	2026	57.70
Singh (2013)	2020	23.21
Ganeshkumar et al. (2012)	2026	20.80
IIPR (2015)	2050	39.00

Source: *Ahlawat et al., 2016*

The percentage of people who are undernourished has decreased from 23.3% to 12.9% of the global population thanks to international efforts to fulfill the UN's Millennium Development Goals. Nevertheless, despite these efforts, malnutrition still affects more than 800 million people globally (UNICEF and World Health Organization, 2017). The 2030 Agenda's Sustainable Development Goals (SDGs) include the second goal of achieving Zero Hunger, which aims to end both hunger and poverty by that year. Currently, an estimated 2.3

billion people lack regular access to balanced, nutrient-rich diets, and 720–811 million people are thought to be chronically malnourished. A further 70–161 million people are now facing hunger as a result of the recent pandemic. About one-third of the world's population suffers from malnutrition in one form or another. Both undernourishments, the main sign of hunger, and stunting, which refers to being young-for-age, are common. Obesity, overweight, and micronutrient deficiencies are also serious issues. One-third of women who are childbearing age have anemia, and 22% of kids under the age of five have stunted growth (UNDP, 2022). Furthermore, between 2001 and 2011, significant growth was seen in South Pacific and Asian countries, where middle-class families now make up at least 13% of the world's population (Pew, 2017). Undernourished and lacking in vital micronutrients during pregnancy, expectant mothers may experience difficulties such as intrauterine growth restriction, low birth weights, protein-energy malnutrition, persistent energy deficiencies, and elevated risks of maternal and neonatal mortality (Alae-Carew *et al.,* 2019).

Environmental costs associated with food production systems include deforestation, land degradation, biodiversity loss, habitat loss, resource depletion, and contamination of soil, air, and water (IPBES, 2018). For instance, according to UNICEF and the World Health Organization (2017), food systems are in charge of about one-fourth of all anthropogenic greenhouse gas emissions and about 70% of all freshwaters used in agricultural production. Pesticides, synthetic fertilizers, and hormones used in animal husbandry are used in agricultural practices that contaminate and pollute terrestrial and marine ecosystems and food supplies, posing serious health risks. (Landrigan *et al*., 2018). The ability to achieve sustainable and wholesome food production for future generations are further hampered by several unsustainable practices and escalating competition for water, land, and energy.

Pulses are essential in the effort to provide accessible, healthy diets at minimal environmental cost. Throughout the world, pulses and legumes like soybeans, chickpeas, lentils, peanuts, peas, and beans are commonly used as both human food and animal feed. These crops provide a variety of nutritional, agronomic, and environmental advantages, such as increasing soil organic matter, encouraging crop rotation, and lowering the need for mineral fertilizers, which reduces greenhouse gas emissions (Singh *et al*., 2021). Pulses are regarded as a nutritious food choice that is high in protein and can help lower the risk of heart disease and stroke (Mandal *et al.,* 2020). Because of climate change on agricultural production, the world food system is currently experiencing difficulties. Climate change can have an impact on food security and production, especially in developing nations. Pulse intercropping systems have been identified to improve farming's climate resilience (Guntukula, 2020). When eaten in place of dairy and meat, pulses also help to promote dietary diversity and ease the strain on natural resources and agricultural land. Despite the health benefits and environmental advantages of pulses, factors like the destruction of traditional and indigenous food crops, climate change, and shifting dietary habits have had an impact on their production and availability. Major pulses can be grown, consumed, and bio-fortified to help address nutritional deficiencies and increase food security (Singh *et al*., 2021).

III. PULSE IS A POWERHOUSE OF HEALTH AND VITALITY

Pulses provide a variety of essential nutrients, including vitamins and minerals. They contribute around 55-60% of total carbohydrates, which encompass starch, soluble sugars, fiber, and carbohydrates that aren't readily available. These nutritious seeds are rich in calcium, magnesium, zinc, iron, potassium, and phosphorus (Table 5). Additionally, pulses contain minor quantities of carotene, a precursor to vitamin A and vitamins B like folate, thiamin, and niacin are however, the nutritional content can vary among different types of pulses (Table 5). In general, the nutritional values of pulses are roughly as follows: crude protein (21-25%), carbohydrates (60-65%), moisture (10%), and lipids (1-1.5%). Lentils, cowpeas, and chickpeas can be consumed in quantities of 100–200 gm. to meet daily mineral needs, while most dietary legumes can be consumed in quantities of 100 gm. to meet daily iron needs. Beans and other pulses are also rich sources of folic acid and pantothenate, two types of vitamin B. Vitamins like riboflavin, niacin, thiamin, folate, and the precursor to vitamin A are all abundant in chickpeas. They do, however, also contain some anti-nutritional elements (Jukanti *et al.*, 2012). Protein, carbohydrates, soluble and insoluble fiber, as well as vital minerals like iron, zinc, manganese, phosphorus, and potassium, are all abundant in cowpeas. Despite being low in lipids, it has a high unsaturated fatty acid profile (Frota *et al.*, 2008). Pigeon pea seeds contain fiber in one-third of the seed coat, protein in the embryo, and carbohydrates in the cotyledons. They could, however, also include anti-nutritional components like oligosaccharides, polyphenols, and enzyme inhibitors (Saxena *et al.*, 2010).

Table 5: Nutritive Value of Pulses (Per 100g)

Pulses	Energy (Kcals)	Protein (g)	Fat (g)	Mineral (g)	Carbohydrate (g)	Fiber (g)	Calcium (mg)	Phosphorous (mg)	Iron (mg)
Chick pea	360.00	17.00	5.00	3.00	4.00	4.00	202.00	312.00	5.00
Pigeon pea	335.00	22.00	2.00	3.00	58.00	1.00	73.00	304.00	3.00
Lentil	343.00	25.00	1.00	2.00	59.00	1.00	69.00	293.00	7.00
Green gram	334.00	24.00	1.00	3.00	4.00	4.00	124.00	326.00	4.00
Black gram	347.00	24.00	1.00	3.00	1.00	1.00	154.00	385.00	4.00
Khesari	345.00	28.00	1.00	2.00	57.00	2.00	90.00	317.00	6.00
Horse gram	321.00	22.00	0.00	3.00	5.00	5.00	287.00	311.00	7.00
Cow pea	323.00	24.00	1.00	3.00	3.00	4.00	77.00	414.00	9.00
Field bean	347.00	25.00	1.00	3.00	1.00	1.00	60.00	433.00	3.00
Peas	315.00	20.00	1.00	2.00	56.00	4.00	75.00	298.00	7.00
Rajmah	346.00	23.00	1.00	3.00	61.00	5	260.00	410.00	5.00
Moth beans	330.00	24.00	1.00	3.00	56.00	4.00	202.00	230.00	9.00

Source: TNAU Agritech Portal

IV. HARMFUL COMPONENTS FOUND IN PULSES

The seeds of pulses encompass both consumable and non-consumable varieties. Even among the legumes suitable for consumption, there exist toxic components that must be eliminated to render them safe for eating. Two vulnerable elements contribute to these toxic effects. Enzyme inhibitors such as trypsin, chymotrypsin, and amylase inhibitors hinder the absorption of digested products in the gastrointestinal tract. Furthermore, legumes also harbor detrimental substances including haemagglutinins, which are substances impeding nutrient absorption, as well as goitrogens, toxic saponins, cyanogenic glycosides, and alkaloids.

V. REMOVAL OF HARMFUL COMPOUNDS FROM PULSES

The reduction or elimination of most toxic compounds in pulses can be achieved through methods like soaking in 0.5% $NaHCO_3$ for 18 hours, heating at 121°C or15 psi for 30 minutes, and fermentation. Applying the appropriate cooking techniques to pulses effectively eradicates harmful elements without compromising their nutritional content. Additionally, cooking enhances the digestibility of pulses. Heat induces changes in the protein structure, leading to the deactivation of proteins responsible for trypsin inhibition, hemagglutination, and the enzyme that triggers the breakdown of cyanogenic glycosides. The manner in which heat is applied plays a crucial role. Methods such as autoclaving and a combination of soaking followed by heating have proven to be effective. Another effective approach for detoxification is fermentation, which results in products that are not only more digestible but also boast higher nutritional value compared to raw pulses.

Chickpeas are one example of a food that contains anti-nutritional elements that can hinder the digestion and absorption of nutrients. However, by using processing techniques like soaking, germination, blanching, and boiling, these anti-nutritional elements, such as tannins, phytates, proteolytic enzyme inhibitors, and trypsin inhibitor activity, can be diminished or eliminated. By enhancing the protein digestibility and increasing the bioavailability of minerals like zinc and iron, these techniques help improve the nutritional quality of chickpeas. Similarly, when consumed, oligosaccharides like stachyose and raffinose found in dry beans can cause flatulence. However, these oligosaccharides can be effectively reduced by cooking the beans at high temperatures (121°C or 15 psi) for 30 minutes or soaking them in a solution containing 0.5% $NaHCO_3$ for 18 hours. This makes the beans easier to digest and less likely to cause flatulence.

Soaking *Lathyrus sativus* seeds in boiled water, tamarind, or alkaline solutions is an effective method to eliminate the neurotoxin β-N-Oxalyl-L-α, β-diamino propionic acid present in the seeds. However, it is essential to standardize the duration and time of these processing approaches to ensure proper toxin removal (FAO, 2016). To increase the amount of low glycemic-resistant starch in plant-based foods, various processing methods have been used, especially in whole pulse flours like black bean, chickpea, broad bean, and lentil. Annealing hydrothermal treatments and heat moisture treatment are two frequently employed methods (Chávez-Murillo *et al.,* 2018).

The resistant starch and slow-digesting starch fractions in pulses have been found to be improved by these processing techniques. The molecular bond between proteins and starch is strengthened because of the hydrothermal treatments' promotion of an improvement in protein degradation *in vitro*. As a result, there are more resistant starch fractions (Magrini *et al.,* 2018). The regulation of both protein and starch digestion depends on the molecular interaction between starch and protein. Thermal treatments improve this interaction, enhancing the pulses' nutritional and practical benefits. These modified pulses with more resistant starch are better suited for consumption by those with diabetes or those trying to control their blood sugar levels because they have lower glycemic index values. Additionally, the increased resistant starch content may also have positive effects on metabolism, satiety, and gut health.

VI. IMPROVEMENT OF THE NUTRITIONAL PROFILE OF PULSES THROUGH BIOFORTIFICATION

The method of enhancing the concentration of essential minerals or micronutrients in edible parts of food crops, in a reliable and cost-effective manner, is commonly referred to as biofortification (Kaur *et al*., 2020).

Although the nutritional value of pulses is well known, it can be further increased through biofortification, a practical and affordable technology designed to raise the concentration of vital micronutrients in crops. To create better varieties of pulse crops, biofortification uses a variety of techniques like traditional breeding, population mapping, and genetic selection. Despite the potential advantages, less effort has been put into biofortifying pulses and legumes than has been done with other staple crops like rice, wheat, and maize. However, it is imperative to implement biofortification in a variety of pulses, such as lentils, field peas and chickpeas, to address global health issues caused by micronutrient deficiencies. This entails enriching these crops with easily assimilated types of micronutrients like iron, zinc, selenium, and iodine, which can significantly improve nutrition and lower deficiency rates among vulnerable populations.

In the past, agriculture has mainly concentrated on boosting crop yield and productivity without taking human health issues seriously enough. The agricultural industry is now moving towards growing nutrient-dense crops in sufficient quantities to improve the nutritional value of food. We can successfully combat "hidden hunger" brought on by micronutrient malnutrition by implementing biofortification in pulses, which are already abundant in crucial nutrients, and ensuring food security. With the potential to significantly improve human health and nutrition, biofortification offers a practical way to meet nutritional needs. This strategy is especially important for addressing nutritional deficiencies in underdeveloped and impoverished countries. Consuming biofortified staple crops on a regular basis will help combat hidden hunger and ensure food security, improving overall health (Sellamuthu and Malathi, 2021). Various approaches can be employed for biofortification and enhancing the nutritional content of pulses (Figure- 2).

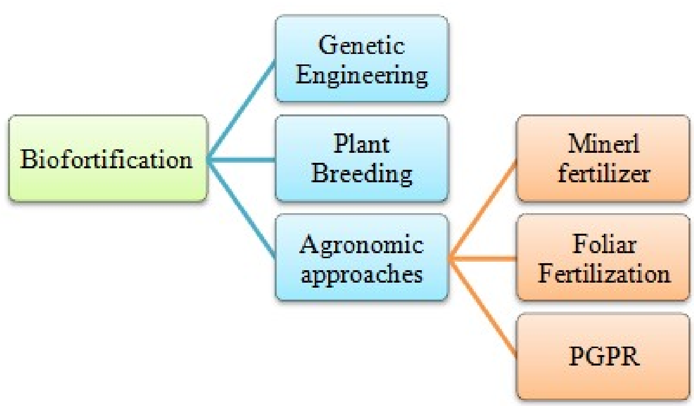

Figure 2: Approaches of Biofortification for Improvement of Nutritional Profile

1. **Genetic Engineering:** Genetic engineering represents the most recent technological advancement in the arsenal of biofortification strategies aimed at addressing deficient mineral nutrients in targeted crops. This approach leverages advanced biotechnological tools to introduce foreign genes carrying traits related to deficient micronutrients into the crop (Singh *et al*., 2016). As of now, genes implicated in enhancing essential micronutrients like Fe, Zn, Se, as well as proteins and provitamins in plants have been identified. The genetic engineering methodology is considered a sustainable means to tackle hunger and malnutrition by utilizing genes associated with diverse metabolic processes in plants. Additionally, genes from bacteria and other microorganisms can also be isolated and integrated using this approach (Hefferon, 2016).

   The nutritional profiles of pulse crops can be improved through genetic engineering, particularly when the desired traits are absent from the germplasm naturally or cannot be developed through conventional breeding. Transgenic crops engineered to possess a substantial concentration of micronutrients offer a tangible solution for ensuring both nutritional and food security. This is achieved by facilitating the accumulation of essential micronutrients in the grains. While genetic engineering approaches have been utilized for nutrient profiling in pulse crops, specific examples of biofortification involving Fe, Zn, Se, I, and β-carotene through this method are lacking. However, in the context of other nutrient enhancements, this strategy has been employed in pulse crops. For instance, through the incorporation of the methionine-rich storage albumin gene from the Brazil nut (*Bertholletia excelsa*), transgenic common bean and lupin crops have been developed. This resulted in a significant increase in methionine content, reaching up to 94%, by introducing the sunflower (*Helianthus annuus*) seed albumin gene expression (Jha and Warkentin, 2020). To accomplish these objectives, genes from various plant species, bacteria, or other organisms can be inserted. Genetic engineering has been successfully applied to pulse crops to enhance other nutritional properties as well. For instance, the essential amino acid methionine concentration in transgenic common bean plants significantly increased (up to 23%) after the introduction of a gene for a methionine-rich storage albumin from the Brazil nut. Similar to this, transgenic lupins' methionine concentration increased by up to 94% as a result of the expression of the sunflower seed albumin gene (Dhaliwal *et al*., 2022).

   This novel approach holds the potential to revolutionize the scientific community's ability to create biofortified pulse crops with multiple nutrients, such as Fe, Zn, and β-carotene, in a single step (Straeten *et al*., 2020). Similarly, ongoing research into metal transporters like zinc-regulated transporter (ZRT)/iron-regulated transporter (IRT)-like proteins, P1B-ATPases, cation diffusion facilitators (CDFs), and natural resistance-associated macrophage proteins (NRAMPs) presents a promising avenue for future developments. These metal transporters, involved in the transportation of essential elements like Fe, Zn, and Mn, hold considerable potential for engineered biofortification in pulse crops (Kumar *et al*., 2016).

   When conventional breeding methods are insufficient, genetic engineering offers a potent tool to improve the nutritional value of pulse crops. It permits the targeted enhancement of particular micronutrients and the potential removal of anti-nutrients, which improves the nutritional quality of pulse crops and may be advantageous to a large population, especially in areas with nutritional deficiencies.

2. **Plant Breeding:** Biofortification through plant breeding offers a sustainable method for enhancing the nutritional content of essential food crops. Given that a significant portion of the global population relies on staple food crops, addressing the deficiency of vital micronutrients in these crops becomes crucial. Over the last ten years, biofortification has gained prominence in various breeding initiatives, particularly for pulse crops. The primary focus has been on improving the levels of critical micronutrients such as iron, zinc, selenium, iodine, carotenoids, and folates. Notably, the significance of biofortification in pulse crops has grown substantially, prompting numerous breeding programs to incorporate this approach. Harvest Plus, in collaboration with international partners and focusing on developing countries, has taken a lead role in this endeavor. This effort has yielded positive outcomes in the form of biofortified pulse crops, including but not limited to common beans and lentils. These newly developed crops have been specifically tailored to address the issue of micronutrient deficiency within the target populations. In essence, the introduction of biofortified pulse crops represents a noteworthy advancement in combating nutritional deficiencies among communities heavily reliant on staple foods. By enhancing the micronutrient content of commonly consumed crops, this approach contributes to a healthier and more nourished global population, particularly in regions where such deficiencies are prevalent (Ambuj and Thomas, 2020).

   Plant breeding, which focuses on creating improved varieties with desirable traits, is essential to the production of pulses. Here are a few significant ways plant breeding has helped the production of pulses. Plant breeding for pulse crops aims to combine beneficial traits from various parent plants to produce new and improved varieties. The process of breeding, which includes selection, recombination, rigorous testing, and subsequent cycles of refinement, demands a substantial investment of financial resources, time, and expertise to achieve successful outcomes. The objective is to create varieties with desirable traits, like the right phenology, an effective plant type, a higher yield, and better nutritional value. While conventional plant breeding techniques have produced more than 3700 improved pulse crop varieties worldwide, they have not produced the significant genetic gains required to close the supply-demand gap. A limited genetic base and significant environmental and genotype-environment interactions in multi-location environment trials (MET) have both been noted as difficulties by studies. These elements have made selection less effective and lengthened the breeding cycle. Modern tools and techniques are crucial to overcoming these obstacles and accelerating genetic advancements in pulse crops to meet the demands of a growing population. These incorporate improved experimental design, effective data management, sophisticated statistical analysis, and the digitalization and mechanization of breeding and testing pipelines. They also include advanced phenotyping and genotyping techniques. Researchers can improve their capacity to create high-yielding, disease-resistant, and nutritionally superior varieties of pulse crops by incorporating these contemporary approaches into pulse crop breeding programmes. As a result, farmers will be able to meet the growing demand for pulses and contribute to global food security (Kumar *et al.,* 2020).

The development of early maturing and high-yielding genotypes, especially in pulses like pigeon pea and green gram, has played a significant role in diversifying cropping systems and boosting agricultural productivity in India. This shift towards non-conventional cropping systems holds great promise for enhancing food security and economic returns for farmers. n India, the dominant cropping system has been cereal-cereal based, aimed at increasing food productivity. To fit well into multiple cropping systems and crop rotations, the key characteristic of any genotype is early maturity. Early maturing pigeon pea varieties were introduced in crop development programs to address this need. Srivastava *et al.* (2012) worked on developing elite x elite crosses in pigeon pea, focusing on improving traits like test weight, grain yield, and early maturity. One of the challenges associated with pigeon pea is its thermos/photo sensitivity. However, this issue has been addressed by the development of super-early lines, such as the two extra short duration green gram genotypes by IIPR, Kanpur. These genotypes mature in just 45 to 48 days during summer and *Kharif* seasons and have also shown resistance against mungbean yellow mosaic India virus. New genotypes like IPM 409-4 and IPM 205-7 have a maturity period of 47 days, compared to the 60 days taken by the check variety PDM 139. This 13-day advantage in maturity contributes to their promising economic returns from pulses and has the potential to replace upland paddy in non-conventional cropping systems.

Plant breeding stands as an alternative strategy to enhance the nutritional content of pulses while simultaneously maintaining high yield and desirable agricultural characteristics. In this process, germplasm is screened for genetic diversity, micronutrient-dense germplasm is developed and evaluated, genetic research is done, and molecular markers are made to speed up breeding. For populations, including those in rural areas with limited access to fortified foods, traditional plant breeding techniques are especially advantageous. Plant breeding requires an initial investment, but once improved germplasm is created, farmers can propagate and grow it over time with little additional expense. Recurring costs are reasonably low, and germplasm can be obtained from different parts of the world. (Shahzad *et al*., 2021). Through screening programs, various innovative and wonder biofortified cultivars of lentils have been identified and released under Harvest Plus Programme in India like Pusa Vaibhav contain around 102 ppm of iron (Fe), while L-4704 offers an increased Fe content of 125 ppm along with 74 ppm of zinc (Zn). Another cultivar, IPL-220, presents a variable Fe range of 73 to 114 ppm and a Zn range of 51 to 64 ppm. Additionally, Pusa ageti masoor showcases a Fe content of 65 ppm (Ghosh *et al*., 2019). Cowpea varieties, such as Pant Lobia-1, Pant Lobia-2, Pant Lobia-3, and Pant Lobia-4, have been developed in India with a focus on higher iron (Fe) content (Garg *et al*., 2018). Lentil's biofortified cultivar Pusa Ageti Masoor has been introduced in India, also with an emphasis on increased iron (Fe) content (Yadava *et al*., 2017).

Initially, high iron-dense accessions served as the fundamental building blocks for commencing crosses. These accessions were combined to impart the high-mineral attribute while maintaining satisfactory quality and characteristics (Andersson *et al*., 2017). The concept of genotypes-environment interaction (G × E) is employed to pinpoint suitable accessions or breeding lines that consistently demonstrated reliable mineral uptake across various locations and generations (Blair *et al*., 2010).

VII. AGRONOMIC APPROACHES

Agronomic bio fortification shows promise as a means to address micronutrient deficiencies and hidden hunger by enhancing the nutritional content of staple crops. However, more research is needed to establish a direct link between improved crop nutrition and enhanced human health. In the meantime, integrating micronutrient fertilizers with other soil fertility management practices can optimize the effectiveness of this approach. Ultimately, a combination of agronomic and genetic bio fortification approaches may be the most sustainable strategy to tackle hidden hunger in Indian subcontinents.

The prevalence of micronutrient deficiencies, also known as 'hidden hunger,' is a significant issue among the population in Indian subcontinents due to unbalanced diets based on starchy staple crops. This review examines the potential of agronomic bio fortification, which involves applying mineral micronutrient fertilizers to soils or plant leaves to increase the micronutrient content in edible parts of crops, as a strategy to combat hidden hunger. Although there is evidence supporting the effectiveness of agronomic bio fortification in increasing crop yields and improving the nutritional quality of staple crops, there is a lack of direct evidence linking these improvements to enhanced human health.

To achieve the best results, micronutrient fertilization is most effective when combined with Nitrogen, Phosphorus, and Potassium (NPK) fertilizers, organic fertilizers, and improved crop varieties. This emphasizes the importance of integrated soil fertility management. Agronomic bio fortification offers a quick and efficient method of increasing micronutrient concentrations in edible crops. However, in the long run, genetic bio fortification may prove to be a more cost-effective approach.

1. **Enhancing Crop Productivity Through New Cropping Systems, Intercropping, and Crop Diversification:** In recent years, farmers have been able to switch from the conventional cereal-cereal cropping system to the more advantageous rice-chickpea system thanks to the introduction of early maturing chickpea varieties, which are suitable for planting until mid-December and have a high yield potential of 15-20 quintals per hectare. The tail end of the command areas in eastern Uttar Pradesh and Bihar are where this shift is most obvious. A similar pattern has also been noticed in the upland areas of Punjab, Haryana, and western Uttar Pradesh. Due to the advantages provided by early maturing chickpea varieties, which can be sown later in the season and still produce significant yields, farmers in these regions are also implementing the rice-chickpea system. The rice-chickpea system has shown to be a more advantageous choice for farmers in these areas because it offers better crop diversification, increased yields, and overall agricultural sustainability. These early maturing chickpea varieties, which have gained popularity among growers looking to increase their agricultural productivity and income, are what's causing this change in cropping patterns. They're widely available and have a good track record of yielding good results.

   In a number of Indian states, including Maharashtra, Uttar Pradesh, Madhya Pradesh, Karnataka, and Gujarat, pigeon pea is an important crop. The pigeon pea-wheat cropping system has gained popularity as a promising agricultural technique in the irrigated areas of northern and central India. In irrigated areas of western Uttar Pradesh, Punjab, Haryana, Delhi, and North-East Rajasthan, the introduction of short-duration pigeon pea varieties, such as UPAS 120, Manak, ICPL 151, and Pusa 992 that mature within 120–160 days has facilitated their integration into the current rice-wheat cropping systems. Pigeon peas can be added to the wheat rotation to increase land use effectiveness and boost overall agricultural productivity. These short-duration pigeon pea varieties allow farmers to maximize their yields within a relatively short period, making it feasible to include pigeon pea in the cropping system alongside rice and wheat. The pigeon pea-wheat system offers several benefits, including better crop diversification, reduced risk of pest and disease buildup, and improved soil health through nitrogen fixation by pigeon pea. This cropping system has shown great promise in the irrigated regions mentioned, contributing to sustainable and profitable agricultural practices in those areas.

Although *rabi* urdbean and mungbean cultivation in South India's coastal regions has a long history, it didn't really take off until genotypes resistant to powdery mildew were created. The late 1980s saw the development of varieties with high yield potential and resistance to powdery mildew, including LBG 17, LBG 402, LBG 611, and LBG 22. The cultivation of urd beans and mung beans has undergone a revolution thanks to these resistant varieties, especially in Andhra Pradesh's rice-fallow regions. In rice fallow areas, the use of these powdery mildew resistant genotypes has led to a highly productive and reliable cropping system. Additionally, this system has helped to improve soil health. Due to its success in Andhra Pradesh, the same cropping system is now being widely practiced in other states like Odisha, Tamil Nadu, and Karnataka. In addition to increasing the productivity of the urdbean and mungbean crops, the use of resistant varieties has also lessened the effects of the powdery mildew disease, resulting in more dependable and higher yields. This cropping method is now a viable and profitable choice. The crop sequence of mungbean/urdbean - mustard/barley is significant in the rainfed regions of north-western India, including Punjab, Haryana, Western Uttar Pradesh, Rajasthan, Himachal Pradesh, and Jammu & Kashmir. In contrast, farmers rotate their crops in irrigated areas using the rotations maize-potato-mustard-mungbean/urdbean and maize-wheat-mungbean/urdbean. Moving towards the eastern parts of India, such as Uttar Pradesh, Bihar, West Bengal, Orissa, and Assam, the rainfed conditions favor the rotation of maize-horse gram. Under irrigated conditions in these regions, the cropping system shifts to maize-wheat-mungbean/urdbean.

Farmers use a variety of cropping sequences under rainfed conditions in the central Indian states of Madhya Pradesh, Gujarat, and Maharashtra, including urdbean-wheat, mungbean-sorghum, cowpea/urdbean/mungbean-safflower, and mungbean-niger. These areas use the maize-wheat-summer cowpea and maize-wheat-summer urdbean/mungbean farming practises. Farmers frequently follow the crop sequences of cowpea-finger millets, mungbean-sorghum/safflower, and rice-mungbean/urdbean/cowpea in the rainfed regions of South India, including Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala. However, rice-rice-mungbean/urdbean/cowpea is the most common cropping system when there is irrigation. These various cropping sequences can help farmers maximize their agricultural output while taking into account the availability of water resources and other environmental factors because they are tailored to the unique agro-climatic conditions of each region.

To diversify cropping systems and increase agricultural productivity in India, early maturing and high-yielding genotypes, particularly in pulses like pigeon pea and green gram have been developed. This move towards unconventional cropping systems has a lot of potential to improve farmer income and food security. The primary cropping system in India has been a cereal-based one that aims to boost food productivity. The most important trait of any genotype is early maturity, which allows it to adapt well to a variety of cropping systems and crop rotations. To meet this need, crop development programmes introduced early maturing pigeon pea varieties. Srivastava *et al.* (2012) focused on enhancing traits like test weight, grain yield, and early maturity when creating elite x elite crosses for pigeon pea. Pigeon pea's thermos/photo sensitivity is one of its difficulties. The development of super-early lines, such as the two extra short duration green gram genotypes by IIPR, Kanpur, have, however, addressed this issue. These genotypes exhibit resistance to the mungbean yellow mosaic India virus and reach maturity in just 45 to 48 days during the summer and *Kharif* seasons. New genotypes like IPM 409-4 and IPM 205-7 mature in 47 days as opposed to the check variety PDM 139's 60 days. This 13-day maturity advantage helps explain their optimistic economic returns from pulses and has the potential to replace upland paddy in non-conventional cropping systems.

2. **Enhancing Productivity Through Farmer Awareness and Optimal Utilization of Critical Inputs and Low-Cost:** For pulse crops to avoid moisture shortage during their growth phase, planting timing is essential. Plant growth, fruiting, and biological nitrogen fixation can all be negatively impacted by delayed planting, which can ultimately result in forced early maturity. However, in some circumstances, growing certain legume vegetables like green peas, beans, and cowpeas outside of the growing season can be profitable because of higher market prices, despite lower yield levels brought on by unfavorable climatic conditions. (Rahi *et al*., 2013). In areas with mild winters, especially in the southern part of the country, sowing for Rabi green gram can go as late as the end of December. However, it has been discovered that planting summer green gram in the first two weeks of March produces better results than planting it in the last week. (Patel, 2003). Similarly, horse gram is best sown during the Rabi season in the first week of September (Kalita *et al*., 2003).

VIII. APPLICATION OF MINERAL FERTILIZERS

Enhancing bio fortification through the application of mineral fertilizers involves the use of these fertilizers to increase the micronutrient content in edible parts of crops. Bio fortification aims to improve the nutritional quality of crops by increasing the levels of essential vitamins and minerals, such as iron, zinc, and vitamin A, in the plant tissues that humans consume. Mineral fertilizers containing micronutrients are applied to the soil or directly to the plant leaves to ensure that the crops take up these essential nutrients during their growth and development. The availability of micronutrients in the soil is crucial for the plants to absorb them and incorporate them into their tissues. Adequate levels of micronutrients in the crops can significantly improve the nutrient intake of populations, especially in regions where micronutrient deficiencies are prevalent.

Mineral fertilizers are a successful strategy to increase the mineral content in the edible parts of plants. Since ancient times, mineral fertilizers have been used to improve the soil's health for plants. They can also be used to increase the mineral content of grains for human nutrition. This technique is particularly effective for increasing minerals like selenium (Se), iodine (I), and zinc (Zn), which have good soil and plant mobility (Gomez-Galena *et al*., 2010). In the case of common beans, the application of foliar $ZnSO_4$ and $FeSO_4$ resulted in a considerable improvement. The zinc (Zn) and iron (Fe) content in the grains were enhanced by 46.85% and 54.83%, respectively, in comparison to the control treatment, as reported by Głowacka *et al.*, (2015). Yadav and Sharma (2018) carried out a pot experiment involving cowpea. They applied soil treatment at a rate of 10 g kg–1 soil and conducted foliar applications of zinc (Zn) and iron (Fe) at 0.5% concentration using $ZnSO_4$ and $FeSO_4$. The results indicated that the concentrations of Zn and Fe were elevated by 17.41% and 68.90%, respectively, with individual treatments of either Zn or Fe. When both Zn and Fe were applied together, their concentrations were further enhanced, showing an increase of 26.92% for Zn and 8.83% for Fe in cowpea seeds compared to the control group. In a lentil experiment that involved three different varieties and five varying doses of zinc (Zn) (ranging from 0 to 2.0 kg day^{-1}), an observation was made. The study revealed that as the Zn doses increased, there was a corresponding elevation in the concentrations of zinc (Zn), iron (Fe), and copper (Cu) in the seeds of all cultivars. This finding was documented by Gulser *et al.* (2004). Reports have indicated trends in enhancing the contents of copper (Cu), iron (Fe), zinc (Zn), and manganese (Mn) in pea (Nenova, 2008). Similarly, separate studies have focused on improving Zn levels in pea (Singh *et al*., 2015a), while the enhancement of Fe and Zn content has been observed in cowpea (Guillén-Molina *et al*., 2016;). Furthermore, research findings have highlighted increased Zn and Fe concentrations in faba bean, adzuki bean, and mung bean (Luo *et al*., 2013). These insights into various pulse crops provide valuable strategies to enhance the micronutrient contents across different varieties, offering potential solutions to address nutritional deficiencies.

Foliar fertilization is another ethical and practical method for enhancing grains with micronutrients. Direct fertilizer application to plant leaves is known as foliar fertilization. When mineral elements are not easily obtainable in the soil or are not efficiently transported to the edible parts of the plant, this method is especially helpful. Numerous studies have shown that foliar applications of micronutrients like iron (Fe), zinc (Zn), and selenium (Se) have successfully biofortified pulse crops like cowpeas, mung beans, and chickpeas (Prasad and Narayanan, 2014). Ali *et al*. (2014) iron was applied foliarly to mung beans, resulting in a 46% rise in iron content. Similar to how iron and zinc were applied foliarly, the levels of both these minerals and protein in cowpea and chickpea seeds were significantly increased. Additionally, foliar fertilization with urea has been shown to improve yield attributes, overall yield, and chlorophyll content of chickpeas (Dhaliwal *et al.,* 2022). Overall, both mineral fertilizers and foliar fertilization offer practical methods for increasing the mineral concentration in grains, thereby improving their nutritional value and contributing to enhanced human health.

Enhancing the concentration of selenium (Se) exclusively necessitates agronomic fertilization, primarily administered via foliar application, as indicated by Sima and Gissel-Nielsen in 1985. In a study conducted by Rahman *et al*., (2014), selenium was introduced in the form of potassium selenate (K_2SeO_4) during the full bloom stage at a rate of 10 grams per hectare (10 g ha^{-1}) .The research further revealed that a range of seven different selenium doses (ranging *from* 0 to 60 g ha^{-1}) were administered using selenate and selenite. The study verified that the application of 20 g ha–1 in 2016 and 10 g ha^{-1} in 2017 successfully met the daily selenium requirement (ranging from 20 to 55 μg day^{-1}) for human consumption (Silva *et al*., 2019).

Iodine plays a crucial role in various physiological processes within plants. To enhance its effectiveness and accumulation in seeds, soil application of iodine is considered the optimal approach, (Gonzali *et al*., 2017). Iodine biofortification of crops represents a recent strategy aimed at elevating iodine concentrations in seeds, consequently mitigating malnutrition-associated diseases globally. This approach is particularly prominent in vegetable crops that are inherently rich in iodine. Its application serves diverse physiological functions. For instance, in the case of green beans (common beans) and lettuce, the application of 0.10 and 0.25 mg L^{-1} of iodine via irrigation water was found to stimulate growth. Consequently, the edible parts of green beans and the leaves of lettuce exhibited iodine concentrations of 1.8 mg kg^{-1} and 5.6 mg kg^{-1}, respectively. Notably, this iodine application also led to the enhanced translocation of other essential macro- and micro-nutrients, including phosphorus (P), magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B), in lettuce and green beans, exhibiting increases ranging from 20% to 260% (Dobosy *et al.* , 2020). Various crops have undergone agronomic biofortification, involving the enhancement of micronutrient content. For instance, common beans have been enriched with micronutrients such as Fe, Zn, Mn, Cu, and Ni, as indicated by Lopez-Morales *et al.* (2020) and Ramos *et al*. (2020) who focused on Se enrichment. Cowpeas were fortified with Fe and Zn as reported by Hanumantappa *et al*. (2018). Similarly, faba beans were subjected to Fe and Zn biofortification according to Luo *et al*. (2013), while peas were fortified with Cu, Fe, Zn, and Mn, as studied by Nenova (2018). Lentils have seen an increase in Zn, Fe, and Cu content, documented by Gulser *et al*. (2004) and Se enhancement as explored by Rahman *et al.* (2014). Chickpeas were fortified with Fe and Zn, as per Rathod *et al*. (2020), and also Se-enriched as studied by Poblaciones *et al*. (2014). Mung beans underwent biofortification with Fe, Zn, Mn, Cu, and B, as outlined by Divyashree *et al*. (2018).

IX. PLANT GROWTH PROMOTING RHIZOBACTERIA (PGPR)

The soil is treated as a black box of millions of microorganisms that make it a diverse complex body. Certain microorganisms play a pivotal role in facilitating the mineralization of soil minerals, while others actively enhance plant growth through diverse mechanisms, collectively referred to as "plant growth-promoting microorganisms" or "plant growth-promoting rhizobacteria." Research findings pointed out that developing countries such as India, China, Pakistan, Iran, and Turkey exhibited deficiencies in various minerals, including micronutrients. Notably, studies indicated that a significant number of Indian soils lacked extractable quantities of essential minerals like iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) by approximately 11.2%, 48.1%, 7%, and 5.1%, respectively, as reported by Gupta (2005). Furthermore, there are projections suggesting an anticipated increase in soil zinc deficiency from 49% to 63% in the soil by 2025 (Singh, 2009)

To bridge this deficiency gap, it is feasible to address it through the enhancement of micronutrient mineralization in the soil by augmenting the introduction of specific microbial strains. Consequently, the application of microbial inoculations holds promise in bolstering the mineralization procedure, consequently elevating the absorption and accessibility of minerals for plants within the soil. This potential has been acknowledged in various studies (Meena *et al.*, 2022)

Micronutrient availability in pulses can be improved by using soil bacteria that promote plant growth (PGP), such as *Enterobacter, Bacillus*, and *Pseudomonas*. By producing growth hormones, antibiotics, chitinases, siderophores, systemic resistance, and mineralization, these bacteria are frequently used as seed inoculants and promote plant growth. Studies have shown that mycorrhizal associations and the inoculation of microorganisms can increase the concentrations of vital micronutrients like iron (Fe), selenium (Se), and zinc (Zn) in pulses (Singh *et al*., 2021). Additionally, colonization of certain bacteria in legume roots and nodules, such as *Pseudomonas sp*., *Brevibacterium sp*., *Bacillus sp*., *Enterobacter sp*. and *Acinetobacter sp*. has been discovered to increase grain yield, plant growth, and nitrogen fixation in legumes like peas, beans, and chickpeas (Kushwaha *et al*., 2021). When compared to uninoculated plants, PGP actinobacteria inoculation has been shown to increase the seed mineral concentration, including Fe (10-38%) and Zn (13-30%) in chickpeas. Similar to this, increasing the Fe and Zn content of chickpea grains as well as yield and protein content through field inoculation with Vesicular Arbuscular Mycorrhizae (VAM) fungi has been successful in improving the nutritional profile of chickpea grains.. Germplasm is screened for genetic diversity, micronutrient-dense germplasm is developed and evaluated, genetic research is done, and molecular markers are made to speed up breeding. For populations, including those in rural areas with limited access to fortified foods, traditional plant breeding techniques are especially advantageous. Plant breeding requires an initial investment, but once improved germplasm is created, farmers can propagate and grow it over time with little additional expense. Recurring costs are reasonably low, and germplasm can be obtained from different parts of the world. (Shahzad *et al*., 2021). Table 10 provides a compilation of researchers who have focused their efforts on diverse microorganisms employed for the purpose of biofortification in various pulse crops.

Various crops have been associated with specific microorganisms or genera in efforts to enhance micronutrient content. For example, in the case of chickpea and pigeon pea, microorganisms such as *Acinetobacter tandoii*, *Bacillus altitudinis*, *Brevibacterium antiquum*, *Enterobacter ludwigii*, *Pseudomonas monteilii*, and *Pseudomonas plecoglossicida* have been linked to increased iron (Fe) levels, as reported by Gopalakrishnan *et al.* (2016). Similarly, for chickpeas, *Funneliformis mosseae* and *Rhizophagus irregularis* have been associated with zinc (Zn) enrichment, as investigated by Pellegrino and Bedini (2014). Mung beans have been found to benefit from microorganisms such as *Pseudomonas sp*., *Pantoea dispe*rsa MPJ9, and *Pseudomonas putida* MPJ6 for Fe enrichment, and *Klebsiella spp*. and *Pseudomonas spp*. for Zn enhancement, as indicated by Sharma *et al.* (2014) and Patel *et al.* (2018). Lentils have shown Fe enrichment through the involvement of *Pseudomonas sp*. and *R. leguminosarum*, according to Mishra *et al*. (2011), while beans have been associated with *Pseudomonas japonica* and fluorescent pseudomonads for Zn enrichment, as highlighted by Eshaghi *et al.* (2019) and Omidvari *et al*. (2010).

X. CONCLUSION AND FUTURE SCOPE

There are difficulties in providing nutrient-rich diets due to the rapid growth of the world's population and rising food demands. A major Sustainable Development Goal (SDG) for food is to produce foods that will be available in the future while also meeting dietary needs. By acting as the dominant and primary source of plant-based protein in the human diet, pulses like chickpeas, lentils, beans, and peas play a critical role in addressing these issues. They improve protein malnutrition in developing and underdeveloped nations by providing a variety of nutritional and physiological benefits. Protein, carbohydrates, dietary fiber, and bioactive substances like flavonoids, phenolics, tannins, and phytosterols are all abundant in pulses. Pulses are very good for overall health because of these phytochemicals' anti-inflammatory, anti-ulcerative, anti-microbial, and anti-cancer properties. Pulses also significantly contribute to the management of weight, blood sugar, and in weight management, blood sugar stabilization, and improving insulin resistance. A region's agricultural landscape can be made more diverse by expanding the variety of pulse crops grown there. Different pulse species and varieties have unique characteristics, such as the ability to withstand drought, resist disease, and adapt to particular environments. Farmers can reduce the risks brought on by pests, diseases, and climate change by fostering diversity. Essential nutrients like protein, fibre, vitamins, and minerals are abundant in pulse crops. By growing a variety of pulse crops, it is possible to increase agro-biodiversity and increase dietary diversity, which will boost food security and public health. Uncertain weather patterns, higher temperatures, and changed pest dynamics are all effects of climate change. Because different varieties of pulse crops may respond differently to various climatic conditions, they can be more resistant to such changes.

Despite the significance of pulses, there are sizable research gaps in a number of areas, including genetics and nutrition. More analytical compositional information on foods based on pulses is required to promote the inclusion of pulses in diets and create efficient nutritional programmes. It is urgently necessary to update food composition databases frequently to include diverse pulses, particularly those that include micronutrients. The FAO/INFOODS Analytical Food Composition Database may be improved by international cooperation and data sharing among researchers and academic journals about pulses. The yield potential of pulse crops is lower compared to cereals, making them less remunerative for farmers and less affordable for consumers. The cereal-focused green revolution had little effect on the pulses industry. Research in developmental biology, photosynthesis, canopy enhancement for solar radiation capture, and source-sink relationships is required to break the yield barrier in pulses. It is necessary to create effective pulse transformation protocols in order to make use of contemporary breeding strategies like genome editing. Increasing pulse production and consumption is essential for ensuring that the general public has access to affordable nutrition and for fostering environmental sustainability. There can be significant improvements in global food security and nutrition if research gaps are filled and efforts in pulse-related studies are stepped up.

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