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# Challenges and Opportunities for the Global Cultivation and Adaptation of Legumes B. Opportunities for Increasing Legumes Production and Availability

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## Abstract

Legumes cultivation is subjected to different constraints, which reduce productivity, particularly effects of global warming, and other constraints. While the large diversity of legumes play an important contributing role to food and nutrition security by the sustainable agriculture (crop and livestock systems) and food systems worldwide.

Improving legumes production needs numerous strategies achievement proper production for humanity. Through different ways that include policy creativities to encourage legume cultivation, produce legume varieties adapted to changing climatic conditions. In addition to using proper agricultural strategies to increase the availability of legumes like increasing annual cultivation by both horizontal extensions by increasing planted area and reclamation the poor soil and using intensive planting system as a Vertical development tool. Besides, planting legumes with other crops in the intercropping system, as well as involving legumes into the annual agriculture system, improving postharvest processing to minimize crop losses. Furthermore, using modern technology in agriculture like smart agriculture to increase legumes productivity. There are many health benefits to legume crops due to their component, particularly protein, which reaches two or three-fold as in other crops such as cereals, which contain less than half of the protein in legumes. In addition to carbohydrates, folic acid, fibers, also, legumes are considered low-fat seeds. In addition, to using leguminous crops as fodder resources for animals both directly and as a part of different feeds for livestock and poultry.

**Keywords:** Fodder; Horizontal extensions; Legumes; Protect environment; Smart agriculture

## Introduction

Leguminous crops considered one of healthy food for humanity due to their valuable component, such as protein, carbohydrates, folic acid, fibers, in addition, legumes seeds are low fats foods, and therefore, legumes are very important crops worldwide [1]. There are numerous legume species growing in different regions globally, about 1300 species approximately, while, the consumed not more than 20 species, however, the common dry bean (Phaseolus vulgaris) is considered the first legume crop consumed worldwide [2]. Under continuous increment in world population which a combined with harsh climate change conditions that affect drastically on legumes crops particularly in arid and semi-arid regions, consequently, legumes production facing a very crucial situation. Therefore, there is more attention worldwide for new strategies to improve legumes production to provide food requirements for humanity [3].

Improving legumes production needs numerous strategies achievement proper production for humanity. Through different ways that include policy creativities to encourage legume cultivation, produce legume varieties adapted to changing climatic conditions [4]. Using smart agriculture application to increase crop productivity and fighting poverty particularly in developing countries [5]. Moreover, leguminous crop are one of the main fodder for different animals, whether as green manure or as an essential components of different types of animal feed [6]. In addition, leguminous crop play important role in agricultural biodiversity agricultural biodiversity.

Developing leguminous crop productivity and availability requires using proper agricultural strategies to encourage the farmer to plant legumes. On another side, including pulses into the agricultural rotation as part of the annual crop system provide numerous advantage for soil, feed. In addition, legumes cultivation could be decreasing the adverse effects of environmental stress by fixing atmospheric nitrogen in the soil, which improves soil fertility and sustains agricultural productivity [7,8].

Legumes need more attention to be a part of the cropping system to produce enough food, nutritional security by the abolition of starvation especially in developing countries [9].

Figure 1. Explained the importance of the leguminous crops in different agricultural activities, both as a part of human food, or as fodder for livestock and poultry, and improve soil properties. Legumes represented the second consumed food crop after cereals worldwide. There is growing interest in pulses and a large number of people consume pulses as a staple food with grains as cheap source




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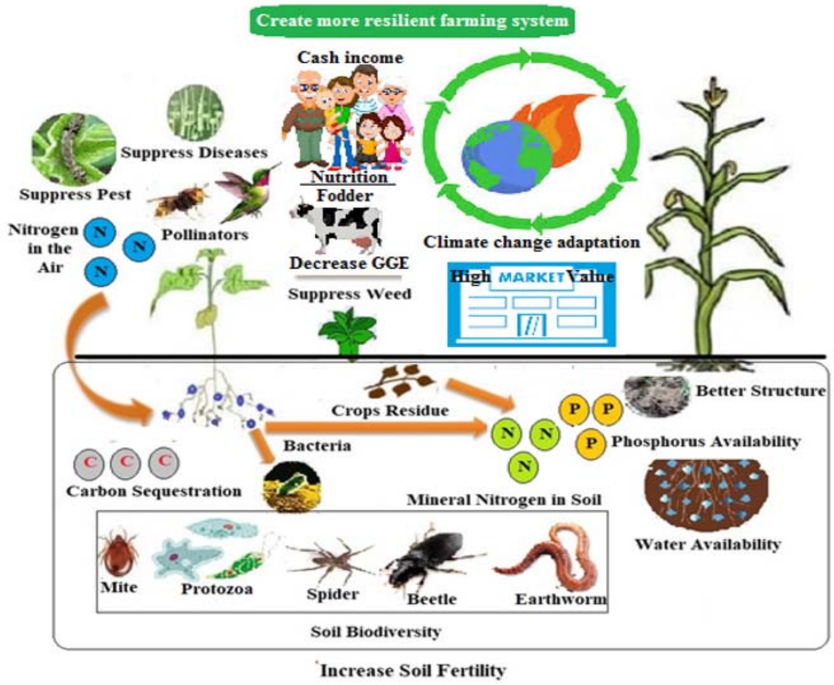


**Figure 1:** Importance of legume crops in agricultural biodiversity (Prepared by Abobatta WF, El-Hashash EF and Hegab RH).

to meet their protein needs. Pulse protein accounts for a relatively large proportion of total protein consumption in low-income countries, ranges from 10 to 35% in Africa [10]. Thus, the legumes could contribute significantly to the existence of different types of food for rural families in poor areas of developing countries and underdeveloped nations if consumed as a complement to starchy diets [11,12] (Figure 1).

The legumes crops are keystone species in generating observed biodiversity impacts on ecosystem processes, which depends on natural resources such as fixing nitrogen to enhance soil fertility and minimize the use of chemical fertilizers and preserving natural resources [13].

Climate change conditions that accompanied with economic slowdowns increasing the adverse impact on the agro-ecosystem which increases food insecurity [14]. Therefore, are more needs to produce more leguminous crops in the coming decades, this increment could be through various directions like the horizontal expansion of the arable areas with legumes crop, multiple intercropping systems with other crops, and reclamation of desert lands [15].

Moreover, Genetic diversity is important for plant breeders because it provides an opportunity to develop new varieties with desirable characters for improving productivity [16].

According to FAOSTAT [17], the cultivated area of legume crops reduced in the last decade compared to cereal crops, while, the production of legume crops can be increased through the horizontal expansion of the arable areas of legume crops in two directions, increase the area harvested (multiple intercropping systems and crop rotation cycle) and reclamation of desert lands.

The legumes crops benefits in intercropping can be exploited at cereal-dominated crop production systems to their increase area harvested, these benefits classified into nitrogen-fixing effect and crop impacts such as increasing the ability of ecosystems to reduce weed growth and minimizing the spreading of various pathogens[18].

This works aims to discuss developing an action plan to increase the production and availability of legumes.

## Factors Affect Legumes Productivity

There are many factors limit production of legume crops in both large-scale modern farming systems and small labor-intensive farm systems in developed and developing countries respectively (Figure 2). For example genetic, socio-economic, soil and climatic constraints, technological and institutional constraints (Figure 2), also low investment and failure of breeders to produce improved varieties, in addition to the widening gap in production between legume crops inside and outside the countries of the world, especially developing countries. The production of legume crops is oftentimes limited in area, which limits contributions to the cycling of agricultural nutrients and sustainability although the legume crops occupy a minimal part of arable land.

## How to Increase Legume Production and Availability?

There are large diversity benefits of leguminous plants, besides their important contributing role in food security by the sustainable agriculture (crop and livestock systems) and food systems in the world, especially for poor rural communities in the semi and arid regions [19].

During the past two decades, the pulse production increased because it has been broad-based across pulse crops and major

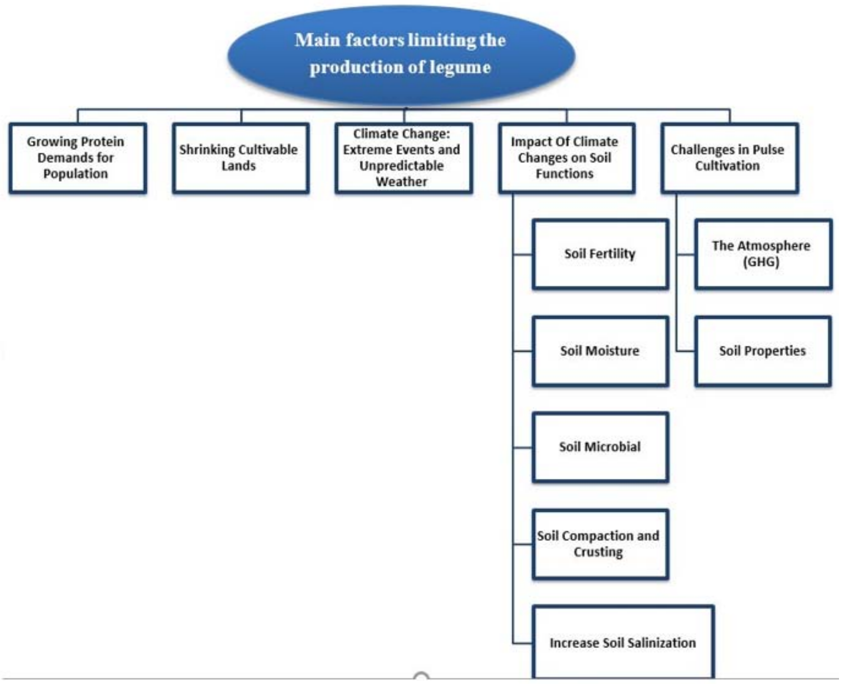


**Figure 2:** Main factors limiting the production of legume (Prepared by Abobatta WF, El-Hashash EF and Hegab RH).

**Table 1:** Area harvested, yield level and production of grain legumes compared to major cereal crops worldwide (2019).

| Crop | Area harvested (million ha) | Yield level (MT/ha) | Production (million MT) |
|---|---|---|---|
| **Grain Legume Crops** | | | |
| Bambara beans | 0.25 | 0.62 | 0.23 |
| Beans, dry | 33.07 | 0.87 | 28.9 |
| Beans, green | 1.65 | 16.36 | 26.98 |
| Chick peas | 13.72 | 1.04 | 14.25 |
| Cow peas, dry | 14.45 | 0.62 | 8.90 |
| Groundnuts, with shell | 29.60 | 1.65 | 48.76 |
| Lentils | 4.80 | 1.19 | 5.73 |
| Lupins | 0.89 | 1.14 | 1.01 |
| Peas, dry | 7.17 | 1.98 | 14.18 |
| Peas, green | 2.78 | 7.82 | 21.77 |
| Pigeon peas | 5.62 | 0.79 | 4.43 |
| Pulses nes | 6.00 | 0.76 | 4.55 |
| Soybeans | 120.50 | 2.77 | 333.67 |
| Vegetables, leguminousnes | 0.25 | 6.27 | 1.57 |
| Vetches | 0.42 | 1.83 | 0.76 |
| **Major Cereal Crops** | | | |
| Wheat | 215.90 | 3.55 | 765.77 |
| Corn | 197.20 | 5.82 | 1148.49 |
| Rice | 162.06 | 4.66 | 755.47 |

producing regions but until now (Table 1), the cultivated area with legumes is still much less compared to other crops, especially cereal crops such as corn, wheat and rice.

In 2018, the world production was 92.4 million MT of pulses [20], while was 2625 million MT of grains crops [21].

The total harvested area, yield, and production of soybeans (Glycin max) which represents the most important type of cultivated legumes, reached 126.87 million ha, 2.92 MT/ha, and 370.40 million MT worldwide in August 2020, respectively. While, The total area harvested, yield and production of wheat (221.33 million ha, 3.46 MT/ha and 766.03 million MT, respectively), corn (196.14 million ha, 5.97 MT/ha and 1171.03 million MT, respectively), and rice (162.37 million ha, 4.60 MT/ha and 500.05 million MT, respectively) were higher than soybean [21]. With the increase in the global demand for legume crops, their production can be increased by horizontal expansion in areas, vertical expansion, reducing post-harvest losses, and policy initiatives (Figure 3), where it is likely that the integration among these points leads to an increase in production for these crops.

## Horizontal expansion in areas

The arable area of legume crops reduced compared to cereal crops, as mentioned above (Table 1). The production of legume crops can be increased through the horizontal expansion of the arable areas of legume crops in two directions, increase area harvested (multiple intercropping systems and crop rotation cycle) and reclamation of desert lands [22].

Due to horizontal expansion of lands is not an option for use in densely populated regions [23] and the arable crop area is limited or if there are several crops products competing for the same area [24]. Multiple intercropping systems and crop rotation cycle can be used to increase the production of legume crops. For example, in summer rest, diversification of rice-based cropping systems with the inclusion

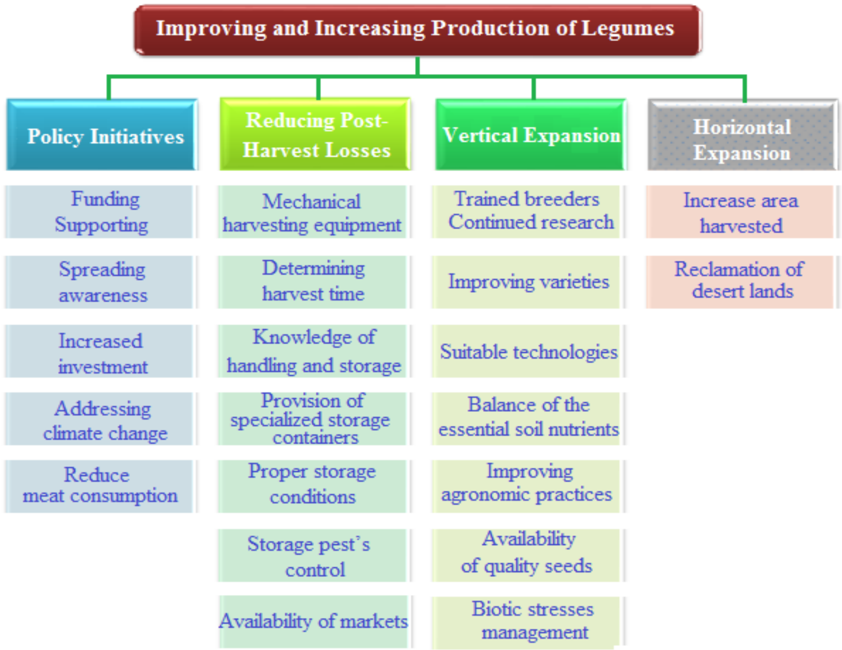


**Figure 3:** Required actions of improving and increasing of legume crop production (Prepared by Abobatta WF, El-Hashash EF and Hegab RH).

of legume crops is an option for horizontal expansion [25]. Also, the use of leguminous crops within the agricultural cycle increase other crops productivity, for instance pulses were used as one of the crops in the crop rotation as a beneficial and attractive scenario for large farms at different regions of North America, Australia and Canada [26]. The methods by which legume crops can be included must be adapted to both local multiple intercropping systems, legume varieties, and products with potential for expansion in Europe and World [27].

In India, around 4 million hectares of land were allocated for production of chickpea between 2011 and 2014, because of the transformation in the chickpea production conditions [26]. Also, in Sweden, the total area for growing pulses will be increased from 2.2% (current level) to 3.2% of arable land, which is technically feasible as there will be a net surplus of about 21,500 hectares that can be used to produce bioenergy, produce crops for export, and conservation of nature, as well as reducing the impact of climate changes [28]. The invasion of legume crops into the desert increased their production, where in sub-Saharan Africa; there was a significant increase in the production of some pulse crops like cowpeas and common bean [26].

## Vertical expansion

The increasing population is affecting food security due to pollution, global warming, industrialization, and the expensive of fertilizers affected negatively on soil health [29]. For agricultural sustainability, soil sustainability research must be increased, where, the soil is an alive body that contains biological, physical, and chemical properties [30]. Cultivation of legumes in an important agriculture rotation, where there are many benefits of legumes and their role in soil sustainability, increase the SOC, improve in the N release, and increase the yield of succeeding crop [31]. So, it must be included in the cropping system either in sequential (horizontal) or intercropping (vertical). The genetic and agricultural innovations to resource-poor farmers are increasing the production and profitability of legumes [32].

The use of high levels of technology for instance "Precision agriculture tools" leads to increased production in huge industrial farms in developed countries, unlike smallholder production. In addition, increasing use of enhanced varieties of seeds, inoculants, chemicals, and machines used to prepare the land, protect plants and harvest increase pulses productivity, though, the growth in legume productivity is also due to smallholder farms in developing countries such as India [26]. Therefore, In order to obtain the maximum yield of pulses, a balance must be struck in the essential nutrients of the soil necessary for their growth and reproduction [33].

One of the most important elements of the vertical expansion of legume crops in the presence of a new generation of well-trained breeders [34]. Breeding programs can be led to the improvement of production and quality of legume crops by effective and integrated use of all the tools of conventional breeding, biotechnological techniques, and germplasm resources in legume crops. The efficient breeding programs of pulses are aimed to develop new improved varieties with high yield, yield stability, early maturity, biotic stresses resistance (weeds, pests, and diseases), abiotic stresses resistance (drought, salinity, and temperature), efficiency of water/nutrient use, suitability within farming systems (such as engineering mechanized plants and animal feed), challenges of nutrition (such as high-iron varieties for therapy anemia), and valuation of untapped legume species [26]. In addition, plant breeders are concerned with reducing the negative effects of agriculture, improving the natural environment for the provision and maintenance of ecosystem services (like clean of soil, water and air, as well as carbon sequestration). As well as creating new agricultural models, moreover, farmers have an interest in improving the environment of natural to provide and protect/maintain

**Figure 4:** Field image of intercropping of legumes with corn cultivation under Egyptian desert conditions, Ismailia district. (Photo by Abobatta WF, El-Hashash EF and Hegab RH).

services of ecosystem and to create new agricultural paradigms [35]. Therefore, it should be improving one character does not adversely affect another character/characters.

### Intercropping green manure legumes with cereal

Planting two or more crops at the same time and piece of land during growing season, it called intercropping [36,37]. Where, this practiced increases natural regulation mechanisms, biological diversity, and reducing climatic change [38]. In general, intercropping between different crops, which the chief crop for food production and secondary crop for providing additional benefits like N-fixation, increase soil microbial, and improve soil fertility. The objective of Intercropping leguminous with a non-leguminous is to produce more yields from the same field and increased natural resources' efficiency compared to single-cropping [39]. Where Legumes improve soil properties from the symbiosis of legume-rhizobia [40]. Moreover, intercropping with legumes, for instance like corn (Figure 4), considered beneficial for soil by reducing soil erosion, improving soil processes [41], reduce the input of N in agroecosystems and reduce mineral N fertilizer [36], reducing $N_2O$ fluxes, that decrease the environmental pollution, and decreasing $NO_3$ leaching and $N_2O$ emission [15].

**Intercropped with vegetables:** It could be recommended that the intercropping vegetables with legumes, like plant tomato and cowpea at a density of two rows to one row respectively). These patterns produce a better economy than the sole cropping of each of the individual vegetable [42].

**Under trees:** Now, planting legumes crops such as bean under various trees like a Date palm, orange, and pears particularly in the juvenility stage to, improve soil fertility and increase fodder production [43].

### Crop rotations

Leguminous cover crop rotations increase productivity, breaking pest cycles, reducing using chemical fertilizer, increasing soil microbial, improve soil fertility, and prevent soil erosion due to their N-fixation and increasing soil microbial [44-46] and can be adapted to any legume-based cropping system [47]. While incorporated legume in soil provides N to following crops depends on the quantity of N-fixed [37,48].

### Newly reclaimed desert land

Leguminous cover crops may be planting on the sharp soil to control soil erosion, like, Clover (*Trifolium alexandrinum*) because of its ability to cover the ground quickly [49].

### Reducing post-harvest losses

Economically, Value chains of post-harvest are a critical component of the pulses in the world [26]. Before being ready for homes or industrial use, legumes undergo several post-harvest processes as threshing, winnowing, cleaning, drying, sorting, splitting, dehulling, milling, and fractionating. Agricultural processing increases shelf life, reduces losses, and can increase subsistence farmers' income, the availability of pulses markets leads to an increase in the production of pulses crops through the speed of their sale [50].

## Policy Initiatives

Food security are a complex task and required promote with multiple policy actions that include environmental, economic, political, cultural, and social dimensions (Figure 5). Brüssow et al., [51] mentioned that to achieve or maintain achieve food security must be provided four components i.e., availability, access, utilization, and stability. The legume crops are a multifunctional strategy for food security and health, thus they can be included in food security and safety programs due to excellent several nutritional, agronomic, environmental, and economic advantages [52].

A set of policy actions helped increase the area planted with legume crop in some European Union countries [53]. For example, policy actions to increase production, processing, and consumption

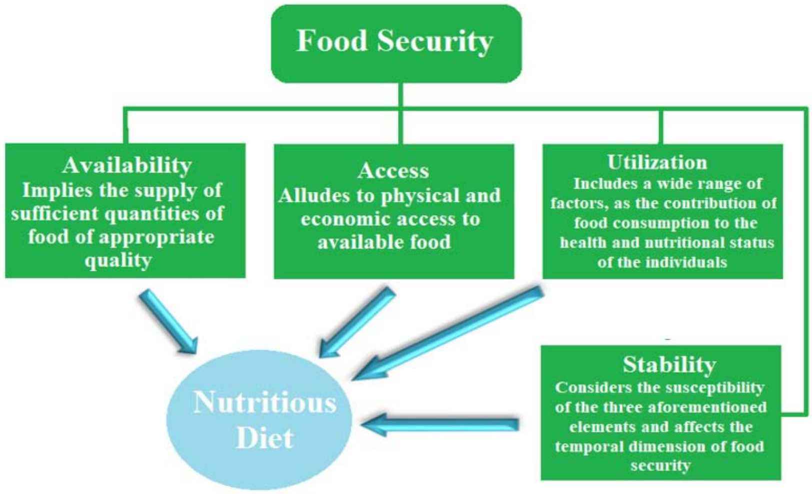


**Figure 5:** Food security components (Prepared by Abobatta WF, El-Hashash EF and Hegab RH).

of pulses and reduce meat consumption [28]. Governments should provide the necessary financial support to provide the requirements for the production, processing, and consumption of pulse crops, especially in developing countries. Among the most important policy measures that can be followed is to increase support for smallholder producers, in financial and scientific terms, by providing improved new technologies and inputs, and the availability of financing, credit, and insurance facilities, as well as increasing investment in research, development, and extension activities, thus increasing the production of legume crops by 1.8% over the coming decade [26]. Therefore, policy actions that lead to discontinuities among research, extension, and farmers' practice delay the flow of new and improve technique to the farmers [32]. Also, correct policy actions will lead to reduced consumption of meat in all its forms, increased production of local pulses and proper processing of them, as well as consumption, to a successful transition to more sustainable and healthy vegetarian diets [28].

## Virtual Learning Information and Communication Technology for Technology Transfer

The required acceleration in the growth of crop productivity is obstructed by degeneration of available natural resources, loss of important biodiversity, and the prevalence of Trans boundary pests and diseases affecting both plants and animals, some of which have already become resistant to antimicrobials [54]. As we mentioned earlier that, the progress in the breeding and improvement of leguminous crops was relatively slow, where the investment in programs of breeding research for legume crops has remained at a very low level, unlike for other crops such as wheat, rice, corn and cotton,

The use of agricultural strategies can improve productivity in the short term by improving farm management practices such as seeding timing, seeding intensity, cropping cycle, intercropping, and introducing of new complementary crop systems for grains and pulses [26], as well as development and sustainability of production technologies such as identifying suitable agronomic varieties, soil fertility, improved irrigation facilities, mechanized harvest, and natural resources conservation.

## Future Needs of Pulse Research

Legume crops can be developed for future exploitation, where the legumes provide many direct and indirect benefits in agriculture, health, feed, environmental protection, and fuel. The research efforts of legume crops should be directed in five directions: financing, breeding, production, farmers, and marketing. Provide financing for legume crops improvement as availability of credit, insurance facilities, besides working to increase support for scientific work and knowledge transfer activities to legumes farmers, also, technology could play different roles in improving legume production under climate change and the increased global food demand, using precision agriculture tools could help farmers to overcome different negative impacts of many problems, which contributes to increasing productivity and improving farmer's profitability and protects the environment [5]. So, serious and fruitful investment in development and innovation research in order to create new, distinct and sustainable agricultural processing facilities large-small in scale of legumes for the marketing process [33].

Future research for legume green manures is needed on the following topics:

a) The previous studies established the benefits of green manures on soil physical, chemical, and biological properties. However, their application to the farm level is still at a limited stage.

b) Interest in the cultivation of crops with legumes in the same season and in the free vegetation period

c) Awareness farmers about the importance and role of legumes in terms of fertilizer saving, water saving, increase in crop productivity, and improve soil health,

d) Find out alternative techniques like brown manuring of legume crops by growing intercropped, which can save time as well as the need for incorporation.

e) Production of biotic or abiotic stresses tolerant cultivars

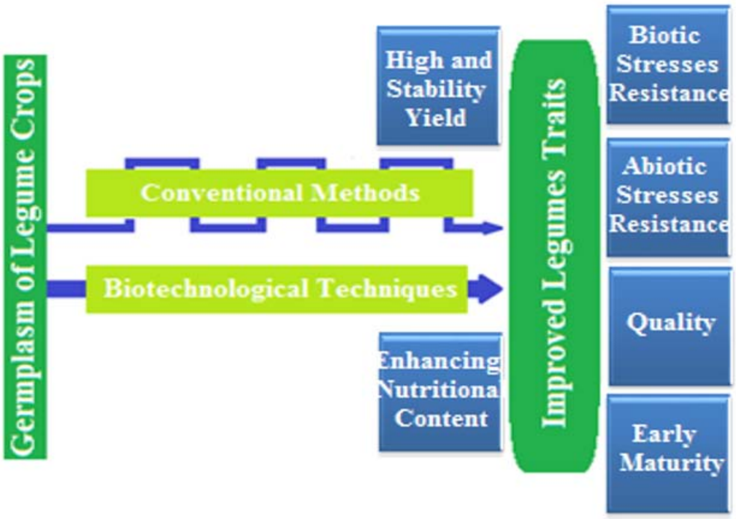


**Figure 6:** New directions of improvement in the legume crops (Prepared by Abobatta WF, El-Hashash EF and Hegab RH).

with the ability to adapt to changing climate is needed to meet the increasing demands for food, forage, wood, through genetic and genomics-assisted breeding and biotechnological approaches.

f) There is a crucial need to produce drought and salinity tolerance and pests and disease-resistant legumes varieties for arid and semi-arid regions.

Farmers need more training in various management practice includes i.e., prepare suitable soil for planting, sowing and harvesting in a timely manner, use of varieties resistant to biotic and abiotic stresses, application of agricultural fertilizers, and other agricultural practices. As well as they must also be better trained and knowledgeable so that they are able to estimate gains, dangers, differences in crop yields and costs of opportunity in order to introduce pulses crops in their cropping systems at own farm [26]. The number of grain legume products in the market is 1/3 the cereal products number [55]. To increase grain legume utilization and value chains (e.g. market requirements), a product diversification strategy could be employed that is highly dependent on agro-processing as a strategy to market grain legumes, as well as provide value-added products that will attract a wider market and that will sell faster, this is the main goal of strategies to mitigate food and nutrition security [33].

Conventional breeding techniques are time consuming and often very imprecise and unsuitable for enhancing the plant genome to develop new plant varieties [35], thus biotechnology can be used in the breeding of legume crops to provide thrilling opportunities to overcome the many limitations of traditional breeding and supply access to more diverse sources of genes as well as for selecting and improving genotypes (Figure 6). In contrast to conventional plant breeding, the biotechnology methods for genetic modifications work effectively at the molecular, protoplast, cell, tissue and organ levels.

In the future, decision-makers, breeders, and everyone involved with leguminous crops must work in full coordination to develop and improve leguminous crops, and raise awareness of the nutritional and health benefits of food products that mainly based on legume crops to meet the biggest and most important challenge represented by the increasing global request for food in the future. Furthermore, legumes can be considered important crops for research, development and innovation towards food and nutritional security in addition to the social and economic development benefits of rural areas as these species are abundant obtainable there [56]. Major and effective investment in legume crops research is necessary and critical to revitalizing improvement programs in each region of the world, ranging from equipping breeders with knowledge of appropriate techniques for improvement to providing producers with improved varieties of grains, especially for unexploited varieties of legume crops [57].

## Accelerating in Genetic Gain

The immense genetic diversity of legume crops is a genetic gain to increasing their productivity, quality, and profitability through breeding techniques. The biotechnology methods are complementary to conventional methods of efficient and precise crop breeding [58]. For example, molecular Marker-Assisted Breeding (MAB) has tremendous potential for improving traditional crop breeding and making it more efficient and proper. In legume crops, conventional breeding can benefit from the use of biotechnology like transgenes and molecular technologies for various tasks to smooth programs without mixing foreign genes into the bred cultivar. Also, tissue culture and micropropagation can be used to beat reproductive barriers (such as abortion of embryos) with being able to produce fertile haploid plants [59]. A revolution in molecular plant breeding has occurred in the 21$^{st}$ century, resulting in improved yields of crops based on genomics, molecular marker selection, and traditional plant breeding practices [60].

Pulses genetic and genomic resources are important and strategic tools currently subject to the application of molecular and genetic engineering techniques. Providing full knowledge and opportunities to smooth identification of specific germplasm, trait mapping, and allele mining for more effective and resistant of biotic and abiotic stresses as well as premium quality grains for food and forage [52]. Plant breeding is a strong tool to improve legume crop characteristics, to achieve harmony between agriculture and the environment as well as to improve the species for sustainable agriculture utilization, so that the crop are more eligible healthy, agronomically, environmental, and economically. Genomic and genomic methods can be used as innovative tools in the breeding of legume crops to increase resistance to biotic and abiotic stresses, increase seed size, enhance nutritional content as well as nitrogen fixation capacity. Genetics can help produce a sustainable plant protein to feed a growing population amidst the challenges brought about by changes of climate [57]. Both nutritional and market characteristics are considered as genetic gains that will increase the profit of farming and provide low-cost nutritious food in the world, especially in developing countries [61].

## Conclusion

Leguminous crops are one of the essential crops for humankind, due to nutrition values, also, legumes play important role in food security and fodder for livestock and poultry. There are different factors affecting the production of legumes. Moreover, the large diversity of legumes play an important contributing role to food and nutrition security by the sustainable agriculture (crop and livestock systems) and food systems worldwide. Legumes have numerous health benefits due to low-fat contents and their content, like high protein, which reaches two or three-fold as in other crops, folic acid, and fibers. As well as, legumes improve soil properties and encourage diversity in the rhizosphere areas, and protect the environment. There are different strategies to improve legumes production to achieve adequate pulses production for humanity, such as policy decisions to encourage farmers to plant legumes, breeding legume varieties to tolerate various environmental stress. Furthermore, using agricultural practice management improves the availability of legumes such as increasing annual planting crops by both horizontal extensions and Vertical development tools like intensive cultivation system, planting legumes with other crops in the intercropping system, like corn, vegetables, and within fruit trees.

Legumes have numerous health benefits due to their content, like high protein, which reaches two or three-fold as compared to other crops, folic acid, and fibers.

There are different strategies to improve legumes production to achieve adequate pulses production for humanity, such as policy decisions to encourage farmers to plant legumes, preeding new legume varieties to tolerate various environmental stress. Furthermore, using agricultural practice management improves the availability of legumes such as increasing annual planting crops by both horizontal extensions and Vertical development tools like intensive cultivation system, planting legumes with other crops in the intercropping system, like corn, vegetables, and within fruit trees.

Besides, involving legumes into the agricultural rotation system, enhancing post-harvest processing to minimize crop losses through using new harvesting techniques. Furthermore, using precision agriculture practice in legumes cultivation increase productivity.

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