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Genetic enhancement for yield and nutritional quality in cowpea [*Vigna unguiculata* (L.) Walp.]

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Abstract

Cowpea [*Vigna unguiculata* (L.) Walp.] is an important source of nutritious food and fodder in the semi-arid tropics and sub-tropics covering over 65 countries. Systematic cowpea breeding programs started in a few countries from 1960 onwards and became further strengthened with the establishment of the International Institute of Tropical Agriculture (IITA) in 1967 with a world mandate to develop improved cowpea varieties for all regions. Over 40 stress resilient high yielding varieties with erect and semi-erect growth habit and 60 to 75 days maturity have been developed and released in over 45 countries. These varieties yield up to 2.5 t ha^{-1} grain and fodder with 25% to 30% protein in the grains and 15% to 18% protein in the haulms and fit well as a niche crop in the existing cereal based intensive cropping systems and contribute to soil fertility and thereby enhance system's productivity and sustainability. With rapid adoption of the new improved varieties and improved cropping systems, the world cowpea production has increased from about one million ton in 1974 to over 7 million tons in 2014 – the largest increase among all the pulses. The ongoing research on '60-day' cowpeas as a niche crop in 'wheat-rice' system in Northern India and in the rice fallows in central and southern India, as well as in various niches in the *kharif* season, has shown a good potential to produce over 10 million tons cowpeas over and above the existing pulses production. This would eliminate the need for importing pulses and bring down the escalating prices. In view of the promising research results and recent release of 5 short duration cowpea varieties, it would be highly appropriate for the Government of India to launch a special research and development project to introduce short duration cowpea in relevant cropping systems throughout India.

Key words: *Vigna unguiculata*, 60-day cowpea, heat tolerance, drought tolerance, niche cropping, *Striga*, *Alectra*

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is a widely cultivated food legume in the tropics and sub-tropics covering over 65 countries and all the continents. Distribution of the wild cowpea species and phenotypic diversity indicate that cowpea originated in Southern African region (Padulosi 1993; Padulosi and NG 1997) and first domesticated as a crop in Africa about 1700-1500 BCE. Cowpea was subsequently taken from Africa to Asia and Europe by the early travelers and explorers. It has been suggested that cowpea probably moved from eastern Africa to India before 150 BCE (Steel and Mehra 1980), and to West Asia and Europe about 300 BCE. Since the climatic conditions in South Asia and South East Asia were highly suitable for cowpea growth and development, a great deal of genetic variability and selection occurred over time making this region as the secondary center of cowpea diversity. Cowpea came to the Americas from Africa through Jamaica about 1675 by the slave traders carried as food for their captive slaves on the way to Americas. Due to its adaptability to the warm weather of the tropics, cowpea cultivation spread in the West Indies. From there it was brought to Florida about 1700 and subsequently spread to several southern and central states in the USA primarily as a fodder, cover and food crop. The name 'cowpea' is of American origin and it appeared in print in 1798 (Singh, 2014).

With up to 30% protein in its grain, tender leaves and immature pods, cowpea is consumed in a variety of ways and it has been given indigenous names such as 'lobia', 'chowlee' and many other names in India,

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'kunde' in East Africa, 'beans' and 'wake' in Nigeria, 'niebe' in francophone Africa, southern pea', crowder pea and 'black eye pea' in the United States of America, 'feijão caupe', in Brazil, and a host of other names in local languages in different countries around the world. Current estimates indicate that it is grown in about 14.5 million hectares with an annual production of over 7 million tons on a worldwide basis (Singh, 2014). The important cowpea growing countries are Nigeria, Niger Republic, Mali, Burkina Faso, Senegal, Ghana, Togo, Benin, Cameroon and Tchad in the West and Central Africa; Sudan, Somalia, Kenya, Malawi, Uganda, Tanzania, Zambia, Zimbabwe, Botswana and Mozambique in East and Southern Africa; India, Bangladesh, Nepal, Myanmar, Sri Lanka, Indonesia, China and Philippines in Asia; Southern USA in north America and Brazil, Cuba, Haiti, and the West Indies in Central and South America. However, the bulk of cowpea production comes from the drier regions of northern Nigeria (4 million ha and 2.7 million tons), Niger Republic (5 million ha and 1.5 million tons) and North East Brazil (about 1.9 million ha and 0.7 million tons).

Cowpea is inherently tolerant to drought and heat and has the ability to fix nitrogen even in very poor soils with a pH as low as 4-5, organic matter below 0.2% and sand content of over 85% (Kolawale et al. 2000; Sanginga et al. 2000). Also, it is shade-tolerant and, therefore, very compatible as an intercrop with a number of cereals and root crops, as well as with cotton, sugarcane and several plantations tree crops (Henriet et al. 1997, Singh and Emechebe, 1998). Coupled with these attributes, its quick growth and rapid ground cover have made cowpea and essential component of sustainable subsistence agriculture in marginal drier regions of the tropics where rainfall is erratic and scanty and soils are sandy with little organic matter (Carsky et al. 2001; Mortimore et al. 1997).

Unlike other crops, cowpea has diverse plant types, pod types, seed types, growth habit, and time to maturity and it is grown and used in many different ways. These attributes have been amply exploited by farmers in selecting suitable varieties for different regions. For example, in West Africa the preferred varieties are photosensitive spreading types with large white and brown seeds and a rough seed coat. In contrast, countries in Central America and the Caribbean prefer non-photosensitive varieties with red, black or white seeds and a smooth coat. The preference in Mexico, Guatemala, Nicaragua, Costa Rica and Cuba is for black seeds, while in Honduras, El Salvador, Venezuela and Jamaica it is for red. In East Africa and Asia, any color other than black is acceptable, but tan and red are preferred in East Africa and white and cream in Asia. Varieties in these regions are erect, semi-determinate and non-photosensitive.

The preference for a rough coat in West Africa is related to its use in food products. About 50% of the region's crop is used for snack foods, for which the seed coat must be removed before making a paste of the cotyledons. In the absence of mechanical devices to remove seed coats, the West African women soak the seeds in water for a few minutes. The rough seed coat absorbs water faster than the cotyledons, such that a gentle rubbing by hand easily removes it. This is not possible if the seed coat is smooth. However, smooth seed coat is desirable if cowpeas are eaten as boiled beans, as is the case in East and Southern Africa and parts of Asia and Latin America.

Production constraints

In spite of its wide cultivation and importance, the overall productivity of cowpea has been very low with average yield particularly in Africa ranging from 100 to 400 kg/ha. This is due to several biotic and abiotic constraints as well as due to cultivation of cowpea as an intercrop with cereals in marginal environments without inputs (Henriet et al. 1997; Singh 2005). Also, the local varieties have low yield potential because of their spreading growth habit and late maturity.

Diseases, insects and parasitic weeds : Cowpea is attacked by several diseases, insect pests (Singh and Allen 1979) and parasitic plants (Singh and Emechebe 1990; Singh et al. 1993). The major diseases are anthracnose, web blight, brown blotch, *Cercospora* leaf spot, *Septoria*, scab and *Macrophomina* caused by fungi; bacterial pustule and bacterial blight caused by bacteria; and cowpea yellow mosaic, cowpea aphid borne mosaic, blackeye cowpea mosaic, cowpea severe mosaic and southern bean mosaic caused by viruses. Nematodes are important in some areas and parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii* are important in Africa. *Striga* causes severe damage to cowpeas in the Sudan savanna and Sahel of West Africa whereas *Alectra* is more prevalent in the Guinea and Sudan savannas of West and Central Africa. *Alectra* is also widespread in Eastern and Southern Africa but *Striga* is not a problem there.

The major insect pests of cowpea are leaf thrips (*Sericothrips occipitalis*), leaf hppers (Empoasca dolichi aphid (*Aphis craccivora*), flower thrips (*Megalurothrips sjostedti*) Maruca pod borer (*Maruca vitrata*), a complex of pod sucking bugs (*Clavigralla* spp., *Acanthomia* spp., *Riptortus* spp.) and the storage weevil *Callosobruchus maculatus*. Of these, thrips and *Maruc*a cause major damage in sub-Saharan Africa. There are some location specific insect pests such as *Lygus* in Americas, bean fly in Asia and East Africa and Ootheca beetles in wetter regions of the tropics.

Drought, heat and low soil fertility : Cowpea is inherently more drought tolerant than other crops (Singh and Matsui 2002) but it still suffers considerable yield reduction from erratic rainfall in the beginning and towards the end of the rainy season which are common in the semi-arid tropics. Early maturing cultivars escape terminal drought (Singh 1987) but if exposed to intermittent moisture stress during the vegetative or reproductive stages, they perform very poorly especially in the Sahelian region where rainfall is scanty and irregular. Low soil fertility due to low organic matter and low phosphorus in the savanna soils is also a major constraint for cowpea production.

Breeding objectives

In view of the fact that cowpea is cultivated in a range of environments and cropping systems and is used for grain, leaves, pods, and fodder etc, no single variety can be suitable for all conditions which makes cowpea breeding more challenging and a need to develop a range of varieties with diverse for plant type, growth habit, maturity and seed quality combining high yield potential and resistance to major biotic and abiotic constraints to meet the regional preferences. Some of the specific objectives are: i) Extra-early maturing (60-70 days) grain type for use as sole crop in multiple and niche cropping systems and short rainy seasons; ii) Medium-maturing (75-85 days) grain type and dual purpose for use as sole crop and intercrop; iii) Resistance to major diseases, insect pests, and parasitic weeds; iv) Tolerance to drought, heat and adaptation to low-p soils and v)` Desirable seed types with high protein, micronutrients and health factors.

Genetic resources for cowpea improvement

Initially, the cowpea germplasm collection programs were started by the national programs such as Nigeria, Senegal, Tanzania, Uganda, India, and USA and subsequently by the International Institute of Tropical Agriculture (IITA) which was established in 1967 with a global mandate for cowpea improvement. Since then, IITA in collaboration with different national programs has collected over 15,000 cowpea accessions of cultivated varieties drawn from over 100 countries including over 500 accessions of wild cowpeas. These collections are being maintained by IITA as TVu (Tropical *Vigna unguiculata*), numbers TVu-1, TVu-2, TVu 3… etc. Most of these lines have been evaluated and characterized for selecting desirable traits (Ng and Singh 1997). A great deal of genetic variability for plant type, seed type, growth habit, maturity, (Fig. 1) heat, drought and low-P tolerance (Figs. 2 and 3), root architecture, resistance to major bacterial, fungal and viral diseases, resistance to root-knot nematodes, resistance to aphid, bruchid and thrips, and parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii* etc was observed (Singh 2002a, 2005). Some of the important sources of resistance from the germplasm screening are indicated in Table 1.

Table 1. Sources of resistance to major diseases, insects and parasitic weeds

Diseases and parasitic weeds		Resistant lines
Anthracnose & Bacterial pustule	-	TVu 201, TVu 408, TVu 410, TVu 697
Brown blotch	-	TVu 201, TVu 1977
Scab	-	TVu 843, TVu 1977
Bacterial blight	-	TVu 410, TVu 1190, TVu 1977
Septoria	-	TVu 456, TVu 483, TVu 1977
Web blight	-	TVu 317, TVu 2483, TVu 4539
Phakospora rust	-	TVu 612, TVu 1258, TVu 4540
Root knot nematode	-	TVu 264, TVu 401, TVu 1560
Major viruses	-	TVu 201, TVu 410, TVu 1190
Striga and Alectra	-	TVu 9238, TVu 11788, TVu 12415, B301
Insect-Pests		
Aphid	-	TVu 57, TVu 410, TVu 3000 (high resistance)
Leafhopper	-	TVu59, TVu 662, TVu 1190 (moderate resistance)
Flower thrips	-	TVu 1509, TVu 2870 (moderate resistance)
Maruca pod borer	-	TVu 946, TVu 13271 (low resistance)
Pod sucking bugs	-	TVu 1977, TVu 7274 (moderate resistance)
Bruchid weevil	-	TVu 2027, TVu 11952, TVu 11953 (high resistance)
Drought tolerance	-	TVu 11979, TVu 11986

Fig. 1. Genetic diversity in plant type and maturity

Fig. 2. Sources of tolerance to low-P soils

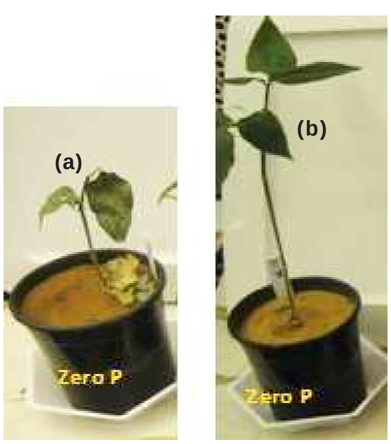

Fig. 3. Breeding for Low-P tolerance in cowpea (a) Dan Ila (susceptible), (b) IT98K-476-8 (tolerant)

Over the years, systematic genetic studies have identified over 207 major genes which control these traits (Ferry 1985; Ferry and Singh 1997; Singh 2002b). Some of the major genes controlling resistance traits are listed in Table 2. Most of these desirable traits have been bred into improved breeding lines

Progress in breeding improved cowpea varieties

Limited programs for cowpea improvement began in many countries from early 1920s to identify promising land races and varieties for varied cropping systems. However, systematic cowpea breeding programs and sustained efforts continued only in a few countries including India, Nigeria, Senegal, and USA where greater resources were allocated from 1960 onwards. Cowpea breeding received a big push and international attention from 1967 onwards after establishment of the International Institute of Tropical Agriculture (IITA) which was tasked with a global mandate for cowpea research and development. A comprehensive cowpea breeding program was initiated at IITA from 1970 with a critical mass of scientists involving breeders, agronomists, microbiologists, soil scientists, biochemists, food scientists and economists who began working as a team in collaboration with national cowpea scientists in Asia, Africa, and Central and South America and IITA emerged as the center of

Table 2. Genes for resistance to major biotic and abiotic constraints in cowpea

Resistance to:	Gene symbol
Bacterial pustule	*Bpl-1, Bpl-2*
Bacterial canker	*Bc-1*,
Cercospora leaf spot	*Cls-1, Cls-2*
Septoria leaf spot	*Rsv-1, Rsv-2* (resistance to Septoria vignae)
Vercitilium wilt	*Vw*
Uromyces rust	*Uv-1, Uv-2*
Root knot nematode	*Rk*
Blackeye mosaic virus	*blc*
Cowpea yellow mosaic	*Ymr*
Southern bean mosaic	*Sbm*
Tobacco ring spot virus	*Tr*
Striga gesnerioides	*Rsg-1, Rsg-2, Rsg-3* (resistance to *Striga gesnerioides*)
Alectra vogelii	*Rav-1, Rav-2*, (resistance to Alectra vogelii)
Aphid	*Rac* (resistance to Aphis craccivora)
Bruchid	*rcm-1, rcm-2* (resistance to *Callossobruchus maculatus*)
Drought tolerance	*Rds-1, Rds2* (resistance to drought stress)
Heat tolerance	Single dominant gene
Low-P tolerance	Single dominant gene

excellence for cowpea research. Since then, the cowpea breeding and international variety testing programs have led to the involvement of over 60 countries and development and release of a large number of varieties suitable for each country. The author worked as the Cowpea Breeder at IITA from 1979 to 2006. A brief description of the successive progress over time is presented below:

Before 1970 – Country specific breeding programs

Efforts to identify and select improved varieties from land races and germplasm collections began in several countries from 1920 onwards but the systematic cowpea breeding programs with sufficient resources were initiated in 1960s in India, Kenya, Uganda, Tanzania, Nigeria, Senegal, Burkina Faso, and USA. The focus was to develop improved cowpea varieties to meet specific needs of the countries and selections were made from the land races and new varieties were also developed using hybridization. A few examples are given below:

Nigeria	– Ife brown, Dan Ila, Kanannado, Borno brown,
Senegal	– Bambey 21,
Burkina Faso	– Suvita – 2, Kamboinse local, Ouahigouya 1,
Uganda	– Emma,
Kenya	– Emma 60,
Tanzania	– SVS-3
India	– Chaula, Pusa Phalguni, Pusa barsati etc.
USA	– Black eye, purple eye, pink eye, Alacrowder, Alabunch etc.

1970-1980: Selection of promising varieties from germplasm and early crosses

The cowpea breeding program at IITA was fully integrated with national programs and a collaborative international cowpea breeding and testing program was initiated. The initial focus from 1970 to 1980 was to collect and screen germplasm lines and identify the most promising lines. These were subjected to a series of field and green houses evaluations for multiple disease resistance and agronomic traits. Several selected promising lines were then multiplied and directly distributed to international collaborators for broad based testing. The results from these trials indicated four lines, TVu-201, TVu-1190, TVu-1977 and TVu-4577 to be resistant to many diseases and had high yield potential. These were described as varieties VITA-1, VITA-3, VITA-4 and VITA-5 (Vigna IITA-1, 3, 4, 5) respectively and subsequently released in many countries. These VITA lines were also extensively used as parents for the initial crossing programs and development of segregating populations and selection. The focus was primarily to develop multiple disease resistant breeding lines with high yield potential. Based on the good performance across many countries, 5 new lines were described as VITA numbers and released in many countries. These were TVx 1193-7D as VITA-6, TVx 289-4G as VITA-7, TVx 66-2H as VITA-8, TVx 1948-01F as VITA-9, and TVx 1836-013J as VITA-10. However, all these VITA lines were primarily released in Asia and South America and not in West Africa where bulk of the cowpea is grown. This was because all these lines (except for

VITA-5) had smooth seeds that are not acceptable in West Africa. The desired types in West Africa are brown and white seeds with rough seed coat texture. Also, these varieties were semi-spreading in growth habit and took 120 to 130 days for maturity.

1980-1990: extra-early varieties combining diseases and insect resistance with desirable seed types for all regions

Concerted efforts were made to incorporate desirable seed types, extra-early maturity, erect plant type and resistance to major diseases and insect pests suitable for multiple cropping systems including short rainy seasons and improved intercropping systems in the semi-arid regions throughout the tropics and sub-tropics including all cowpea growing countries in Asia, Africa and South America.

The concept of 60-day cowpeas

Tanzania has a bimodal rainfall with a long rainy season from March to June and a short rainy season from October to December. Maize being the major staple of the country, farmers plant maize in both the seasons. The maize crop in the main rainy season performs well but suffers frequent terminal drought during the short rainy season. An extra-early grain legume crop with 60-70 day maturity would be an ideal alternative crop for the short rainy season. Through rigorous testing of various leguminous crops, only early maturing cowpea was found to gain satisfactory yield (1.5-2.0 tons/ha) in 60 days. This marked the concept of 60-day cowpeas under full-fledged breeding program to develop a range of high yielding 60-day cowpea varieties with resistance to major diseases with wider adaptability. Using irrigation facilities and tropical environment, it was possible to advance and test 3-4 generations each year and thus within a short period from May 1979 to September 1981, a number of cowpea lines were developed that looked very promising (Singh and Mligo 1981). Discussions with international collaborators confirmed the need for developing extra-early cowpea varieties to be grown in areas with short rainy seasons as well as a niche crop in multiple cropping systems in many countries. A systematic breeding program with greater resources was initiated by IITA, Nigeria which resulted in the development of more than 40 improved cowpea varieties now released in over 40 countries. These varieties with desirable plant type, resistance to major diseases, early maturity and good yield were collectively called as '60-day' cowpea varieties (Singh and Sharma 1996).

Breeding for disease resistance

Using a combination of field and laboratory screening, a number of new of sources of resistance to insects like aphid, thrips, and bruchid and to major diseases like Cercospora, smut, rust, Septoria, scab, Ascochyta blight and bacterial blight, Macrophomina, anthracnose, were identified and used in the breeding programs (Adjadi et al. 1985; Abadassi et al. 1987; Bata et al. 1987; Singh and Emechebe1990, 1993; Atokple et al. 1995; van Boxtel et al. 2000). Several cowpea breeding lines have been developed with combined resistance to major insects and diseases. Some of the prominent varieties are IT82E-9 (black), IT 82E-60 (white blackeye), IT82E-16 (red), IT82E-18 (tan), IT82E-32 (red), IT82D-752 (tan), IT82D-789 (light brown), IT82D-889 (red), IT83S-818 (white blackeye), IT85F-867-5, IT86D-1010 (white blackeye), IT93K-452-1(white blackeye), Of these, IT82D-889, IT83S-818, IT85F-867-5, IT86D-1010 are resistant to all the major viruses (Singh and Sharma 1996; Singh et al. 2003; Singh and Ajeigbe 2007; Singh et al. 2011). Some of the promising medium maturing varieties were IT89KD-288, IT89KD-391, IT90K-277-2 with multiple disease and insect resistance. Of these, IT89KD-288 is a high yielding variety with high level of resistance to aphid bruchid and nematodes in Nigeria (Mohamed et al. 2000) and it is the most popular variety in the dry season in northern Nigeria. IT89KD-288 was also found to be resistant to 4 strains of *Meloidogyne incognita* in USA (Ehlers et al. 2000).

1990-2000: Breeding for resistance to diseases, insects and parasitic weeds

With the release of the new extra-early varieties, cowpea cultivation became more intensive and wide spread particularly in Africa. This led to emergence and identification of several new biotic production constraints which were earlier observed as sporadic and minor ones. These included severe incidence of aphid, bruchid and the parasitic weeds *Striga gesnerioides* and *Alectra vogelii*. Therefore, the major thrust in 1990s was to incorporate resistance to aphid, bruchid and parasitic weeds, *Striga gesneriodes* and *Alectra vogelii* combined with early maturity and desirable seed types. Resistant sources of aphid and bruchid were already available and several sources of resistance to striga and alectra were identified and genetic studies indicated major gene inheritance for all the traits (Adjadi et al. 1985; Bata et al 1987; Singh and Emechebe 1990, 1993; Atokple et al. 1995).

Striga gesnerioides is primarily prevalent in West Africa only but *Alectra vogelii* is widely distributed in West as well as East and southern Africa. A total of five strains of striga were identified – Strain 1 from Burkina Faso, Strain 2 from Mali, Strain 3 from Nigeria and Niger, Strain 4 from Benin and Strain 5 from Cameroon. A local landrace, B 301 from Botswana, was found to be completely resistant to *Striga* and *Alectra* in Burkina Faso, Mali, Cameroon, Niger and Nigeria but only moderately resistant to the striga strain from Benin Republic (Lane et al. 1994). A few other lines such as IT81D-994, IT89KD-288, 58-57 and Gorom local were found to confer complete resistance to strains from Benin Republic and Burkina Faso but highly susceptible to striga strain from Nigeria and Niger. Resistance to both parasitic weeds is simply inherited and by using the complementary resistant parents in crosses, a number of new varieties have been developed with combined resistance to *Alectra* as well as all the five strains of *Striga*. The most promising new cowpea varieties are IT90K-59, IT90K-76, IT90K-82-2, IT90K-277-2, IT90K-372-1-2, IT93K-693-2, IT97K-499-35, and IT97K-819-118, IT98K-205-8, IT98K-506-1, and IT98K-1111-1. Of these, IT 97K-499-35 and IT98K-205-8 are resistant to major fungal, bacterial and virus diseases as well as resistant to insects like aphid, thrips, bruchid, and parasitic weeds like Striga and Alectra with much higher yield potential than the local varieties. These lines also serve as a false host for *S. hermonthica* reducing its seed bank in the soil when grown as intercrop or in rotation with cereals. Performance of selected improved varieties is presented in Table 3.

Table 3. Grain and fodder yield (kg/ha) of selected improved cowpea varieties

Variety	Grain	Fodder
IT98D-1399	2558	3257
IT99K-409-8	2507	2171
IT98K-131-2	2305	3201
IT97K-494-3	2259	2533
IT98K-506-1	2050	1642
IT97K-499-35	1924	2728
IT98K-589-2	1800	2923
IT97K-499-38	1966	1865
IT86D-719	1351	974
Dan Ila (local)	546	3326
Aloka (local)	617	418
SED	253	588

Pyramiding resistance genes in improved varieties over time

With systematic crosses and selection, genes for resistance to major diseases, insects and parasitic weeds were pyramided in improved breeding lines (Table 4). These improved are being widely used as parents in the breeding programs.

The rapid adoption of these varieties and other newer varieties and in many countries has led to the increase of global cowpea production from about 1 million ton in 1981 to over 7 million tons in 2013 (Singh et al. 2014; Singh 2014).

Breeding for abiotic stresses and nutritional quality

Tolerance to drought and heat (2000 – 2015)

Following the good progress made in breeding for early maturity, resistance to major diseases and insect-pests, concerted efforts were then initiated from 1995 onwards to incorporate tolerance to drought, heat and low-P soils which appeared to be major yield reducing factors in the semi-arid and Sahelian regions where soils were sandy with low organic matter, rainfall were low and erratic and temperatures were above normal during most of the crop growing period. Even the early maturing varieties which normally escape terminal drought, performed poorly if exposed to intermittent moisture stress during the vegetative or reproductive stages. Using simple screening methods for tolerance to heat, drought tolerance, root architecture and low-P, major gene inheritance have been for all these traits have been identified and incorporated into improved lines (Singh et al. 1999; Mai-Kodomi et al. 1999a and 1999b, Singh and Matsui 2002; Verbree et al. 2014; Verbree et al. 2015; Angira et al. 2016). The best drought tolerant varieties are IT89KD-374-57, IT88DM-867-11, IT89KD-288, IT98D-1399, IT98K-131-1, IT97K-568-19, IT98K-452-1, IT98K-241-2 and the best heat tolerant lines are IT93K-452-1, IT98K-1111-1, IT93K-693-2, IT97K-472-12, IT97K-472-25, IT97K-819-43, IT97K-499-35, and TX08-49-3.

Enhanced N-fixation and efficient acquisition of phosphorus from low-P soils

Most of the cowpeas in West Africa are grown in sandy soils which have low organic matter and low-phosphorus. Therefore, efforts are being made to screen and identify cowpea lines with enhanced nodulation and nitrogen fixation as well as efficient acquisition and utilization of phosphorus from low-P soils and rock phosphates. Significant variation in

Table 4. Pyramiding of genes for resistance in improved cowpea varieties*

Pest/disease	Ife brown 1973	TVx3236 1978	IT82D-716 1982	IT84S-2246 1984	IT90K-59 1990	IT97K-499 1997	IT00K-1251 2000
Anthracnose	S	R	R	R	R	R	R
Cercospora	S	R	R	MR	R	R	R
Brown Blotch	S	R	R	MR	R	R	R
Bact.Pustule	S	R	R	R	R	R	R
Bact. Blight	MR	MR	MR	MR	MR	R	R
Septoria	S	S	S	S	S	R	R
Scab	S	MR	MR	MR	MR	R	R
Web Blight	S	MR	MR	MR	MR	R	R
Yellow mosaic	S	S	R	R	R	R	R
Aphd b mosaic	S	S	R	R	R	R	R
Golden mosaic	R	R	R	R	R	R	R
Aphid	S	S	S	R	R	R	R
Bruchid	S	S	R	R	R	R	R
Striga	S	S	S	S	R	R	R
Alectra	S	S	S	S	R	R	R
Nematode	S	S	S	R	R	R	R

*The earlier variety is one of the parents of the next variety; R = Resistant, MR = Moderately resistant, S = Susceptible

cowpea rhizobium strains has been observed for nodulation in cowpea (Mandal et al. 1999) but the local Rhizobia invariably out-populates the introduced strains. Therefore, in recent years, major efforts are concentrated to exploit genetic variability in cowpea as a host for effective nodulation and nitrogen fixation. Sanginga et al. (2000) screened 94 cowpea lines and observed major varietal differences in cowpea for growth, nodulation and arbuscular mycorrhizal fungi root infection as well as for performance under low and high phosphorus. The improved cowpea variety IT86D- 715 showed equally good growth under low as well as high phosphorus levels. It also showed better N-fixation than others. Based on its adaptability to grow in low P soils and overall positive N balance, they recommended cultivation of IT86D-715 cowpea variety in soils with low fertility. Kolawale et al. (2000) screened 15 cowpea varieties for tolerance to aluminum and to determine the effect of phosphorus addition on the performance of Al-tolerant lines. The results indicated IT91K-93-10, IT93K-2046-1 and IT90K-277-2 cowpea varieties to be tolerant to aluminum and they gave higher response to phosphorus fertilization when grown in soils with aluminum toxicity problems. Recent work (Saidu et al. 2011; Allexander et al. 2011) have shown major varietal differences in cowpea for growth, nodulation and performance under low phosphorus and under rock phosphate application. Some of the promising lines under low-P condition were IT90K-372-1-2, TN5-78, IT98D-1399, TN27-80, IT99K-1060, IT89KD-374-57, TN 256-80, IT97K-1069-6 and IT98K-476-8. Screening cowpea varieties for tolerance to aluminum has also indicated major varietal differences and cowpea varieties IT91K-93-10, IT93K-2046-1 and IT90K-277-2 appear to be tolerant to aluminum and they gave higher response to phosphorus fertilization when grown in soils with aluminum toxicity problems. It is expected that the ongoing research may lead to the development of new cowpea varieties which would perform well in marginal lands where soil fertility is low.

Improved nutritional traits

Following the development of a diverse set of improved cowpea varieties with high yield potential and multiple pests resistance, a systematic improvement program for nutritional and health traits was initiated in 2001 (Singh 2001). To begin with all the existing high yielding varieties and advanced breeding lines were analyzed for protein, minerals, antioxidants and cooking properties and a great deal of variability was observed (Table 5). The best varieties in respect of high protein

Table 5. Genetic variability for quality traits in cowpea germplasm

Seed size	-	9 to 27g /100 seeds
Protein	-	20.9 to 32.5%
Ash	-	2.9 to 3.9%
Fat	-	1.4 to 2.7%
Carbohydrate	-	59.7 to 71.6%
Cooking time	-	21.1 to 61.9 min
Iron	-	51 to 109 ppm
Zinc	-	33 to 51 ppm
Calcium	-	581 to 1252 ppm
Potassium	-	12084 to 15133 ppm
Magnesium	-	1611 to 2052 ppm
Phosphorus	-	3867 to 4922 ppm
Sulfur	-	1880 to 2354 ppm

and high iron, zinc, calcium and potassium were IT97K-1042-3 and IT98K-205-8 (Table 6). The IT 97K-1042-3 was also best for antioxidant activity.

Table 6. Genetic variability for quality traits in improved breeding lines

Variety	Protein (%)	Fe (ppm)	Ca (ppm)	Zn (ppm)	K (ppm)	Na (ppm)
IT97K-1042-3	30.7	77	980	46	16000	107
IT99K-216	27.5	65	780	39	15650	47
IT97K-556-4	27.4	63	660	38	15750	25
IT98K-205-8	26.1	64	1180	39	14050	35
IT95K-1072	25.7	62	1175	40	13800	44
IT86D-719	24.1	61	1300	27	16000	86
Aloka (local)	23.1	49	1070	40	15900	49
IT97K-131-2	20.9	49	790	23	13800	163

Improved cowpea varieties released by national programs

The collaborative interactions between the IITA, Bean/ Cowpea CRSP and the national program scientists have been very effective. A total of 65 countries have identified and released improved cowpea varieties for general cultivation (Table 7). Many countries, where new cowpea varieties are making a difference, have given specific names to the new varieties and, in some areas, farmers themselves have given names and facilitated farmer to farmer diffusion of seeds.

Biotechnology for resistance to Maruca pod borer in cowpea (2007 to 2016)

The level of resistance to Maruca pod borer in the existing cowpea germplasm is very low and it causes 80-100% yield losses if not protected. Therefore, all the improved varieties still require at least two sprays of insecticides to protect against this insect. Unfortunately, most of the farmers in Africa do not have access to insecticides and often adulterated and expensive when available. Therefore, efforts were initiated in 2004 onwards to introduce Bt (*Bacillus thuringiensis*) gene in cowpea which imparts very high level of protection against cotton bollworm and maize stalk borer. Laboratory studies using the Bt endotoxins were highly effective against *Maruca* pod borer larvae in cowpea. Therefore, concerted and joint efforts were made by many international partners including IITA, USAID, Rockefeller Foundation, advanced laboratories in the USA and Australia, African Agricultural Technology Foundation (AATF), Network for Genetic Improvement of Cowpea for Africa (NGICA) and Monsanto Corporation agreed to donate Bt gene free of royalty to develop Maruca resistance cowpea varieties for Africa. The group then requested Dr. T.J. Higgins of Council of Scientific and Industrial Research Organization (CSIRO), Australia and provided him funds to introduce the BT gene in cowpea. This work has progressed very well and Bt gene was successfully introduced in cowpea in 2008 and confined tests were initiated from 2009 onwards. Controlled greenhouse and field tests of Bt-cowpea have been conducted in Nigeria, Ghana and Burkina Faso for many years with excellent results in controlling Maruca and it is expected that some Bt-cowpea varieties would be released to farmers in these countries 2017.

Marker assisted selection for relevant traits

Limited efforts been made to develop markers and protocols for marker assisted selection (MAS) for Striga resistance in cowpea and already two markers for Striga resistance have been identified (Boukar et al. (2004) and Ouadraogo et al. 2001, 2002). Similar efforts would also be made to develop markers for aphid resistance and tolerance to heat, drought and low-P tolerance (Tulle et al. 2011; Lukas et al. 2013; Huynh et al. 2015; Angira et al. 2016). Limited genomic studies and additional gene transfer work are also underway in cowpea (Singh et al. 2014).

Sixty day cowpea research in India

Majority of the people in India are vegetarian but the

Table 7. Improved cowpea varieties from IITA released and given local names

Country	Variety and local name	Country	Variety and local name
Australia	IT82E-18 (Big buff)	Namibia	IT81D-985, IT89KD-245-1
Brazil	VITA-7 (Epace-1), VITA-3 (EMAPA), IT87D-1627 (BRS-Mazagao)	Nicaragua	VITA-3
Burkina Faso	VITA-7 (KN-1), KVx 396, IT98K-205-8 (Nizwe)	Nepal	IT82D-752 (Akash), IT82D-889 (Prakash)
Burma	VITA-4 (Yezin-1)	Nigeria	IT84S-2246-4, IT90K-82-2, IT90K-277-2 IT93K-452-1 IT89KD-288, IT89KD-391
Cameroon	IT81D-985 (BR-1), IT81D-994 (BR-2), IT90K-277-2 (GLM-3)	Niger	IT89KD-374, IT90K-372-1-2
Cuba	IT84D-449 (Titan), IT84D-666 (Cubinata), IT86D-792 (Yarey), IT88S-574-3 (OR-3)	Panama	VITA-3
El Salvador	VITA-3 (Tecpan-3), VITA-5 (Tecpan-5)	Peru	VITA-7
Equador	VITA-3	Paraguay	IT86D-1010
Gambia	IT84S-2049 (Sosokoyo)	Sudan	IT84S-2163 (Dahab El Goz–gold from sand)
Ghana	IT82E-16 (Asontem), IT83S-728-13 (Ayiyi), IT83S-818 (Bengpla)	South Africa	IT82E-16 (Pannar 311), IT90K-59 (Alectra resistant), TAM C-1, TAM C-2
Guinea Konakry	IT84S-2246-4, IT85F-867-5 (Pkoku Togboi)	Swaziland	IT82D-889 (Umtilane)
Haiti	VITA-3, VITA-4, IT87D-885	Sri Lanka	IT82D-789 (Wijaya-Victory), IT92D-889 (Varuni-Breeze)
India	IT85F-2020 (Vamban 1), IT81D-897 (Pusa Reshmi), IT97K-1042-3 (Pant Lobia-2), IT98K-205-8 (Pant Lobia-1), IT82D-889-1(Pant Lobia-3), IT98K-205-8 OC-1 (Pant Lobia-4), IT82E-18 (Pant Lobia-5)	Surinam	IT82D-889
Jamaica	VITA-3, IT84S-2246-4	Tanzania	IT82D-889 (Vuli-1), IT85F-2020 (Vuli-2)
Mali (Sangaraka)	IT89KD-374 (Korobalen), IT89KD-245	Togo	IT81D-985 (Vitoco)
Malawi	IT82E-16, IT82D-889	Zambia	IT82E-16 (Bubebe)
Mozambique	IT82E-18	Zimbabwe	IT82D-889

production of pulses in India has remained stagnant since 1961 and population has grown over three times causing declining per capita availability and high prices of food legumes wide spread malnutrition. India is currently importing about 3-5 million tons of pulses each year and even then the pulses prices are too high and beyond the reach of the masses who belong to the low income group. The stagnant production of grain legumes is partly because most of the good lands have gone to the green revolution led 'wheat-rice' and 'rice-rice' cropping systems and food legumes have been pushed to marginal lands and partly because the traditional food legume varieties are late in maturity with low yield potential and susceptible to many diseases. The major food legumes in India are chickpea, lentil, pigeon pea, beans, dry peas, green gram, and black gram. Most of these food legumes mature between100 to 130 days and pigeon pea matures between 130 to 240 days and therefore, they compete with cereals for land and farmers prefer to grow cereals because of their igher yields. How can pulses production be increased in India? The only answer is to introduce short duration food legumes in the existing niches between cereal-cereal systems. For example, in northern India, wheat is harvested in late March to early April and rice is transplanted in late June to early July leaving about 80-90 days gap in which a short duration food legume can be grown. This 'wheat-rice' system covers about 10 million ha in northern India. Similarly, there is a large area under rice-based system in the Central and Southern India showing a great potential for increasing pulses production through cultivation of a short duration food legume in these niches.

Cowpea breeding at G.B. Pant University of Agriculture and Technology

Systematic program of breeding short duration (60-days) cowpea varieties for intensive and multiple cropping systems in India was started in 2007 with financial support from GBPUA&T, Pantnagar Government of Uttarakhand, Government of India and the HarvestPlus program of the Consultative Group on International Agriculture (CGIAR). The major objective of the programme was to: i) evaluate selected improved '60-day' cowpea varieties in 'wheat-rice' system and other possible multiple cropping systems, ii) initiate systematic cowpea breeding program to develop new improved short duration cowpea varieties and iii) popularize cultivation and use of improved short duration cowpea varieties in different state of India through farmers field demonstrations especially for dry regions.

The programme has made excellent progress in short span of 8 years (Singh et al. 2010). In total, five improved varieties were released and complete package of cultural practices have been developed for general cultivation in different cropping systems. The plant type of these varieties is erect with near synchronous maturity and the yield performance, seed types and nutritional properties of these varieties are presented in Tables 8 and 9 and seed types in Fig 4. In spite of the short maturity period (60-70 days), the average yields of these varieties is about 1.5 tons and much above yields of the existing pulses in India.

The new emerging breeding lines include all possible colors to mimic popular pulses currently consumed in India in order to enhance acceptability of the new cowpea varieties in different regions (Fig. 5).

Table 8. Mean grain yield (kg/ha) of released cowpea varieties in multi-location trials

Varieties	2012	2013	2014	2015	Mean
Pant Lobia-1	14.97	13.14	10.59	19.69	14.60
Pant Lobia-2	13.71	17.04	18.45	17.29	16.62
Pant Lobia-3	17.46	14.35	19.48	20.72	18.00
Pant Lobia-4	16.30	13.44	15.49	17.94	15.79
Pant Lobia-5	16.30	15.37	17.46	21.61	17.69

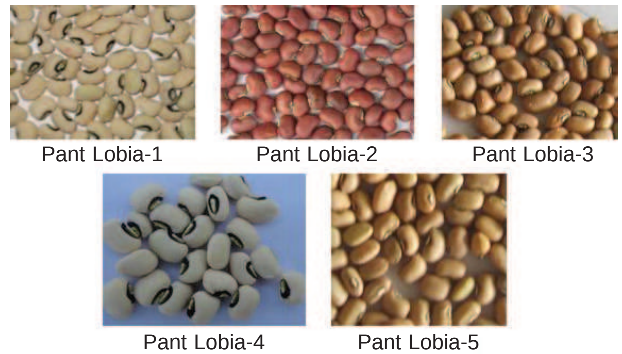

Fig. 4. Seed types of the released cowpea varieties

Table 9. Quality traits of the released cowpea varieties

Varieties	Seed color	protein (%)	Iron (ppm)	Zinc (ppm)	Mn (ppm)
Pant Lobia-1	White	28	89	45	14
Pant Lobia-2	Red	31	90	45	31
Pant Lobia-3	Brown	27	97	51	34
Pant Lobia-4	White	25	109	51	12
Pant Lobia-5	Tan	24	66	36	13

Fig. 5. New advanced cowpea breeding lines with different seed colors comparable to the popular pulses in India

Production package and diversified uses of cowpea

The ongoing cowpea research project at Pantnagar is also focusing on development of improved package of cultural practices to ensure higher yields in different cropping systems and on the development of diversified food products other than chhole and dal to expand cowpea utilization and marketing opportunities. Research on food utilization of cowpea includes use of cowpea besan (in place of chickpea flour) for traditional sweets and snack foods as well as commercial products like cowpea bhujia, cowpea chips and cowpea papad currently prepared from moth bean and black gram.

Future priorities in cowpea breeding

To accelerate the pace of increased cowpea cultivation and production in future, there is a need for the cowpea research community to consolidate the gains made in the past and use a combination of conventional and emerging biotech interventions to further develop a diverse set of 'region-specific' and 'niche-specific' cowpea varieties to expand cowpea cultivation in the world and help improve family food security and nutrition. Some of the future research priorities in cowpea should include:

Higher yield: Major success in the past has been achieved in the development of a range of cowpea cultivars with diverse maturities and plant types with combined resistance to major biotic and abiotic stresses to ensure yield stability in sole crop as well as intercropping systems. The current improved varieties have the maximum yield potential of about 2.5/ha within 60 to 70 days. This is quite acceptable yield level on per day productivity basis but innovative breeding strategies should be developed to raise the grain yield potential to over 4t/ha. This is within the realm of achievement by exploiting the existing variability for plant type and photosynthetic efficiency in cowpea germplasm. Breeding for adaptation to higher density has been the key strategy in raising the yield potential in maize and soybean and this is possible in cowpea also given the availability of erect, non-branching and early maturing plant types. Keeping the maturity within 60-70 days would ensure the cultivation of cowpea as a niche crop in the existing cereal and root crops based.

Adaptation to marginal lands: Good progress has already been made in identifying cowpea varieties with enhanced levels of drought tolerance, heat tolerance, high biological nitrogen fixation and efficient acquisition and use of limited availability of phosphorus in the soils. Therefore, concerted efforts should be made to incorporate these adaptive traits in improved early erect type varieties for better adaptation to the semi-arid regions and other marginal lands where rainfall is low and erratic and soils have little organic matter and low phosphorus. Cowpea would have a comparative advantage over other crops in these regions because of its early maturity, low fertility requirement and its high value grain and fodder.

Nutritional quality and health promoting factors: With increasing incidence of protein malnutrition in developing countries and higher incidence of diabetes, heart problems and cancer in the developed countries, the use of cowpea with high protein content, high fiber, low glycemic index and high levels of cancer fighting antioxidants would become popular. The major focus in cowpea breeding in the past has been on breeding for diverse plant types, early maturity and pest resistance with little efforts to breed for higher protein and other quality traits. However, recent screening of cowpea germplasm has shown great variability for protein content and many health promoting factors. Therefore, there is a need to strengthen breeding efforts to develop cowpea varieties with higher protein and minerals as well as health promoting factors. A beginning has been made under the HarvestPlus Bio-fortification Project but such efforts should be further strengthened.

Specialty foods: Cowpea is consumed as leaf spinach, green pods for vegetable, green canned beans, dry seeds and recently there is a growing need for using cowpea for baby foods and specialty snacks. Cowpeas also have high levels of antioxidants and other health factors and therefore, a potential for nutraceutical uses. The cowpea breeders should work hand in hand with food technologists and agro-industries in developing improved varieties with high protein in grain and leaves for novel uses of cowpea. Since cowpea leaves have up to 30% protein with high levels of minerals and vitamins, cowpea leaf-based foods including fortification of cereals and cassava flours with cowpea leaf powder should be promoted.

Biotechnology interventions

Pest resistance: The level of resistance to insects like thrips, Maruca pod borer, pod bugs and bruchid in the improved varieties is still low. Also, weeds are a major problem in cowpea cultivation because of frequent rains during the crop season and continued shortage and high cost of labor. Recent advances in biotechnology have provided new powerful tools to transfer desirable genes beyond the conventional species boundaries. The most successful examples are the transfer of insect resistance and herbicide tolerance genes from the bacteria to several crops. The herbicide tolerant soybean and insect resistant cotton and maize with Bt-genes have already become very popular in many countries. Preliminary studies have shown that products of the same Bt- genes are highly effective against Maruca pod borer in cowpea and a number of recently developed Bt-cowpea lines are being tested in Nigeria, Burkina Faso and Ghana. Fast track efforts should be made to transfer the Bt gene from the Bt-cowpeas being tested to all the popular cowpea varieties to ensure fast and significant impact in those areas where Maruca is a problem. Work should also be initiated to transfer and stack the known genes for herbicide tolerance and bruchid resistance in cowpea lines already transformed with Bt-gene. A long term strategy should be undertaken to identify, isolate and transfer genes for resistance to thrips and pod bugs which also cause considerable damage to cowpea in many regions.

Quality protein: New cowpea varieties have fairly high protein content ranging from 27 % to 31 % but the cowpea protein, as in other food legumes, is deficient in sulphur containing amino acids like methionine and cysteine. Conventional breeding for higher levels of sulphur containing amino acids is not possible because the genetic variability for this trait is very limited. Recent biotechnology efforts have shown a good possibility of introducing genes from other species for higher levels of methionine in cowpea (F. Aragao, EMBRAPA - personal communication). Such efforts should be encouraged and supported and the cowpea breeders should work closely with biotechnologists to quickly transfer these traits to popularly cultivated varieties in different regions. In addition to improving cowpea varieties through genetic transformation, efforts should be made to develop markers and marker assisted selection protocols for resistance to Striga, bruchid, viruses and tolerance to drought, heat and low-P soils for which the current phenotyping and screening protocols are expensive and time consuming. Some markers for Striga resistance genes have already been identified but much has still to be done.

Summary: cowpea as a major food legume in the 21st century

Majority of the population in India and throughout the tropics continue to depend upon food legumes as a source of protein and minerals in their daily diets. However, the production of many food legumes has remained stagnant causing reduced per capita availability, high prices and progressive malnutrition. This is partly because bulk of the agriculture is now based on the green revolution led cropping systems involving cereals like wheat, rice and maize and food legumes have been pushed to marginal lands and partly because the food legumes like chickpea, lentils, pigeon pea, field pea and beans mature in 120 days or more and compete with cereals for land. The recently developed 60-70 day high yielding cowpea varieties fit well as a niche crop in various cereals based cropping systems. Such extra-early cowpea varieties are already being adopted and cowpea production is steadily increasing in many countries leading to over 7 fold increase in the world cowpea production during the first decade of the 21st century compared to little or no increase in other pulses (Table 10). It is expected that cowpea would emerge to be one of the most important food legumes in the 21st century because of its new early maturing and pest resistant varieties with ability to fit as a niche crop in cereals–based multiple cropping systems. The intensive cereals-cowpea strip cropping and multiple cowpea cropping coupled with the upcoming Maruca resistant Bt-cowpeas would bring a surge in cowpea productivity within the next 10-15 years in Africa.

Table 10. World production of food legumes (x106 tons)

Crop	1961	1981	2001	2009	% +61%	+01**
Beans	11.2	15.3	18.2	19.7	75	8.0
Broad bean	4.8	4.1	4.1	4.1	-14	0.0
Chickpea	7.7	5.8	6.9	9.7	25	40.0
Cowpea	0.87	1.3	3.7	6.4	635	73.0
Lentils	0.85	1.4	3.3	3.6	323	9.0
Pea	7.3	7.7	10.3	10.3	41	0.0
Pigeon pea	2.2	2.1	2.9	3.5	59	21.0
Total pulses	40.8	41.6	55.8	61.5	51	10.0

*Based on FAOSTAT, ** % increase in 2009 over 1961 and % increase in 2009 over 2001

The production of other food legumes may remain stagnant in future also because they cannot compete with cereals for land. Also, in spite of the efforts of several national and international research institutions, it has been difficult to increase their yield due to many widely prevalent diseases like anthracnose and bacterial blight in beans; wilt, blight and pod borers in chick pea and pigeon pea; wilt, powdery mildew and rust in peas and lentils etc for which there is little or no success in breeding for resistance.

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