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# Pulses for food and nutritional security: The technology perspective

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**Abstract**

**Pulses though extremely important from a food security and nutrition perspective in India have lagged behind cereals and have been moved increasingly to marginal environments. The persistent demand supply gap in pulses poses several challenges including technological ones that stem from movement of pulses to difficult environments and its place in relation to the competing crops. Technologies in pulses have evolved in line with the needs such as short duration to meet intercropping requirements. Given the long history of technology development that lags behind principal crops marked by near absence of private sector in R&D in pulses, it may be time to rethink and try demand pull systems of research with Advance Marketing Commitments along the lines suggested for vaccines.**

**Key words:** Nutritional security, technology, pulses, nutrition perspective, food security

## Introduction

Food security has always been a very important public policy issue in India emanating from severe food scarcity until the mid-1960s. With strong policy attention given to the high-yielding cereal crops like rice and wheat, 1960s and 1970s witnessed high growth in their production and yields with the introduction of green revolution technologies. The adoption of high-yielding varieties and access to irrigation resulted in wheat and rice recording spectacular growth but this happened at the cost of other crops, particularly coarse cereals, pulses, and oilseeds.

Pulses are particularly important given that the largest number of malnourished people in the world live in India. A large percentage of Indians suffer from nutrition problems including protein deficiency. Given the levels of poverty and incidence of vegetarianism, ameliorating the problem of protein deficiency implies an important place for pulses. Pulses have been vegetarian's and poor man's meat. They complement the cereals with proteins, essential amino acids, vitamins, and minerals. Pulses contain substantially more protein than staples (estimated to be almost twice than in wheat and thrice than in rice). Moreover, pulses constitute the most common source of protein (its frequency of consumption is higher than any other source of protein) contributing to more than 10% of protein intake. Around 89% consumers have pulses at least once a week in India, while the corresponding number for fish or chicken/meat is only 35.4% (IIPS and ORC Macro, 2007).

The animal source foods (ASF) are the most expensive sources of protein in India. Patwardhan (1962) elaborated on the role legumes play in the diets of populations in the tropics and subtropics in contexts where ASF consumption is less common. In these areas, the use of comparatively protein-rich legumes is an essential strategy in people's attempt to balance their diets. The seeds of pulses contain two to three times more protein than cereals and root tubers. Depending on the species and variety, pulses have a protein content that ranges between 17 and 32%. Besides being rich in protein, pulses contain a wide range of nutrients, including carbohydrates, dietary fiber, unsaturated fat, vitamins, and minerals, as well as non-nutrients, such as antioxidants and phyto-estrogens. Pulses contribute to reduced colon cancer and cardio-vascular disease, increased satiety, lower Body Mass Index, and the risk of obesity (Boye, Zare, and Pletch, 2010; McCrory et al. 2010; Jukanti et al.

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(2012). These health benefits assume great importance in the wake of increasing incidence of diabetes and other lifestyle-related diseases.

Pulses are not only important because of their nutritional value, they also enhance productivity of soil and can improve yields of the crops that follow its harvest. Pulses in the rice-wheat cropping systems are likely to be quite important given that continuous mono-cropping of cereals has led to depletion of soil fertility and greater pest and disease incidence. The inclusion of the legumes in rice–wheat cropping system can help soil fertility. Pulses help in crop rotation and help reduce soil pathogens and fix nitrogen. Lower usage of fertilizer, pesticide, and irrigation further makes pulses an environmentally sustainable crop.

With these benefits, pulses should have received adequate attention by growers, consumers, technologists and policy makers alike. Unfortunately, that has not been the case. India has persistently faced a deficit and a substantial part of domestic demand has been met by imports for over one and a half decade now. On the consumption side, the long term trend has been a declining per capita consumption (though at an aggregate level the demand has risen).

With this background, this paper looks at the pulses sector from the point of technology and relevant policies. We conclude that there are several features of pulses and bottlenecks that have jointly led to earlier stagnation and later limited improvement in pulses. The crux of the problem lies in understanding pulses in a context with its crowding out by more lucrative and comparatively risk free cereal crops. At the policy level and in technology development as well, pulses sector have lagged behind many other sectors.

Pulses is not one commodity but comprises a mix of many different ones. The major pulses in India include chickpea, pigeon pea, lentil, green gram, and black matpe that account for nearly 80% of total production. The minor pulses include different beans, viz. kidney beans, black eyed beans, cow peas, lablab beans, green beans, and green peas. India accounts for 33% of the world area and 22% of the world production of pulses. About 90% of the global pigeon pea, 65% of chickpea and 37% of lentil area is in India, corresponding to 93%, 68% and 32% of the global production, respectively (FAO 2011).

However, relative to cereals, pulses have performed poorly. Between 1975 and 2005, the mere 32% increase in production of pulses pales in comparison to about 280% increase for cereals. The corresponding figures in yields are 25% and 211% respectively (Srivastava, Sivaramane, and Mathur 2010). Not only has the pulses yield growth been low, it has also been widely variant across growing areas. It seems that whenever irrigation and infrastructural facilities become accessible, the farmers have shifted away from pulses (Gowda et al. 2013).

**Performances of pulses sector in India**

There are several factors behind the current state of pulses sector but in this paper we will focus on technology. Pulses in India to a large extent mimic the case of oilseeds where inadequate domestic production has led to import penetration of as high as 50%. In some years, in pulses as well, close to a quarter of consumption came from imports. Yet, pulses in India offer a wealth of opportunities and there exists significant unexploited potential that can be redeemed through technology. First, there are significant yield differences between India and other leading producers in the world. Bridging that gap is one goal. Further, compared to the potential of the existing technology itself the performance of pulses has been subpar.

Nationally, pulse production has been near stagnant for a long time (except for the spurt in last 3-4 years), several changes have occurred at the sub-national level. The regions of prominence in pulses have changed with main production centers moving from eastern to western region and from northern to southern region in the country. Most importantly, the pulses have increasingly shifted away from the areas of green revolution. The expansion of irrigation in northern India displaced pulses by wheat, rice, and maize. On the other hand, the area under pulses increased in central and south India. Among pulses, chickpea area had a steep fall in north India. Moreover, irrespective of the region, pulses are mainly produced by small and poor farmers, usually, on marginal lands. In 2013, 87% of the pulses were grown under rain-fed conditions. Apart from this, abiotic stresses like moisture, drought, high temperature and biotic stresses like pests and diseases are quite frequent in pulses.

Though there has been a trend upward shift in pulses' yields after 1980s, over the entire period, pulses' yields have continued to be quite unstable. Moreover, whatever little yield growth has happened in pulses, it is concentrated in a few pulses, mainly chickpea (Figs. 1 and 2). Even at its peak, yield of pulses in India have been significantly lower than in some leading countries like Israel (3 tons/ha), Australia (over 2 tons/ha), and China (2 tons/ha). Similarly in pigeon pea, countries like Philippines have yields over 1 ton per hectare compared to just about 800kg/ha in India.

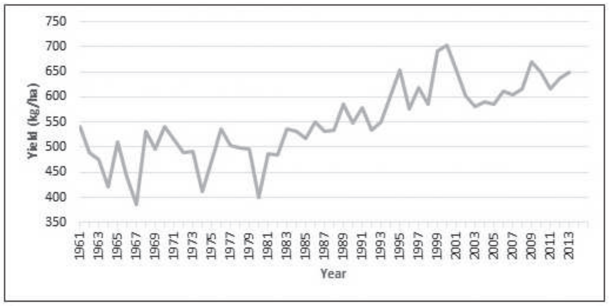


**Fig. 1. Pulses yield at aggregate level in India, 1961-2013**

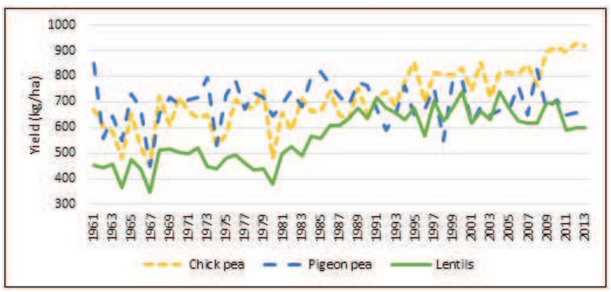


**Fig. 2. Yield by pulse type in India, 1961-2013**

In analyzing the yield performance, a very important aspect is that pulses need to fit in the rice-wheat or cereals system in general. Consequently, it is possible that the attribute of technology that could be valued the most might not be yield per se, but the duration. Indeed, the successful pulse varieties are characterized by short duration or very short duration to maturity. Further, incidence of pests is a significant problem in pulses owing to richness in protein.

Like in all pulses, development of short-duration and wilt-resistant chickpea varieties as part of technology development has been desirable. With these attributes developed, in case of chickpea, there has been significant technology adoption in new niches of southern India (Gowda and Gaur 2004; Gaur et al. 2008).

Barring few successful cases, overall, from the point of view of technology, there seems to be a significant unexploited potential in the pulses sector. For example, the program to boost productivity of rain-fed agriculture through science-led interventions in the state of Karnataka (called the 'Bhoochetana' project) that improved management practices (including application of micronutrients) increased pulses' yield by 31-57 % of green gram, 26-38 % of pigeon pea and 27-39 % of chickpea during 2010/11 (Gowda et al. 2013).

## Government initiatives in pulses technology and dissemination

Before 1970, there were no large scale government schemes to support pulses production. In 1967, the government established All India Coordinated Pulses Improvement (AICPI) Project, which was later elevated to the Indian Institute of Pulses Research. The institute between 1990 and 2010, released around 250 new varieties of seeds.

During 1971-1990, several pulses development schemes were launched such as Pulses Development Scheme (4th Five-Year Plan) (1969/70 to 1973/74), National Pulses Development Project (7th Five Year Plan) (1985/86 to 1989/90) and Special Food Grain Production Program (1988/89). In the 1990s, some short-duration and wilt-resistant varieties of pulses were developed. At the turn of the century, the government also launched schemes for pulses development like Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize – ISOPOM (2004), National Food Security Mission–NFSM (2007/08) and Special plan to achieve more than 19 million tons of pulse production by *kharif* (rainy season)-2012/13. The schemes were: OPP — Oilseed Development Programme, OPDP — Oil Palm Development Programme, NPDP — National Pulses Development Programme, and AMDP — Accelerated Maize Development Programme.

Finally, pulses were also made a focus crop in the National Food Security Mission (NFSM in 2007) in 171 districts across 14 states with the objective to increase the production by 2 million tons by the end of Eleventh Plan (2011/12). About 80% of the pulse area falls in the 171 NFSM-Pulses districts. A comprehensive set of interventions has been undertaken under NFSM-Pulses, for example, the legislation that the certified seeds of newly developed improved varieties/hybrids of pulses produced in the private sector, will also qualify for distribution subsidy. Further, the Government of India allocated Rs 3 billion under Rashtriya Krishi Vikas Yojana (RKVY) for integrated development of 60,000 pulse villages during

2011/12. Farmers were also provided assistance under other programs like Macro Management of Agriculture (MMA), Bringing Green Revolution to Eastern India (BGREI) for increasing crop productivity and strengthening market linkages.

With all these different schemes what is intriguing is that there has actually been a secular reduction in per-capita availability of pulses, from 66 g/day during TE 1965 to 33 g/day during TE 2005 (Agricultural Statistics at a Glance 2007). The level is lower than the Indian Council of Medical Research (ICMR) norms of 40 g/day.

**Production policies and technology in pulses**

India has a long history of programs relating to technology development in pulses. Since the preferences vary across regions, technologies have to focus on different types of pulses. Also, as pulses have moved across regions in a significant way, technology has to keep pace with the movement and help the expansion across different regions (ago-climatic conditions). As the green revolution happened in cereals, it affected the prospects for pulses. Technology development had to focus not only on improving the yields but has to fit in the cropping complex that includes cereals. Alongside, as pulses have increasingly been pushed to marginal environments, less irrigation and arid conditions demand special type of technologies.

Further, among important constraints in increasing the production and productivity of pulses in the country, has been the lack of availability of seeds of improved varieties to the farmers. Hence, it is not only the development of technology, but the delivery systems also have to be strengthened in pulses.

Importantly, the private sector has been missing from the Research and Development (R&D) in pulses. It is mainly the public sector including government as well as international organizations such as International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and International Center for Agricultural Research in the Dry Areas (ICARDA) that have been driving pulses research. Government policies in combination with efforts of international organizations has had some success in the development of new technologies in pulses. This has happened more so in the previous decade. Yet these successes seem to be too few and concentrated only in some pulses, for example chickpea.

The nationally representative situation assessment surveys in 2003 and 2013 by National Sample Survey Organization (NSSO) show a continuous decline in the use of public extension services for dissemination of technology (Birthal et al. 2015). In crops like maize and pearl millet where private sector has been important, the diminishing role of public extension has been met with increased private extension (Feder, Birner, Anderson 2011).

India's private seed sector has been quite active even in some minor crops like pearl millet. In the case of pulses technology, the private sector is conspicuous by its absence. Examples from cotton, maize, and pearl millet in India show that the dissemination of technology is faster when the private sector is also active. Profit motives in private sector create a system of active extension. To maximize adoption, the private seed suppliers provide extension services themselves often using the input suppliers as the agents on ground. Near complete absence of the private sector seed producers and availability of their services is quite stark in case of pulses.

**Technology challenges for the pulses sector**

How pulses and technologies in pulses perform is contingent on interactions with other crops, not only cereals, but also other crops like oilseeds. With commensurate support from the technology, there seems to be a clear case for enhancing the utilization of rice-fallow lands for growing more pulses (up to 3-4 million hectares of rice fallow can be utilized for pulses). This area is spread mainly across Bihar, Chhattisgarh, Jharkhand, Odisha, and Madhya Pradesh. In reality, many rain-fed areas in Chhattisgarh, Madhya Pradesh, Jharkhand, Bihar, Odisha, and Andhra Pradesh remain fallow during *rabi* season due to lack of cultivation knowledge of field crops and non-availability of irrigation water.

Hence, a better engagement with fallow systems can go a long way in improving the outcomes. Farmers of such areas can be encouraged to grow pulses in the *rabi* season on residual moisture–lentil in upland, chickpea in medium and lowlands. In addition, some pulses can act as filler crops in different agro-ecological conditions. For example, summer green gram can be a filler crop in north-west India, Gujarat and West Bengal. Overall, the unharnessed potential of intercropping in pulses may be looked afresh. Some examples are green gram and black matpe with spring sugarcane, chickpea with mustard, pigeon pea with groundnut/soybean/millets, and pigeon pea on rice-bunds.

In utilizing the rice fallow system, there is a case for reducing yield dispersion in pulses and this is a task for technology developers to be sensitive about. As discussed above, the pulses sector in India does not compare well internationally in terms of yields or its variance. Hence, there is a scope to aim for the technology frontier in pulses. Moreover, even with low yields nationally, the vast differences across regions in India highlight the existence of significant potential for raising pulses productivity in different areas. Some other low-yielding crops in some areas, such as upland rice, millets, barley, mustard, and even wheat may be substituted by high-yielding pulse crops when suitable.

Also, if pulses were to be more attractive by growing in irrigated areas such as ones with watershed development, it would require demonstration of consistently high yields. Technologies that ensure this stability will be the ones adopted. Recent episodes of high prices in pulses and record production in the past 3 years, provide an excellent opportunity to foster the production of pulses in non-rainfed areas, particularly where recent watershed development has taken place. Technology has to provide the support for this to happen.

How technology can help pulses sector is demonstrated by the expansion of pulses in south where many institutional and technological factors contributed. These include introduction of chickpea into black cotton soils, availability of fallow lands, and adoption of short-duration and high-yielding varieties (Reddy et al. 2013). Further, as part of technology uptake, large-scale mechanization also helped in consolidation of operational holdings where labor-intensive works like harvesting and threshing, are contracted out (Reddy et al. 2013).

How to incentivize the private sector in R&D and technology dissemination in neglected crops such as pulses remains a first order research and policy question. Possibly a demand pull research system that awards large sums for innovators who deliver on pre-specified technology outcomes in pulses can bring about promising technologies (see below for details). Against the reward of a large sum the rights for marketing would be transferred to the government.

Note the historical context in this. The production of pulses for example in 2002-03 was 11.14 million tons, which was much significantly below the target of 16 million tons. This was the situation despite scientists' claim that around 92 improved varieties of gram, arhar, moong, urad, massar and moth with high potential of yield improvement had already been released. In addition, new plant protection practices such as Integrated Pest Management were also available.

Hence, normally the gap between actual and potential yield has remained quite high even in agriculturally advanced states like Haryana. Thus, challenges in raising production of pulses three decades ago, still exist and the situation has not improved despite the government adopting a mission mode approach under the Technology Mission on Oilseeds and Pulses since 1990-91.

Undoubtedly, constraints faced by pulse production from technology perspective are daunting. Apart from problems such as rain fed marginal land, susceptibility to pest and disease attacks, weather aberrations, lack of genetic breakthrough in pulses are also hard realities. These constraints affect growers' enthusiasm to intensify input use or to adopt improved technology.

**Review of technologies and innovations in pulses**

Pulses research had to focus Mishra and Joshi (2016) on the areas such as breaking the yield barrier; developing resistance to pests and diseases; breeding varieties for nontraditional and marginal areas; reducing the length of the growing season by developing short-duration varieties; and improving quality, especially in grain size.

Compared to cereals, performance of pulses technology has been subpar. Mishra and Joshi (2016) present indicators to illustrate this. The number of full time scientists engaged in pulse research remains very low: at present the ratio is only 2.5 full-time scientists per million hectares of pulse area (ASTI 2014-15). The effective number could be a little higher because of scientists also in the international organizations such as ICRISAT and ICARDA.

The reality is that pulse research has been unable to develop varieties to compete with the dwarf and high-yielding rice and wheat varieties that led to the green revolution. Conditional on existing technology, pulses have been crowded out of green revolution areas. Surely pulses did find some new niches in the rain-fed areas of the southern, western, and central India. These nontraditional areas faced problems of drought, heat, pests, and diseases, so the challenge has been to fit pulses into new production systems under different agro-ecologies.

As discussed, challenge has been to develop varieties adapted to the stresses of marginal environments rather than achieving high yield potential under unlimited conditions. The total number of varieties developed and released for major pulses has been quite significant mostly after 1990. In chickpea 180 varieties have been released, 130 and 129 in pigeon pea and green gram. Black matpe and lentil have experienced release of 90 and 45 varieties respectively.

### *Technology experience in chickpea*

In Chickpea (*Cicer arietinum* L.), a large number of varieties have been developed by the national program alone or in partnership with international institutions. Also, the anchors of the program have evolved. During the 1970s, most varieties were developed through selection from landraces, with a major emphasis on increasing yield potential. During the 1980s, the emphasis changed towards disease resistance. During the 1990s, the major thrust was to develop varieties for multiple-disease resistance, stress tolerance, and high input-response.

These changing factors are consistent with the dynamics of pulses across areas and environments. Arguably, the most significant technological breakthrough in chickpea has been the development of short-duration varieties. A large array of short-duration varieties tolerant to heat stress, have found a niche in hot and dry climate of central and peninsular India. During the 1990s, genetic sources were deployed to breed varieties tolerant to drought, cold weather, and salt. A number of varieties were released that are resistant to wilt, to root rot, and to *Ascochyta* blight (Singh and Sewak 2013).

Some varieties were also high yielding compared to the local landraces, and some were well suited to growing in non-traditional areas as well. Similarly, varieties tolerant to *Ascochyte blight* were developed for the country's Northwest Plain zone (especially Punjab, Haryana, north-western Rajasthan, and western Uttar Pradesh). According to the ASTI, the rate of adoption of improved chickpea varieties in select Indian states in 2010 is as follows: Andhra Pradesh—99%, Karnataka—100%, Madhya Pradesh—84%, Rajasthan—68% and UP—65%.

As these improved varieties expanded into new areas, chickpea stands out as the leading example of success of technology in pulses. By 1995 itself, about 52% of the existing chickpea area was allocated to improved varieties in Andhra Pradesh, Gujarat, and Madhya Pradesh (Joshi et al. 1999). The result was substantial gains in both chickpea yields and farmers' incomes. The yield advantage was reported to range from 28% in Andhra Pradesh to 67% in Gujarat. Moreover, the yield gains were much higher for high-yielding bold (*Kabuli*) varieties, ranging from 108% in Andhra Pradesh to 123% in Madhya Pradesh (Joshi et al. 1999). The farmers also benefited from the price premium due to varieties' size, color, and shape (Shiyani et al. 1998).

More recent figures show much higher adoption of improved varieties in chickpea in south India. Suhasini et al. (2012) show adoption of improved chickpea varieties in southern India's major chickpea growing areas to be as high as 97% covering nearly 86% of the growing area. Overall Bantilan et al. (2014) report that in Andhra Pradesh, as of 2011 nearly 90% of the area under chickpea was planted in improved varieties (Bantilan et al. 2014). For any adoption, these figures are striking particularly for a disadvantaged crop like pulses.

Such heights in chickpea have not been achieved with varietal improvement *per se*. In addition, there has been a spread of integrated pest management (IPM) and the development of farm machinery. The first machine-harvestable chickpea variety (NBeG 47) was recently released in Andhra Pradesh to overcome labor shortage and high wages (ICRISAT 2016). The machine can harvest 2.25 tons in 75 minutes, a major improvement.

### *Almost similar technology success - just about-case of pigeonpea*

Chickpea stands out in the development and uptake of technology in pulses. Among other very important pulses crops is Pigeon pea [*Cajanus cajan* (L.) Millspaugh]. Pigeon pea is a long-duration and indeterminate crop that is prone to numerous diseases and insects and also suffers from low yield. The focus of research therefore has been to develop varieties of medium to short duration without compromising yields; to develop resistance to pests and diseases; to develop determinate varieties for uniform crop maturity and to increase yield levels.

Traditionally, the pigeonpea crop matured in 280 to 300 days, and in some cases ratooning was done for two to three years. Therefore, developing short and medium duration varieties became a high research priority. During the 1980s and early 1990s, several medium- and short-duration varieties were developed, some of which found new niches and were adopted in nontraditional areas. These varieties matured in 140 to 160 days without compromising yields. Some estimates suggest that such short-duration varieties expanded the pigeon pea area in northern and northwest India by roughly 200,000 hectares. The falling water table and remunerative pigeon pea prices are believed to be the leading factors motivating farmers to adopt these varieties.

However, the first available medium- and short-duration varieties were susceptible to a few diseases (such as sterility mosaic, *Fusarium* wilt, and *phytophthora* blight), and had a tendency to prolong their maturity into the late monsoon rains. Therefore, a breeding program focused on developing varieties that would mature by early November to escape these diseases, and fit well into the multi-crop production system to ensure the timely sowing of wheat. One variety was particularly successful like ICPL 87 with determinate growth habit, short stature, and early maturity (120-130 days), it proved to be suitable for both sole cropping and multiple harvesting. The ICPL 87 variety emerged from the National Pulse Development Program for Western Maharashtra, where with acute water shortage and sustainability of water and soil were adversely affected by cultivation of sugarcane and banana. By the mid-1990s it had been adopted across all districts with access to irrigation in Western Maharashtra (Bantilan and Parthasarathy 1999).

Wilt is one of the major diseases that seriously harmed pigeon pea yield in earlier decades. Research efforts yielded several wilt-resistant varieties for India and Africa. Among others, ICP 8863 was widely adopted in the semi-arid tropics. Adoption studies in India revealed that this variety occupied almost 60% of the pigeon pea area in the wilt-affected districts of northern Karnataka and the bordering districts of Andhra Pradesh and Maharashtra. According to an ASTI study in 2010, the rates of adoption of improved pigeon pea varieties in some Indian states is as follows: Andhra Pradesh—70%, Maharashtra—70%, Tamil Nadu—70%, Madhya Pradesh—65%, Uttar Pradesh—25%.

An additional program to break the yield barrier was an effort in India to develop a hybrid pigeon pea, which resulted in the world's first pigeon pea hybrid (ICPH 8), released in 1991. This hybrid was of short duration, offered a high yield potential, and was drought tolerant. Since then, the successful development of hybrids has opened up new avenues for enhancing the yield potential in pigeon pea (Saxena et al. 2005; Saxena 2009). Extensive testing of pigeon pea hybrids has shown yield advantages of 40 to 47% over the local varieties and even over other improved varieties in farmers' fields in India (Saxena and Nadarajan 2010).

In trials of hybrids conducted in five states, the mean yield was 47% higher than the yield of a popular variety (ICP 8863). The hybrids also exhibited high levels of resistance to the *Fusarium* wilt and sterility mosaic diseases (Saxena et al. 2013). Two of the recently released hybrids (ICPH 2740 and ICPH 14003) possess resistance to wilt and sterility mosaic diseases in Andhra Pradesh. These hybrids have a high yield potential of 2.5 to 3.5 tons per hectare, which is 25 to 40% higher than the local varieties.

Though several of these hybrids have been released for cultivation, they have not been particularly successful at getting adopted. Four major constraints to their adoption have been documented: (i) the high labor cost for seed production; (ii) the high seed rate (amount of seed sown per hectare); (iii) heavy damage from pod borers; and (iv) lack of knowledge among farmers about seed production (Niranjan et al. 1998).

The next generation of breeding and agronomic efforts in pigeon pea will be focused on improving the plant type. Unfortunately, the genetic base of pigeon pea is quite narrow, with only 57 ancestors having been used for the development of 47 varieties through hybridization following selection. Only 32 wild species are known as valuable sources for resistance or tolerance to several biotic and abiotic stresses. But only 1% of the entire collection has actually been used to identify the sources of resistance to diseases, drought, and other abiotic stresses (Upadhyaya et al. 2009). Scientists are now using specific attributes, such as determinate growth habit, short stature, and early maturity (120-130 days), to develop varieties suitable for sole cropping and single or multiple harvesting.

Research on developing transgenic varieties in pigeonpea is now at an advanced stage, and pigeonpea is amenable to genetic transformation using recombinant DNA and tissue culture. Effective protocols are available to carry this out regeneration through organogenesis and somatic organogenesis. Transgenic plants with the *Bt* gene have been tried for imparting resistance against *lepidopteron* insect pests that affect pigeon pea, but there is no product as yet. It remains to be seen when such a produce becomes available and more importantly is approved.

### *Experience in Green gram* (*Vigna radiata* L. Wilczek)

Green gram is mainly a rainy-season crop, though it is also grown during winter and summer. The varietal development program has largely occurred with four areas of focus: (i) increasing yield potential; (ii) reducing the duration; (iii) developing resistance against diseases (powdery mildew and mosaic virus); and (iv) breeding for large grain size.

During the 1970s, research efforts mainly employed hybridization and mutation to breed high-yielding varieties. In the 1980s, hybridization was used widely to combine agronomically useful traits and disease resistance. This led to the development and release of several varieties resistant or tolerant to powdery mildew and mungbean yellow mosaic virus (MYMV). During the 1990s, several sources of large grain size (> 6 grams per 100-seed weight) were introduced from the World Vegetable Center (AVRDC) and widely utilized in the Indian breeding program.

By the mid-1990s, several large grain size varieties were developed and released, as were several multi-trait varieties with properties including large grain size, short duration, photo-thermo insensitivity (resistant to heat and high temperature), synchronous maturity, and resistance to major diseases. Recently, the incidence of MYMV disease has become a serious problem in the rice fallows of south India, so efforts have been diverted toward incorporating MYMV-resistant genes along with powdery mildew resistance.

Like in other pulses, in green gram also, only a limited genetic variability has been exploited in development programs. There is enormous potential to utilize known wild species and cultivate *Vigna* species to incorporate novel traits and broaden the genetic base. The gene introgression has already resulted in derivatives that show potential for raising yields and building disease resistance. Moreover, these derivatives facilitate further genetic enhancement in green gram. The efforts made have led to the development of several improved cultivars of green gram, such as IPM 99-125, IPM 02-3, and IPM 02-14 (Singh et al. 2010).

To further boost yield and find new niches, researchers are looking for ways to change the plant's architecture. To remain commercially competitive, green gram will have to fit into the production cycle of an input intensive cereal-based cropping system. Therefore, future research has to develop a plant type that is determinate, photo-thermo insensitive, early maturing, high yielding (1.5-2 tons per hectare), with a high harvest index, and resistant to lodging and diseases. There is a need to develop varieties of varying duration for different agro-climatic zones.

### *Black matpe* (*Vigna mungo* L. Hepper)

Early research on black matpe focused on varietal development for improving locally adapted, but genetically variable populations, mainly pure-line and mass selections with a major emphasis on traits rather than yield. This resulted in the release of a number of pure lines, some of which are still cultivated in certain areas. Before 1970, several varieties were developed from locally adapted varieties while in the 1980s, the priority was to develop disease resistant varieties.

At that time, powdery mildew was the major disease of concern. The first variety resistant to powdery mildew was LBG 17, developed and released in 1983 for the rice-fallow systems of coastal areas. It revolutionized black matpe cultivation in coastal Andhra Pradesh. Later, more varieties were developed and released, which led to an expansion in growing area in rice fallow of the coastal peninsula. Since 1990, major emphasis has been on breeding short-duration, varieties along with resistance to biotic stresses (yellow mosaic virus and powdery mildew).

As with other pulse crops, the varietal development program for black matpe has only exploited a limited amount of the plant's potential variability. One variety, T9 alone has contributed 75% to the development of new varieties. The genetic base of the available varieties is very narrow, but there is good scope for utilizing the available gene pools from wild species to broaden the genetic base and borrow novel traits. Gene introgression in black matpe has already resulted in derivatives that have shown potential for yield-contributing traits and disease resistance. These derivatives have facilitated further genetic enhancement, which has led to the development of improved cultivars like Mash 1008 and VBN 5 (Singh et al. 2010) and have facilitated the cultivation of black matpe in diverse agro-ecological regions.

### *Lentil* (*Lens culimaris* Medic)

According to Mishra and Joshi (2016), the research efforts in lentil have been lacklustre particularly until the 1990s and confined mainly to identifying landraces for better adaptability and yields. During the 1980s, a few land races were collected and utilized in recombination breeding through single crosses, followed in the 1990s by crosses involving more parents. The narrow genetic base has also been utilized to breed high-yielding, short-duration, and disease-resistant varieties, including varieties resistant against rust, *Fusarium* wilt, and vascular wilt.

Four comparatively high-yielding varieties in lentils have been commercialized, namely the Priya, Sheri, Noori, and Angoori. In the early-1990s, ICARDA introduced an early flowering line (Precoz: ILL 4605) that was utilized in hybridization with indigenous lines and has resulted in the selection of extra-early genotypes. Several varieties have been developed and released for cultivation using the source material received from ICARDA (Sarker et al. 2007).

Improved varieties have made it possible to achieve wide adaptability in varying agro-environments. Available short-duration varieties fit well into any production system with residual moisture. Varietal development has been associated with increased production, through yield increase as well as area expansion in the 1990s. National average yield increased from a mere 497 kilograms/hectare to around 800 kilograms, while in Bihar yield rose to more than 1,100 kilograms. Lentil area also doubled over the last four decades from 0.75 million to 1.42 million hectares due to varieties with disease resistance and short-duration.

### Production of improved varieties of pulses

There have been technology improvement in main pulses, but these developments have not been substantive enough to reach the technology frontier. Further, even as the availability of improved-quality seeds is one of the important drivers for increasing pulse production, the scarcity of breeder's seed and certified seed of improved varieties is constraining their adoption. There is a weak linkage between R&D systems and the mass production and multiplication of breeder, foundation, and certified seeds. The linkage of the seed system with the market in terms of the desired varieties is also weak. Gowda et al. (2013) point to several factors for low seed replacement rates, such as low seed multiplication rate; reuse of grains from previous harvest as seeds and demand for varieties adapted to more narrow agro-ecologies and consumer needs.

Gowda et al. (2013) point out that grain legume seed business in general in India does not attract large seed companies since profit margins are low. In this context, Materne and Reddy (2007) point out that more than 95% of lentil seeds in India are sourced from the informal sector. The emerging small and medium seed companies still have limited capacities and apart from marketing problems, lack a good supply of foundation seeds (Gowda et al. 2013).

Note that in case of breeder seed production, some varieties are quite old and need to be gradually substituted by new varieties. Among chickpea varieties, JG 11, JG 16, JG 322 and Vijay are more than 15 years old and the situation is similar in case of pigeon pea and green gram. According to Singh and Saxena (2016), the average seed replacement rate (SRR) of pulses in India was about 25% at the end of 2011. The highest SRR was in case of black matpe (34.41%) followed by green gram (30.29%), and pigeon pea (22.16%). Singh and Saxena (2016), like Gowda et al (2013), point out that limited availability of quality seed of improved varieties has been a major constraint in enhancing production and productivity of pulses in India.

There is lack of an organized pulses seed production program and a proper medium term (4-5 years) seed rolling plan for major pulse producing states. The indent for breeder seed is often for very low quantity and it often is for old and obsolete varieties. The conversion rate of breeder seeds into foundation seeds and certified seeds is also low. To ensure timely availability of quality seeds, capabilities of seed production must be enhanced with multi-agency participation such as seed societies, farmers, private sectors and NGOs, besides state agricultural universities, Indian Institute of Pulses Research and State Seed Corporations (Singh and Saxena 2016).

### Technology-farmer linkage

At present, there is a significant unexploited potential of pulses in terms of yields. This is demonstrated in Figure 3 derived from Singh and Saxena (2016). It shows existing yields of different types of pulses in India alongside the yields achieved at experimental

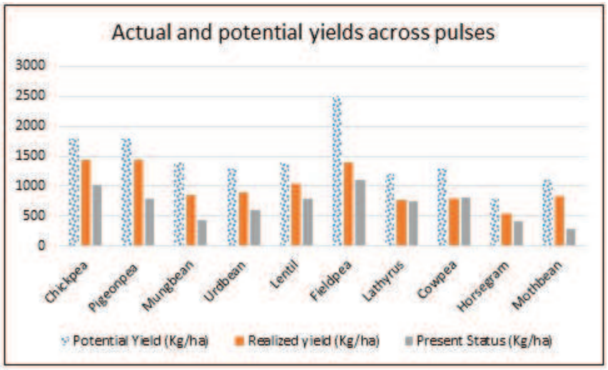


**Fig. 3. Actual and potential yields in different pulses Source: Singh and Saxena (2016)**

stations and in field trials. The yield gaps are quite significant, ranging from 75% in lentil to 224% in green gram. Singh and Saxena (2016) suggest that the underlying reasons for these gaps are mainly poor quality of seed and poor management practices.

### *Potential and niche areas for pulses*

The extent of technological progress in pulses has largely been a function of the ability to use fallow lands. According to NAAS (2013), rice fallows are found in Andhra Pradesh, Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, West Bengal, and Uttar Pradesh. Climatic condition of rice fallow areas is suitable for growing cool and warm season pulses by utilizing the residual moisture after harvest of *kharif* paddy. Lentil, green gram, black matpe, lathyrus, and peas are some of the pulses that can be grown into rice fallow areas.

Diversifying the rice-wheat cropping system by planting short-duration green gram varieties offers another opportunity. Naturally, such an expansion into a rice fallow system works best if the rice variety itself is of short duration and vacates the field early. Since lentil is more suitable and assured than chickpea in lowland areas with excessive soil moisture, lentil could be popularized in the lowlands of eastern Uttar Pradesh, Bihar, Jharkhand, and West Bengal (NAAS 2013).

Data shows that in the coastal areas of Odisha and Andhra Pradesh, as technologies were developed for rice-fallow systems, an expansion in pulse cultivation occurred. Further utilization of rice fallow systems for pulse expansion in non-coastal areas, backed by the development of improved varieties of pulses and other technologies and by extension services, needs to be explored and prioritized. Indeed, a case may be made that expanding pulses into rice fallow systems should be tried first before attempting to extend the growth of pulses in new areas at the cost of competing crops like cereals or oilseeds.

## Way forward

Pulse research needs to place a stronger emphasis on developing improved varieties that can break the existing low-yield barrier. There is a need for horizontal expansion to new niches (such as rice-fallows in coastal Odisha, Andhra Pradesh, Karnataka, and Tamil Nadu). Diversification in rice–wheat system has to be extended through short-duration green gram varieties and intercropping in sugarcane, pigeon pea, and cereals. Popularization of hybrid pigeon pea developed at ICRISAT also offers an opportunity. Also, the progress made in using wild species for the introgression of valuable genes for their agronomic traits in different pulse crops—an approach that has largely been under-utilized due to crossability barriers—can be scaled. Following areas need greater attention in pulses research for technology development to meet the future demand.

### *Breaking the yield plateau and enhancing productivity*

Three areas stand out as needing attention. First, the potential of biotechnology needs to be harnessed, including gene characterization for yield-determining traits using bi-parental populations, MAGIC populations, association mapping, and the development of functional markers for the genes. These research methods can be used without wading into the deeply divisive issue around commercializing GM crops in India. Second, the genetic base/gene pool needs to be widened. This includes pre-breeding with wild pulse relatives. Third, hybrid technology needs to be developed with a suitable level of heterosis.

### *Developing crops resilient to climatic adversities*

Resilient pulse varieties and technologies need to be developed. Better monitoring of disease and pest dynamics in relation to climate change is needed as well.

### *Developing quality pulses*

Grain quality traits needs due attention when pulse varieties are identified for release.

***Producing quality seed***

Quality seed needs to be produced in sufficient quantities, effectively utilizing the chain from breeder seeds to foundation and certified seeds.

***Resource management***

Ways to increase the input-use efficiency of nutrients and water need to be developed, with consideration for the differing macro and micro nutrients needed by different pulses and across environments. The efficiency of symbiotic processes for enhanced nitrogen fixation by Rhizobia also needs to be improved. Finally, research is needed on microorganisms, like phosphate-solubilizing bacteria, fungi and bio-fertilizers such as vesicular arbuscular mycorrhiza (VAM) which are capable of solubilizing non-available phospate into an available form and, helping in phosphate uptake by pulse crops. Efforts should be made to identify and map genes of economic importance from a large array of wild species and develop a molecular linkage map.

Much of technology development has focused on disease and pest resistance. Recent research that indicates the possible effectiveness of Bt-based technology in controlling pulses pests suggests directions for future research focus. The recent development of bio-pesticides could also be valuable in reducing the harmful residues of chemicals used in controlling pests. Also, given that several types of pests are involved in infestations, policy should be directed toward developing multiple-resistant pulse varieties to simultaneously control against many pests.

As discussed above, the availability of improved-quality seeds is one of the most important drivers for increasing pulse production. However, it is not only the development of technology. In fact, there have been stumbling blocks in the pulse sector not only in technology development but also in uptake post-development. For example, hybrid pigeon pea shows the limits of a promising technology that has not been adopted extensively owing to the lack of extension services (Niranjan et al. 1998). Moreover, in pulses there is a stark lack of private-sector participation. In both technology development and in extension, the private sector is conspicuous by its absence. For crops where the private sector has become important, such as maize and pearl millet, the diminishing role of public extension services has been compensated for by increased private extension (Feder et al. 2011).

The supply-push policies for research do not seem to have been lucrative for the private sector. It is possible that a demand-pull based research policy where both private and public sectors would get rewarded if they developed technology based on pre-determined traits, could make a difference.

The case of wheat in India testifies to the potential for success of public sector driven research, development, and dissemination. Public sector research and development however has been in decline for a long time and the research undertaken by the private sector is limited to crops that are commercially more attractive, such as maize, cotton, and vegetables. Further, because pulses have been pushed to marginal environments, willingness to pay for new technology is often limited. Also, the flexibilities in selecting the traits in a technology are driven to a large extent by the relationship with competing crops.

India has a comparatively well-developed private sector in seed development, in comparison with many other developing countries. It caters even to some minor crops like pearl millet. In this context, the near complete absence of the private sector seed producers and extension services in pulses development is striking. To some extent, the reason for this low engagement may be structural. With the exception of pigeon pea, pulses do not outcross. Hence, the scope for private-sector investment in hybrids and in seed production may be limited. With absence of hybrids and low seed replacement rates, appropriating the returns on R&D investment is difficult.

An important policy question, therefore, is how to increase the engagement of the private sector in the development of pulses technology and its dissemination. Literature on incentives for innovation suggests that prizes can be a powerful mechanism for accelerating technological development (Brunt et al. 2011). NASA has sponsored prizes for technological innovation since 2004 and several other governmental prize challenges, or AMC have been announced (Kalil, 2006). Prizes and patents can serve as demand pull policies for fostering innovation.

Elliott examines the potential for using AMC and proportional prizes to stimulate agricultural innovation in developing countries. Traditional “push” funding entails funds donated for agricultural research and development. With “pull” mechanisms, on the other hand, “donors seek to engage the private sector, which is almost entirely absent in pulses research currently.

Pull mechanisms along the lines suggested by Elliott (2010) can be tried in pulses.

Pull mechanisms may be needed for pulses for several reasons. First, it might be difficult for inventors to reap the benefits of their innovations in varieties, if seeds could be reused. Secondly, with push funding—funds can be wasted if the end product of the research is not as expected. The Center for Global Development developed 12 proposals to encourage commercial investment in agriculture, five of which were "pull" mechanisms: AMC, proportional prizes; best entry tournaments; and patent buyouts. They disqualify the last three because prizes and best entry tournaments are winner take all, they could facilitate monopolies and a "race-to-patent" mindset that gives insufficient attention to product implementation. Patent buyouts would not necessarily encourage crop-specific innovations. Therefore, Elliot focuses on AMC and proportional prizes.

Under an AMC system for stimulating research in pulses with a level playing field for private and public sector, the government would guarantee to pay on delivery for a targeted innovation developed. The traits of the pulses technology desired would be specified ex-ante. It is possible that potential purchasers are too poor, and markets too small for innovations in pulses. A commitment could be made to pay an above-market price up to a certain number of units of a new product demanded by special groups of buyers. Another key element of the AMC idea is to ensure long-term access by requiring suppliers to continue to supply the product at an affordable price for some period after the government or donor commitment ends (Elliott 2010). The incentives to adopt will also be affected if supply increases significantly and brings down the prices. So, an AMC might need to be combined with some price mechanisms for the farmers. The idea is that the novel "pull" mechanisms, already being tested in the field of healthcare and vaccines, could be potentially useful in stimulating the private investment in agricultural R&D necessary in neglected crops like pulses to meet India's food security needs.

### Declaration

The authors declare no conflict of interest.

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