**Enhancing pulse agro-biodiversity for improving food security, nutritional security and economic sustainability amidst changing climate scenario**

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**Introduction:**

Pulses hold significant importance as food crops globally, mainly due to their high protein content.Pulses are a subgroup of legumes and include beans, lentils, and peas. Legumes are plants that belong to the family Fabaceae and are characterized by their ability to fix nitrogen in the soil. This means they have a symbiotic relationship with certain bacteria that allows them to convert atmospheric nitrogen into a form that can be used by plants. Pulses are the edible seeds of leguminous plants. India cultivates several key pulses, including chickpeas (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), green gram (*Vigna radiata*), black gram (*Vigna mungo*), lentil (*Lens esculenta*), peas (*Pisum sativum*), chikling pea (*Vigna unguiculata*), horse gram (*Vigna unguiculata*), cow pea (*Vigna unguiculata*), faba bean (*Vicia faba*) and different types of beans. These legumes are grown extensively in the country in different seasons (Table-1) and play a crucial role in meeting the nutritional needs of its population.

**Table-1: Pulses and their growing seasons**

|  |  |
| --- | --- |
| Growing Seasons | Pulses |
| Kharif | Pigeon pea, Green gram, Black gram, Cowpea, Horsegram and Moth bean |
| Rabi | Chick pea, Lentil, Pea, Chikling pea and Rajmash |
| Summer | Greengram, Blackgram and Cowpea. |

In India, pulses are a crucial group of crops that contribute significantly to the country's economy by constituting a substantial portion of exports. These legumes serve as the primary sources of protein in the Indian diet, playing a vital role in providing much-needed protein to the predominantly carbohydrate-rich meals. India holds the title of being the world's largest producer of pulses. With protein content ranging from 20 to 25 percent by weight, pulses offer twice the protein found in wheat and three times that of rice. The entire legume plant is often used in various agricultural applications: cover crops, livestock feed, fertilizers, dinner Plate. Pulses are an excellent source of plant-based protein, rich in dietary fiber, provides complex carbohydrates, good source of various vitamins, contain essential minerals such as iron, magnesium, potassium, phosphorus, and zinc (Table-2). Iron is crucial for oxygen transport in the blood, while magnesium and potassium are essential for muscle and nerve function. It contains antioxidants, including flavonoids and polyphenols, which help neutralize harmful free radicals in the body and protect against oxidative stress. Pulses are naturally gluten-free, making them suitable for individuals with celiac disease or gluten sensitivity. It has generally had a low glycemic index. Due to their protein and fiber content, pulses can help promote feelings of fullness and satiety, which may aid in weight management.

**Table-2: Nutritive value of pulses**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pulses | Energy(Kcals) | Moisture(g) | [Protein](http://medindia.net/patients/foodcalories/FoodDetails.asp?id=20&cate=1&subcate=1&food=BAJRA)(g) | Fat(g) | Mineral(g) | CHO (g) | Fiber(g) | Ca(mg) | P(mg) | Fe(mg) |
| Chick pea  | 360 | 10 | 17 | 5 | 3 | 4 | 4 | 202 | 312 | 5 |
| Black gram  | 347 | 11 | 24 | 1 | 3 | 1 | 1 | 154 | 385 | 4 |
| Cow pea | 323 | 13 | 24 | 1 | 3 | 3 | 4 | 77 | 414 | 9 |
| Field bean | 347 | 10 | 25 | 1 | 3 | 1 | 1 | 60 | 433 | 3 |
| Green gram | 334 | 10 | 24 | 1 | 3 | 4 | 4 | 124 | 326 | 4 |
| Horse gram,  | 321 | 12 | 22 | 0 | 3 | 5 | 5 | 287 | 311 | 7 |
| Chikling pea | 345 | 10 | 28 | 1 | 2 | 57 | 2 | 90 | 317 | 6 |
| Lentil | 343 | 12 | 25 | 1 | 2 | 59 | 1 | 69 | 293 | 7 |
| Moth beans | 330 | 11 | 24 | 1 | 3 | 56 | 4 | 202 | 230 | 9 |
| Peas green | 93 | 73 | 7 | 0 | 1 | 16 | 4 | 20 | 139 | 1 |
| Peas dry | 315 | 16 | 20 | 1 | 2 | 56 | 4 | 75 | 298 | 7 |
| Rajmah | 346 | 12 | 23 | 1 | 3 | 61 |       5     | 260 | 410 | 5 |
| Pigeon pea | 335 | 13 | 22 | 2 | 3 | 58 | 1 | 73 | 304 | 3 |
| Soyabean | 432 | 8 | 43 | 19 | 4 | 21 | 4 | 240 | 690 | 10 |

***CHO: Carbohydates, Ca: Calcium,P: Phosphorus, Fe: Iron, Source: TNAU Agritech Portal***

In the face of constantly evolving diet patterns, food preferences, advancements in food processing technologies, shifting cultural norms, and increased awareness about nutrition, the challenge of providing nutritious food to a growing global population is becoming increasingly complex and demanding (Changan *et al*., 2017). The central concern revolves around finding sustainable solutions to meet the rising demand for healthy and nutritious food in the future without depleting the earth's resources (Langyan *et al*., 2022). The global food demand is on a rapid rise due to a fast-growing population, which presents a significant challenge in meeting the nutritional requirements of balanced diets. One solution to combat these challenges and provide essential nutritional and physiological benefits is the incorporation of pulses into the human diet. Pulses contain phytochemicals such as flavonoids, phenolics, tannins, phytates, saponins, lectins, oxalates, phytosterols, peptides, and enzyme inhibitors, which offer numerous health benefits. Some of these phytochemicals exhibit anti-inflammatory, anti-ulcerative, anti-microbial, and anti-cancerous effects. Additionally, pulses are rich in vitamins and minerals, further enhancing their nutritional value.

In the past few years, the effects of climate change have become more apparent, affecting different aspects of society, particularly agriculture, which is highly susceptible. With rising global temperatures, an increase in extreme weather events, and changing rainfall patterns, conventional farming methods are facing considerable challenges. As a solution to address the negative impacts of climate change on food security and economic stability, there has been a growing interest in promoting diversity among pulse crops.

Pulse agro-biodiversity has been recognized as a potential strategy to tackle the challenges posed by climate change. Pulses, such as beans, lentils, chickpeas, and peas, offer unique traits that make them valuable in sustainable agriculture. Their adaptability to various agro-ecological conditions and nutritional benefits contribute to their significance in combating the effects of a changing climate and fostering agricultural sustainability. Climate change has indeed posed significant challenges to the quality and production of pulses, as it has affected agricultural systems worldwide. Pulses are particularly vulnerable to the impacts of climate change due to their sensitivity to temperature, water availability, mineral content, pest disease incidence and other environmental factors. Here are some ways in which climate change can negatively affect pulses. Therefore, the challenges posed by climate change to pulse production requires adopting climate-resilient agricultural practices, developing improved pulse varieties that are more tolerant to temperature and water stress, efficient water management techniques, and sustainable farming practices. Additionally, policy makers and governments need to implement strategies to mitigate climate change and support farmers in adapting to the changing climate to ensure food security and sustainable agriculture.

In this Chapter, we emphasize the crucial role of pulses in global food systems and diets, pulse is a powerhouse of health and vitality and exploring biofortification for major pulses: enhancing nutrition for global health. We delve into the significance of food composition databases concerning pulses, explore the impact of processing techniques on their nutritional content, and present various approaches to improve the overall nutritional profile of pulses.

**Crucial Role of pulses in global food systems and diets**

The integration of pulses into our diets can play a pivotal role in addressing the current food-related challenges. By harnessing the benefits of these nutrient-dense sources, we can pave the way for healthier food choices and contribute to a more sustainable food future. Over the last 25 years, the global population has grown by two billion people, and projections suggest that it will further increase to 8.5 billion by 2030 and 9.8 billion by 2050, according to the United Nations World Population Division, 2017. Whereas in India, is projected to have a population of 1.515 billion by 2030 and 1.668 billion by 2050 (Outlook, 2023). Indeed, there is a necessity to increase food grain production in order to fulfill the rising demand for pulses and meet the dietary requirements of both the Indian and global populations. Between 2013-14 and 2021-22; the total acreage dedicated to pulses experienced a slight increase. However, the most significant growth rates in both area and production occurred in 2016-17, with a remarkable 18% rise in area and a substantial 42% increase in production compared to the previous year (2015-16). This positive trend has been consistently maintained, resulting in the highest area of 31.24 million hectares and production of 27.75 million metric tons during 2021-22 (based on the 3rd Advanced Estimate). Moreover, this production level also marked the highest recorded figures for both area and production in the past 8 years. Additionally, the productivity during 2021-22 was recorded at an impressive 888 kg per hectare. Over time, there has been a significant increase in the productivity of pulses, rising from 764 kg per hectare (2013-14) to 888 kg/ha (2021-22) illustrated in table-3.

**Table–3 : Contribution of pulses to food grains basket.**

 {Area- Million ha, Production- Million Tones, Yield- kg/ha}

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Pulses** | **Food grains** | **Pulses share food grain production****(%)** |
| **A** | **P** | **Y** | **A** | **P** | **Y** | **A** | **P** |
| 2013-14 | 25.22 | 19.26 | 764 | 125.05 | 265.05 | 2120 | 20 | 7 |
| 2014-15 | 23.55 | 17.15 | 728 | 124.30 | 252.03 | 2028 | 19 | 7 |
| 201-16 | 24.91 | 16.32 | 655 | 123.22 | 251.54 | 2041 | 20 | 6 |
| 2016-17 | 29.45 | 23.13 | 786 | 129.23 | 275.11 | 2129 | 23 | 8 |
| 2017-18 | 29.81 | 25.42 | 853 | 127.01 | 285.01 | 2235 | 23 | 9 |
| 2018-19 | 29.16 | 22.08 | 757 | 124.78 | 285.21 | 2286 | 23 | 8 |
| 2019-20 | 27.99 | 23.03 | 823 | 126.99 | 297.50 | 2343 | 22 | 8 |
| 2020-21 | 28.78 | 25.46 | 885 | 129.80 | 310.74 | 2394 | 22 | 8 |

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

Between the agricultural years 2013-14 and 2021-22, the total acreage dedicated to pulses witnessed a gradual and slight increase. However, the most significant growth rate in both area and production occurred during the year 2016-17, with a remarkable 18% increase in area and a substantial 42% increase in production compared to the previous year, 2015-16. This positive trend has been consistently maintained, leading to a record-high in both area and production during 2021-22. The highest area of 31.24 million hectares and production of 27.75 million tonnes were achieved, accompanied by an impressive productivity of 888 kg/ha. This marks the highest recorded figures for both area and production in the past 8 years shown in table-4.

**Table-4: Yearly Growth Rate of Total Pulses**

(Area-Million ha, P- Million tones, Y-kg/ha, Growth Rate (GR)-%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Area | YGR | Production | Yearly growth rate | Yield | Yearly growth rate | % coverage under irrigation |
| 2013-14 | 25.21 |  | 19.25 |  | 764 |  | 19.72 |
| 2014-15 | 23.54 | -7 | 17.51 | -11 | 728 | -5 | 19.86 |
| 2015-16 | 24.91 | 6 | 16.32 | -5 | 655 | -10 | 19.26 |
| 2016-17 | 29.44 | 18 | 23.12 | 42 | 785 | 20 | 18.83 |
| 2017-18 | 29.81 | 1 | 25.41 | 10 | 852 | 9 | 22.87 |
| 2018-19 | 29.15 | -2 | 22.07 | -13 | 757 | -11 | 23.20 |
| 2019-20 | 27.98 | -4 | 23.02 | 4 | 823 | 9 | - |
| 2020-21 | 28.78 | 3 | 25.46 | 11 | 885 | 8 | - |
| 2021-22 | 30.37 | 9 | 26.96 | 9 | 888 | 0.4 | - |
| CAGR | 3% |  | 5% |  | 2% |  |  |

***Note:*** *YGR – Yearly Growth Rate over the Previous Year; CAGR- Compound Annual Growth Rate* ***Source:*** *DES, Min. of Agri. & FW, GoI, (DA&FW). 2021-22\* - IIIrd Adv. Estimates.*

Several studies focusing on demand projections for pulses in India have provided varying estimates, primarily due to differences in methodologies and assumptions. However, they generally indicate that the country would need approximately around 39 million tonnes by 2050 (Table- 5). For instance, Narayanmoorthy (2000) projected the total demand for pulses to reach 27.45 million tonnes by 2030. On the other hand, the Indian Institute of Pulses Research (IIPR) in Kanpur projected the country's demand for pulses at 39 million tonnes by 2050, necessitating an annual production growth rate of 2.2% (IIPR, 2015). To meet this growing demand and maintain domestic production competitiveness, it is essential to implement more efficient crop-production technologies. Alongside, favorable policies and market support are crucial in motivating farmers to cultivate larger areas of pulses. By taking these measures, the country can successfully fulfill the increasing requirement for pulses and ensure nutritional security for its population, especially those relying on a vegetarian diet ((Ahlawat *et al.,*2016).

 **Table 4. Projected demand of pulses in India by different studies**

|  |  |  |
| --- | --- | --- |
| **Study by** | **Projections for the year** | **Demand****(million tonnes)** |
| Narayanmoorthy (2000) | 2030 | 16.10 |
| 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*

 Global efforts aimed at achieving the Millennium Development Goals set by the United Nations have been successful in reducing the percentage of undernourished individuals from 23.3% to 12.9% of the world population. However, despite these efforts, more than 800 million people still suffer from malnourishment worldwide (UNICEF and World Health Organization, 2017). The Sustainable Development Goals (SDGs), outlined in the 2030 Agenda, include the second goal of achieving Zero Hunger, with the aim of eradicating hunger and poverty by 2030. Currently, approximately 2.3 billion people are unable to access regular nutritious and balanced diets and an estimated 720–811 million individuals suffer from chronic undernourishment. The recent pandemic has exacerbated the situation, leaving an additional 70–161 million people facing hunger. Malnutrition takes various forms, affecting around one-third of the global population. Stunting, which refers to being short-for-age, is prevalent, as is undernourishment, which is the primary indicator of hunger. Micronutrient deficiencies, overweight, and obesity are also significant concerns. Anemia is prevalent among one-third of women of childbearing age, and 22% of children fewer than five years of age suffer from stunted growth (UNDP, 2022). Furthermore, the number of middle-class families worldwide has doubled, constituting at least 13% of the total population, with significant growth observed in South Pacific and Asian countries between 2001 and 2011 (Pew, 2017). A significant portion of the population relying on plant-based diets often fails to meet the recommended daily allowances for essential micronutrients. This deficiency can lead to severe complications, including intellectual impairment, poor growth, perinatal complications, and an increased risk of mortality and morbidity. It may also contribute to the development of chronic and infectious diseases, such as thyroid dysfunction, osteoporosis, colorectal cancer, osteomalacia, and cardiovascular diseases. Pregnant mothers who are undernourished and lacking essential micronutrients can face challenges like intrauterine growth restriction, low birth weights, protein-energy malnutrition, chronic energy deficiencies, and increased risks of maternal and neonatal mortality (Alae-Carew *et al.,* 2019).

 Food production systems carry significant environmental costs, including deforestation, land degradation, loss of biodiversity and habitat, depletion of natural resources, and contamination of soil, air, and water (IPBES, 2018). For example, food systems are responsible for emitting approximately one-fourth of anthropogenic greenhouse gases and utilizing around 70% of total freshwater in agricultural production (UNICEF and World Health Organization, 2017). Agricultural practices involving pesticides, synthetic fertilizers, and hormones in animal husbandry contribute to pollution and contamination of terrestrial and marine ecosystems, as well as food products, leading to severe health complications (Landrigan *et al*., 2018). Various unsustainable practices and increasing competition for water, land, and energy further hinder the ability to achieve sustainable and healthy food production for future generations. These environmental challenges highlight the urgency for adopting more sustainable and eco-friendly approaches in agriculture and food systems to ensure the well-being of both people and the planet.

 To address the challenge of providing affordable, nutritious diets with low environmental costs, pulses play a crucial role. Pulses and legumes such as soybeans, chickpeas, lentils, peanuts, peas, and beans are widely used for human consumption and as animal feed globally. These crops offer numerous environmental, nutritional, and agronomic benefits, including enhancing soil organic matter, promoting crop rotation, and reducing the need for mineral fertilizers, thus mitigating greenhouse gas emissions (Singh *et al*., 2021). In terms of nutrition, pulses are considered a healthy and protein-rich dietary option that can help reduce the risk of stroke and heart disease (Mandal *et al.,* 2020). Their consumption is associated with various health benefits due to their rich nutrient profile, including vitamins, minerals, dietary fiber, and bioactive compounds with anti-inflammatory and anti-cancer effects. The global food system is facing challenges due to climate change and its impacts on agricultural production. Unpredictable changes in climate can affect food production and security, particularly in developing countries. Intercropping systems with pulse crops have been identified as a method to enhance climate resilience in farming (Guntukula, 2020). Pulses also contribute to promoting dietary diversity and reducing the pressure on resources and agricultural land when consumed in place of dairy products and meat. More than 50% of the daily protein requirements worldwide are met by pulses, indicating their importance as a protein source for a large portion of the global population. Despite their nutritional benefits and environmental advantages, the production and availability of pulses have been impacted by factors such as erosion of indigenous and traditional food crops, climate change, and changing dietary patterns. Efforts to promote the cultivation, consumption, and bio-fortification of major pulses can help address nutritional deficiencies and improve food security (Singh *et al*., 2021).

**Pulse is a powerhouse of health and vitality**

 Pulses are a highly nutritious food source, providing essential nutrients such as carbohydrates (fiber and starch), vegetable protein, folate, and a range of vitamins and minerals like potassium and iron, which offer various health benefits. Pulses are particularly rich in important micronutrients, including iron, potassium, magnesium, zinc, and B vitamins like folate, thiamin, and niacin (Figure 1). However, the nutritional content can vary among different types of pulses (Table 5). Generally, pulses have approximately the following nutritional values: crude protein (21-25%), carbohydrates (60-65%), moisture (10%), and lipids (1-1.5%). Consuming 100-200 grams of pulses, such as lentils, cowpeas, and chickpeas, can satisfy daily mineral requirements, while consuming 100 grams of most dietary legumes can meet daily iron requirements. Pulses, such as beans, are also high in various forms of vitamin B, including folic acid and pantothenate. Chickpeas are rich in vitamins like riboflavin, niacin, thiamin, folate, and the precursor of vitamin A. However, they also contain some anti-nutritional factors (Jukanti *et al.*, 2012). Cowpea is a good source of protein, carbohydrates, insoluble and soluble fiber, and essential minerals like iron, zinc, manganese, phosphorus, and potassium. It has a high unsaturated fatty acid profile despite being low in lipids (Frota *et al*., 2008). Pigeon pea seeds provide carbohydrates in the cotyledons, protein in the embryo, and fiber in one-third of the seed coat. However, they may also contain anti-nutritional elements such as oligosaccharides, polyphenols, and enzyme inhibitors (Saxena *et al*., 2010).

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**Fig.1:**  Nutritional profile of different pulses (Source: [Venkidasamy](https://www.frontiersin.org/articles/10.3389/fsufs.2022.878269/full%22%20%5Cl%20%22B117) *[et al](https://www.frontiersin.org/articles/10.3389/fsufs.2022.878269/full%22%20%5Cl%20%22B117)*[., 2019](https://www.frontiersin.org/articles/10.3389/fsufs.2022.878269/full%22%20%5Cl%20%22B117)). NA, not reported.

**Table-5**: Protein and carbohydrate content in common pulses.



**Impacts of Processing on the Nutritional Profile**

Pulses undergo various processing techniques before they are consumed as food, and these methods can significantly impact their nutritional content, quality, digestibility, and potential health benefits. Different processing methods, such as soaking, dehusking, germination, roasting, and cooking, can lead to changes in the composition of pulses. One example is chickpeas, which contain anti-nutritional factors that can interfere with nutrient absorption and digestion. However, these anti-nutritional factors, including tannins, phytates, proteolytic enzyme inhibitors, and trypsin inhibitor activity, can be reduced or removed through processing methods like soaking, germination, blanching, and boiling. These techniques help improve the nutritional quality of chickpeas by increasing the bioavailability of minerals such as zinc and iron and enhancing protein digestibility. Similarly, dry beans contain oligosaccharides like stachyose and raffinose, which can lead to flatulence when consumed. However, cooking the beans at high temperatures (e.g., 121°C, 15 psi) for 30 minutes or soaking them in a solution containing 0.5% NaHCO3 for 18 hours effectively reduces these oligosaccharides, making the beans more easily digestible and reducing the likelihood of causing flatulence. Overall, processing techniques play a crucial role in enhancing the nutritional value and digestibility of pulses, making them more suitable for consumption and optimizing their health benefits. By understanding and applying appropriate processing methods, we can make the most of the nutritional potential of pulses and incorporate them effectively into a balanced and nutritious diet.

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-diaminopropionic 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). Germination is a simple and beneficial method for improving the palatability, digestibility, and nutritional quality of pulses. During germination, the vitamin content, including vitamins A and C, increases in pulses, along with improved availability of carbohydrates and proteins. Additionally, germination also reduces the levels of anti-nutritional factors in pulses, making them more nutritious and safer for consumption. Thermally treating black gram, lentils, and chickpeas in a pressure cooker enhances their water absorption efficiency. This process results in decreased absorption of fat and reduces the potential for foaming during cooking, making the pulses more suitable for various culinary applications. Extrusion cooking is another processing approach used to modify the composition of pulses. It is effective in reducing the content of raffinose, an oligosaccharide responsible for flatulence, and increases the dietary fiber content of the pulses. This makes extruded pulses more easily digestible and beneficial for gut health. In conclusion, various processing methods offer significant advantages for pulses, including the elimination of toxins, improved nutritional content, reduced anti-nutritional factors, and enhanced digestibility. By adopting appropriate processing approaches, we can enhance the overall quality and nutritional value of pulses, making them a more valuable and healthy addition to our diets.

Various processing techniques have been utilized to increase the content of low glycemic-resistant starch in plant-based foods, particularly in whole pulse flours like black bean, chickpea, broad bean, and lentil. Two approaches commonly used are annealing hydrothermal treatments and heat moisture treatment (Chávez-Murillo *et al.,* 2018). These processing methods have been found to enhance the fractions of resistant starch and slow digestible starch in the pulses. The hydrothermal treatments promote the improvement of protein degradation in vitro, and as a result, the physical linkage between proteins and starch is strengthened at the molecular level. This leads to a greater number of resistant starch fractions (Magrini *et al.,* 2018). The molecular interaction between starch and protein is crucial for regulating the digestion of both protein and starch. By enhancing this interaction through thermal treatments, the nutritional and functional values of the pulses are improved. These modified pulses with increased resistant starch content have lower glycemic index values, making them more suitable for consumption by individuals with diabetes or those seeking to manage their blood glucose levels. Moreover, the increased resistant starch content also offers potential health benefits related to gut health, satiety, and overall metabolic health. In summary, the use of annealing hydrothermal treatments and heat moisture treatment on whole pulse flours has been shown to enhance the content of resistant starch and slow digestible starch. This processing approach improves the molecular interaction between starch and protein, resulting in increased nutritional and functional value of the pulses. It provides an innovative way to optimize the health benefits of pulses and make them a valuable component of a balanced and health-promoting diet.

**Improvement of the Nutritional Profile of Pulses through Biofortification**

Pulses are known for their nutritional value, but their nutrient content can be further enhanced through biofortification, a cost-effective and practical technology aimed at increasing the concentration of essential micronutrients in crops. Biofortification involves various strategies like classical breeding, population mapping, and genetic selection to develop improved varieties of pulse crops. Despite the potential benefits, biofortification efforts in pulses and legumes have been limited compared to staple crops like rice, wheat, and maize. However, to address global health issues arising from micronutrient deficiencies, it is crucial to urgently implement biofortification in a diverse range of pulses such as lentils, field peas, and chickpeas. This involves enriching these crops with readily absorbable forms of micronutrients like iron, zinc, selenium, and iodine, which can have a significant impact on improving nutrition and reducing deficiencies among vulnerable populations.

Traditionally, agriculture has mainly focused on increasing crop yield and productivity without giving enough consideration to human health concerns. However, there is now a shift in the agricultural sector towards cultivating nutrient-dense crops in sufficient quantities to enhance the nutritional quality of food. By implementing biofortification in pulses, which are already rich in essential nutrients, we can effectively combat "hidden hunger" caused by micronutrient malnutrition and ensure food security. Biofortification provides a cost-effective solution to meet nutritional needs and has the potential for significant improvements in human health and nutrition. This approach is particularly crucial for addressing nutritional deficiencies in impoverished and developing nations. Regular consumption of biofortified staple crops will help fight hidden hunger and ensure food security, leading to better overall health and well-being (Sellamuthu and Malathi, 2021). Various approaches can be employed for biofortification and enhancing the nutritional content of pulses (Figure- 2).

BIOFORTIFICATION

Plant Breeding

Genetic Engineering

Agronomic approaches

Foliar fertilization

PGPR

Mineral fertilizer

**Figure- 3:** Approaches of biofortification for improvement of nutritional profile.

**Genetic Engineering**

Genetic engineering can be employed to enhance the nutritional profiles of pulse crops, especially when the desired traits are not naturally present in the germplasm or cannot be achieved through conventional breeding. This approach, known as biofortification through genetic engineering, offers an alternative strategy for improving micronutrient content in crops (Jha and Warkentin, 2020). The availability of fully sequenced genomes in various crops has significantly supported this strategy. Using genetic engineering, micronutrient concentrations in pulse crops can be increased, and anti-nutrients can be removed to improve the bioavailability of essential nutrients. Genes from different plant species, bacteria, or other organisms can be introduced to achieve these goals. In pulse crops, genetic engineering has been successfully used to improve other nutritional aspects as well. For instance, introducing a gene responsible for a methionine-rich storage albumin from the Brazil nut led to a significant increase (up to 23%) in the essential amino acid methionine concentration in transgenic common bean plants. Similarly, expressing a sunflower seed albumin gene resulted in up to a 94% increase in methionine concentration in transgenic lupins (Dhaliwal *et al*., 2022).

Genetic engineering provides a powerful tool to enhance the nutritional content of pulse crops, especially when conventional breeding methods are limited. It allows for the targeted improvement of specific micronutrients and the potential removal of anti-nutrients, contributing to improved nutritional quality in pulse crops and potentially benefiting a large population, especially in regions with nutritional deficiencies.

**Plant Breeding:**

Plant breeding plays a crucial role in pulse production by focusing on developing improved varieties with desirable traits. Here are some key contributions of plant breeding in pulse production. Plant breeding in pulse crops aims to create new and improved varieties by combining valuable traits from different parent plants. This breeding process involves cycles of selection, recombination, testing, and further selection, which require significant resources, time, and expertise. The goal is to develop varieties with desirable characteristics, such as appropriate phenology, efficient plant type, higher yield, and improved nutritional quality. While classical plant breeding methods have led to the development of over 3700 improved pulse crop varieties globally, they have not achieved the substantial genetic gains needed to bridge the gap between demand and supply. Studies have identified several challenges, including a narrow genetic base and significant environmental and genotype × environment interactions in multi-location environment trials (MET). These factors have reduced selection efficiency and prolonged the breeding cycle. To overcome these challenges and accelerate genetic gains in pulse crops to meet the demands of a growing population, modern tools and techniques are essential. These include advanced phenotyping and genotyping methods, improved experimental design, efficient data management, sophisticated statistical analysis, and the digitalization and mechanization of breeding and testing pipelines. By integrating these modern approaches into pulse crop breeding programs, researchers can enhance their ability to develop high-yielding, disease-resistant, and nutritionally superior varieties. This will enable farmers to meet the increasing demand for pulses and contribute to food security in the future (Kumar *et al.,*2020).

**Enhancing Productivity through Farmer Awareness and Optimal Utilization of Critical Inputs and Low-Cost**

The timing of planting is crucial for pulse crops to avoid moisture deficiency during their growth period. Delayed planting can negatively impact plant growth, fruiting, and biological nitrogen fixation, ultimately leading to forced early maturity. However, in some cases, off-season cultivation of certain legume vegetables like green peas, beans, and cowpea can be profitable due to higher market prices, despite lower yield levels resulting from less favorable climate conditions (Rahi et al., 2013). For Rabi green gram, sowing can extend until the end of December in regions with mild winters, particularly in the southern part of the country. On the other hand, for summer green gram, sowing in the first fortnight of March has been found to yield better results compared to sowing in the last week of March (Patel, 2003). Similarly, horse gram is best sown during the Rabi season in the first week of September (Kalita et al., 2003).

**Enhancing Crop Productivity through new cropping systems, intercropping, and Crop Diversification**

In recent years, 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, has allowed farmers to shift from the traditional cereal-cereal cropping system to a more beneficial rice-chickpea system. This shift is particularly noticeable in the tail end of command areas in eastern Uttar Pradesh and Bihar. Furthermore, in the upland regions of Punjab, Haryana, and western Uttar Pradesh, a similar trend has been observed. Farmers in these areas are also adopting the rice-chickpea system due to the advantages offered by the early maturing chickpea varieties, which can be sown later in the season and still achieve substantial yields. The adoption of the rice-chickpea system has proven to be a more favorable option for farmers in these regions, as it provides better crop diversification, improved yields, and overall agricultural sustainability. This shift in cropping patterns is driven by the availability and success of these early maturing chickpea varieties, which have become a preferred choice for farmers seeking to enhance their agricultural productivity and income.

Pigeonpea is a significant crop in several Indian states, including Maharashtra, Uttar Pradesh, Madhya Pradesh, Karnataka, and Gujarat. In irrigated regions of northern and central India, the pigeonpea-wheat cropping system has gained popularity as a promising agricultural practice. The introduction of short-duration pigeonpea varieties, such as UPAS 120, Manak, ICPL 151, and Pusa 992, which mature within 120-160 days, has facilitated their integration into the existing rice-wheat cropping systems in irrigated areas of western Uttar Pradesh, Punjab, Haryana, Delhi, and North-East Rajasthan. By incorporating pigeonpea into the rotation with wheat, farmers can enhance the efficiency of land use and improve overall agricultural productivity. These short-duration pigeonpea varieties allow farmers to maximize their yields within a relatively short period, making it feasible to include pigeonpea in the cropping system alongside rice and wheat. The pigeonpea-wheat system offers several benefits, including better crop diversification, reduced risk of pest and disease buildup, and improved soil health through nitrogen fixation by pigeonpea. This cropping system has shown great promise in the irrigated regions mentioned, contributing to sustainable and profitable agricultural practices in those areas.

The cultivation of rabi urdbean and mungbean in the coastal regions of South India has a long history, but it gained significant momentum only after the development of powdery mildew resistant genotypes. Varieties such as LBG 17, LBG 402, LBG 611, and LBG 22, which are resistant to powdery mildew and have high yield potential, were developed in the late 1980s. These resistant varieties have brought about a revolution in urdbean and mungbean cultivation, particularly in rice fallow areas of Andhra Pradesh. The adoption of these powdery mildew resistant genotypes has resulted in a highly productive and stable cropping system in rice fallow areas. Moreover, this system has been beneficial in improving 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. The use of resistant varieties has not only enhanced the productivity of urdbean and mungbean crops but also reduced the impact of powdery mildew disease, leading to more reliable and higher yields. This cropping system has become a sustainable and profitable option. In the rainfed areas of the north-western region of India, including Punjab, Haryana, Western Uttar Pradesh, Rajasthan, Himachal Pradesh, and Jammu & Kashmir, the crop sequence of mungbean/urdbean – mustard/barley is significant. In contrast, in irrigated areas, farmers follow the practices of maize-potato-mustard-mungbean/urdbean and maize-wheat-mungbean/urdbean rotations. 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-horsegram. Under irrigated conditions in these regions, the cropping system shifts to maize-wheat-mungbean/urdbean.

In the central regions of India, comprising Madhya Pradesh, Gujarat, and Maharashtra, farmers adopt various cropping sequences under rainfed conditions, including urdbean-wheat, mungbean-sorghum, cowpea/urdbean/mungbean-safflower, and mungbean-niger. For irrigated areas in these regions, the practices include maize-wheat-summer cowpea, maize-wheat-summer urdbean/mungbean. In the rainfed areas of South India, including Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala, farmers commonly follow the crop sequences of cowpea-finger millets, mungbean-sorghum/safflower, and rice-mungbean/urdbean/cowpea. However, under irrigated conditions, the prevalent cropping system is rice-rice-mungbean/urdbean/cowpea. These diverse cropping sequences are tailored to suit the specific agro-climatic conditions of each region, enabling farmers to optimize their agricultural output while considering the availability of water resources and other environmental factors.

The development of early maturing and high-yielding genotypes, especially in pulses like pigeonpea 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 pigeonpea varieties were introduced in crop development programs to address this need. Srivastava *et al.* (2012) worked on developing elite x elite crosses in pigeonpea, focusing on improving traits like test weight, grain yield, and early maturity. One of the challenges associated with pigeonpea is its thermo/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.

**Application of Mineral Fertilizers**

To enhance the mineral content in the edible parts of plants, one effective approach is the use of mineral fertilizers. Mineral fertilizers have been utilized for centuries to promote plant health in the soil, and they can also be employed to increase the accumulation of minerals in grains for nutritional purposes. Particularly, minerals like selenium (Se), iodine (I), and zinc (Zn), which have good mobility in both soil and plants, can be successfully increased using this method (Gomez-Galena *et al*., 2010). Another sustainable and economically viable strategy for enriching grains with micronutrients is foliar fertilization. Foliar fertilization involves applying fertilizers directly to the leaves of the plants. This method is particularly useful when mineral elements are not readily available in the soil or are not efficiently transported to the edible parts of the plant. Various studies have demonstrated successful biofortification of pulse crops, such as cowpeas, mungbeans, and chickpeas, with micronutrients like iron (Fe), zinc (Zn), and selenium (Se) through foliar application (Prasad and Narayanan, 2014). Ali *et al*. (2014) observed a 46% increase in iron concentration in mungbeans through foliar application of iron. Similarly, foliar application of iron and zinc significantly raised the levels of these minerals as well as protein in cowpea and chickpea seeds. 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.

**Plant Growth Promoting Rhizobacteria (PGPR)**

The use of plant growth-promoting (PGP) soil bacteria, such as Enterobacter, Bacillus, and Pseudomonas, can enhance the availability of micronutrients in pulses. These bacteria are commonly applied as seed inoculants and promote plant growth by producing growth hormones, antibiotics, chitinases, siderophores, and by inducing systemic resistance and mineralization. Several studies have demonstrated that microorganism inoculants and mycorrhizal associations can lead to increased concentrations of essential 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 found to improve nitrogen fixation, plant growth, and grain yield in legumes like chickpeas, soybeans, and peas (Kushwaha *et al*., 2021). Inoculation of PGP actinobacteria has shown to increase the seed mineral concentration, including Fe (10-38%) and Zn (13-30%) in chickpeas when compared to un inoculated plants. Similarly, field inoculation with Vesicular Arbuscular Mycorrhizae (VAM) fungi has been effective in boosting the nutritional profile of chickpea grains by increasing Fe and Zn content, as well as yield and protein content. Plant breeding is another approach to improve the nutritional levels in pulses while maintaining high yield and desirable agronomic traits. This process involves screening germplasm to identify genetic diversity, developing and evaluating micronutrient-dense germplasm, conducting genetic studies, and creating molecular markers to expedite the breeding process. Traditional plant breeding methods are particularly beneficial for populations, including those in rural areas with limited access to fortified foods. It requires an initial investment in plant breeding, but once developed, the improved germplasm can be propagated and grown by farmers at minimal additional cost over time. Recurring costs are relatively low, and germplasm can be sourced from various regions globally (Shahzad *et al*., 2021).

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**Foliar application of Micronutrients:**

The foliar spray of micronutrients such as Zinc (Zn), Iron (Fe), and Manganese (Mn) has been found to significantly increase crop yields. Among these micronutrients, Zn and Fe play crucial roles in influencing the plant's susceptibility to stress conditions. Iron is a key component of many plant enzymes involved in respiration, which is essential for energy production. Insufficient iron in plants can lead to significant changes in plant metabolism and induce chlorosis, particularly affecting young leaves. It also results in limited reutilization of resources within the plant. On the other hand, Manganese is considered an activator of various enzymatic reactions and is involved in the process of photosynthesis. By applying foliar nutrition of these micronutrients, plants showing signs of micronutrient deficiency can be specifically targeted. Foliar feeding allows for direct absorption of nutrients through the leaves, making it an efficient method to address deficiencies. Applying micronutrients before visible signs of deficiency appear can be beneficial in promoting more vigorous regrowth and maximizing the yield potential during critical growth stages. By enhancing the plant's resistance to environmental stresses, micronutrient applications can improve overall crop health and increase the potential yield of the crops.

**Biofortification: Enriching pulse crops with specific nutrients**

Bio-fortification is a process in which the nutritional value of crops is enhanced through traditional breeding techniques or biotechnology to address specific nutrient deficiencies in human diets. Pulse crops, which include various types of legumes like chickpeas, lentils, beans, and peas, play a significant role in improving nutrition and food security, especially in developing countries**.** Biofortification efforts are carried out through conventional breeding techniques or genetic engineering approaches. Researchers focus on identifying and utilizing genes responsible for nutrient accumulation and then cross-breeding or modifying crops to express these genes effectively. Promoting the consumption of biofortified pulse crops can have a significant impact on reducing nutrient deficiencies and improving overall public health, particularly in regions where pulses are staple foods in the diet. However, it is essential to conduct rigorous safety assessments and engage with stakeholders to ensure the successful adoption and acceptance of biofortified crops by local communities. Several nutrients can be targeted for bio-fortification in pulse crops, depending on the prevalent nutritional deficiencies in a particular region. Some key nutrients that can be enhanced in pulse crops through bio-fortification include:

**Iron:** Iron deficiency is a common nutritional problem worldwide, leading to anemia. Pulse crops can be bred to accumulate higher levels of iron in their seeds, making them a valuable source of this essential mineral. Iron (Fe) is a crucial micronutrient necessary for various metabolic processes in living organisms, including DNA synthesis and electron transport. It is essential for the production of oxygen-carrying proteins like hemoglobin and myoglobin, as well as for enzymes involved in oxidation/reduction and electron transfer. The recommended dietary allowance for iron is 18 mg/day for women and 8 mg/day for men, and iron deficiency can lead to anemia, affecting approximately two billion people globally and causing various complications like dizziness, fatigue, and poor pregnancy outcomes (Bailey *et al*., 2015). Iron concentration in pulse crops, such as common beans, peas, lentils, chickpeas, and mung beans, can vary significantly. Different cultivars of these pulses have been found to contain iron concentrations ranging from 47.7 to 80.7 mg/kg. A 100 g serving of these pulses can provide around 50% of the daily iron requirement based on the recommended dietary allowance. Researchers have identified accessions with high iron concentrations in chickpeas and mung beans, and these have been used to develop cultivars with higher iron content. Environmental factors, such as location and soil conditions, can also influence iron concentration in pulse crops. Genetic factors have been identified as contributing to iron concentration variations in different pulse crops, and marker-assisted selection using SNP markers has been used to target and improve iron content in lentils, chickpeas, and peas (Dissanayaka *et al*., 2020). Understanding and manipulating the genetic factors responsible for iron concentration in pulse crops can be essential for developing biofortified varieties with higher iron content, which could help combat iron deficiency and improve the nutritional value of these crops.

**Zinc:** Zinc deficiency can lead to various health issues, especially in children and pregnant women. Biofortifying pulse crops with higher zinc content can help combat this problem. Zinc (Zn) is a vital nutrient for humans, serving various biological functions. It plays a crucial role in wound healing, cell growth and proliferation, membrane signaling systems, protection against oxidative damage by reactive oxygen species, and may even help prevent certain types of cancer. The recommended dietary allowance for zinc is 8 mg/day for women and 11 mg/day for men. Zinc deficiency can lead to several consequences, including increased susceptibility to infections, weakened immune system, mental health issues, and impaired fertility and growth, particularly affecting women during pregnancy. Similar to iron, the concentration of zinc also varies significantly in pulse crops such as chickpeas, lentils, common beans, and peas. Different accessions and cultivars of these pulses have been found to contain varying levels of zinc. For example, in a study with 94 chickpea accessions grown in Canada, several accessions of both kabuli and desi types were identified to have the highest zinc concentrations. Additionally, zinc concentration variations have been observed in chickpeas, common beans, lentils, and peas grown at different locations in Saskatchewan. Genetic factors, including SNP markers and quantitative trait loci (QTLs), have been identified to be associated with zinc concentration in these pulse crops. For instance, QTLs for zinc concentration have been found in common beans, and specific Single nucleotide polymorphisms markers were identified for zinc concentration in chickpeas, lentils, and peas, associated with different chromosomes. These genetic markers could be utilized in breeding programs to develop pulse crop varieties with higher zinc content, contributing to improved nutrition and potentially reducing the risk of zinc deficiency-related health issues. Understanding and manipulating the genetic factors responsible for zinc concentration in pulse crops can play a crucial role in developing biofortified varieties, which could be an effective strategy to address zinc deficiency and enhance the nutritional quality of these crops.

**Protein:** Pulse crops are already known for their high protein content, but efforts can be made to further enhance their protein levels to address protein deficiencies in populations with limited access to other protein-rich foods. Legumes are known for being rich in micronutrients; however, they also contain antinutrients that can hinder the absorption of these essential nutrients. To enhance the bioavailability of micronutrients, it is crucial to minimize these antinutrients. A study explored the potential of inter-specific breeding, which involves crossing two species from the same genus, to improve the protein quality of mungbean. Mungbean, with a relatively low methionine content of 0.17 g/kg, was crossbred with black gram, which has a high methionine content of 1.8-2.0 g/kg. The results showed that this breeding significantly improved the protein quality of mungbean. The resulting hybrid variety, known as BC1F2, contained γ-glutamyl-S-methyl-cysteine and γ-glutamyl-methionine, which are dipeptides found in mung bean and black gram, respectively. This inter-specific breeding approach proved effective in increasing the protein content of mung bean and could be a valuable method for enhancing the nutritional value of legumes.(Nair et.al, 2013)

**Folate:** Folate is a B-vitamin essential for proper cell division and growth. Pulse crops can be biofortified to contain higher folate levels, particularly to support maternal and child health.

**Vitamin B6:** Also known as pyridoxine, vitamin B6 is vital for metabolism and nerve function. Biofortification of pulse crops with vitamin B6 can contribute to better overall health.

**Vitamin A:** While pulses are not natural sources of vitamin A, they can be biofortified with provitamin A carotenoids, which the body can convert into vitamin A. This can be beneficial in regions where vitamin A deficiency is a significant public health concern.

**Conclusion and Future scope**

The global population's rapid growth and increasing food demands present challenges in providing nutrition-rich diets. Food sustainability, a key sustainable development goal (SDG), involves producing foods that meet dietary requirements and future availability. Pulses, such as chickpeas, lentils, beans, and peas, play a crucial role in addressing these challenges by serving as dominant and plant-based primary protein sources in human diets. They offer various nutritional and physiological benefits and contribute to improving protein malnutrition in underdeveloped and developing countries. Pulses are rich sources of proteins, carbohydrates, dietary fibers, and bioactive compounds like flavonoids, phenolics, tannins, and phytosterols. These phytochemicals have anti-inflammatory, anti-ulcerative, anti-microbial, and anti-cancer effects, making pulses highly beneficial for overall health. Additionally, pulses play a significant role in weight management, blood sugar stabilization, and improving insulin resistance. Increasing the variety of pulse crops grown in a region helps diversify the agricultural landscape. Different pulse species and varieties have distinct traits, such as drought tolerance, disease resistance, and adaptability to specific environments. By promoting diversity, farmers can mitigate the risks associated with climate change, pests, and diseases. Pulse crops are rich in essential nutrients such as protein, fiber, vitamins, and minerals. Enhancing agro-biodiversity by cultivating a wide range of pulse crops can improve the nutritional diversity of diets, contributing to better food security and improved public health. Climate change brings about uncertain weather patterns, increased temperatures, and altered pest dynamics. A diverse range of pulse crops can be more resilient to such changes, as some varieties may perform better under specific climatic conditions, ensuring a stable food supply for communities.

 Despite the importance of pulses, there are significant research gaps in various aspects, from genetics to nutritional research. To promote the incorporation of pulses in diets and design effective nutritional programs, more analytical compositional data on pulse-based foods is needed. Regular updates of food composition databases with diverse pulses, especially including micronutrients, are urgently required. Global collaboration and sharing of pulses-specific data among researchers and scientific journals can enhance the FAO/INFOODS Analytical Food Composition Database. The yield potential of pulse crops is lower compared to cereals, making them less remunerative for farmers and less affordable for consumers. The green revolution, which focused on cereals, had minimal impact on the pulses sector. To break the yield barrier in pulses, research in developmental biology, photosynthesis, canopy enhancement for solar radiation capture, and source-sink relationships is needed. Efficient protocols for pulse transformation should be developed to utilize new breeding techniques like genome editing. Increasing pulse production and consumption is crucial for providing affordable nutrition to the masses and promoting environmental sustainability. Addressing research gaps and intensifying efforts in pulse-related studies can lead to significant advancements in global food security and nutrition.

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