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Challenges and opportunities for the global cultivation and adaption of legumes

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Abstract

There are many challenges facing the cultivation of legumes that lead to lowering productivity, making it unattractive for cultivation in different areas worldwide. Which include genetic, socio-economic restrictions, in addition to institutional constraints, environmental conditions, besides the technological restrictions. Genetic constraints, affect the production and breeding of leguminous crops due to difficulties of crossbreeding cultivated and wild species. Climate change conditions represent another factor pressure legumes production that requires the urgent achievement of agronomic and genetic practice. Legumes need more attention in the near future to improving productivity and provide the required food needs for the population around the world. There are various ways include policy initiatives to promote food security. Produce legume varieties adapted to changing climatic conditions of heat and drought considered essential factors to legume production worldwide. Furthermore, developing the production and availability of legumes through using proper agricultural strategies to increase annual cultivation whether by horizontal expansion through increasing cultivated area and reclamation of desert lands or by Vertical expansion and intensifying cultivation as well as intercropping legumes with other crops and introducing legumes into the agricultural rotation, reducing postharvest losses, in addition to using technology. On another side, including pulses into the agricultural system as part of the crop system, provide many direct and indirect benefits in agriculture, health, feed, also, contributes to reducing the negative impacts of climate change, protecting the environment, and sustain legumes productivity.

Keywords: environment conditions, genetic restrictions, legumes, protect environment, socio-economic restrictions

Introduction

Legumes one of the essential crops for humanity, there are more than 1300 legume species growing worldwide. Whereas, only 20 species are consumed by humans, due to higher content of protein, fibers, carbohydrates, and low fats. Protein contents in legumes two or three folds than cereals, whereas, common dry bean (*Phaseolus vulgaris*) representing the largest quantity consumed of legumes globally.[1] In addition, legumes use as animal feeds directly or as main components for various animal feeds, also, legumes improving soil characters by fixing atmospheric nitrogen in the soil. 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, as well as, legumes are very important for sustainable soil fertility.[2]

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 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.[3] 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.[4,5] 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.[6]

There are various challenges facing legume cultivation and productivity include genetic, socio-economic, soil, climatic constraints. Soil and climatic constraints, technological, and institutional constraints that reduce the yield of legumes, which limit the farmers' willingness to cultivate more areas. Genetic diversity is important for plant breeders because it provides an opportunity to develop new varieties with desirable characters for improving productivity.[7]

Due to climate change conditions that accompanied an increase in the global population, economic slowdowns increasing the adverse impact on the agro-ecosystem which increases food insecurity.[8]

Whereas, the limited use of inputs, unavailability of adequate seeds, and the lack of knowledge of different types of legumes, in addition to poor extension services considered the main socio-economic constraints to pulses production.[9] There are other constraints such as lack of adequate output markets for legume crops, post-harvest losses, and costs. Furthermore, there are adverse effects of global warming on the productivity of legumes that have been decreasing for the last few decades despite growing cultivated areas.[10] Moreover, institutional constraints increase the weakness in the pulses production sector as it adversely affects the productivity of leguminous, like in some sub-Saharan countries that increase the losing confidence between various actors in this sector.[11] Due to more growth of population, there 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.[12] According to FAOSTAT,[13] 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.[14]

This works aims to discuss challenges facing legumes cultivation, which include biotic and abiotic stresses, socio-economic constraints, technological constraints, institutional constraints. Furthermore, developing an action plan to increase the production and availability of legumes.

Results and discussion

Current availability and future target of legumes

There are major issues affecting global legumes production including genetic, socio-economic, soil, climatic constraints, technological, and institutional constraints that lead to depressed grain legumes yields. Thus have made them unattractive to agriculture for farmers. Legume crops are one of the basic ingredients of global food security and agricultural biodiversity as shown in Figure 1. Where legume crops provide food with its various components of carbohydrates, protein, fatty acids, dietary fiber, vitamins, and elements such as iron and zinc, fodder, as their vegetative materials are rich in protein, fiber, and vitamins. In addition, they are a source of cash income (intercropping systems), improved soil fertility (fix atmospheric nitrogen), suppress biotic and abiotic stresses, the environment preservation and create more resilient farming systems. Thus, the legume crops are one of the basic components of the intensification of agroecological, which it uses the principles of ecological to promote agricultural productivity in addition to maintaining agroecosystem services and working to increase them.[15] Due to the many benefits of legume crops, we must recognize the constraints facing the cultivation and use of these crops and work to solve them.

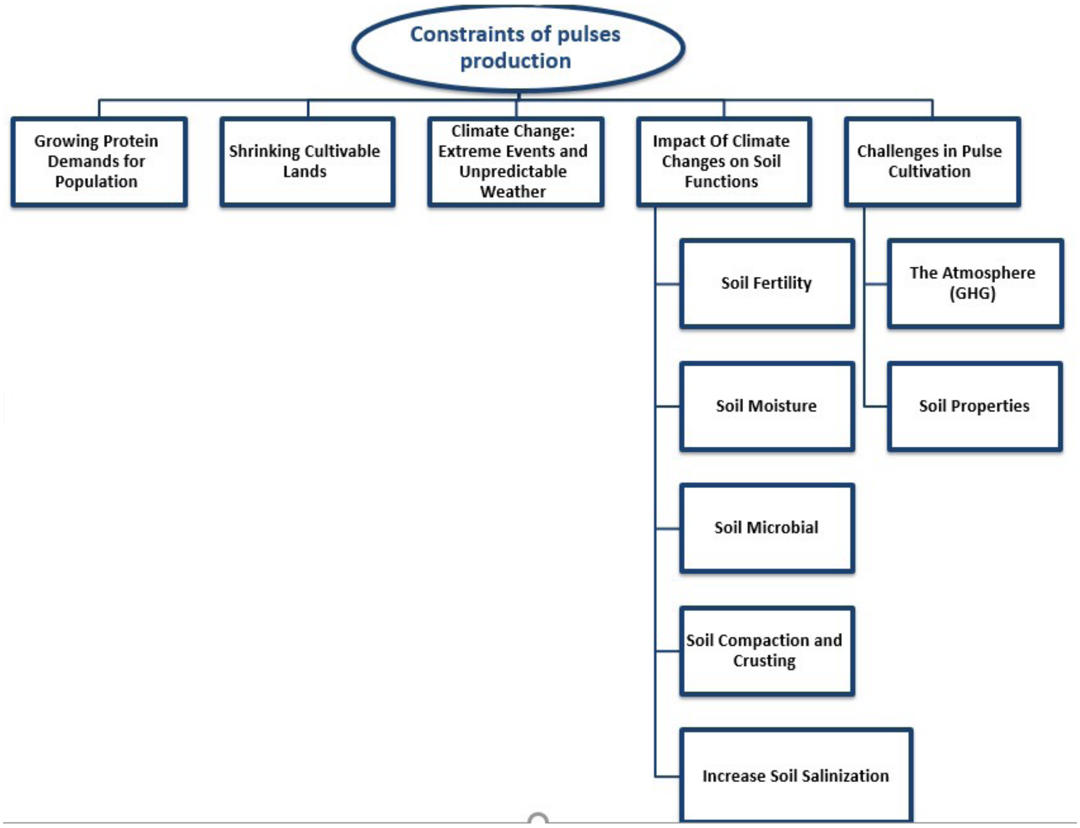

Figure 1 Main constraints facing pulses production.

Challenges in legumes cultivation

Growing protein demands for population:

Due to the growing world population, there is increasing in the demand for food production raised the issue of available resources.[16] Natural resources depletion and climate change has continuous potential to reach the required level of food production. In 2050, food security with the goal of high nutrition and yield productivity is a major challenge for the researchers and the agricultural community.[17] High protein intake is essential for the growth of infants and children as well as for building muscle and facilitating cell repair and replacement among adults and especially the elderly.[18]

Pulse contain high amounts of protein, carbohydrates, dietary fiber, vitamins, omega-3, fatty acids, and certain important micronutrients (e.g. Fe, Ca, Zn, Mg, folate and tocopherols). The protein content of grain legumes depends largely on the type of legume, species, cultivar, and growing.[19] In addition to noting that protein content had a negative relationship with yield, seed size, starch and oil content, also, according to germination and fertilizer application, the protein content and amino acid composition differ.[5]

Diets system of humans in most developed nations contains far too many calories from animal,[20] while, pulses are an important and essential source of plant protein in developing nations.[3] During livestock

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farming and animal feed manufacturing, the intensive agricultural production of animal protein has negative and destructive impacts on the environment, as it is responsible for 18% of anthropogenic greenhouse gas emissions, including 65% of N_2O emitted 35-40% of emitted CH_4, and 9% of CO_2 emissions.[21] The amount of greenhouse gas emissions from legumes growing is five to seven times,[14] and 36 times less per unit area than other crops and dairy beef agriculture, respectively.[22] With the expected increase in meat prices and global population growth, the families seeking to reduce food costs may start including more pulses in their diets. Furthermore, seeking to reduce food costs may start including more pulses in their diets.[20]

In recent years, plant-based diets (pulses) have grown in popularity at many countries of the world, due to the severe and growing concern over the environmental, ethical and health impacts of diets dominated by animal-derived foods.[23] The dietary shift from higher meat consumption to more plant foods leads to reduced consumption of unhealthy foods from animal sources and increased consumption of pulses thus improving human health and well-being,[22] in addition to reducing premature deaths by 19-23% in the world.[24] The number of vegetarians in the United Kingdom (UK) quadrupled between 2014 and 2019, while, in 2019, there were 600,000 vegetarians or 1.16% of the population, it appears that vegans will make up a quarter of the British population in 2025.[25]

In the United States of America, sales of plant-based foods that replace animal products in grocery stores have directly increased by 29% over the past two years, reaching $ 5 billion,[26] as well as in the UK, the population's consumption of red and processed meat has decreased more than the last decade. Plants are an alternative to animal products, as the simultaneous consumption of proteins from pulses and cereals reproduces the essential amino acid pattern found in animal products[27,28] the simultaneous consumption of proteins from pulses and cereals reproduces the essential amino acid pattern found in animal products. Thus, enhancing the nutritional properties of pulses can lead to increased consumption of pulse proteins as a partial substitute for animal proteins.

Grain legumes are the best source of proteins among all the other food crops as vegetables and cereal crops.[29] The legumes content of protein ranged from 5% in white lupine to 45% in soybean being the highest protein sources, while, the protein content in vegetables and cereal crops varied from 2% and 8% to 12%, respectively.[30] The pulses content of protein is up to three-fold or double higher than that found in cereal crops,[5,19] as well as they have very low-fat content,[18] but the cereal crops are major sources of carbohydrates.[31] Furthermore, the amino acid lysine amounts in pulses are higher than in cereal crops, however it contains low levels of other amino acids such as methionine. Thus, pulses protein favorably complements cereals protein in diets, meaning that together they provide adequate amounts of all amino acids essential for the human body.[5,18,29]

Legumes ranking as second consumed food crop after cereals globally, there is growing interest in pulses and more people consume pulses particularly the grain one as a staple food with grains and depend on them as the main source for protein needs. Therefore, the pulses could contribute significantly to the dietary diversity of poor people in rural regions especially in developing countries if consumed as compliment to starchy diets, for instances, pulses consumption ranges from 10 to 35% in low-income countries in Africa.[4,29]

The germplasm resources of pulses in the world can be investigated and discovered in order to be used in improving many aspects of the nutritional value of grain legumes (as increasing of protein) through the genetic variation of these crops. Traditional breeding and biotechnology methods (molecular technologies) will be essential to make the most of the advantages of pulses that are an important source of protein for human nutrition but reducing the levels of anti-nutrients in pulse seeds.[23,32]

Genetic studies help to identify the genetic bases for many genetic traits (especially protein), which leads to the success of promoting pulse crops biologically by increasing the protein content in their seeds. Indeed and over the years, the pulses breeders have achieved some success in developing high yielding cultivars without sacrificing their content of protein, despite the health and nutritional benefits of pulses. The data on pulses consumption shows that the average per person intake of pulses is well below recommended levels, at around 21 g/person in the day, for the past three decades.[18] Hence, there is a need to revive pulses as an important food crop, as this could provide a solution too many dietary system challenges both for human and animal consumption.[19] Also, as a source of plant protein and has increasing importance in improving human health.[33] The impact of the pulses on the environment is much lower than that of animal sources of protein, especially when considering protein conversion efficiency, which opening up new and high-value markets, as well as they, would play a major role in future cropping systems.[14,23]

The increasing global population and consumption of pulses requires several things, such as increasing the productivity of pulses, improving economic access, and increasing awareness of their nutritional value.[18] Also, encouraging farmers to grow legumes and consider the quality and yield together, broad dietary shift to relieving anthropogenic climate change, providing an environmentally sustainable source of protein in order to pulses crops are an important component of this change. In addition encouraging of Plant breeders to develop breeding methods, which strove to merge production of food into the healthy performance of agricultural ecosystems.[34]

Shrinking cultivable lands

Legumes Productivity declined for the late last century, although a large area of legume, because of adverse environmental conditions like drought, soil degradation that may limit their productivity.[35] Drought problems for legume productivity are probable to with the increase of dry areas of the world from 28–30 countries to 50 countries by 2030.[36]

The main constraints to legume yield in tropical and subtropical regions are Diseases and pests due to higher rain and temperature. There are some pathogens that infect legumes include viruses, fungi, anthracnose, angular leaf spot, bean rust, white mould, Ascochyta blight, Fusarium wilt, and common bacterial blight,[37,38] soil characters, soil pH conditions and low P affect Nodulation, Nitrogen fixation, and survival of rhizobia.[39]

Climate change and legumes cultivation

Under change climate conditions rising temperature causes rapid degradation of soil, reduced agriculture land, and change of soil properties as changes in soil stability, soil biodiversity, plant-soil interactions, and nutrient cycling. Changes in vegetation cover might change runoff and nutrient losses and soil organic matter content. However, socio-economic trends may have a major role in determining land-use patterns. Grain legumes influence the rhizosphere and soil quality, there are numerous benefits that legumes contribute climate change alleviation like.[14]

Climate change: Extreme events and unpredictable weather

The influence of climate change on soils is not direct. Where it affected on decomposing of soil organic matter and changes in soil moisture, also emit the gases responsible for climate change,[40]

There are different effect of climate changes on the soil properties like:

1. Minimizing the release of (GHG) as CO_2 and N_2O compared with agricultural systems based on mineral N fertilization,
2- Play vital role in the sequestration of carbon in soils.
3- Decrease the fossil energy inputs in the system.

Impact of climate changes on soil functions

The effects of soil carbon stocks in the upper soil horizons would drop by 30 Bt of carbon under one degree of temperature, it is planned to increase soil organic carbon decomposition, which increases soil N availability, lead to higher soil CO_2 efflux.[41] Each Ton of carbon lost from the soil releases 3.7 Tons of CO_2 in the atmosphere.[42] While, legumes give about 12–25 Tg N fixed per year.[43]

Soil fertility

Increases soil temperature will raise the decomposition of Organic matter, improved microbiological activity, quick nutrients release, enhance the nitrification rate, and chemical weathering of minerals.[44] Climate change affects negatively soil properties; decrease the bioactivities in soil, loss of nutrients by leaching, volatilization, runoff, and Soil acidification, salinization, and alkalization.

Soil moisture

Impacts of climate change affects like precipitation, evaporation, influence soil moisture. Increasing temperatures lead to more evapotranspiration and quick loss of water from the soil,[45] whereas it decreased water holding capacity in the soil and available water to plant which increases drought.[46] Wind erosion increases evaporation rate, filtration losses, and groundwater.[47]

Soil microbial

Rising temperature increase soil organic decomposition, so it is a negative decomposition on soil microbial communities.[44,48] The soil fungi activity may increase in the warmer soil.[49] In addition, the effect of climate change on the soil microbial enhanced CO_2 levels in the atmosphere leading to enhanced plant growth and increased carbon below soil. Therefore, the soil microbial increase fixation of atmospheric nitrogen, nitrogen immobilization, and denitrification, and thus improve mycorrhizal activity, enhancing soil aggregation, and increased weathering of clay mineral.[50]

Soil compaction and crusting

Soil structure influences the movement of gases, water, pollutants, decline soil organic matter lead to a decrease in soil aggregate, infiltration rates, soil aeration, soil water available and crop productivity, and, increase compaction, bulk density, run-off, soil N loss and erosion.[50,51]

Increase soil salinization

Increased salinization and alkalization due to rising temperature and decreased precipitation (Okur and Örçen, 2020). Where salinity increases as capillary rise, where get salts into the root zone in sodic soils. Leaching may be incomplete due to increasing drought of subsoil increases the concentration of salts in the soil solution in semi-arid zones.[52]

a. Soil properties

Cultivation system based- legumes has many positive effects on soil characters like enhancing SOC and humus content, increased N and P availability.[53]

(1) Physical properties:

Legumes improve the physical soil properties by being a soil conditioner.[54] Leguminous cover produced huge biomass, which provides the substrate for soil biological activity and soil organic matter (SOM).[55] Enhance soil C/N ratio and increase soil organic carbon (SOC) stock,[56] improved infiltration of water and soil aggregation.[57]

(2) Chemical properties

The leguminous improves chemical properties by N-fixation, increase root biomass, nutrient availability, and SOC pool.[58,59] In addition, legumes root exudates and releasing organic acids improve P availability,[60] increase soil N, SOC, and improves soil chemical characteristics.[61] Incorporated legume residues into soil increase SOC concentration, enhanced sequestration of C of atmospheric CO_2, and increase agricultural productivity.[55]

b. The atmosphere (GHG)

Legumes crop growing reducing the fertilizer rate in agricultural rotations, consequently decrease the GHG emissions.[62] In rotations including leguminous crops, half of the CO_2 generated in NH_3 synthesis converted to urea.[53] Agricultural field is the main source of N_2O emissions, about 60% result from the application of nitrogen fertilizers, N_2O about 5–6% of the total atmospheric GHG, each 100 kg of N fertilizer added released about 1.0 kg N_2O emitted.[63]

c. Increasing intensity and frequencies of biotic and abiotic stresses

Agricultural production is affected by a number of abiotic and biotic stresses resulting from the impact of global warming. Where plants face these stresses under field conditions.[30] Due to reduced density and diversity of inputs, negative environmental effects are exacerbated in multiple cropping systems. In addition, yield instability linked to climate is higher in pulses crops (as soybean) and broad-leaf crops compared to cereals grown in the.[62] Good integration among crop breeders, molecular biologists, and agronomists, crop modeling experts, field pathologists and physiologists leads to the development of crops to resist stress conditions of both types under field conditions.

The crop varieties ability to implement reasonably well under stressful environments is critical to production stability of crops. Breeding for stress tolerance is usually performed using selecting genotypes for high yields under various stress conditions. To produce stress-resistant genotypes different stress resistance indices have been suggested basis on a mathematical relationship between yield during stress and non-stress conditions as shown in (Table 1). These indices are based on either stress resistance or stress susceptibility of genotypes. Among all drought tolerance indices i.e., mean productivity index, geometric mean productivity, stress tolerance index, harmonic mean and yield index can be used as the most suitable indicators and alternative for each other to select drought-tolerant genotypes.[64] In order to develop drought-tolerant legumes varieties, it is imperative that there be integration among several methods like agronomic and biotechnology strategies in addition to advanced genome editing tools.[65]

Table 1 Stress tolerance indices used for the genotypes evaluation under non-stress and stress conditions

No.	Stress tolerance indices	Equation	Reference
1	SSI	$[1-(Y_s - Y_{p)}]/[1-(\overline{Y}_s - \overline{Y}_p)]/$	Fischer and Maurer
2	TOL	$Y_p - Y_s$	Rosielle and Hamblin
3	MP	$(Y_p - Y_s)/2$	Rosielle and Hamblin
4	YSI	Y_s / Y_p	Bouslama and Schapaugh
5	HM	$\left[2(Y_p x Y_s)\right] x (Y_p + Y_s)$	Hossain et al.
6	GMP	Y_s / Y_p	Fernandez
7	STI	$(Y_p x Y_s)/(\overline{Y}_p)^2$	Fernandez
8	YI	$Y_s / \overline{Y}_s$	Gavuzzi et al
9	DI	$[Y_s x(Y_s / Y_p)]\overline{Y}_s$	Lan
10	YR	$1 - Y_s / Y_p$	Golestani–Araghi and Assad
11	ATI	$\left[(Y_p - Y_s)/(\overline{Y}_p - \overline{Y}_s)\right] x \left[\sqrt{Y_p x Y}\right]$	Moosavi et al
12	SSPI	$\left[(Y_p - Y_s)/2(\overline{Y}_p)\right] x100$	Moosavi et al
13	GOL	$(Y_p + Y_s)/(Y_p - Y_s)$	Moradi et al.

Table 2 Area harvested, yield level and production of grain legumes compared to major cereal crops worldwide

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	28.90
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

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Table Continued...

Crop	Area harvested (million ha)	Yield level (MT/ha)	Production (million MT)
Major Cereal Crops			
Wheat	215.90	3.55	765.77
Corn	197.20	5.82	1148.49
Rice	162.06	4.66	755.47

Source: FAOSTAT (2020)

SSI: Stress susceptibility index; TOL: Stress tolerance index; MP: Mean productivity index; YSI: Yield stability index; HM: Harmonic mean; GMP: Geometric mean productivity; STI: Stress tolerance index; YI: Yield index; DI: Drought resistance index; YR: Yield reduction ratio; ATI: Abiotic tolerance index; SSPI: Stress susceptibility percentage index; GOL: Golden mean; Y_p: grain yield of each genotype in non-stress condition; Y_s: grain yield of each genotype in stress condition.; $\overline{\overline{Y_p}}$: mean grain yield of all genotypes in non-stress condition; $\overline{Y_s}$: mean grain yield of all genotypes in stress condition.[66]

d. Constraints of pulses production

Legume production affected by various biotic and abiotic stresses like many other crops. Various constraints play a major role in determining the crop and productivity of legumes and affects the distribution of the legumes species worldwide (Figure 1). There are genetic constraints, Socio-economic constraints, soil, climatic constraints, technological constraints, institutional constraints, as well as policy issues.[67]

Genetic constraints

The mutually accurate and widespread evolutionary processes based on many factors that include the genetic foundation for the characters that motivate the benefits of mutuality.[68] Many genes control many quantitative important characters like grain yield, nutritional components, and some forms of tolerance to environmental and biological stresses. Genetic constraints to adaptive development can be understand as those genetic aspects that inhibit or reduce the likelihood that natural selection leads to the direct elevation of the intermediate phenotype to the optimum level.[69] Genetic constraints appearing under variance of additive genetic conditions in preferred directions selectively but small (quantitative constraints) or absent (absolute constraints).

A quantitative constraint exists when the ability to respond to selection is present but is limited.[70] It is possible that multivariate genetic limitations are present in natural populations, as genetic differences is found in nearly all characters in the presence of strong natural and sexual selection, whereas, there is a direct conflict between natural and sexual selection depleting genetic variation.[71] Directional selection acting consistently over time is expected to produce negative genetic correlations between pairs of adaptively significant traits.[72] Genetic associations among traits can restrict responses to natural selection, but to what extent these associations depend on adaptation to patterns of directional selection.[73]

Connallon and Hall[74] mentioned five classes of genetic constraint in population as follow:

1. Genetic dominance.
2. Pleiotropy.
3. Fitness trade-offs among individuals of a population.
4. Sign epistasis.
5. Genetic linkage between loci.

Gregor Johann Mendel was the first to introduce the term genetic dominance that describes the relationship between alleles of the same gene where one of the dominant alleles hides the phenotypic contribution of the recessive allele.[75] Dominance is an evolutionary constraint, as dominance interactions between alleles influence each site's (locus) contribution to variance of additive genetic for the fitness and efficacy with which natural selection enhances adaptation.[76] Pleiotropy is the main theoretical reason behind the hypothesis that morphological development occurs more frequently through cis-regulatory changes than changes in protein sequences.[77] In addition, the conditions for stable polymorphism are somewhat restricted, especially with low selection.[78] Polymorphism can lead to a lack of genetic and evolutionary independence among various characters, genetic trade-offs among various components of fitness and reduced adaptability by pleiotropic genetic variance.[79] The effect of polymorphism on the adaptation rate depending on the scale of the mutation size with dimensions.[74] Thus, when conditions for stable polymorphism satisfied by antimorphic pleiotropy, substantial dominance variance in one or both fitness components is expected but rarely observed in experiments.

There is essential role for epistasis in the maintenance of genetic variation, central to many theories of speciation,[80] the epistatic interactions evolution during the interspecific level, the populations ability on respond to selection, and the conservation genetics if it contributes to the external breeding depression.[81] In epistasis, the effect of a mutation on fitness depends on the genetic background in whose it arises.[82] The theory has shown that the sign epistasis, as it is in the mutation is beneficial in the context of some genetic backgrounds, but harmful in.[83] In addition, development in one or both partners can be speed or slow by the genetic correlations between traits. When the direction of genetic variance in the multivariate character space does not align with the selection vector, an evolutionary constraint occurs.[84] The genes / loci related with a quantitative trait considered quantitative trait loci (QTLs). The high degree of affinity between wild relatives and leguminous relatives' germplasm groups exploit to improve gene maps and recognize elect genes for agricultural characters that improving leguminous productivity.[85] In general, genetic constraint in population as low level of polymorphism, non-availability of resistance sources of biotic and abiotic stresses in cultivated gene pools and wild species and landraces are valuable sources of new genes and alleles that can be introduce into cultivated species. While, the hybridization difficulties of cultivated species with wild species considered a major constraint in developing genetic maps in the legume crops, for example, peanut, chickpea, and pigeon pea.[86] Despite the importance of wild species and landraces, they remained largely underutilized to improve crops due to barriers to interspecific hybridization, lack of assessment data on specific traits. Lack of easy access to advanced breeding tools, and link withdrawals due to negative alleles in surrounding areas the desirable alleles and the tendency to stress result in the short term in breeding projects.[87] Improving these traits through conventional breeding is a long-term and difficult process. New methods, based on classical genetics, such as linkage disequilibrium (LD) based correlation mapping, advanced back-cross QTL (AB-QTL) analysis offer the possibility of overcoming at least some barriers.[86] The methods span from quantitative, population, and environmental genetics, to molecular genetics. Much attention is devoted to genetic associations, the maintenance of quantitative genetic diversity, and the intimate relationship between genetics, ecology, and evolution.[88]

Genetic diversity is important for crop breeders because it provides an opportunity to develop new and improved varieties with desirable traits that include the preferred traits of farmers and breeders such as yield and its components traits.[7] In order to improve pulses in the future, the immense genetic diversity of legume crops must be exploit for increased productivity, quality and profitability. Genetic and genomic resources of legume crops are among the important strategic tools that are currently subject to the application of molecular and genetic engineering techniques. Thus providing knowledge and opportunity that lead to easy identification of particular germplasm, trait mapping, and allele mining for more effective biotic and abiotic stresses resistant and high-quality grains for food and forage.[32] Plant breeding is a strong tool to improve legume crop characteristics, to achieve harmony between the environment and the agriculture as well as to improve the varieties for sustainable agriculture utilization, so that the crop becomes more desirable healthy, agronomic, ecological and economical.

1. Socio-economic constraints

There are many social and economic constraints facing the production of legumes, including the following:

- Low input use, seeds limited availability of quality seeds, limited lack of knowledge of the improved varieties of present legumes and poor extension services.[9]
- Poor income reduces the ability to buy legumes seed, no or lack of markets, cultural belief and not edible.[89]
- Postharvest losses as well as costs.[90]
- Legumes need more technology to produce those.
- Fluctuate or decreasing prices and low productivity of legumes.[91]
- Legumes provide fewer benefits when compared to cereal crops, and increases sensibility to pests and diseases.[92]
- The farmer's reluctance to grow legume crop.[93]

This reduced the overall competitiveness of legume crops in relation to the cereal crops in farming systems. The challenge of lack of funding considered one of the most important social and economic constraints for legume crops, as it was noted a lack of reliable information on legume crops due to lack of funding to backup scientific research, development and innovation for these crops. The breeding and improvement of legume crops limited by the weak request for seeds. A 41% high level of food insecurity leads to seed shortages in legumes, which expected to put pressure on preserved seeds due to the domestic consumption of legume crops.[89] The pesticides, habitat loss, and agricultural intensification led to reducing pollinator groups, due to low pollinator abundance and diversity, seed yields reduced for some legume crops, for example, *Trifolium pratense*.[94] Plant-pollinator is important for the maintenance of biodiversity, human food security, and is one of the critical services for sustainable ecosystems.[95]

The farmers lack knowledge based mostly on indigenous knowledge of agricultural practices of leguminous crops and lack of diversity in farms. Diversity occurs in the farm through the changes in cultivation from the cultivating cereal species to cultivating pulse species, this diversity cannot achieved through cereal crops only. In addition, the farmers are not interested in growing legumes crops on their own farms due to some technical, climatic and economic limitations,[96] as well as responding to institutional, agronomic.[97] In addition to the lack of awareness of farmers and consumers of the benefits of legumes crops.[19] Rural farmers reluctance to grow legume crops and low their production due to the fact that legume crops have become a poor and slow income source for them and that pulses (grains) do not reach their potential shelf life when storage.[93]

Another major obstacle facing legumes production is the lack of adequate markets for leguminous crops, higher post-harvest losses, and costs,[98] therefore, spread higher price due to high processing costs, Also, the legumes markets were weak and fragmented in compared to cereal crops as wheat, corn and rice.[99] The number of ineffective intermediaries operating between producers and the customer markets is large, weak, and operates in limited geographic areas.[9]which, leading to a lack of transparency in markets.[100] High marketing costs due to high transportation costs, inadequate and poorly designed storage facilities, insufficient market information flow, quantity and quality of supplies, affecting the production and marketing of leguminous crops, as well as lack of processing facilities to provide food industry with functional components that depend on legumes.[101,102] In addition, the lack of processing facilities to supply the food industry with functional ingredients based on legumes. Farmers, especially smallholders, need easy ways to connect them to markets to achieve good profitability. On the other hand, the price of pulses and their availability, along with social habits, play an important role in changing consumption patterns, so the low production of leguminous crops leads to a decrease in farmers' profitability despite the low cost of farming and the high prices of legumes production compared to cereal crops like rice and wheat. The low productivity of pulses may shift them from the production system at some areas in the world. Whereas, we find that the manufacturing of legumes allows opening new markets by adding value and diversifying products. Smallholder farmers need a connection to markets so that they can generate more income, besides social and subjective norms, price and availability are important in changing consumption patterns. Poor yield performance of legume crops leads to their lower profitability in spite of the lower cost of cultivation and higher output prices of legumes when compared with that of cereal crops such as rice and wheat. Where the existing low yield levels of legume crops will further displace them from the production system in some region of the world. Furthermore, there are numerous opportunities in agro-processing can open up new markets by value addition and diversifying products as well as improving storage for longer periods, thus Improved income for rural farmers.

The expansion of the cultivation of legume crops, the increase in production, processing, and consumption, as well as the increase in the price paid to farmers, can be achieve by increasing awareness of customers about the healthy and environmentally benefits of legumes. Also, increasing consumer demand through local production and diversity of policy measures. Besides opening new markets increase the opportunities for legume-based foods, as well as, more resources need to be devoted to advanced research in legume crops (Zander

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et al.,[35] as well as, more resources need to be devoted to advanced research in legume crops (as Biotechnology) to face these constraints in legume crops.

Technological constraints

It is known that the immediate farmer's food security issue limits his ability to integrate legume crop technologies into their traditional system (based on cereal crops), resulting in a lack of diversity in agricultural systems, which decrease the resilience of this system and ultimately increases the risks. Despite, the challenges can be mitigated by providing nutritional, biological and resources benefits, as well as diversifying risks by incorporating cereals and legumes technologies in agricultural systems.[117] There is still a lack of researchers understanding of the barriers associated with grain-legume technologies. Also, the dependence of farmer's on these technologies is still low or limited, because the farmers prefer the traditional corn-based system that dominates the majority of the studied grains and legumes technologies, for its high capacity to meet farmers food security and yield requirements.[104]

Technological constraints limiting legume production and minimize exploiting high yield potential which causes the most crucial yield gap. The main limitations of adopting technologies based on legume crops include the limited usage of production technologies to farmers and use them effectively. Availability of knowledge about technology or practice, ease of household access to capital or assets, production market for agricultural products of leguminous crops, biophysical link to technology. Developing of agricultural research and development systems including extension, advanced education or literacy for farm family members, cultural factors, alternative technologies or livelihoods that rival technology and government support.[105] Application of biotechnology such as genomics and bioinformatics in legume breeding is low,[106] low awareness and poor adoption of legume-based technological innovations.[107] As well as poor identification of entry points and target groups, and the difficulties correlated with establishing and maintaining legume crops, isolated efforts in soil improvement.[108]

The acceleration of progress in breeding and crop improvement through biotechnology, which includes three interacting technical components as follow:

1. Microbial bioprocessing techniques.
2. Techniques for culturing somatic and reproductive cells, tissue, organs.
3. Molecular and cellular techniques for the characterization and modification of genomes including techniques for the identification, recombination, cloning, transfer and expression of genetic material (according to El-Hashash and El-Abs[64]).

Molecular markers include protein markers, DNA markers, and metabolite-based biomarkers, while, genetic engineering include gene transfer, transgene expression as well as the selection and plant regeneration.[108] the United States of America and around the world, the gene tagging and marker-assisted selection for disease resistance has evolved to the point where indirect selection for resistance to a major diseases number has become routine in breeding programs of bean.[109] While, many of these measures proposed above exceed the resources of subsistence farmers, which is another reason for the low in legume yields in third world countries, the world needs to balance in future breeding activities due to the molecular engineering debate, with some countries rejecting the cultivation of transgenic soybean.[106] Developed technologies like next-generation sequencing and high-yield methods will contribute to the development and improvement of legume crop breeding programs, with the advantage of being budget-efficient, environmentally friendly, and less time-consuming.[17]

Smallholder legume crops producers in developing countries lack access to technological improvements or the transfer of agricultural technology to their rural communities due to lack of funding and resources, therefore, there is a wide gap of legume crops production in smallholder farms whereas. The technology that could significantly increase and stabilize food legume yields is available in most regions, but its rapid adoption appears to be limited to industrial agriculture.[110] In addition, Muoni farmers do not want to test new legume species/varieties on them due to limited resources and technologies used for improvement.

Simplify of the marketing and promotion of pulses technologies to farmers and stakeholders can be by effectively distributing them, print and electronic media, contests, on-farm research, demos, tours of educational and training workshops, thus improving awareness and adoption of legume-based technologies.[107] The successful adoptions of technology often related with the need to production increased and produce income for farmers.[111] Everyone (government and private institutions) should pursue effective policies to strengthen, promote and create positive awareness and implement improved technologies of cereal-legume cropping to improve farmers' profits and feed an increasingly large population. The use of existing low-cost technologies, for example rhizobial inoculation, must be expand to small farmers.[103]

Institutional constraints

The institutional system achieves many positive and negative effects on various activities, by following the controls roles by different institutions to organize work. There are different institutional constraints facing legume production, therefor, the international agricultural organizations aiming to address the theoretical and methodological gap on improving the production of legumes and implementing the institutions dealing with the complex challenges that facing legumes production worldwide especially in the developing countries.[112,113]

In some sub-Saharan African countries, the weakness of the institutions in the pulses production sector have negative impacts on the cultivation and production of legumes represented in the loss of confidence between various actors in this sector.[114] In addition, increasing transportation costs and limitation of market efficiency affecting negatively food security and delay development.[115] Therefore, executives and institutions must play an effective role in finding novel solutions to import or develop new roles to improve agriculture production.[113] There are various actors effort that many undertake related to legumes production to make markets better, more efficient, and inclusive, therefore, scientists discussed how weak institutions affect negatively legume production around the world.[115] Due to different recognized restrictions and lack of market institutions, illegal trade of pulses is taking place in different regions, such as the informal trade of bean between Kenya and Uganda, also, between Tanzania and Congo.[116]

There are many institutional restrictions facing the production of legumes, including formal constraints such as (rules and laws) and informal constraints like (agreements and codes of conduct) that regulate the production and trade of pulses.[117] Therefore, enhancing institutions' efficiency provides multiple functions and alternative mechanisms by facilitating contract implementation, preserving property rights and contracts, and manages the degree of competition. Thus reducing market failures particularly in areas with underdeveloped road and communication networks like in the sub-Saharan region, so, limitation of institutional capacity to support agricultural strategies affect negatively integrate smallholders in rural areas into larger entities to cope with market fluctuations.[118]

Soil and climatic constraints

Now, there are different challenges in front of agriculture to ensure food security for the global population, which expected to reach 8.55 billion by 2030, 9.77 billion by 2050, and 11.18 billion by 2100,[119] accompanied with an expected increase in food demand, while, about 782 million live in developing countries, (12.5%) of world population.[120] The incorporation of legumes into agriculture increases soil fertility, particularly in developing countries.

Previous work[2] indicated that improving agricultural production includes:

- Manage food security for the increasing population.
- Alleviate global warming.
- Improve soil fertility.

The most commonly discussed GHGs are

1. Global warming

Due to the emission of huge amounts of greenhouse gases (GHG) (i.s. CO_2, CH_4, and N_2O) accumulate in the troposphere, the earth's temperature increased 2–4°C over the previous century.[121]

The emissions of warming gases into the atmosphere, which estimated to reach 37 Bt CO2 eq. at 2014 that was 60% higher than in 1990, moreover, CH_4, N_2O, and CO_2 are the major GHG emissions resulted from agricultural production.[122]

a. Carbon dioxide (CO_2): it is formed by burning fossil fuel and industrial activities, it is roughly 55% of GHGs and increasing Global Warming Potential.[122]

b. Methane (CH_4): the anaerobic decomposition considered the main source of Methane production in the agriculture sector, such as, in flooded rice paddies, pig and cow stomachs, and pig manure ponds that is a precursor of ozone.

c. Nitrous oxide (NO/N_2O): formed during fertilizer manufacture and other industrial processes, Nitrous oxide lasts a very long time in the atmosphere.

Because of climate change, there is more pressure on the production of legumes, which require the urgent achievement of agronomic and genetic practice. The global warming observed about the world in the last century and it will be continue throughout the twenty-first century, furthermore, rain will reduce in the tropics and semi-arid tropics where most legumes are grown; in hot areas.[123] Climate change is affecting on future legume crops production, and it is expect to reduce the yield.[110]

Using a predictive modeling program to estimate that a temperature increase of 3°C will reduce the yield of peanuts in Zimbabwe by 33% and pigeon pea in Kenya by 19%, due to short growth time and early maturity to raise temperatures.[124] Adoption of legumes to the excess of temperature and rain is largely unknown. Prasad et al., (2006) showed that the panicle emergence in sorghum was late by more than 20 days and vegetative growth reduced due to the temperature increased from 36/26°C to 40/30°C.

Future perspectives needs of legumes 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.[125] 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.[29]

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 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.

Due to the growing world population, there is increasing demand for food products worldwide, which has posed many challenges toward agricultural productivity and increase in food quality, quantity, and production of protein-rich crops. Legume crops are vulnerable to abiotic constraint particularly drought which affects negatively crop yield. Therefore, Legumes production needs more attention in the near future to provide adequate food for humanity. Innovative breeding drought-tolerant varieties considered a new approach to enhancing legumes production under arid and semiarid regions, using precision agriculture tools could help farmers to overcome different negative impacts of many threats. Also, new agricultural strategies and management practices are required to improve and introducing new complementary crop systems for grains and pulses, 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. Policy and institutional decisions are required to promote legume productivity.

Conclusion

Legumes one of the essential crops for humanity due to nutrition values, it's providing food requirements and nutritional security, used as animal feeds, and sustaining soil fertility, in addition to Legumes cultivation as intercropping crops decreasing fertilizing rate in agricultural rotations, consequently, reduce the emissions of GHG. There are major challenges facing legumes cultivation and reducing yields that made them unattractive for farming, like genetic, socio-economic, soil and climatic constraints, technological, and institutional constraints. Legumes production needs more attention particularly in the near future to provide enough food for the population worldwide. The increment in production of legume can be through horizontal expansion as the cultivated area and reclamation of desert lands. In addition, through multiple intercropping systems and crop rotation cycle, in addition, plant breeders increase legume productivity through using biotechnology for adapted legumes to global climatic changes particularly drought stress. Legumes crop can be develops for future exploitation, through a crop system adapted to environmental conditions, where leguminous crops are an essential component either as intercropping or between nonlegumenous crops.

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Conflicts of interest

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References

1. Câmara C R, Urrea C A, Schlegel V. Pinto beans (*Phaseolus vulgaris* L.) as a functional food: implications on human health. *Agriculture*. 2013;3(1):90–111.
2. Meena R S, Lal R. Chapter "Legumes and Sustainable Use of Soils" From. *(Legumes for Soil Health and Sustainable Management)*. 2018;1–31.
3. Joshi P K, Rao P P. Global and regional pulse economies–current trends and outlook. *IFPRI Discussion Paper. International Food Policy Research Institute* (IFPRI), Washington, DC. 2016;149.
4. Abberton M. Enhancing the role of legumes: potential and obstacles. In: Abberton M, Conant R, Batello C, editors. Integrated crop management, vol. 11: Grassland, carbon sequestration: management, policy and economics. Proc Workshop on the role of grassland carbon sequestration in the mitigation of climate change, Rome. 2010. p. 177–187.
5. Singh N. Pulses: an overview. *J. Food Sci. Technol*. 2017;54(4):853–857.
6. Duchene O, Vian J F, Celette F. Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agriculture, Ecosystems & Environment*. 2017;240;148–161.
7. Govindaraj M, Vetriventhan M, Srinivasan M. Importance of genetic diversity assessment in crop plants and its recent advances: an overview of its analytical perspectives. *Genet. Res. Int*. 2015;431487.
8. Erokhin V, Gao T. Impacts of COVID–19 on trade and economic aspects of food security: Evidence from 45 developing countries. *International journal of environmental research and public health*. 2020;17(16):5775.
9. Kebede E. Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. *Kebede, Cogent Food & Agric*. 2020; 6(1):1722353.
10. Nedumaran S, Abinaya P, Shraavya B. et al. Grain Legumes Production, Consumption and Trade Trends in Developing Countries–An Assessment and Synthesis, Socioeconomics Discussion Paper Series Number. 2013;3.
11. Koroma S, Molina P B, Woolfrey S. Promoting regional trade in pulses in the Horn of Africa. 2016.
12. Senbayram M, Wenthe C, Lingner A. et al. Legume–based mixed in.tercropping systems may lower agricultural born N2O emissions. *Energy, Sustainability and Society*. 2015;6(1):2.
13. FAOSTAT. 2020.
14. Stagnari F, Maggio A, Galieni1 A. Multiple benefits of legumes for agricultural sustainability: an overview. *Chem. Biol. Technol. Agric*. 2017;4(1):1–13.
15. Wiggering H, Weihuhn P, Burkhard B. Agrosystem services: An additional terminology to better understand ecosystem services delivered by agriculture. *Landsc Online*. 2016;49:1–15.
16. Fedoroff NV. Food in a future of 10 billion. *Agric. Food Security*. 2015;4(1):11.
17. Afzal M, Alghamdi S S, Migdadi H H.et al. Legume genomics and transcriptomics: From classic breeding to modern technologies. *Saudi J. of Biol. Sci*. 2020;27:543–555.
18. Rawal V, Navarro D K. The Global Economy of Pulses. *Rome, FAO*. 2019.
19. Röös E, Carlsson G, Ferawati F. et al. Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. *Renewable Agric. and Food Systems*. 2018;1–14.
20. Magrini M B, Anton M, Chardigny J M, et al. Pulses for Sustainability: Breaking Agriculture and Food Sectors Out of Lock–In. *Front. Sustain. Food Syst.* 2018;2:64.
21. Steinfeld H, Gerber P, Wassenaar TD, et al. *Livestock's long shadow: environmental issues and options*. Food & Agriculture Organization of the United Nations: Rome. 2006.
22. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. *Sci*. 2018;360: 987–92.
23. Robinson GHJ, Balk J, Domoney C. Improving pulse crops as a source of protein, starch and micronutrients. *Nutrition Bull*. 2019;44:202–215.
24. Lucas, T., Horton, R., . The 21st–century great food transformation. The Lancet. 2019;393:386–387.
25. TVS, (The Vegan Society) 2020.
26. TGFI, (The Good Food Institute) U.S. Plant Based Market Overview–Research from Nielsen – The Good Food Institute. 2020.
27. PHE, (Public Health England). The Eatwell Guide. 2018.
28. Laleg K, Barron C, Cordelle S, et al. How structure, nutritional and sensory attributes of pasta made from legume is impacted by the legume protein. *Food Sci Tech*. 2017;49:471–478.
29. Chibarabada TP, Modi T, Mabhaudhi T. Expounding the Value of Grain Legumes in the Semi– and Arid Tropics. *Sustainability*. 2017;9:60.
30. Pandey P, Irulappan V, Bagavathiannan MV, et al. Impact of Combined Abiotic and Biotic Stresses on Plant Growth and Avenues for Crop Improvement by Exploiting Physio–morphological Traits. *Front Plant Sci*. 2017;8:537.
31. McKevith B. Nutritional aspects of cereals. *Nutr Bull*. 2004;29:111–142.
32. Jimenez–Lopez JC, Singh KB, Clemente A, et al. Editorial: Legumes for Global Food Security. *Front Plant Sci*. 2020;11:926.
33. Tharanathan RN, Mahadevamma S. Grain legumes– a boon to human nutrition. *Trends Food Sci Tech*. 2003;14: 507–18.

34. Palmer RG, Perez PT, Ortiz–Perez E, et al. The role of crop–pollinator relationships in breeding for pollinator–friendly legumes: from a breeding perspective. Euphytica. 2009;170:35–52.
35. Zander P, Amjath–Babu TS, Preissel S, et al. Grain legume decline and potential recovery in European agriculture: a review. *Agron for Sustainable Development*. 2016;36:26.
36. Postel SL. Entering an era of water scarcity. *Ecol Appl.* 2000;10: 941–948.
37. Coyne DP, Steadman JR, Godoy–Lutz G, et al. Contributions of the ean/cowpea CRSP to the management of bean diseases. *Field Crops Res*. 2003; 82:155–168.
38. Miklas PN, Coyne, D. P., Grafton, K. F., et al. . A major QTL for common bacterial blight resistance derives from the common bean great northern landrace cultivar Montana No.5. *Euphytica1*. 2003;31: 137–146.
39. Howieson JG, O'Hara GW, Carr SJ. Changing roles for legumes in mediterranean agriculture: developments from an Australian perspective. *Field Crops Res.* 2000; 65:107–122.
40. Gelybó G, Tóth E, Farkas C, et al. Potential impacts of climate change on soil properties. *Agrokémia és Talajtan.* 2018;67(1):121–141.
41. Dang Y, Ren W, Tao B, et al. Climate and land use controls on soil organic carbon in the Loess Plateau Region of China. *PLoS ONE*. 2014;9(5):95548.
42. Garnett T. Climate change and agriculture. International Institute for Environment and Development, UK. ISBN: 978–1–84369–2012;853–1.
43. Herridge DF, Peoples MB, Boddey M. Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil*. 2008;311:1–8
44. DEFRA (Department for Environment, Food and Rural Affairs),. Impacts of climate change on soil functions. DEFRA Research and Development, UK, Final Project Report. 2005.
45. Resende NC, Miranda JH, Cooke R, et al. Impacts of regional climate change on the runoff and root water uptake in corn crops in Parana, Brazil. *Agricultural Water Management*. 2019; 221:556–565.
46. Muluneh A. Impact of climate change on soil water balance, maize production, and potential adaptation measures in the Rift Valley drylands of Ethiopia. *Journal of Arid Environments*, 2020;179:104195.
47. Jones DL, Nguyen C, Finlay RD. Carbon flow in the rhizosphere: carbon trading at the soil–root interface. *Plant Soil*. 2009;321:5–33.
48. Feng X, Simpson AJ, Wilson KP, et al. Increased cuticular carbon sequestration and lignin oxidation in response to soil warming. *Nat Geosci*. 2008;1(12):836–839.
49. Bardgett RD, Freeman C, Ostle NJ. Microbial contributions to climate change through carbon cycle feedbacks. *ISME J.* 2008;2:805–814.
50. Bot A, Benites J. The importance of soil organic matter key to drought–resistant soil and sustained food and production. In: FAO soils bulletin, Food and Agriculture Organization of the United Nations, Rome. 2005;80:78.
51. Parisi A, Monno V, Fidelibus MD. Cascading vulnerability scenarios in the management of groundwater depletion and salinization in semi–arid areas. *International Journal of Disaster Risk Reduction.* 2018;30:292–305.
52. Jensen ES, Peoples MB, Boddey RM, et al. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agron Sustain Dev*. 2012;32:329–64.
53. Srinivasarao C, Venkateswarlu B, Lal R. Long–term effects of soil fertility management on carbon sequestration in a rice–lentil cropping system of the Indo–Gangetic plains. *Soil Sci Soc Am J.* 2012; 76(1): 167–178.
54. Lal R. Restoring soil quality to mitigate soil degradation. Sustainability. 2015; 7:5875–5895.
55. Schädler, S., Morio, M., Bartke, S., et al., . Designing sustainable and economically attractive brownfield revitalization options using an integrated assessment model. J Environ Manag. 2011; 92:827–837.
56. Mousavi, S., Yousefi–Moghadam, S., Mostafazadeh–Fard, B., et al., . Effect of puddling intensity on physical properties of a silty clay soil under laboratory and field conditions. *Paddy Water Environ*. 2009; 7(1): 45–54.
57. Mugwe J, Mugendi D, Okoba B, et al. Soil conservation and fertility improvement using leguminous Shrubs in central highlands of Kenya: NARFP Case study. In: Bationo A, editor. Managing nutrient cycles to sustain soil fertility in sub–Saharan Africa. Academy Science Publishers, Nairobi, p 608
58. Juma KA, Van Averbeke W. Response of Muxe to N and P availability in pots. In: Tenywa JS, Adipala E, Nampala P, Tussiime G, Okori P, Kyanmuhangire W (eds). *African Crop Science.* 2005;7:1179–1182.
59. Meena RS, Meena PD, Yadav GS, et al. Phosphate solubilizing microorganisms, principles and application of MicrophosTechnology. *J Clean Prod.* 2017;145:157–158.
60. Ogunwole JO, Iwuafor ENO, Eche NM, et al. Effect of organic and inorganic soil amendments on soil physical and chemical properties in a West Africa Savanna agroecosystem. *Trop Subtrop Agroecosyst.* 2010;12:247–255.
61. Reckling M, Doring TF, Berkvist G, et al. Grain legume yield instability has increased over 60 years in long-term field experiments as measured by a scale-adjusted coefficient of variation. *Aspects of Appl Biol*. 2018;138:15–20.
62. Reay DS, Davidson EA, Smith KA, et al. Global agriculture and nitrous oxide emissions. *Nat Clim Change*. 2012;2:410–416.
63. El–Hashash EF, EL–Agoury RYA. Comparison of Grain Yield–Based Drought Tolerance Indices under Normal and Stress Conditions of Rice in Egypt. *Sch J Agric Vet Sci.* 2019;6(1):41–54.
64. Nadeem M, Li J, Yahya M, et al. Research Progress and Perspective on Drought Stress in Legumes: A Review. *Int J Mol Sci*. 2019;20: 2541.
65. El–Hashash EF, El–Absy KM, Barley (*Hordeum vulgare* L.) Breeding. In: Al–Khayri J., Jain S., Johnson D. (eds) Advances in Plant Breeding Strategies: Cereals. Springer, Cham. 2019.
66. Khan MA, Akhtar MS. Agricultural adaptation and climate change policy for crop production in Africa. In Crop production and global environmental issues. 2015. (pp. 437–541).
67. Wade MJ. The co–evolutionary genetics of ecological interactions. *Nat Rev Genet*. 2007;8:185–195.
68. Lande R. Adaptation to an extraordinary environment by evolution of phenotypic plasticity and genetic assimilation. *Journal of evolutionary biology.* 2009;22(7):1435–1446
69. Richard G, Houle D. Demographic and genetic constraints on evolution. *The American Naturalist*. 2009;174(6): 18–29.
70. Walsh B, Blows MW. Abundant genetic variation+strong selection = multivariate genetic constraints: a geometric view of adaptation. *Annual Review of Ecol Evol and Systematics*. 2009;40: 41–59.
71. Pilson D. Herbivory and natural selection on flowering phenology in wild sunflower, Helianthus annuus. *Oecologia*. 2000;122(1):72–82.
72. Chevin LM. Genetic constraints on adaptation to a changing environment. *Evol*. 2012;67(3): 708–721.
73. Connallon T, Hall MD. Genetic constraints on adaptation: a theoretical primer for the genomics era. *Annals of the New York Academy of Sci*. 2018;1–23.
74. Rodríguez–Beltrána J, Sørumc V, Toll–Rierad M, et al. Genetic dominance governs the evolution and spread of mobile genetic elements in bacteria. *PNAS*. 2020;117(27):15755–15762.

75. Charlesworth B, Hughes KA. The maintenance of genetic variation in life history traits. In Evolutionary Genetics from Molecules to Morphology. R.S. Singh & C.B. Krimbas, Eds.: 369–391. Cambridge, UK: Cambridge University Press. 2000.

76. Carroll SB. Evolution at two levels: On genes and form. *PLoS Biol*. 2005;3:e245.

77. Flatt T, Heyland A. Mechanisms of life history evolution: the genetics and physiology of life history traits and trade–offs. OUP Oxford. 2011.

78. Kawecki TJ, Ebert D. Conceptual issues in local adaptation. *Ecology letters*. 2004;7(12):1225–1241.

79. Arnqvist G, Dowling DK, Eady P, e al. Genetic architecture of metabolic rate: Environment specific epistasis between mitochondrial and nuclear genes in an insect. *Evolution*. 2010;64: 3354–3363.

80. Dudash MR, Fenster CB. Inbreeding and outbreeding depression in fragmented populations. Pp. 35–53 in A. Young and G. Clarke, eds. Genetics, demography and viability of fragmented populations. Cambridge Univ. Press, Cambridge, U.K. 2000.

81. Phillips P. Epistasis the essential role of gene interactions in the structure and evolution of genetic systems. *Nat Rev Genet*. 2008;9:855–867.

82. Weinreich DM, Watson RA, Chao L. Perspective: Sign epistasis and genetic constraint on evolutionary trajectories. *Int J of organic Evol*. 2005;59:1165–1174.

83. Blows MW. A tale of two matrices: multivariate approaches in evolutionary biology. *J Evol Biol*. 2007;20(1): 1–8.

84. Gentzbittel L, Andersen SU, Ben C, et al. Naturally occurring diversity helps to reveal genes of adaptive importance in legumes. *Front Plant Sci*. 2015;6: 269.

85. Varshney RK, Hoisington DA, Upadhyaya HD, et al. Molecular genetics and breeding of grain legume crops for the semi–arid tropics. Chapter 10 In: R Varshney & R Tuberosa, editors. *Genomic Assisted Crop Improvement: Vol 2: Genomics Applications in Crops.* 2017;207–241.

86. Ojiewo C, Monyo E, Desmae, H, et al. Genomics, genetics and breeding of tropical legumes for better livelihoods of smallholder farmers. *Plant Breed*. 2019;138: 487–499.

87. Großkinsky DK, Svensgaard J, Christensen S, et al.Plant phenomics and the need for physiological phenotyping across scales to narrow the genotype–to–phenotype knowledge gap. *Journal of experiment botany*. 2015;66(18):5429–5440.

88. Mhango WG, Snapp SS, Phiri GYK. Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi. *Renewable Agriculture and Food Systems*, 2012;1–11.

89. Jones MS, Alexander CE, Smith B. Economic consequences of post–harvest insect damage in Rwandan common bean markets. *Crop protection*. 2018;104:92–100.

90. Jeuffroy MH. The ecological services of protein crops: the basis of sustainable farming systems. Meeting organized by the National Institute of Agricultural Research at the International Agricultural Show, France. 2006. 6p.

91. Gueguen J, Duc G, Boutin JP, Dronne, et al. The protein chain, what challenges for research? Meeting at the International Agricultural Show. INRA, Paris, France. 2008.

92. GmbH BV. A decade of Tropical Legumes projects: Development and adoption of improved varieties, creation of market-demand to benefit smallholder farmers and empowerment of national programmes in sub-Saharan Africa and South Asia. *Plant Breeding*. 2019;138:379–388.

93. Bommarco R, Lundin O, Smith HG, et al. Drastic historic shifts in bumble–bee community composition in Sweden. *Proc Biol Sci*. 2012;279(1727):309–315.

94. Biella P, Ollerton J, Barcella M, et al. Network analysis of phenological units to detect important species in plant–pollinator assemblages: can it inform conservation strategies?. *Community Ecology*. 2017;18(1):1–10.

95. Von Richthofen JS, Pro Partner GL. Economic and environmental value of European cropping systems that include grain legumes. Grain legumes No. 45–1st quarter 2006 Special report UNIP, France. 2006.

96. Preissel S, Reckli M, Schläfke N, et al. Magnitude and farm–economic value of grain legume pre–crop benefits in Europe: A review. *Field Crops Res*. 2015;175: 64–79.

97. Byerlee D, White R. Agricultural Systems Intensification and Diversification through Food Legumes: Technological and Policy Options. In: Knight R, edtor. Linking Research and Marketing Opportunities for Pulses in the 21st Century. Current Plant Science and Biotechnology in Agriculture, 34. Springer, Dordrecht. 2000.

98. Reddy A. Market integration of grain legumes in India: the case of the chickpea market. Market Integration of Grain Legumes in India: The Case of the Chickpea Market (December 6, 2011). Market Integration of Grain Legumes in India: The Case of the Chickpea Market, *SAARC J Agri*. 2012;10(2): 11–29.

99. Yirga C, Rashid S, Behute B, et al. Pulses value chain potential in Ethiopia: Constraints and opportunities for enhancing exports. *Int Food Policy Res Institute*. 2010;1–53.

100. Atnaf M, Tesfaye K, Dagne K. The importance of legumes in the Ethiopian farming system and overall economy: An overview. *American J of Exp Agric.* 2015;7(6): 347–358.

101. Habte E, Alemu D, Amsalu B, et al. Production and marketing of major lowland pulses in Ethiopia: Review of developments, trends and prospects. *Ethiopian J of Crop Sci*. 2018;6(3):435–465.

102. Liu L, Basso B. Spatial evaluation of maize yield in Malawi. *Agric Syst*. 2017;157: 185–192.

103. Andersa EJ, Zulub LC, Jamboc ER. Limits to grain–legume technology integration by smallholder farmers: The case of time–sensitive labor demands and food security primacy in Malawi. *Agricultural Systems.* 2020;184:102879.

104. Farrow A Review of conditioning factors and constraints to legume adoption, and their management in Phase II of N2Africa. 2014.

105. Graham PH, Vance CP. Legumes: Importance and Constraints to Greater Use. *Plant Physiology*. 2003;131:872–877.

106. Mapiye C, Mupangwa JF, Mugabe PH, et al. A review of forage legumes research for rangeland improvement in Zimbabwe. *Tropical Grasslands*. 2006;40:145–149.

107. Kumwenda M, Ngwira A. Forage demand and constraints to adoption by livestock keepers in Malawi. *Tropical grasslands*. 2003;37:274–278.

108. Kelly JD, Gepts P, Miklas PN, et al. Tagging and mapping of genes and QTL and molecular marker–assisted selection for traits of economic importance in bean and cowpea. *Field Crops Res.* 2003;82(2–3):135–154..

109. Siddique KHM, Johansen C, Turner NC. et al. Innovations in agronomy for food legumes. *A review Agron Sustain Dev.* 2012;32:45–64.

110. Pengelly BC, Whitbread A, Mazaiwana PR, et al. Tropical Research for Future– Better Use of Research Resources to Deliver Adoption and Benefits to Farmers. In: Whitbread, A. and Pengelly, B.C, editors. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia. Australian Centre for International Research (ACIAR) Proceedings. 2004;115:28–37.

111. Villamayor–Tomas S, García–López G. The influence of community–based resource management institutions on adaptation capacity: A large–n study of farmer responses to climate and global market disturbances. *Global Environmental Change*. 2017;47:153–166.

112. Dentoni D, Krussmann F. Value network analysis of Malawian legume systems: implications for institutional entrepreneurship. Food Supply and Distribution System Dynamics, Italy: Food and Agriculture Organisation. 2015.

113. Akibode CS, Maredia MK. Global and regional trends in production, trade and consumption of food legume crops. 2012.

114. Eifert B, Gelb A, Ramachandran V. the Cost of Doing Business in Africa: Evidence from Enterprise Survey Data. *World Development*. 2008;36(9): 1531–1546.

115. Sunga C. An analysis of spatial market integration: a case of Zambian dry bean markets connected by informal trade to Tanzania and the Democratic Republic of Congo (Doctoral dissertation, Stellenbosch: Stellenbosch University). 2017.

116. Lesser C, Moisé–Leeman E. Informal cross–border trade and trade facilitation reform in Sub–Saharan Africa. 2009.

117. Shiferaw B, Hellin J, Muricho G. Improving market access and agricultural productivity growth in Africa: What role for producer organizations and collective action institutions?. *Food Security*. 2011;3(4):475–489.

118. UN. 2016. United Nations proclaims 2016 as "International year of pulses". Global pulse confederation.

119. UN. 2015. United Nation Department of Economics and Social Welfare, Population Division, Revision of World Population Prospects.

120. Tadross M, Suarez P, Lotsch A, et al. Changes in growing season rainfall characteristics and downscaled scenarios of change over southern Africa: implications for growing maize. In: IPCC Regional Expert Meeting on Regional Impacts, Adaptation, Vulnerability, and Mitigation, Nadi, Fiji. 2007;20(22): 193–204.

121. CO2–Earth. 2017.

122. Christensen JH, Hewitson B, Busuioc A, et al. Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editros. Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York. 2007.

123. Cooper P, Rao KPC, Singh P, et al. `T Agric Res. 2009;7:19.

124. Abobatta WF. Precision Agriculture: A New Tool for Development. In Precision Agriculture Technologies for Food Security and Sustainability. 2020;23–45.

125. Meena RS, Yadav RS, Meena H, et al. Towards the current need to enhance legume productivity and soil sustainability worldwide: a book review. *Journal of Cleaner Product*ion. 2015;104:513–515.

126. Okur B, Örçen N. Soil salinization and climate change. In Climate Change and Soil Interactions. 2020;331–350.

127. Prasad PVV, Boote KJ, Allen LH. Adverse high temperature effects on pollen viability, seed set, seed yield and harvest index of grain–sorghum [*Sorghum bicolor* (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. *Agric For Meteorol*. 2006;139:237–251.

128. Shaheen NA, Othman AA, Ismail MR. Environmental Risk Assessment as an Approach of Resilience to Climate Change in Architectural Heritage. 2019.