Challenges and Opportunities for Enhancing Sustainable Cowpea Production

Edited by

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About IITA

The International Institute of Tropical Agriculture (IITA) was founded in 1967 as an international agricultural research institute with a mandate for improving food production in the humid tropics and to develop sustainable production systems. It became the first African link in the worldwide network of agricultural research centers known as the Consultative Group on International Agricultural Research (CGIAR), formed in 1971.

IITA's mission is to enhance the food security, income, and well-being of resource-poor people primarily in the humid and subhumid zones of sub-Saharan Africa, by conducting research and related activities to increase agricultural production, improve food systems, and sustainably manage natural resources, in partnership with national and international stakeholders. To this end, IITA conducts research, germplasm conservation, training, and information exchange activities in partnership with regional bodies and national programs including universities, NGOs, and the private sector. The research agenda addresses crop improvement, plant health, and resource and crop management within a food systems framework and targetted at the identified needs of three major agroecological zones: the savannas, the humid forests, and the midaltitudes. Research focuses on smallholder cropping and postharvest systems and on the following food crops: cassava, cowpea, maize, plantain and banana, soybean, and yam.

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Recent progress in cowpea breeding

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Abstract
Considerable progress has been made in breeding improved cowpea varieties in the last five years. The major breeding objectives were to develop high yielding cowpea varieties for sole cropping as well as intercropping with acceptable seed types and resistance to major diseases, insect pests, nematodes, and the parasitic plants *Striga* and *Alectra* and tolerance to heat and drought. Good progress was also made in breeding early maturing grain type, dual purpose, and fast growing fodder type cowpea varieties. The informal network of world cowpea researchers catalyzed by IITA and the Bean/Cowpea Collaborative Research Support Program has been very effective in evaluating and selecting improved cowpea varieties for a wide range of environments. As a consequence, total world cowpea production has substantially increased.

Importance

Cowpea is an important food legume and an essential component of cropping systems in the drier regions of the tropics covering parts of Asia and Oceania, the Middle East, southern Europe, Africa, southern USA, and Central and South America. Being a fast growing crop, cowpea curbs erosion by covering the ground, fixes atmospheric nitrogen, and its decaying residues contribute to soil fertility. Cowpea is consumed in many forms: the young leaves, green pods, and green seeds are used as vegetables; dry seeds are used in various food preparations; and the haulms are fed to livestock as nutritious supplement to cereal fodder. In West and Central Africa, cowpea is of major importance to the livelihoods of millions of people providing nourishment and an opportunity to generate income. Trading fresh produce and processed food and snacks provide rural and urban women with the opportunity for earning cash income and, as a major source of protein, minerals, and vitamins in daily diets, it positively impacts on the health of women and children. The bulk of the diet of rural and urban poor Africa consists of starchy food made from cassava, yam, plantain and banana, millet, sorghum, and maize. The addition of even a small amount of cowpea ensures the nutritional balance of the diet and enhances the protein quality by the synergistic effect of high protein and high lysine from cowpea and high methionine and high energy from the cereals. This nutritious and balanced food ensures good health and enables the body to resist infectious diseases and slow down their development.

World production of cowpea

Singh et al. (1997) estimated a world total of about 12.5 million ha grown to cowpea with a production of 3 million tonnes (t). The exact statistics are still not available but there

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seems to be an increase in the area as well as production since 1997. The available data on area, production, and average yield of cowpea in 11 selected countries (Table 1) totals 11.3 million ha and 3.6 million t. The estimated area and production in over 50 other countries in Asia, Africa, and Central and South America that grow cowpea would make a world total of over 14 million ha and 4.5 million t. Nigeria is the largest producer and consumer of cowpea with about 5 million ha and over 2 million t production annually. Each Nigerian eats cowpea and the per capita consumption is about 25 to 30 kg per annum. Niger Republic is the next largest producer with 3 million ha and over 650 000 t production. Northeast Brazil grows about 1.5 million ha of cowpea with about 491 558 t production that provides food to about 25 million people. In Brazil as a whole, per capita consumption of cowpea is about 20 kg annually. In southern USA, about 40 000 ha of cowpea is grown with an estimated 45 000 t annual production of dry cowpea seed and a large amount of frozen green cowpeas. India is the largest cowpea producer in Asia and together with Bangladesh, Indonesia, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, and other Far Eastern countries, there may be over 1.5 million ha under cowpea in Asia. There is a need to make concerted efforts to collect accurate statistics on cowpea area and production in different countries.

Progress in cowpea breeding

Recent reviews by Singh et al. (1997) and Hall et al. (1997) have described progress in cowpea breeding in different regions of the world. The aim of this paper is to update both articles. The International Institute of Tropical Agriculture (IITA) continues to be the center for cowpea research. However, recently, cowpea improvement programs at the University of California, Riverside (USA) and Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Brazil have been strengthened and expanded. Significant research on various aspects of cowpea improvement is also being done in Burkina Faso, India, Mali, Nigeria, and Senegal, and to a lesser extent in a number of other countries. A brief review of the progress made is presented.

Breeding methods

Singh (1996) reported the results of an experiment conducted to ascertain whether segregating populations such as F_2, F_3, F_4, F_5, and others should be grown under intercrop or sole

Table 1. Major cowpea growing countries in the world (1999–2000).

Country	Area under cowpea (ha)	Production (t)	Yield (kg/ha)
Nigeria	5 050 100	2 108 000	417
Niger	3 800 000	650 000	171
Brazil	1 500 000	491 558	324
Mali	512 455	113 000	220
Tanzania	145 000	46 000	317
Myanmar	105 000	100 000	952
Uganda	64 000	64 000	1000
Haiti	55 000	38 500	700
USA	40 000	45 000	1000
Sri Lanka	15 000	12 120	808
South Africa	13 000	5600	430
Total	11 299 555	3 669 778	324

Source: FAOSTAT and national reports.

crop for selecting high yielding lines for intercropping. Two crosses involving IT89KD-374 and IT89KD-288 as local improved parents and IT90K-48-1, which is resistant to aphid, bruchid, thrips, and *Striga* and *Alectra*, were made in 1990 and F_2 seeds from the two populations were subdivided into two sets each. One set was grown in sole crop with two insecticide sprays and the other set was grown under intercropping with millet, without insecticide spray in 1991. The F_3 progenies selected from these populations were grown in sole crop and intercrop, respectively, maintaining separate sole crop and intercrop streams in 1992. Likewise F_4 progenies were grown in separate streams in 1993, F_5 progenies in 1994, and F_6 progenies in 1995. The standard pedigree method was followed to select desirable plant/progenies while evaluating F_2 to F_6 generations. The promising F_6 progenies were bulk harvested in 1995 and multiplied in the dry season for a yield trial under intercrop and sole crop in the 1996 crop season. A total of 52 F_6 lines selected from the segregating progenies of the two crosses advanced in sole crop and intercrop streams were yield tested along with eight checks, including the original parents as well as best local and improved checks. The trial included sole crop and a combination of 1-row millet with 1-row cowpea intercropped with and without spray of insecticide. The grain and fodder yields of the breeding lines selected under intercropping were significantly better than those selected under sole crop averaged over the two crosses. The mean grain yield of all the lines derived from the sole crop was 1149 kg/ha in sole-crop sprayed and 190 kg/ha in intercrop with no spray, compared to 1328 kg/ha and 265 kg/ha, respectively, of the lines derived from intercrop. This indicated that selection under intercropping without spray is more effective for higher yield than selection under sole crop. This may be due to greater stress and selective pressure under intercropping.

In a comparative study of different breeding methods, the mean performance of F_3 progenies derived from single seed descent method was better than that of progenies developed via single plant selection for yield and yield components (Mehta and Zaveri 1997). Also, the broad-sense heritability was higher in the population developed through the single seed descent selection method. Vishwanathan and Nadarajan (1996) conducted G × E analysis of several cowpea varieties and they observed IT86D-1056 and C04 cowpea varieties to be the most stable. Singh (2000) showed that by testing and selection of varieties at known hot spots for different diseases, insect-pests, and *Striga/Alectra*, the genotype × environment interaction can be minimized to ensure stable performance of improved varieties over a wider range of environments. He also showed that by simultaneously testing and selecting under sole crop with only two sprays of insecticide, sole crop without spray and intercrop without spray, high yielding varieties with stable performance with little or no insecticide could be identified (Singh 1999a, 2000). Diallel analysis of six cowpea genotypes and their F_1 hybrids revealed additive gene action for most of the quantitative traits including green fodder and total dry matter (Ponmariammal and Das 1996).

Interspecific crosses

Gomathinayagam et al. (1998) reported successful crosses between *Vigna vexillata* and *Vigna unguiculata* using embryo culture. They grew the F_1 hybrids and harvested F_2 seeds that were planted and then backcrossed to *V. unguiculata*. However, the resulting backcross seeds looked closer to *Vigna vexillata*. Therefore, there is a need to further examine the progenies obtained from this cross before ascertaining whether this was a true hybrid. Tyagi and Chawla (1999) also reported successful crosses between *Vigna radiata* and

Vigna unguiculata using in vitro culture techniques. Gibberellic acid treatment sustained the pods for 9–10 days, which were then used for embryo culture. About 10% of total embryos cultured resulted in plantlet formation. However, the authors did not report further growth and culture of these plantlets and therefore, it is not certain whether the crosses were true hybrids.

Extreme wide crosses have been possible in other crop species using large numbers of pollinations along with newer techniques and perseverance. For example, Knyast et al. (2000) successfully crossed oat (var. Seneca 60 hexaploid) with maize pollen and added maize chromosomes to oat genome. This involved pollinating 60 000 oat spikelets by maize pollen 48 hours after emasculation. The spikelets were sprayed with 100 ppm 2-4-D about 48 hours after pollination. A total of 4300 embryos were isolated and cultured on modified M.S medium 14 days after pollination. From these only 379 F_1 plantlets developed successfully and these were transferred to pots of which 135 plants survived and had retained one or two maize chromosomes in addition to the complete oat haploid genome. From these four fertile disomic and two fertile monosomic oat-maize addition lines were developed, which are now being used to widen the genetic base of barley and to breed improved varieties with completely new traits. This study indicates that a very large number of pollinations and application of new embryo culture techniques along with a lot of patience is needed to achieve success in wide hybridization. Therefore, there is a need to continue efforts to cross *Vigna vexillata* and other *Vigna* species with cowpea to broaden its genetic base using new emerging techniques.

Mutations

Adu-Dapaah et al. (1999) reported a fasciated mutant and Singh and Adu-Dapaah (1998) reported a partial sterile mutant, both of which originated spontaneously. The fasciated mutant does not have much breeding value but the partial sterile mutant can be used for facilitating hybridization in cowpea. John (1999) reported 50 Kr of gamma rays to be most effective for inducing mutations in cowpea and Odeigah et al. (1996) obtained several male sterile mutants using gamma rays, ethyl methane sulphonate (EMS), and sodium azide. Saber and Hussein (1998) reported induced mutants using gamma rays showing resistance to rust. Gunasekaran et al. (1998) treated seeds of the cowpea variety C04 with gamma rays and ethidium bromide and analyzed M_1 and M_2 progenies for different agronomic traits. They observed a great deal of variation in M_2 population for different traits and further noticed that gamma rays were more effective in inducing mutation than ethidium bromide.

Disease resistance

Latunde-Dada et al. (1999) studied the mechanism of resistance to anthracnose in TVx 3236 cowpea. In this variety the initially injected epidermal cells underwent a hypersensitive response restricting the growth of the pathogen. The phytoalexins "kievitone" and "phaseollidin" accumulated more rapidly in the stem tissue of TVx 3236 compared to the sucessible variety. Lin et al. (1995) screened 131 cowpea varieties by artificially inoculating with *Cercospora cruenta* (*Mycosphaerella cruenta*) from which 15 varieties were identified immune and seven resistant. Singh et al. (1997), Singh (1998), and Singh (1999a) developed several cowpea lines with resistance to *Cercospora*, smut, rust, *Septoria*, scab, *Ascochyta* blight, and bacterial blight (Table 2). Some of the varieties, which showed multiple resistance

Table 2. Sources of resistance to major diseases in cowpea.

Diseases	Sources of resistance
Anthracnose	TVx 3236
Cercospora	IT89KD-288, IT97K-1021-15 IT97K-463-7, IT97K-478-10 IT97K-1069-8, IT97K-556-4
Smut	IT97K-556-4, IT95K-1090-12 IT95K-1091-3, IT95K-1106-6 IAR-48, IT97K-506-6
Rust (Uromyces)	IT97K-1042-8, IT97K-569-9 IT97K-556-4, IT97K-1069-8 IT95K-238-3, IT97K-819-118 IT90K-277-2, IT97K-1021-15 IT96D-610, IT86D-719
Septoria	TVu 12349, TVu11761, IT95K-398-14 IT90K284-2, IT95K-1090-12 IT97K-1021-15, IT98K-205-8 IT98K-476-8, IT97K-819-118, IT95K-193-12 TVu 1234, IT95K-1090-12,
Scab	IT98K-476-8, IT97K-1069-8 TVx 3236, IT95K-398-14 IT97K-1021-15, IT95K-1133-6
Ascochyta	TVu 11761
Bacterial blight	IT95K-398-14, IT95K-193-12 IT81D-1228-14, IT95K-1133-6 IT97K-556-4, IT97K-1069-8, IT90K-284-2, IT91K-93-1, IT91K-118-20

were IT97K-1021-15, IT97K-556-4, and IT98K-476-8. Wydra and Singh (1998) screened 90 cowpea breeding lines and identified IT90K-284-2, IT91K-93-10, and IT91K-118-20 to be completely resistant to three virulent strains of bacterial blight. Eight varieties were resistant to two strains and two varieties were resistant to one strain. All the remaining varieties were susceptible to bacterial blight. Santos et al. (1987) screened 156 cowpea varieties under field infestation with smut and identified three highly resistant ones. Nakawuka and Adipala (1997) identified Kvu 46, Kvu 39, and Kvu 454 to be resistant to scab in Uganda. Rodriguez et al. (1997) found L-198 and CNx 377-1E to be resistant to *Macrophomina*. Uday et al. (1996) identified V-265 also to be resistant to *Macrophomina*. In an interesting study, Zohri (1993) artificially inoculated 16 cowpea varieties with *Aspergillus flavus* to monitor aflatoxin production. He found that two cowpea varieties from IITA, IT82E-16 and IT81D-1032, did not support *Aspergillus* growth and therefore no aflotoxin production was observed on these varieties. This indicates the possibility of breeding for resistance to *Aspergillus flavus* in cowpea.

Resistance to nematodes

Several sources of resistance to nematodes were identified including some of the improved breeding lines with high yield potential (Rodriguez et al. 1996; Roberts et al. 1996,1997;

Fery and Dukes 1995a; Ehlers et al. 2000a; and Singh 1998). Some of the varieties with high yield and nematode resistance are IT849-2049, IT89KD-288, IT86D-634, IT87D-1463, IT95K-398-14, IT96D-772, IT96D-748, IT95K-222-5, IT96D-610, IT87K-818-18, and IT97K-556-4. Among these varieties, IT89KD-288 was found to be resistant to four strains of *Meloidogyne incognita* in USA (Ehlers et al. 2000a). Singh et al. (1996, 1998a) found IT89KD-288 to be high yielding and highly resistant to nematodes in the trials conducted at Kano (Nigeria), where nematode attack is very severe in the dry season planting with irrigation. IT89KD-288 was taken by one farmer in 1994 and through farmer to farmer diffusion, it has become a popular variety because of its nematode resistance and high yield in the dry season. Cowpea cultivation in the dry season was not possible before because all the local cowpea varieties were susceptible to nematodes.

Resistance to viruses

Singh and Hughes (1998, 1999) reported several cowpea breeding lines to be completely resistant to cowpea yellow mosaic, blackeye cowpea mosaic, and cowpea aphid borne mosaic. Of these IT96D-659, IT96D-660, IT97K-1068-7, and IT95K-52-34 were most promising in terms of resistance and yield potential. Bashir et al. (1995) screened several cowpea varieties from IITA and observed that IT86F 2089-5, IT86D-880, IT90K-284-2, IT90K-76, IT86D-1010, and IT87D-611-3 were immune to blackeye cowpea mosaic. Van-Boxtel et al. (2000) artificially screened 14 cowpea varieties with three isolates of blackeye cowpea mosaic and 10 isolates of cowpea aphid borne mosaic virus in order to identify lines with multiple strain resistance. They observed that cowpea breeding lines IT86D-880 and IT86D-1010 were resistant to all the three isolates of blackeye cowpea mosaic and five strains of cowpea aphid borne mosaic. IT82D-889, IT90K-277-2, and TVu 201 showed resistance to one or the other of the five remaining isolates and thus by using the abovementioned five cowpea varieties as parental lines, it is possible to breed new cowpea varieties with combined resistance to all the 13 strains of the viruses.

The most important factors that constrain cowpea production in the northeastern region of Brazil are the virus diseases, caused mainly by cowpea severe mosaic virus (CSMV) of the group Comovirus, cowpea aphid borne mosaic virus (CABMV) of the group Potyvirus, cucumber mosaic virus (CMV) of the group Cucumovirus, and cowpea golden mosaic virus (CGMV) of the group Geminivirus (Lima and Santos 1988). Substantial efforts have been made in breeding for resistance to viruses and progress has been made. Lima and Nelson (1977) identified the cultivar Macaibo as having immunity to CSMV while Vale and Lima (1995) showed that inheritance of this resistance is conditioned by a recessive gene. Rios and Neves (1982) confirmed the immunity of Macaibo and a new source of resistance to CSMV in line FP 7733-2, from which the variety CNC 0434 was developed (Rios et al. 1982). This variety was recommended for cultivation in the state of Maranhão (EMBRAPA 1986). Lima et al. (1986), in a study that involved 248 genotypes, identified four new genotypes (TVu 379, TVu 382, TVu 966, and TVu 3961) as being immune to CSMV and CABMV. Cultivars Cowpea 535, Dixiecream, Bunch Purple Hull, Lot. 7909-Purple, V-17, and TVu 612 were immune only to CABMV. Lima et al. (1998), in another study that involved 44 genotypes, confirmed the immunity of genotypes TVu 379, TVu 382, TVu 966, and TVu 3961 to three strains of CSMV. Santos and Freire Filho (1986) screened 450 genotypes for resistance to CGMV. Of those genotypes, 57 were classified as highly resistant, among these being CNC 0434, TVu 612, CE-315 (TVu 2331), and

BR 1-Poty. Three lines from the EMBRAPA cowpea breeding program, TE87-98-8G, TE87-98-13G, and TE87-108-6G and two lines introduced from IITA, IT84S-2135 and IT84S-1627, were found to be resistant to CABMV and immune to CMV by the Laboratory of Virology of the Center of Agrarian Sciences of the Federal University of Ceará. Two other lines from IITA, IT85F-2687 and IT86D-716, were immune to both viruses (Rocha et al. 1996). These resistance sources have been used in cowpea improvement in Brazil. Several varieties that have been released commercially, and breeding lines that are still under evaluation were developed from crosses with the varieties CNC 0434, Macaíbo, and TVu 612. Resistance to CSMV, CABMV, and CGMV has already been incorporated in some of the released varieties like BR 10-Piaui (Santos et al. 1987), BR 12-Canindé (Cardoso et al. 1988), BR 14-Mulato (Cardoso et al. 1990), BR 17-Gurguéia (Freire Filho et al. 1994), EPACE 10 (Barreto et al. 1988), Setentão (Paiva et al. 1988), IPA 206 (IPA, 1989), and BR 16-Chapeo-de-couro (Fernandes et al. 1990b). Presently, crosses are being made to improve resistance to CMV.

Resistance to *Striga* and *Alectra*

Cowpea suffers considerable damage due to *Striga gesnerioides* in West and Central Africa and to *Alectra vogelii* in West and Central Africa as well as in eastern and southern Africa. Good progress has been made in breeding improved cowpea varieties with combined resistance to *Striga* and *Alectra* (Atokple et al. 1995, Berner et al. 1995, Singh and Emechebe 1997, Singh et al. 1997, Singh 2000). The most promising new cowpea varieties are IT93K-693-2, IT95K-1090-12, IT97K-499-39, IT97K-497-2, and IT97K-819-154 with combined resistance to *Striga* and *Alectra* and major diseases. The details of breeding for *Striga* and *Alectra* resistance are presented in this volume by B.B. Singh.

Insect resistance

Insect pests are a major constraint in cowpea production. Considerable progress has been made in the last four years in developing cowpea varieties resistant to several insects. Pandey et al. (1995) reported TVu 908 to be resistant to leaf beetles. Singh et al. (1996) reported several improved cowpea varieties with combined resistance to aphid, thrips, and bruchid. Of these, IT90K-76, IT90K-59, and IT90K 277-2 are already popular varieties in several countries. Among the new varieties IT97K-207-15, IT95K-398-14, and 98K-506-1 have a high level of bruchid resistance (Singh 1999c). Nkansah and Hodgeson (1995) confirmed resistance of TVu 801 and TVu 3000 to the Nigerian aphid strain but found that the two lines were susceptible to aphids from the Philippines. Similar differential reactions to aphids has been observed in the USA (A.E. Hall, personal communication) indicating the existence of different aphid strains. Shade et al. (1999) also reported a virulent strain of bruchid (*Callosobruchus maculatus*) which was able to cause severe damage to TVu 2027, which is otherwise resistant to the bruchid strain in Nigeria. Yunes et al. (1998) observed that the 7s-storage protein, "vicillin" is responsible for bruchid resistance in cowpea lines related to TVu 2027. Only low levels of resistance have been observed for *Maruca* pod borer and pod bugs, which cause severe damage and yield reduction in cowpea. Jagginavan et al. (1995) observed cowpea lines P120 and C11 to be least damaged by *Maruca* and Veeranna and Hussain (1997) found TVx 7 to be most resistant to *Maruca* and has a high density of trichomes (21.41/mm^2). Veerappa (1998) screened 45 cowpea lines for resistance to *Maruca* pod borer and observed that the tolerant lines had higher phenol and tannin contents compared to susceptible lines. This is in line with the general observation that cowpea varieties with pigmented calyx, petioles, pods, and pod tips suffer less damage due to *Maruca*.

As indicated earlier, a distant wild relative of cowpea *Vigna vexillata* has shown high levels of resistance to *Maruca* pod borer and bruchid but all the efforts made at IITA to transfer *Maruca* resistance genes from *Vigna vexillata* to cowpea have not been successful (Fatokun in this volume). Gomathinayagam et al. (1998) reported a successful susceptible cross between *Vigna vexillata* and cowpea and also made a backcross in F_2 generation but the resulting seeds looked like the wild parent (personal communications). This work is not being followed further raising the question whether the original cross and the backcross seeds were true hybrids. Over the last 10 years concerted efforts were made by IITA in collaboration with advanced laboratories in the USA and Italy to transform cowpea with the *Bt* gene for *Maruca* resistance. However, no success has been achieved as yet.

While the wide crosses and transformation of cowpea with the *Bt* gene have not been successful, considerable progress has been made in pyramiding minor genes for field resistance to *Maruca* pod borer and pod bugs through conventional breeding. Singh (1999a) screened new improved cowpea breeding lines for field resistance to major insect pests without insecticide sprays and he observed several cowpea lines with grain yield of 500 kg/ha to 856 kg/ha without any chemical protection. The local variety yielded 0 to 48 kg/ha in the same trials. The most promising varieties are IT90K-277-2, IT93K-452-1, IT94K-437-1, IT97K-569-9, IT95K-222-3, IT97K-837, and IT97K-499-38. These lines are resistant to major foliar diseases, aphid, thrips, and bruchid with pods at a wide angle and suffer less damage due to *Maruca*. IT94K-437-1 and IT97K-499-38 also have combined resistance to *Striga* and *Alectra*. Developed through conventional breeding approaches, the new field resistant lines require only one or two sprays of insecticide for a normal yield of 1.5 to 2.5 t compared to four to six sprays needed for the susceptible varieties.

Drought, heat, and cold tolerance

Since cowpea is grown in varied environments it encounters different types of stresses including drought, heat, and cold. Good progress has been made at IITA on breeding for enhanced drought and heat tolerance, and at the University of California, Riverside on water use efficiency, heat tolerance, and chilling tolerance (Okosun et al. 1998a,1998b, Singh et al. 1999a, 1999b; Mai-Kodomi et al. 1999a, 1999b; Hall et al. 1997; Ismail and Hall 1998; Singh 1999e). Simple, cheap, and nondestructive screening methods for drought tolerance have been developed and used to identify and breed for drought tolerant cowpea varieties.

Heat tolerant lines have been developed and heat tolerance is now better understood in cowpea than any other crop (Singh 1999b, Ismail and Hall 1998). Recently the effectiveness of heat tolerance has been quantified using pairs of genetically related and unrelated lines with and without heat tolerance genes (Ismail and Hall 1998). This work is reviewed in detail in this volume by Hall et al. Singh (1999b) grew 102 cowpea breeding lines at IITA Kano Station from March to May when the temperatures ranged from 24 to 27 °C in the night and from 38 to 42 °C during the day. Most of the lines showed severe flower abortion with little or no pods and these were rated as heat susceptible. The most susceptible lines, IT97K-461-2 and IT97K-461-4, showed complete sterility with no development of pollen beyond the microspore stage. These lines are otherwise normal and very high yielding in the regular crop season (July–October) when day temperatures are below 35 °C and night temperatures below 24 °C. In contrast to the heat susceptible lines, the heat tolerant lines had normal pollen, good pod set, and normal grain yield. The best heat tolerant lines were IT97K-472-12, IT97K-472-25, IT97K-819-43, and IT97K-499-38.

The details of work on chilling tolerance are reviewed in this volume by Hall et al. A dehydrin gene involved in chilling tolerance during seedling stage has been identified (Ismail et al. 1997, 1999) and mapped using recombinant inbred lines (Menendez et al. 1997). The role of the dehydrin in chilling tolerance has been confirmed using near-isogenic lines (Ismail et al. 2000) and efforts are underway to understand the mechanism involved in the control of its expression.

Enhanced N-fixation and efficient use of phosphorus

Significant variation in cowpea rhizobium strains has been observed for nodulation in cowpea (Mandal et al. 1999) but the local rhizobia invariably outpopulate the introduced strains. Therefore, in recent years, major efforts have concentrated on exploiting genetic variability in cowpea as a host for effective nodulation and nitrogen fixation (Buttery et al. 1992). Graham and Scott (1983) observed major genetic differences for nodulation and dry matter and N accumulation among 12 cowpea varieties. They also observed a significant relationship between total N and seed yield and nodule weight. Mandal et al. (1999) also observed significant varietal differences in cowpea for nodule number and nodule weight as well as for nitrogenase activity indicating a good possibility of breeding improved cowpea varieties with enhanced N-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 a higher response to phosphorus fertilization when grown in soils with aluminum toxicity problems. Singh et al. (1998) evaluated improved cowpea varieties under low and high fertility and they also observed major varietal differences. They found IT96D-772, IT96D-739, IT96D-740, and IT96D-666 cowpea varieties to be good performers under low as well as high fertility whereas most other varieties were poor in poor fertility and good in good fertility. These studies further indicate a good possibility of developing improved cowpea varieties with enhanced nitrogen fixation and higher yields under low phosphorus as well as in soils with aluminum toxicity. There is a need for closer interactions between cowpea breeders and soil scientists and soil microbiologists.

Improved nutritional quality

Cowpea is a major source of protein, minerals, and vitamins in the daily diets of the rural and urban masses in the tropics, particularly in West and Central Africa where it complements well with the starchy food prepared from cassava, maize, millet, sorghum, and yam. Systematic efforts have just begun at IITA and a few other institutions to develop improved cowpea varieties with enhanced levels of protein and minerals combined with faster cooking and acceptable taste. Singh (1999d) screened 52 improved and local cowpea varieties to estimate the extent of genetic variability for protein, fat, minerals etc. On a fresh weight basis (about 10% moisture), the protein content ranged from 20 to 26%, fat content from 0.36% to 3.34%, iron content from 56 ppm to 95.8 ppm, and manganese content from 5 ppm to 18 ppm. The improved cowpea varieties IT89KD-245, IT89KD-288, and IT97K-499-35 had the highest protein content (26%) whereas the local varieties like Kanannado, Bauchi early, and Bausse local had the lowest protein content (21 to 22%). One of the local varieties, IAR 1696, had high protein content (24.78%) and high fat content (3.28%) as well as high iron content (81.55 ppm). Similarly an improved variety, IT95K-686-2, had high protein (25%), high fat content (3.3%), and high iron content (76.5 ppm). Appropriate crosses have been made to study the inheritance of protein, fat, and iron contents and to initiate a breeding program for improving these quality traits. In another experiment, various physical properties of selected cowpea varieties were determined. The relative density of cowpea seed ranged from 1.01 to 1.09, and hardness (crushing weight) ranged from 3.96 kg for IT89KD-288 to 8.4 kg for Aloka local. The seed hardness was positively correlated with cooking time. There have been earlier reports on the extent of genetic variability for quality traits in cowpea. Hannah et al. (1976) reported high methionine content in TVu 2093 and Bush Sitao (3.24–3.4 mg/g) dry seeds compared to 2.75–2.88 mg/g seeds of the check variety G-81-1. Rosario et al. (1980) observed the highest typsin inhibitor activity in winged bean and lima bean and the lowest activity in mung bean and rice bean whereas the trypsin inhibitor values for cowpea were intermediate. Fashakin and Fasanya (1988) analyzed 10 cowpea varieties and observed a range for protein content from 21.5 to 27% and for iron from 8 to 15 mg/100g dry seeds. Nout (1996) evaluated five newly released cowpea varieties used to make popular snack food, *koose* (also called *akara* and *kosai* in Nigeria). They found that *akara* prepared from high yielding new cowpea varieties Ayiyi (IT83S-728-13) and Bengpla (IT83S-818) were the best. Similarly Singh (1999d) in collaboration with the Women in Agriculture (WIA) section of the Kano Agricultural and Rural Development Authority KNARDA (Nigeria) evaluated three improved cowpea varieties, IT98D-867-11, IT89KD-288, and IT90K-277-2 and one local variety Dan Ila for four popular local dishes—*kosai, danwake, alale,* and *dafaduka*. These were subjected to an independent taste panel of over 50 persons of different economic status and background. The improved variety IT90K-277-2 was rated as the best and others were as good as the local variety. None of the varieties was rated as unacceptable. IT90K-277-2 has already become very popular in Nigeria and Cameroon as a high yielding variety. These observations indicate that high yield is not negatively correlated with improved nutritional and food quality traits and that sufficient genetic variability exists to improve these traits in cowpea.

Development and release of cowpea varieties

A large number of cowpea varieties have been released in several countries around the world and the collaborative interactions between the IITA cowpea breeding program and national program scientists have been very effective. A total of 68 countries have identified and released improved cowpea varieties from IITA for general cultivation. The countries and the name of breeding lines released are presented in Table 3. The availability of high yielding disease and insect resistant varieties with desired seed and growth types is quietly

Table 3. Countries that have released IITA developed improved cowpea varieties.

Country	Variety released	Country	Variety released
Angola	TVx 3236	Argentina	IT82D-716
Australia	IT82E-18 (Big Buff)	Belize	VITA-3, IT82D-889, IT82E-1
Benin Republic	VITA-4, VITA-5, IT81D-1137, IT84S-2246-4	Bolivia	IT82D-889, IT83D-442
Botswana	ER-7, TVx 3236	Brazil	VITA-3, VITA-6, VITA-7, TVx 1836-01J
Burkina Faso	TVx 3236, VITA-7 (KN-1)	Burma	VITA-4 (Yezin-1)
Cameroon	IT81D-985 (BR1), IT81D-994, (BR2), TVx 3236, IT88D-363 (GLM-92), IT90K-277-2 (GLM-93)	Central African Republic	VITA-1, VITA-4, VITA-7, VITA-5, TVx 1948-01F, IT81D-1137, IT83S-818, IT82E-18, IT81D-994
		Colombia	IT83S-841
Costa Rica	VITA-1, VITA-3, VITA-6, VITA-7	Côte d'Ivoire	IT88D-361, IT88D-363
Cuba	IT84D-449 (Titan) IT84D-666 (Cubinata-666) IT86D-314 (Mulatina-314)	Cyprus	IT85D-3577
	IT86D-368, (IITA-Precoz) IT86D-782 (Tropico-782) IT86D-792 (Yarey-792) IT88S-574-3 (OR 574-3)	El Savador	TVx 1836-013J (Castilla deseda), VITA-3 (TECPAN V-3), VITA-5 (TECPAN V-5
Democratic Rep. of Congo	VITA-6, VITA-7 IT89KD-349,	Equador	VITA-3
	IT89KD-349, IT89KD-389, IT89KD-355	Ethiopia	TVx 1977-01D, IT82E-16, IT82E-32
		Equatorial Guinea	IT87D-885
		Fiji	VITA-1, VITA-3
Egypt	TVu 21, IT82D-716 IT82D-709, IT82D-812, IT82E-16	Gambia	IT84S-2049, (Sosokoyo) IT83S-728-13
Ghana	IT82E-16 (Asontem) IT83S-728-13 (Ayiyi) IT83S-818 (Bengpla) TVx 1843-1C (Boafa) TVx 2724-01F (Soronko)	Guinea Conakry	IT81D-879, IT83D-340-5, IT82E-16, IT85F-867-5 (Pkoku Togboi) IT85F-2805, IT83S-990, IT87S-1463, IT84S-2246-4
Guinea Bisau	IT82E-9, IT82D-889	Guyana	ER-7, TVx 2907-02D, TVx 66-2H, VITA-3, IT87D-611-3
Guatemala	VITA-3	Haiti	VITA-4, IT87D-885

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Table 3 (continued)

Country	Variety released	Country	Variety released
India	VITA-4, TVx 1502, IT85E2020 (Vamban 1)	Jamaica	VITA-3, ER-7, IT84S-2246-4, IT82E-124
Lesotho	IT82E-889, IT87D-885 IT82E-16, IT82E-32	Liberia	IT82D-889, TVx 3236, VITA-5, VITa-4, VITA-7
Malawi	IT82D-889, IT82E-16 IT82E-25	Mali	TVx 3236, IT89KD-374 (Korobalen) IT89KD-245 (Sangaraka)
		Mozambique	IT82D-812, IT83S-18, IT85F-2020
Mauritius	TVx 3236		
Namibia	IT81D-985, IT89KD-245-1, IT87D-453-2	Nicaragua	VITA-3
Nepal	IT82D-752 (Aakash) IT82D-889 (Prakash)	Nigeria	TVx 3236, IT81D-994, IT86D-719, IT88D-867-11, IT89KD-349, IT86D-721, IT88D-867-11, IT82E-60, IT89KD-374,IT90K-277-2,
Niger	IT89KD-374, IT90K-372-1-2 IT90K-82-2, IT89KD-288		
Pakistan	VITA-4	Paraguay	IT86D-1010, IT87D-378-4, IT87D-697-2, IT87D-2075
Panama	VITA-3	Philippines	IT82D-889
Peru	VITA-7	Senegal	TVx 3236
Sierra Leone	TVx 1990-01E, IT86D-721, IT86D-719, IT86D-1010, IT82E-32, TVx 3236, TVu 1990, VITA-3	Somaila	TVx 1502, IT82D-889 IT82E-32
South Yemen	VITA-5, VITA-7	South Korea	VITA-5, IT835-852, IT82D-889
		Sudan	IT84S-2163 (Daha ElGoz = Gold from sand)
South Africa	IT90K-59, IT82E-16 (Pannar 311)		
		Swaziland	IT82D-889 (Umtilane), IT82E-18, IT82E-27, IT82E-71
Sri Lanka	IT82D-789 (Wijaya) IT82D-889 (Waruni) TVx 309-01EG, VITA-4 TVx 930-01B, (Lita)	Thailand	VITA-3, IT82D-889
		Uganda	TVx 3236, IT82E-60

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Table 3 (continued)

Country	Variety released	Country	Variety released
Suriname	IT82D-889, IT82-D789 (for nematode resistance)	USA	IT84S-2246-4, IT84S-2049, IT89KD-288
Tanzania	TKx 9-11D (Tumaini) TVx 1948-01F (Fahari) IT82D-889 (Vuli-1) IT85F-2020	Yemen	TVx 3236, IT82D-789, VITA-5
Togo	VITA-5, TVx 3236, IT81D-985, (VITOCO)	Venezuela	VITA-3, IT81D-795, IT82D-504-4 TVx 1850-01E,
		Zambia	TVx 456-01F, TVx 309-01G, IT82E-16 (Bubebe)
		Zimbabwe	IT82D-889

catalyzing rapid increase in cowpea cultivation including its extension in nontraditional areas. 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. A few examples are Big Buff in Australia; BR-1 in Cameroon; Titan and Cubinata in Cuba; Asontem and Bengpla in Ghana; Akash (sky) and Prakash (light) in Nepal; Sosokoyo in Gambia; Pkoko Togboi in Guinea Conakry; Korobalen and Sangaraka in Mali; Dan IITA (son of IITA) and Dan Bunkure in Nigeria; Pannar 31 in South Africa; Vuli-1 in Tanzania; Dahal Elgoz (gold from the sand) in Sudan; Umtilane in Swaziland; and Bubebe in Zambia.

The US Vegetable Laboratory at Charleston, South Carolina, has released several cowpea cultivars in the past five years. These include the "snap" cultivar Bettersnap (Fery and Dukes 1995b), the cream type cultivar Tender Cream (Fery and Dukes 1996), and the persistent-green cultivars Charleston Greenpack, (Fery 1998), Petite-N-Green (Fery 1999), Green Pixie (Fery 2000), and Green Dixie, (USDA 2000). The persistent-green varieties are an important new market class of cowpea for the freezing industry in the US (Ehlers, Fery, Hall in this volume) because they are virtually identical in appearance to fresh-shelled cowpeas after they are imbibed with water, but the harvesting costs are much lower because persistent-green grains may be harvested dry with fast, efficient combines, and cleaned and stored dry. With the appearance of a freshly harvested vegetable product, low product cost, and ease of storage and handing, the persistent-green cowpea is attractive to vegetable processors for use in new products or blends with other vegetables. This could help increase cowpea consumption in the US and elsewhere. California Blackeye No. 27 (CB27) is a new blackeye cowpea cultivar for producing dry grain that was released by the University of California, Riverside in 1999. CB27 has high yield, heat tolerance, strong, broad-based resistance to root-knot nematodes, resistance to two races of *Fusarium* wilt, excellent canning quality, and a brighter white seed, compared to the standard blackeye variety in California, CB46 (Ehlers et al. 2000b).

Brazil has released 18 varieties in the last 12 years for the northern region. Two of these, Monteiro (Freire Filho et al. 1998) and Riso do Ano (Fernandes et al. 1990a) were obtained through collection and selection in local populations. Sixteen varieties were developed using pedigree breeding methods. Most of these have been mentioned in the virus resistance section. Dry grain yields during the rainy season typically range from 1000 to 1200 kg/ha, while the production under irrigation during the dry season is from 1500 to 2000 kg/ha. All these varieties were selected under the rainfed system. Therefore, it is possible that varieties can be developed with much higher yields under irrigation if selection is conducted under these conditions. It is worth noting that even with these low yield levels, positive economic returns are realized. To overcome local constraints, varieties are needed with resistance to a wide spectrum of diseases and pests.

Several other varieties have been released in different countries such as Charodi-1 (Sreekumar et al. 1993) and Vamban 1 (IT85F-2020) (Viswanathan et al. 1997) in India; Big Buff (IT82E-18 Imrie, 1995) and Ebony PR (ADTA 1996) in Australia; IT83S-852 and IT82D-889 (Lee et al. 1996) in South Korea; Melakh and Mouride (Cisse et al. 1997) in Senegal; IT87D-611-3 (Singh et al. 1994) in Guyana; Cream 7 (Hassan 1996) in Egypt; IT90K-76, IT90K-277-2, IT90K-82-2 in Nigeria; Sangaraka (IT89KD-374-57) and Korobalen (IT89KD-245) in Mali; INIFAT 93 (Diaz et al. 1997) in Cuba; and GLM 93 (IT90K-277-2) in Cameroon. This is not an exhaustive list as the information from all countries is not available.

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