Advances, Challenges and Opportunities in Cool-Season Food Legumes in Dry Areas

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Abstract

Cool-season food legumes (CSFL) such as chickpea, lentil, faba bean, field pea, and grass pea are an integral part of subsistence farming in dry areas and the major sources of nutritious food for human, feed for livestock, and income for smallholder farmers. These crops also fix atmospheric nitrogen into usable form and thus contribute to soil fertility in the cereal based cropping systems. The area, production and productivity of these crops are 26.1 million ha, 31.3 million tones and 1197 kg ha^{-1}, respectively. Cool season food legumes cover 33 and 45% of global pulse area and production, respectively, indicating better yield compared to warm-season food legumes. Past research and development efforts have resulted in development of improved varieties with medium to high levels of resistance to key diseases such as Fusarium wilt/root rot complex in chickpea and lentil; Ascochyta blights in chickpea, lentil and faba bean; rust in lentil and faba bean; and chocolate spot and parasitic weeds in faba bean. The most significant improvement in yield stability has resulted from the genetic improvement to develop appropriate phenology so that the durations of the vegetative and reproductive phases are well matched with the expected water supply. Expansion of chickpea in Central and South India, Myanmar and Ethiopia is an example of such development. With increasing pace of climate and farming system changees and reduced genetic diversity at farm levels, intensity and frequency of abiotic stresses especially heat and drought and emergence of new diseases and insect pests have increased manifold with serious yield losses. This drives the demand to produce more crops per drop of water and per unit area to enhance crop and water productivity. The yield potential of pulse crops is still low and requires substantial improvement in source-sink equilibrium to fit in various cropping systems. To achieve this goal, appropriate changes in phenology and plant type that can be grown in conjunction with cereals or fit within the short-season windows available between major cereal crops and are amenable to machine harvest, disease and pest resistance, and post emergence herbicide application to control obnoxious weeds are required. Thus, enhancing economic competitiveness and stability in performance of CSFL crops under climate and farming system changes require a three-pronged research strategy involving stress characterization, trait/gene discovery using high throughput platforms, and trait deployment through precision breeding in the desired agronomic and quality background along with a variety of specific production technologies. This strategy looks promising, particularly for developing more nutritious, input efficient varieties for enhancing food and nutritional security in developing countries.

Keywords: Cool season food legumes, genetic improvement, pre-breeding, production technologies, varieties

Introduction

Cool-season food legumes (CSFLs) *viz.*, chickpea, lentil, faba bean, field pea, and grass pea are an integral part of subsistence farming in the dry areas. These crops are the preferred choice among the smallholder farmers as their cultivation needs external inputs. Legume seeds are a rich source of protein and micronutrients, almost 2-3 times more than the major cereals, and the straw is a valued animal feed (Iqbal *et al*., 2006). Because of their vital role in human and soil health, these crops have been grown with cereals not only for meeting the diversified food systems but also for maintaining favorable equilibrium in agricultural production system. Together, these crops occupy 26.1 million ha area with production of 31.3 million tones and average productivity of 1197 kg ha^{-1} globally during 2011-13 (FAOSTAT, 2015). Chickpea contributes 39% to total CSFLs production followed by dry pea (33%), lentil (15%), and faba bean (13%).

South Asia grows CSFLs on 12.85 million ha and produces 10.52 million tons of grains with India as the major producer, importer and consumer. Chickpea (10 million ha) followed by lentil (2.0 million ha) and dry pea (0.5 million ha) are the major crops in the region (FAOSTAT, 2015, Figure 1). Food legumes in West Asia mainly in Turkey, Syria, and Iran are grown on 0.97 million ha area with production of 1.28 million tones and average yield of 1319 kg ha^{-1}. Chickpea (0.55 million ha) followed by lentil (0.39 million ha) and faba bean (0.03 million ha) are the major crops in the region. North Africa grows these crops on 1.05 million ha area with 1.12 million tones production and an average yield of 1060 kg ha^{-1} (FAOSTAT, 2015). Faba bean accounts for 52%, followed by chickpea (8%) and lentil (4%).

During the last five decades, area under CSFLs in East Africa has almost doubled from 0.76 to 1.58 million ha while the production has increased more than three times from 0.56 to 1.84 million tones (FAOSTAT, 2015), showing a positive yield gain over time (Fig. 1). Ethiopia is the largest producer of food legumes in East Africa with extensive area under faba bean (0.50 million ha), field pea (0.30 million ha), chickpea (0.25 million ha), grass pea (0.14 million ha), and lentil (0.11 million ha) (FAOSTAT, 2015).

In the past, CSFLs production could not keep pace with population growth resulting in drastic reduction in the per capita availability in developing countries. To bridge the demand-supply gap, a paradigm shift is needed in research strategy which supports the overall development, delivery, performance and impact of research on food legumes. Its focus should be on high-priority challenges and new opportunities based on the past successes and recent progress in science and technology. Systematic researches for their improvement are underway in several national and international institutions. The International Center for Agricultural Research in the Dry Areas (ICARDA) has a global mandate for improvement of faba bean, lentil and grass pea and a shared mandate with ICRISAT for chickpea to address specific needs of different agro-ecological regions in the dry areas.

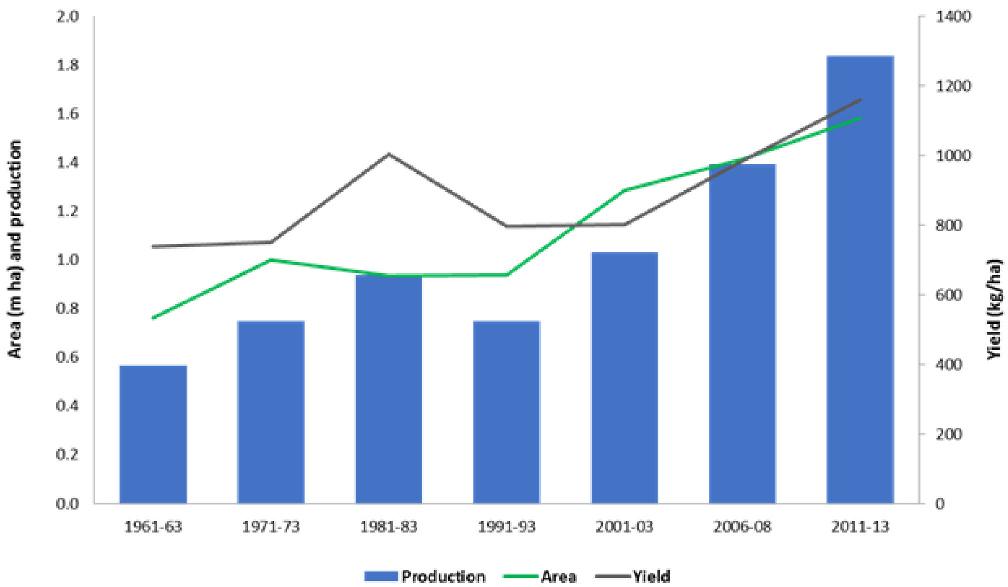

Figure 1: Trends in area, production and yield of cool-season food legumes in East Africa (FAOSTAT, 2015)

Major production constraints

Major constraints that limit the realization of potential yield of CSFLs which include biotic and abiotic stresses; besides socio-economic and policy factors (Table 1). Fusarium wilt/ root rot complex, Ascochyta blight in cool and wet areas and Botrytis grey mold in warm and humid climate are important diseases of chickpea. In lentil, wilt/root rot diseases, rust, Ascochyta blight and *Stemphylium* blight cause considerable damage in many countries. Powdery mildew and Ascochyta blight are the two most important and widely spread foliar diseases of dry pea whereas faba bean suffers great yield losses due to chocolate spot, rust, black and foot root rots, faba bean gall, and viral diseases. In grass pea, diseases limiting its productivity include powdery mildew and root rots. Among key insect pests, pod borer (*Helicoverpa armigera*) and leaf miner on chickpea, aphids on lentil, field pea, and grass pea and stem borer in faba bean cause severe damage (Sharma and Crouch, 2004). Besides annual weeds, parasitic weeds

(*Orobanche* and *Phelipanche* spp.) and dodders have emerged as major threats to CSFLs in West Asia, North Africa and East Africa, leading to substantial reduction in area and production (Sarker and Kumar, 2011). New diseases are appearing because of climate and farming system changes like *Stemphylium* blight, Botrytis gray mold and downy mildew on lentil and faba bean gall disease on faba bean.

Among abiotic stresses, terminal drought, heat, waterlogging and frost during reproductive stage; cold sensitivity during the flowering stages; and salinity/alkalinity throughout the crop growth period in irrigated areas inflict yield variation. All these stresses make the production of these crops low and unstable. Consequently, legume crops are perceived as marginal crops laden with high risk and poor yield. This perception discourages farmers to invest in requisite inputs vital for its successful cultivation. In the technological front, food legumes still need major yield breakthrough through morpho-physiological changes in plant type and development of multi-stress resistant varieties. In the cold-prone highlands of Turkey and Iran, lentil and chickpea are traditionally grown in spring to avoid the harsh cold climates in winter season. Local cultivars are of spring types that do not have winter-hardiness and so are unsuitable for winter cultivation. Frost at vegetative and reproductive stages and water logging in black soils are key constraints in the highlands of East Africa.

Research Advances

Genetic improvement

Food legumes improvement program at ICARDA is built upon the foundation of its vast germplasm collections (cultivated and wild relatives) and its use to breed new varieties better adapted to different agro-ecological conditions. ICARDA gene bank holds 38,000 accessions of chickpea, faba bean, lentil, field pea and grass pea. Except for a few traits, sufficient variability for important economic traits is reported in the existing germplasm. To increase the use of germplasm in breeding programs, the Focused Identification of Germplasm Strategy (FIGS) is recently being pursued at ICARDA with robust geographical datasets and core and minicore collections by ICRISAT. The FIGS strategy has proven successful for various adaptive traits such as tolerance to heat, drought, cold, and salt, besides resistance to insect pests and diseases. Such FIGS sets in chickpea, lentil and faba bean are now available to NARS partners to discover and deploy the useful genes into desired agronomic background.

Table 1. Production constraints of cool-season food legumes in different regions

Production Constraints	South Asia	East Africa	West Asia	North Africa
Chickpea				
Drought stress	x	x	x	x
Heat stress	x	x	x	x
Cold stress			x	x
Fusarium wilt	x	x	x	x
Root rot	x	x		
Ascochyta blight	x	x	x	x
Botrytis gray mold (BGM)	x			
Pod borer	x	x		
Faba bean				
Heat and drought stress	x	x	x	x
Cold stress			x	
Ascochyta blight		x	x	x
Chocolate spot	x	x	x	x
Rust	x		x	x
Viruses		x	x	x
Parasitic weeds		x	x	x
Lentil				
Drought stress	x	x	x	x
Heat stress	x	x	x	x
Cold stress			x	x
Fusarium wilt	x	x	x	x
Root rots	x	x		
Rust	x	x		x
Ascochyta blight		x	x	x
Stemphylium blight	x			
Aphids	x	x		
Parasitic weeds			x	x

Source: CRP-Grain Legumes (2013-16)

ICARDA breeding program generally uses parents of diverse origin with an aim to combine traits contributing to yield, appropriate phenology, adaptation to major biotic and abiotic stresses and market preferred traits. Following a selection-hybridization-selection cycle, ICARDA constructs new breeding lines to deliver to the NARS partners in the form of international nurseries (INs). These nurseries comprise a range of genetically fixed materials and segregating populations to provide opportunities to NARS partners for selection. Based on phenotypic performance, resistance to prevailing stresses, quality parameters and farmers' preference, NARS partners identify and select promising lines/single plants for eventual release as variety for commercial cultivation. Over 368 varieties have been released in lentil 137, kabuli chickpea 162, faba bean 75, and grass pea 7 for cultivation in target countries. During the last ten years, NARS partners have released 85 varieties of these crops using ICARDA material (ICARDA, 2016) (Figure 2).

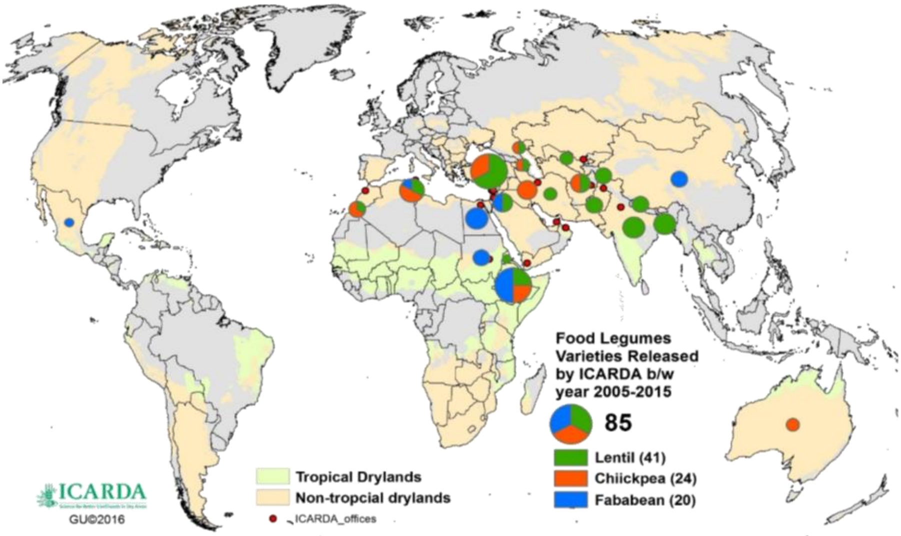

Figure 2. Improved varieties of food legumes released in different parts of the world using ICARDA germplasm

Focused programs on breeding and refinement of production and protection technologies have shown profound effect on production and productivity. The maximum production gain is observed in chickpea (6.32 million tons) and lentil (2.18 million tons). These gains become more spectacular when viewed with markedly reduced crop duration of these varieties. This has increased the per day productivity comparable to any rainfed crops besides making them suitable for introduction in new niches and diversification of the existing cropping systems. Some of the specific success stories of ICARDA partnership with NARS are well documented.

East Africa: Ethiopia is a major producer of cool-season food legumes in sub-Saharan Africa. In Ethiopia, several varieties of faba bean (22), field pea (26), chickpea (19), lentil (14) and grass pea (1) have been released (Yigezu *et al*., 2015). For example, the red lentil variety *Alemaya* is grown on about 10% of lentil area with average yield of 2 tones ha^{-1}. This variety has high level of resistance to rust, Ascochyta blight and wilt/root rot diseases, excellent phenological adaptation in new cropping niches, attractive seed traits, and high in iron and zinc. In chickpea, three kabuli varieties, *Arerti*, *(*FLIP 89-84C) *Ejere (* FLIP-97-263C), and *Habru* FLIP 88-42C *)* , that can yield up to 4 tones ha^{-1}, compared to only 1.7 tones ha^{-1} from landraces. These varieties with combined resistance to Ascochyta blight and Fusarium wilt/root rot complex have great potential due to their suitability for early planting to take full advantage of moisture during growing period. The regional agricultural research institute recently released a rust resistant lentil variety *Derso* and *Jiru* and being under scaling-out. Among faba bean varieties, *Moti, Gebelcho, Obsie,* and *Walki* are prominent. *Walki* is gaining popularity in waterlogged areas of the central highlands. An Orobanhce tolerant faba bean variety *Hashenge* was released recently and being out-scaled by NARS. In grass pea, low-toxin variety *Wasie* is a good example of successful collaboration with NARS partners and can be scaled out in cereal (wheat, barley, Tef and rice) based cropping systems in the mid highlands of the country. This partnership is reaping rewards over the past decade in Amhara and Oromiya regions where yields of faba bean, chickpea and lentil have increased and production is steadily growing, as is the cultivated area. In Ethiopia, the average rate of increase in grain yield potential of lentil over the 30-year period was estimated at 27.82 kg ha^{-1} at Debre Zeit and 18.02 kg ha^{-1} at Enewari (Bogale *et al*., 2015). Similarly, in faba bean, the annual rates of genetic progresses were 8.74 kg ha^{-1} (Tolessa *et al*., 2015).

The diffusion of improved varieties of faba bean, chickpea and lentil has been estimated at 11, 19 and 15% in Ethiopia (Yigezu *et al*., 2015). A study on faba bean showed higher adoption rate of 19% (Bishaw and Alemu, 2017). An IFPRI impact study in 2010 showed that the release and uptake of high yielding, rust and wilt resistant lentil varieties in Ethiopia has increased the growing area and harvest at an annual rate of 15% from 1994 to 2009. This resulted in 105,956 ha cropped with lentil, and 123,777 tones of production in the 2009/10 cropping season. As a result, food legumes have emerged as the third-largest crop export of Ethiopia after coffee and oil seed and represent a US$ 90 million export industry.

South Asia: In South Asia, one of the major achievements is the breaking of an ancient bottleneck of narrow genetic base in lentil. Genetic base has been broadened through introgression of genes from ICARDA germplasm in local landraces of the region. In Bangladesh, adoption of improved varieties like *BARImasur-4, BARImasur-5, BARImasur-6 BARImasur-7* and *BARImasur-8* has helped in improving lentil productivity in the country. Impact study showed that these improved varieties are cultivated over 110,000 ha in Bangladesh, delivering an annual extra production gain of some 55,000 tons, and valued at US$ 38 million annually (ICARDA, 2012). In grass pea, two varieties *BARIKhesari-3* and *BARIKhesari-4* are recently developed for rice systems.

West Asia and North Africa: In the highlands of West Asia and North Africa, kabuli chickpea and lentil suffer from low temperature at seedling stage. To overcome this problem, long duration varieties with winter hardiness, cold/frost tolerance and Ascochyta blight resistance have been developed.

The first winter-sown chickpea variety released in Syria was *Ghab 1* in 1982 followed by *Ghab 2, Ghab 3, Ghab 4, Ghab 5* and *Ghab 6 (*ICARDA, 2016*)*. Winter-sown chickpea area is expanding particularly in drier regions that do not traditionally grow chickpea in Syria, Turkey, and Iran. Winter hardiness has also been incorporated in lentil varieties such as *Kafkas, Uzbek* and *Cifci* in Turkey; *Gachsaran* in Iran; *Shiraz-96* in Pakistan; and *Bichette* and *Zaria* in Morocco. The winter-hardy variety *Kafkas* is getting ground in Central Anatolia. Winter technology in chickpea and lentil has significantly increased productivity compared to traditional spring-grown crop in these countries. Similarly for spring sowing, drought-tolerant chickpea variety *Gokce* released in Turkey was once grown on over 350,000 ha, almost 85% of the chickpea area in the country. Now it is being replaced with new releases because of their better yield and stability. The variety *Gokce* was introduced in Ethiopia and farmers are growing the crop in limited scale in East Shoa.

Like-wise, in lentil, *Firat-87*, locally known as *Commando* and *Syran-96* are popular in South-East Anatolia in Turkey, a major hub of red lentil production. In Morocco, *Bakria*, an early maturing green lentil with resistance to rust has been adopted by farmers in low-rainfall areas. *Idlib-3* is suitable to low rainfall areas (<280 mm) in Syria. Multiple disease-resistant faba bean varieties in Egypt have substantially increased productivity and production in the recent past. The release of Orobanche tolerant varieties, *Misr1, Misr3,* and *Giza843* has encouraged farmers to take up faba bean production in orobanche infested areas in Egypt. Recent efforts made for dissemination of these varieties combined with integrated pest management packages has increased farmers' grain yield by 256 kg ha^{-1} and reduced production costs by 350 USD ha^{-1}. Results from 1997-2014 shows that even with the decrease of faba bean cultivation area (from 135290 to 51680 ha), total productivity with improved varieties has gone up from 2 to 3.53 tones ha^{-1}. Egypt's self-sufficiency in faba bean production saw a downfall in 2011-12, but with the technology package, it improved in 2014-2015 and is on a continuous rise since then.

Supplemental irrigation:

Depleting soil moisture in rainfed areas often occurs during the most sensitive growth stages (flowering and grain filling) of CSFLs. supplemental irrigation (SI), with a limited amount of water applied, especially during the critical crop growth stages, results in a substantial improvement in yield and water productivity in chickpea (Acharya *et al*., 2015), lentil (Oweis *et al*., 2004) and faba bean (Girma and Haile 2014). A four-year (1996–2000) study on supplemental irrigation has identified significant improvement in yield and water productivity for chickpea, lentil, and faba beans (Oweis and Hachum 2003). However, lentil and faba bean are more responsive to supplemental irrigation than chickpea. In Ethiopia, drought period is likely to occur when the crop is at flowering and grain filling stages resulting in premature drying of leaves which in turn result in reduced assimilatory capacity and lower grain yields much below the potential yield of the crop; and SI would help improve yield of faba bean (Girma and Haile 2014).

Integrated pest management

The level of resistance in faba bean, chickpea and lentil for some of the diseases (*Stemphylium* blight, Botrytis Gray mold, wilt/root rots, Ascochyta blights, faba bean gall and rust), insect pests and parasitic weeds ranged from low to high and additional control measures are required. For foliar diseases caused by necrotrophic pathogens of food legumes, a combination of adjusting planting dates, crop rotation, seed treatments, pesticide sprays and uses of pathogen free seeds are used to reduce their impacts. For soil born pathogens, resistant/partially resistant cultivars, adjusting planting date, seed bed preparations to avoid excess water and seed treatments are commonly employed as management strategies. For biotrophic pathogens like rust and powdery mildew, resistant/partially resistant cultivars are mainly used. Parasitic weeds are mainly controlled by application of 1-2 sprays of sub-lethal dosage of Glyphosate on partially resistant cultivars (mainly faba bean) at flowering stage of the crop coupled with 1-2 hand weeding. Since the levels of resistance for insect pests is very low or non-existent, application of pesticides with adjusting planting date is widely used by farmers. For example, losses from leaf miner and pod borer in winter planted chickpea are very low compared with spring planted chickpea in Mediterranean region.

Major Challenges

Climate variability and farming system changes

Predicted climate change brings many challenges and opportunities to farmers and legume scientists. In the past, it may have been sufficient to develop a variety well adapted to a agro-ecological region, taking into account the well understood abiotic and biotic constraints and end-product quality. With climate and farming system changes becoming a reality, a dramatic shift in production base is expected to take place. Being climate smart crops, CSFLs will gain ground in these new niches. This requires development of varieties adapted to environments with larger variability in temperature and water availability and new cropping systems like conservation agriculture, intercropping, double/relay cropping etc. Drought stress, especially after the onset of flowering, is of common occurrence, causing substantial yield losses in South Asia, West Asia and North Africa. Drought research at

ICARDA is conducted at various locations to capture the expression of genotypes under low, medium and high moisture conditions screening a large number of lines for drought include delayed planting of germplasm/improved materials to coincide the critical growth stage with high moisture stress. Additionally, the conventional methodologies are being supplemented with better and automated phenotyping facilities and molecular tools to understand the complex nature of drought tolerance. Similarly, heat stress during the reproductive phase adversely affects pollen viability, fertilization, pod set and seed development leading to abscission of flowers and pods, and substantial losses in grain yield (Gaur *et al*., 2015). Pollen-based screening methods have been useful for evaluating genotypes for tolerance to heat stress in both lentil and chickpea. We also evaluate our germplasm of faba bean, chickpea and lentil in Sudan, where the crops experience heat stress throughout its reproductive phase. Genetic variation for heat tolerance has been identified in these crops. The precision and efficiency of breeding programs for climate smart varieties have been enhanced by integrating novel approaches, such as high throughput phenotyping, rapid generation turnover, marker-assisted selection, and genome wide selection. Efforts are underway to mainstream these tools into routine breeding programs.

Farming system and climate variability, as well as germplasm movement led to emergence of new diseases and insect pests which are becoming new challenges in food legume production. For example, new faba bean gall disease in Ethiopia is damaging the crop for the last five or more years and expanding its area coverage. This disease is threatening both the welfare of farmers and genetic diversity of the crop. On the other hand, parasitic weeds are expanding in East Africa which has never been known in the past. Collar rot has emerged as major disease of lentil with the introduction of relay planting of lentil in standing rice crop in South Asia. In zero tilled cropping with the introduction of lentil in the rotation has resulted in a serious outbreak of downy mildew, which is a minor disease on lentil in Syria. The breeding program and integrated pest management practices should be developed or fine-tuned to address new biotic threats.

Large yield gaps

Combined effect of insect pests, diseases and weed infestations on food legumes is estimated at 37-70% losses in grain yield (Kumar *et al.*, 2016). A great progress has been made in solving individual diseases and now the major challenge is to manage new spectrum of diseases and insect pests under climate change and variability and develop multiple disease resistant varieties. Since the value of resistance sources depends upon levels and stability of their resistance, a complete understanding of resistance-associated factors for critical traits in the available germplasm has the potential to bring them together in a selection index, and ultimately use them in pyramiding using molecular tools in breeding programs. Among major insect pests, pod borers and leaf miner in chickpea, and aphids and Sitona weevil in lentil and faba bean and stem borer in faba bean are the major challenges. The levels of resistance to pod borers in the cultivated germplasm are quite low, and hence, little progress in developing resistant cultivars. Good sources of resistance against pod borers and leaf miner in chickpea and Sitona weevil in lentil have been reported in wild relatives but its transfer into the cultivated germplasm poses a challenge (Kumar *et al*., 2011).

Development of insect-smart production systems integrating various components including rational application of bio- and synthetic pesticides will guide decision-making in pest management. Integration of transgenic plants with high levels of resistance to pod borers and management approaches will act as a major game changer to provide a sustainable solution to these intractable pest problems. For biological control, our approach is 'discovery-to-deployment' pipeline involving identification of better-adapted natural enemies against this pest, and efficient system for rearing of the natural enemies.

Harvest losses

Manual harvest of legume crops is becoming increasingly uneconomical because of the rising cost and shortage of labor at the peak harvest time. In order to use combine-harvesters, legumes varieties need to be modified for machine harvestability. This requires development of varieties with erect and tall plants with strong stem, top pod bearing habits, synchronous maturity, and tolerance to lodging and pod shattering. Utilization of available genetic variability for these traits has led to the development of improved breeding lines suitable for mechanical harvest. A large number of breeding lines with upright growth habit and suitable for mechanical harvesting is under field testing and would soon be available for cultivation. Past efforts at the Center have produced new varieties suitable for mechanical harvesting - such as the *Idlib 2* to *Idlib 5* in Syria and *'Sayran 96'* in Turkey. On-farm trials and demonstrations indicate that on average mechanical harvesting combined with improved cultivars reduces harvest costs by 17-20% in lentil (Sarker and Kumar, 2011).

Mono-cropping of cereals

Expansion of area under irrigation and availability of more productive cereal varieties and production inputs have resulted in substantial reduction in area under legumes especially in the Indo-Gangetic plains and North Africa (Ali and Kumar, 2004). With cereal yields projected to double over the next 30 years, legumes would likely to be further pushed out, unless extra-early varieties of food legumes are developed that can fit in the short season windows of the existing cereal-based systems. Extra-early varieties (<90 days) escape end-of-season drought and heat stresses in addition to fitting the crops in available short windows of these cropping systems. In addition, increased adaptability to marginal soil conditions and matching water availability during the critical growth stages will also be required. In Ethiopia wheat mono-cropping is a major problem in medium and highlands of the country and recently large seeded high yielding kabuli chickpea and faba bean with resistance to foliar diseases and wilt/root rot are showing high acceptability to be included in the rotation.

Non-availability of quality seeds

Neither the public nor the private sector is involved in legume seed delivery due to various reasons. Non-availability of quality seeds of improved varieties in legume crops remains a challenge to transfer agricultural innovations to farmers and realize the impacts of investments in agricultural research. The present seed delivery systems have been constrained by policy, regulatory, institutional, and technical issues or a combination of these factors superimposed by complexity and diversity of farming systems, and socio-economic conditions of farmers. Many countries are grappling with establishing sustainable legume seed delivery and looking into a combination of options including formal (public or private) and innovative alternative informal approaches to ensure availability and access to new technologies.

Opportunities

Different approaches like genetic, management and developmental options are available for improving productivity. Besides restructuring the plant as per the environmental requirements and cropping systems, efforts are needed to design varieties with appropriate growth habit and efficient source-sink relationships. Except faba bean, introgression of unexplored genes from the wild relatives could be rewarding for broadening the genetic base of important traits such as yield, yield attributes and resistance to biotic and abiotic stresses in pulses. We need varieties which are amenable to machine harvest and to commercially available post-emergence herbicides. We also need varieties which provide opportunity of planting in the short-season windows available in the existing cropping systems. Thus, enhancing economic competitiveness and stability in performance of food legume crops under climate change requires a three-pronged Research for Development strategy involving environment characterization using GIS tools, trait discovery using a high throughput phenotyping and genotyping platforms, and trait deployment through precision breeding tools in the desired agronomic background. Some of the opportunities are as follows:

Pre-breeding for widening the genetic base

There is a growing concern on limited genetic diversity due to frequent use of limited germplasm in breeding improved varieties. Genetic enhancement through pre-breeding is proposed for increasing the extent of useful diversity available to breeders through introgression of desirable traits from exotic material and wild species. ICARDA in collaboration with NARS partners in India have initiated a pre-breeding program on chickpea and lentil which has been instrumental in introgressing useful genes in the mainstream breeding. With rapid generation advancement and recent successes and availability of new biotechnology tools have brightened the prospects of transferring useful traits from exotic materials as well as primary and tertiary gene pools into pulses.

Improving plant type

Food legumes are grown under varying agro-ecological conditions and cropping systems and each set of conditions needs a specific plant type for higher productivity. Most of the food legumes still have wild traits like indeterminate growth habit, pod shattering, pre-harvest sprouting and sensitivity to photoperiod and temperature regimes. It is presumed that the determinate types under good management would partition photosynthate to yield components with greater efficiency. Similarly, photo and thermo insensitive varieties will be able to have wide adaptability with minimum seasonal and regional effects on their phenology and yield potential besides a more synchronous reproductive ontogeny and greater harvest index. Breeding objectives need to be directed keeping in mind the impact of altered plant types on the yield of the component crops. Simulation models developed recently for some of the legume crops offer the potential to interpret and predict the performance of individual genotypes in different environments thus offering a possible role in decision-making regarding suitability of the proposed plant type in the target environment and prevailing cropping systems.

Intensification and diversification of cereal based cropping systems

By virtue of atmospheric nitrogen fixation, food legumes can play an increasingly important role in rainfed production environments, especially in soils with low N content. After the harvest of wheat, fields are commonly left fallow as insufficient moisture prohibits the reliable production of rainfed summer crops in the Middle East and North Africa. The use of food legumes to replace the summer fallow phase of the traditional fallow-wheat system is one of the key components for obtaining a reduced or negative carbon footprint besides increased wheat yields, enhanced soil fertility, increased water use efficiency, as well as decreased losses in yield and quality from weeds and soil borne diseases. Typical rainfed wheat-based cropping rotations include food (chickpea, lentil, faba bean, field pea) and forage (*Medicago sativa* and *Vicia sativa*) legumes. In the highlands of Ethiopia, food legume crops are often grown in rotation with cereals or as intercrops, mixed crops to minimize the risks of biophysical stresses and to manage soil fertility. In Ethiopia, in a two-year cropping system, wheat after faba bean significantly out yields wheat-wheat and wheat-barley rotations (Tadesse *et al.*, 2016).

Growing crops in mixtures or as intercrop is a common practice in traditional agriculture. Despite this, a recent recourse by farmers in northern Ethiopia from growing a pure wheat crop to mixed intercropping of wheat with a small population of faba bean and field pea has attracted attention from research and development stakeholders. The farmers' reason for such a practice is land shortage coupled with the need to produce a cereal as the main crop and some legumes as an additional benefit. In South Asia, systematic research on inter/mixed cropping of wheat + legumes with emphasis on genotypic compatibility and spatial arrangement has led to identification of efficient intercrops, such as chickpea/lentil with wheat (Ali and Kumar, 2001). These intercrops, in a particular row ratio significantly increased total productivity and land use efficiency besides improving soil health.

Simulation studies show that there is potential to further expand the geographical area of lentil in East Africa including Uganda, Kenya, Tanzania and Somalia (Ghanem *et al*., 2015). Delaying sowing alone or in combination with a long-season genotype can result in a high probability of crop yield increase in East Africa. For the long-season genotypes, an optimum sowing window was found between June and July (152–229 day of year) for areas to the north of the Rift Valley (Ghanem *et al*., 2015). Late sowing dates (229–243 day of year) were found to be optimal in southern areas of East Africa (Ghanem *et al*., 2015). These simulations indicated that selection and breeding for lentil accessions in East Africa should consider changes in plant phenology and/or sowing dates.

Conservation agriculture

Zero-tillage, together with crop residue management (mulches) and crop rotation are the pillars of CA. Inclusion of legumes in the cereal-based rotation improves the soil physico-chemical properties and provide opportunity to increase the legume area and production. The rotational soil fertility benefits of legumes to subsequent crops can be substantial increase in the yield of subsequent cereal crops. But often the crop residues are removed from the field at harvest, so they do not provide the mulch cover wanted for CA.

Cereal–legume rotations for CA should focus on multipurpose legumes, where expansion of their cultivation will depend on the availability of ready markets for the quantities of grain produced beyond the direct needs of the farming households and suitable machineries. ICARDA has introduced and sxcaled out CA (cereal-lentil rotation) in Syria and northern Iraq where the average grain yield increase with ZT compared to CT was 0.26 t/ha for barley ($n = 278$), 0.33 t/ha for wheat ($n = 264$), and 0.23 t/ha for lentil ($n = 88$). Since 2006/2007, the area under ZT has grown from zero to more than 30,000 ha in Syria and 10,000 ha in northern Iraq in 2012/2013 (Loss *et al.* 2015).

Diseases like downy mildew on lentil and Ascochyta blight on chickpea were more sever on ZT with early planting in Syria (Ahmed *et al.* 2012) and therefore, continue pest monitoring is important for better pest management practices

Bridging yield gaps

In recent years, cultivars resistant to one or other stress have been bred bringing stability to legumes production. Stable resistance sources for many diseases and insect pests besides precise information on important aspects such as identification and characterization of races/biotypes, rate of emergence of new races/biotypes, genetic control, etc., are now available for directed improvement in resistance breeding. In chickpea, varieties need to be developed with multiple resistance against Fusarium wilt, root rots, Ascochyta blights, and botrytis gray mold to succeed in farmers' fields in different regions. Besides, lentil and field pea varieties need to be resistant to root diseases and powdery mildew, respectively. The most significant improvements in yield stability have resulted from genetic modification to develop appropriate phenology such that the durations of the vegetative and reproductive periods are well matched with the expected water supply. From trait evaluation to gene discovery to its deployment into varieties for abiotic stress tolerance is long drawn process and requires the expertise in various disciplines. In the recent past, a great progress has been made in development of high throughput approaches in eco-physiology, genomics, phenomics, and geo-informatics which offer scope for tailor-made solutions to these stresses.

Managing weeds

Weeds (parasitic and non-parasitic) pose serious challenge to food legumes production. Non-parasitic weeds compete with crops for light and nutrients, often leading to significant yield losses of up to 40% in legume crops. Use of non-selective herbicides is effective in removing all types of weeds in a single application; however, herbicide resistant/tolerant varieties need to be developed. Recent progress in identifying herbicide tolerant germplasm within the cultivated species has shown promise for development of herbicide-tolerant varieties. For example, varieties with improved tolerance to herbicide metribuzin have been developed by screening the advanced breeding lines in faba bean, lentil and chickpea. Genotypic differences have been reported for tolerance to imidazolinone class of herbicides in chickpea, lentil and faba bean. Although, genetic variations have been reported in faba bean and lentil to Orobanche, integrated broomrape management practices that include herbicide and other control practices offer an opportunity to recapture the area under CSFLs crops in WANA and East Africa regions.

Improving nutrient use efficiency

Plants differ greatly in their ability to utilize nutrients and adapt in deficient nutrient conditions. It is, therefore, necessary to screen germplasm having better nutrient use efficiency to cut on external use of fertilizers. Manipulation of the production environment with fertilizer application has been the most preferred practice to meet plant requirements. However, the same may not be the most economical solution to all mineral deficiency and toxicity problems of the soils in future. Altering the plants to grow on soils with mineral deficiency without compromising on yield or quality has great potential. Lower input requirements, reduced production costs and less pollution could be some of the benefits expected to accrue with nutrient use efficient plants. Information about genetic aspects of plant mineral nutrition should be derived to augment research strategy for developing nutrient use efficient genotypes for cultivation of legumes in degraded soils.

Enhanced nutritional quality

Over two billion people in the developing world are malnourished and are affected especially by micronutrient malnutrition, the “hidden hunger” (FAO, 2015). Legumes are one of the key food components of daily diet of the people, and valuable source of digestible protein, minerals and vitamins, and low-glycemic carbohydrate. Biofortification, under the Harvest Plus Challenge Program of CGIAR, has led to enrich lentil varieties with micronutrients. More than 1700 germplasm including wild species, breeding lines, and released cultivars from about 20 countries were analyzed for iron and zinc contents. Iron and zinc were found to be present in the range of 43-132 ppm and 22-90 ppm, respectively in these materials. This high presence of iron and zinc contents in wild accessions (ILWL74 and ILWL80) encouraged scientists to proceed further for genetic enhancement through cross breeding.

Conclusion

Systematic and concerted research efforts over the years have resulted in increasingly more productive technologies in CSFLs, which have brought about wider adaptability, higher and stable yield, and better market price due to market specific characteristics like seed size and color besides early maturity, and tolerance to biotic and abiotic stresses. Focusing on improved plant type, widening the genetic base, pyramiding of resistance genes for key stresses, and identifying remunerative cropping systems and intercrops, besides efficient production and protection technologies, can help improve the production on sustainable basis. Looking ahead, escalating costs of producing inorganic nitrogen fertilizer, reducing availability of water for agriculture, climate change, food insecurity and an increasingly nutrition-conscious consumer society collectively give a bright future for CSFLs. There is a need to employ a more integrated approach to use the existing genetic and genomics resources for uplifting the current yield level in lentil, faba bean and chickpea. Application of molecular approaches for legume improvement is expected to be the part of mainstream breeding programs in the international and national programs which will contribute immensely for developing improved cultivars with higher yield and stability. Improving the seed system is critical expand the scale of adoption and impact of improved crop varieties. ICARDA is collaborating with national program of West and South Asia, and East and North Africa to promote improved technologies to increase smallholder legume production, strengthen food and nutritional security, and improve soil fertility and health.

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