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REVIEW

Diversified Approaches to Evaluate Wide Genetic Resources of Cowpea for Enhancing New Variety Development for West Africa and Its Social Implementation by Cowpea Research Program of IITA

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Abstract

Cowpea is a staple food crop and a primary source of protein for millions of people in developing countries. Although the crop is primarily cultivated for its mature grains, immature green pods and young green leaves can be consumed as a vegetable. The International Institute of Tropical Agriculture (IITA) was established in 1967; the organisation's extensive research has developed many improved varieties of most staple food crops to benefit people across Africa. For example, more than 100 IITA-bred materials and numerous germplasm lines of cowpea from the Genetic Resource Center (GRC) of IITA which is a mandate crop have been distributed across sub-Saharan Africa. Currently, IITA GRC houses one of the largest global cowpea collections of over 17,000 accessions from 89 countries. Here, we review the diverse approaches undertaken in cowpea research to evaluate the wide genetic resources of IITA for the development of new varieties and their successful dissemination. Notably, Japanese scientists have made constructive contributions to the progress in cowpea research at IITA over the past 50 years. Finally, in terms of research for development, collaborative measures among various national and international stakeholders for the appropriate delivery and social implementation of research achievements in the future are discussed.

Discipline: Crop science

Additional key words: crop phenotyping, development of evaluation methods/techniques, partnership for delivery, research for development

Transforming Africa's agriculture and nourishing rural development

On 27 July 1967, the International Institute of Tropical Agriculture (IITA) was established as an autonomous, non-profit corporation by a decree of the Federal Military Government of Nigeria to contribute towards global food security. IITA was created with expectation to implement an African version of the Green Revolution that transformed Asia through increased agricultural production in the 1960s. It became the first major African link in an integrated network of international agricultural research centers across the developing world (IITA 2017b). IITA focuses on three strategic objectives: (1) increasing food security and availability, (2) increasing the profitability of food crops and other agricultural products, and (3) sustainable management of natural resources. Its research is organised around several core themes: improving crop varieties, enhancing nutrition, managing natural resources, and increasing livelihoods. The institute also works on special initiatives, including youth engagement in agribusiness, commercialisation of technologies in a business incubation platform, women empowerment, development of seed systems, protection and conservation of biodiversity, and big data and open access. Presently, IITA has become the largest international agriculture research center in tropical Africa (budget size, number of researcher), contributing to food and nutrition security in the region.

The impact of IITA on the progress of smallholder farmers is evident in their adoption of improved varieties of many staple food crops in the continent. This includes

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the adoption of almost 400 varieties of cassava with increased yields and better resistance to pests, disease, and environmental stresses; more than 100 IITA-bred materials and several hundreds of cowpea accessions; 327 maize varieties (70% of which have IITA germplasm); 78 improved yam varieties; drought-tolerant maize in 13 countries in eastern, western, and southern Africa with projected economic gains of US$ 907 million; introduction of cowpea and soybean as a food and cash crop in West Africa; and awareness of nutritional benefits of biofortified yellow cassava (IITA 2017b, 2018). IITA has made great contributions to national food security and capacity development of African researchers and scientists in agriculture as well as support to other agriculture research systems in the continent. The institution has trained over 140,000 individuals from 68 countries, and more than 40,000 of them are women.

From its inception, the institute has had a major focus on plant breeding. It is noteworthy that this mainly included improvements in crop quality and yield, and distributes planting materials to other institutes. However, variety development was not done in isolation; it was an integral part of farming systems along with improvements in soil fertility, farm management, natural resource management, control of insects and diseases, evaluation of various genetic resources and screening methodology, understanding farmer/consumer preferences in the target areas, and social implementation/dissemination of new varieties.

During its half-century run as of 2017, the personnel of IITA included 25 Japanese researchers; seven Japanese board members contributed to the administration and decision-making at IITA (Table 1). In addition, the Japanese government has supported IITA from its early stages as one of the most important donors, and numerous collaborative projects were conducted with Japanese institutes/universities. The first mention of a Japanese scientist in IITA was Dr. Seizo Matsushima in 1976, and Japan was listed in 1978 as a research support/donor. In particular, most Japanese scientists and their research budgets are supported by the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF Japan), the Ministry of Foreign Affairs of Japan (MoFA Japan), and the official development assistance (ODA) project. This article reviews diverse approaches that were undertaken to evaluate the wide genetic resources of IITA for the development of new varieties of cowpea and their social implementation. In addition, the contributions of Japanese researchers are presented in this article.

Introduction of cowpea and its silent food revolution from Nigeria

The cowpea is both an "ancient" as well as a "contemporary" staple crop and food. Early illustrations of the plants from AD 512 revealed that farmers had been growing early-maturing strains of the crop with a "determinate" growth habit, perhaps as a strategy to obtain a grain crop and avoid impending terminal drought; cowpea is indeed considered a strategic crop species to address the complex challenges of hunger, malnutrition, climate change, and increasing food prices that would confront the global community (Widders 2012). Cowpea (*Vigna unguiculata* [L.] Walp.) is an herbaceous annual grain legume crop that is mostly grown in the dry, tropic agro-ecologies of Latin America, Africa, Southern Europe, the USA, and South Asia. Cowpea is an important food security crop in developing countries and cultivated mostly for its edible mature grains to feed millions of people (Tarawali et al. 1997). Nutritionally, cowpea grains contain, on average, 23–32% protein and 50–60% carbohydrate (Cruz et al. 2014), on a dry basis. It is a nutritious and inexpensive source of protein for both rural poor and urban consumers (Inaizumi et al. 1999). Green pods with immature seeds can also be consumed as a vegetable (Ehlers & Hall 1997, Mortimore et al. 1997). In West Africa, eating the green pods is crucial for escaping the "hungry period" of August and September (Hall 2012; Badiane et al. 2014). Additionally, cowpea fodder is a valuable source of feed for livestock (Singh et al. 2003), making it very attractive to small-scale farmers (Kamara et al. 2012). As a leguminous crop, cowpea improves soil fertility through its ability to fix atmospheric nitrogen (Sanginga et al. 2000) and is tolerant to low soil fertility, including low phosphate levels (Suzuki et al. 2018). Collectively, these characteristics have made cowpea a vital component of cropping systems for the dry savannahs of sub-Saharan Africa (SSA) (Table 2; Carsky et al. 2001).

The annual global production of cowpea is approximately 8.92 million metric tons (FAOSTAT 2021), and the bulk of production and consumption is in SSA, particularly in West and Central Africa (Table 3). One other major cowpea-producing country is Brazil, with an annual production of more than 491,000 tons (Singh et al. 2002). Nigeria produces the highest quantity of cowpea grains annually and consumes more than 3.0 million metric tons (Boukar et al. 2018). According to Ortiz (1998), Nigerian cowpea production increased by 441% from 1971 to 1996. As a reference, average production of wheat and rice was increased by 338% and 123%, respectively, during the "Green Revolution" in Asia between 1961 and 1991. This example shows how IITA (based in Ibadan, Nigeria) has

Table 1. List of Japanese board members and researchers in IITA during 1967-2020

Name	Year (in)	Year (out)	Remarks
Hidetsugu Ishikura	1981	1986	Member of IITA Board of Trusty
Kunio Toriyama	1986	1989	Member of IITA Board of Trusty
Keiko Nakamura	1989	1994	Member of IITA Board of Trusty
Kyoko Saio	1994	2001	Member of IITA Board of Trusty
Masaru Iwanaga	2001	2002	Member of IITA Board of Trusty
Akira Iriyama	2003	2005	Member of IITA Board of Trusty
Shuichi Asanuma	2018	-	Member of IITA Board of Trusty
Yoshitaka Tanaka	1977	1980	Rice pathologist
Shuichi Asanuma	1979	1983	Soil microbiologist
Jyunichi Yamaguchi	1980	1982	Rice physiologist
Takashi Kosaki	1982	1985	Soil scientist
Kikuo Wasano	1983	1984	Rice breeder
Minoru Yamauchi	1985	1986	Rice Physiologist
Toshiyuki Wakatsuki	1986	1988	Soil scientist
Hiroo Kanno	1988	1990	Yam entomologist
Osamu Nakayama	1989	1991	Food technologist
Ryohei Terauchi	1990	1991	Yam Geneticist
Iwao Watanabe	1990	1992	Plant physiologist
Tomio Terao	1992	1995	Rice physiologist
Yukihiro Hayashi	1994	1995	Agroecologist, system agronomist
Hiroki Inaizumi	1996	1998	Agricultural economist
Takehiko Matsui	1998	2001	Physiologist
Fusako Ishida	1998	2001	Rice science and rural development specialist
Hironobu Shiwachi	2000	2004	Yam physiologist
Taro Adati	2001	2003	Entomologist
Hidehiko Kikuno	2003	2012	Yam physiologist
Satoru Muranaka	2004	2011	Crop scienstist
	2012	-	JIRCAS visiting scinentist
Haruki Ishikawa	2010	-	Plant physiologist
Yukiko Kashihara	2012	2015	Tissue culture specialist
Kanako Suzuki	2013	2017	Soil scientist
Ryo Matsumoto	2011	-	Yam agronomist
Kohtaro Iseki	2016	-	JIRCAS visiting scientist

been fulfilling its mandate for increasing the production of neglected legume crops such as cowpea (Ortiz 1998). This successful increase in cowpea production involved several methods, such as strengthening and developing partnerships with the National Agricultural Research Institute (NARI), improvement of food policy, and multidisciplinary approaches for sustainable production. One of the key elements is the development of new cowpea cultivars, which combine stable yields with resistance to multiple diseases and pests (including parasitic weeds), optimal photosensitivity, early maturity, erect or determinate growth, and drought tolerance (Latunde Dada 1987).

Conversely, many other abiotic and biotic factors are responsible for low yields, and constitute major constraints for cowpea production. Although cowpea production in Nigeria has improved appreciably over the past 50 years, it is still insufficient to meet the market and consumer demands. With the global population predicted to reach approximately 9 billion by 2050, many countries, especially SSA countries, would face increased food insecurity (Alexandratos 1999).

Table 2. Most important food legumes in Africa[1]

Crop	Scientific name	Area harvested (ha)	Production (tons)	Yield (kg/ha)
Cowpeas, dry	*Vigna unguiculata*	14,205,204	8,616,443	607
Beans, dry	*other beans*	7,893,915	7,052,612	893
Soybeans	*Glycine max*	2,470,555	3,097,318	1,254
Broad beans, horse beans, dry	*Vicia faba*	763,139	1,468,881	1,925
Pigeon peas	*Cajanus cajan*	529,522	666,875	1,259
Peas, dry	*Pisum sativum*	471,025	555,617	1,180
Chick peas	*Cicer arietinum*	426,203	693,369	1,627
Bambara beans	*Vigna subterranea*	370,953	228,920	617
Peas, green	*Pisum sativum*	120,903	651,481	5,389
Lupins	*Lupinus albus*	109,489	75,381	689

[1] FAOSTAT, 2021 accessed 11 May 2021

Table 3. Top 20 cowpea producing countries in the world (2019)[1]

Country	Production (tons)	Area harvested (ha)	Yield (kg/ha)
Nigeria	3,576,361	4,303,005	831
Niger	2,386,735	5,725,433	417
Burkina Faso	652,454	1,354,100	482
Brazil[2]	491,000	-	-
Ethiopia	374,332	220,037	1,701
Mali	246,870	298,120	828
Ghana	215,436	454,274	474
Cameroon	215,016	244,058	881
Kenya	202,735	149,102	1,360
Sudan	184,137	290,677	634
Senegal	161,000	339,780	474
United Republic of Tanzania	127,884	112,657	1,135
Myanmar	108,021	122,637	881
Mozambique	90,461	331,424	273
Democratic Republic of the Congo	76,292	175,418	435
Malawi	66,190	26,062	2,540
Yemen	41,656	97,825	426
Haiti	31,069	34,122	911
Madagascar	30,741	42,145	729
United States of America	21,539	15,794	1,364
Serbia	15,862	4,712	3,366

[1] FAOSTAT, 2021 accessed 11 May 2021
[2] Singh et al. (2002)

Extensive genetic resources for cowpea and geographical domain of IITA

By 1974, IITA was working on a relatively wide range of crops, including maize, cowpea, soybean, banana/plantain, cassava, yam, sweet potato, rice, cocoyam, lima bean, pigeon pea, winged bean, African yam bean, and velvet bean. A key development was the opening of the Genetic Resources Unit (now Genetic Resources Center, GRC) with a mission to collect, conserve, and characterise the genomes of African grain legumes, rice, and root and tuber crops. It was agreed that the geographical domain of IITA would include all humid and sub-humid tropical zones. The focus on mandate crops (maize, cowpea, soybean, cassava, yam, and banana/plantain) was developed in the early 1990s and included the transfer of work on sweet potato to the International Potato Center (CIP) and the regional rice mandate to WARDA (now

Africa Rice Center).

IITA houses one of the largest global cowpea collections with more than 17,000 accessions from 89 countries (IITA Cowpea database: http://my.iita.org/accession2/). The collection started with 2,040 accessions led by the Grain Legume Improvement Program (GLIP) in 1970–1971 (IITA 1972). In 1974, data on germplasm collection and evaluation were summarised as "Cowpea Germplasm catalog", published with 3,800 accessions. VITA-1 (TVu201-1D), VITA-2S (VMS-2×TVu4552), and VITA-3 (TVu-1190 E-1) were registered in Nigeria in 1974 (IITA 1975). Subsequently, based on geographical, agronomical, and botanical descriptors, a core collection of 2,062 accessions was established (Mahalakshmi et al 2007). A reference set, also called the mini core, was composed with 370 accessions representing the entirety of the genetic diversity of the core. The mini core is a critical resource for scientists to study new adaptive traits, conduct comparative genomics studies, and discover new favourable alleles and lines for pre-breeding activities (Boukar et al. 2018). In addition, the first cowpea Multiparent Advanced Generation InterCross (MAGIC) population was developed as an important genomic community resource for trait discovery and breeding by scientists at the University of California, Riverside, USA (Huynh et al. 2018). During this period, researchers identified the various constraints for cowpea production in Africa and engaged consumers/farmers to accept new varieties of cowpea other than their preferred ones (e.g. IITA 1974, 1975, 1977, 1982).

Droughty summers: A major constraint to cowpea production

Rain-fed crops growing in the semiarid tropical zone of Africa are subject to extremely dry and hot conditions. Since 1968, droughts have occurred very often in the Sahelian zone, resulting in very short growing seasons. Although cowpea is one of the most drought-tolerant field crops, the very frequent droughts in these regions lead to critical yield loss and consequently, an increased risk of food shortage. Therefore, the importance of early- and extra-early maturing cowpea was pointed out to escape a droughty season, and programs were initiated to develop extra-early maturing varieties. A number of early-maturing germplasm lines and individual plants from various segregating populations were then selected by IITA (IITA 1982).

IITA and the Japan International Research Center for Agricultural Sciences (JIRCAS) team first evaluated the drought tolerance of 900 cowpea lines at the seedling stage during the 1990/91 dry season (IITA 1995). Watanabe (IITA Kano station 1990–1992) developed the evaluation methods for drought tolerance by both the identification of tolerance genes and the selection of segregating materials after crossing (Watanabe 1998). Using these methods, 21 germplasm lines were found to be highly drought-tolerant, out of 900 lines. Watanabe & Terao (IITA Kano station 1992–1995) found high grain yielding lines from the highly drought-tolerant lines (Watanabe & Terao 1998). Matsui (IITA Kano station 1998–2001) and Singh developed simple screening techniques that use visual observations of young plants subjected to drought and recovery and studied the resistance mechanisms to vegetative-stage drought in cowpea as compared with the other species (Singh & Matsui 2002). Approximately 190 breeding lines were screened using the box method, and most of them (148 lines) exhibited substantial survival of vegetative-stage drought.

The initial concept of early-maturing cowpea (60-day cowpea) was born in 1979 at the Agricultural Research Institute (ARI) in Tanzania, by IITA/USAID/TANZANIA project (Singh 2014). The region has bimodal rainfall with a long rainy season and a short rainy season. It was thought that an extra-early (60–70 days) maturing grain legume crop would be ideal for the short rainy season in terms of food security and would work well in cereal-legume rotation with maize. IITA cowpea breeding team planted all the available germplasm, and selected the lines maturing between 60 and 65 days (Singh 2014). During 1979–1981, selected cowpeas were tested for grain yield (target yield of over 1.5–2 t/ha), resistance to major diseases, wide adaptability, and diverse seed types (IITA 1982). From 1982 onwards, a large number of 60-day cowpea varieties were evaluated and released by IITA (IITA 2018, Abaidoo et al. 2017).

Based on these studies and other breeding activities, IITA holds various drought-tolerant/extra-early maturing cowpeas (Supplemental Table S1), which are transported or disseminated to many sub-Saharan countries to escape a droughty summer.

The enemies below: Another major constraint for cowpea production in Africa

Farmers are not likely to adopt a new cultivar simply because it has an improved adaptation to drought (Hall 2004). They prefer insect and/or disease resistance as well. Cowpea production is typically affected by a number of insect pest species. Troublingly, the crop has many natural enemies in each growth stage. Cowpea seedlings can be attacked and killed by aphids (*Aphis craccivora*). The flower bud thrips (*Megalurothirips sjostedti*) are other major insect pests of cowpea that inhibit anthesis and pod formation. The legume pod borer, *Maruca vitrata*, the most cosmopolitan of cowpea pests, is capable of causing extensive grain yield reduction (20%–80%) if not controlled (Singh et al. 1990, Adati et al. 2012). A number of pod-sucking bugs (*Clavigralla tomentosicollis, Riptortus dentipes*, and *Nezara viridula*) attack the pods and suck sap from the seeds while they still develop within the pods (Boukar et al. 2018). Such seeds become seriously reduced in size and malformed, making them unviable and unattractive to farmers and consumers. In addition, when cowpea seeds are placed in storage, the larvae of weevils (*Piezotrachelus varius*), and bruchids (*Callosobruchus maculatus*), which often accompany seeds from the field, cause extensive damage by feeding inside and boring holes through which the adults emerge.

Cowpea is also affected by several fungal, bacterial, and viral diseases, causing extensive yield reductions (Boukar et al. 2018). The major characteristic disease of cowpea is bacterial blight caused by *Xanthomonas axonopodis* pv. *phaseoli*. Among fungal diseases are preemergence and postemergence damping-off caused by *Pythium ultimum*, Fusarium wilt caused by *Fusarium oxysporium*, Macrophomina blight caused by *Macrophomina phaseolina*, web blight, root rot caused by *Thanatephorus cucumeris* (Rhizoctonia solani), stem rot caused by *Phytophthora vignae*, scab caused by *Sphacelama sp*., and cercospora leaf spot caused by *Pseudocercospora cruenta* and *Cercospora apii* (Singh 2014, Boukar et al. 2018). Cowpea farmers in sub-Saharan Africa are looking forward to the development and deployment of improved varieties characterised by resistance to these various biotic constraints.

Varieties that are resistant to some insect pests have been developed after evaluating hundreds of germplasm accessions from IITA GRC since 1974 (Supplemental Table S2). However, their resistance levels may not be sufficient for practical use (Adati et al. 2008, Singh et al. 2002). Field screening data for varietal resistance are often unreliable because it is not easy to exclude the effects of climate change, crop phenology, and the timing of insect infestation, which differs among sites and years. These studies have highlighted the global trend of integrated pest management (IPM), which is intended to reduce the harmful impact of synthetic pesticides on the environment (Adati et al. 2008). Components of IPM strategies for cowpea in the West Africa savannahs include the use of resistant cowpea varieties, cropping systems, botanical insecticides, biological control, and pest monitoring. Regarding other approaches for IPM, Adati (IITA Kano station 2001–2003) and Tatsuki identified the female sex pheromone of *Maruca* (Adati & Tatsuki 1999), based on the results of which Downham et al. developed sex pheromone traps for monitoring *Maruca* (Downham et al. 2003, Downham et al. 2004). In addition, low soil fertility leads to nutrient deficiency and severe attacks by insects and diseases. Chemical fertilisers provide a quick and simple method for enhancing the levels of plant nutrients in the soil. However, in rural areas of Africa, the prices of chemical fertilisers are usually twice the international prices due mainly to transportation costs (Bumb & Baanante, 1996). Suzuki (IITA HQ, 2013–2015, IITA South Africa hub, 2016–2017) evaluated the efficiency of indigenous rock phosphate (RP) as a natural source of phosphate (Suzuki et al. 2018). While a single new component such as drought or pest resistance may not be effective by itself, specific combinations of the above can work synergistically.

Some like it early: Farmers' preference analysis to improve acceptability of new varieties

As mentioned above, farmers are not likely to adopt a new cultivar simply because it has improved traits. Typically, small-scale farmers produce several crops in the rainy season, and they spend all their savings to survive the dry season. According to Hayashi (IITA HQ 1994–1995), the farmers plant millet, sorghum, maize, and rice as dietary staples. The farmers also plant legumes such as cowpea, groundnuts, Bambara nuts, soybean; root and tuber crops such as cassava, yam, potato; and okra and tomato. They then sell the surplus of legumes to the local market (Hayashi 2002). Therefore, their cash income is mostly attributable to selling their livestock, and the income from cowpea is limited.

To improve cash income for small-scale farmers in the Sahel region, IITA initiated the strategy to develop a "dual-purpose cowpea" (IITA 1987), and it was advanced in collaboration with the International Livestock Research Institute (ILRI) in the early 1990s (Akundabweni et al. 1990, IITA 1997). During the dry season, high-quality fodder is scarce. Thus, a need was identified to develop dual-purpose varieties that would give reasonable grain and fodder yields, where the above-ground parts of cowpea could be harvested for fodder (sometime pods as well) and thereby suit the diverse needs of farmers in the Sahel region (Adesina et al. 1997, Inaizumi et al. 1999). Inaizumi (IITA HQ 1996–1998) evaluated the diffusion and adoption of IT89KD-288 (a dual-purpose variety) in the northern area of Nigeria. He examined the patterns, levels, and rate of adoption of the dual-purpose cowpea variety, and evaluated the impact of the variety. In this study, 75% of farmers in Kano state adopted a dual-purpose variety due to its additional fodder yield within four years (Inaizumi et al. 1999). The evaluation revealed that if the variety fulfilled the farmers preferences and performed well for them, the adoption could be accelerated further. Farmers are also more sensitive to short-term risks than long-term benefits. Nevertheless, the key component to improve their acceptability of new cowpea cultivars is to grasp their requirements appropriately and to demonstrate conclusive evidence.

Cowpea farmers deal with variable environmental, regional, and socioeconomic conditions and have multiple production objectives that affect their choice of cowpea variety. Farmer participatory varietal selection (FPVS) is a more rapid and cost-effective way to identify farmer-preferred cultivars if a suitable choice of variety exists (Witcomber et al. 1996). Muranaka (IITA Kano station 2003–2010, and HQ 2010–2011) and Ishikawa (IITA Kano station in Nigeria and Saria station in Burkina Faso 2010–2013, and HQ 2013-present) conducted FPVS with more than 3,500 cowpea farmers in Niger and Burkina Faso to understand regional farmers' preferences (Muranaka et al. 2012, Ishikawa et al. 2019a, Ishikawa et al. 2019b). From these results, the grain yield was consistently found to be the most important and common selection criterion for farmers in southeastern Niger and north-central Burkina Faso (Ishikawa et al. 2019a). Interestingly, on the several key criteria nominated by farmers in addition to grain yield, differences in preferences were observed between countries as well as among villages. Farmers in north-central Burkina Faso generally showed more interest in the criteria related to grain quality as well as early maturation, than those in Niger. Early-maturing cowpea varieties, bearing higher market value compared with late-maturing varieties, were mostly preferred by these farmers (Bediako et al. 2009).

These results illustrate that the farmers' selection of cowpea varieties varies, reflecting specific environmental, historical, and cultural factors. Even in the same country, they contribute to significant differences in the selection criteria. Grain yield was the most common and the most important criterion affecting farmers' choice in both regions (Ishikawa et al. 2019b). In order to determine the better acceptance of an improved variety, regional preferences should be gathered and analysed before the release of the variety. However, it is a burden for breeders to conduct FPVS in multiple locations before registration. Ishikawa et al. (2019b) developed the "Selection index" as a simple formula. Using this index, breeders can estimate the acceptability of the new lines before a variety is released.

The great "escape from shame": Social implementation of improved cowpea

Strong relationships among farmers (especially small-scale farmers), the seed sector, breeders, and other stakeholders in the value chain are essential for the successful dissemination of newly developed and improved crop varieties. Although extensive efforts by various sectors have been made to disseminate the improved varieties of cowpea, they have not reached many countries in West and Central Africa due to weak links or poor communication among stakeholders (Muranaka 2017). In another approach from a rural development perspective, Ishida (IITA HQ 1998–2001) and Wakatsuki (IITA HQ 1986–1988) stated that some projects had been successful in the initial stages using large amounts of energy, resources, and funds, but could not ultimately benefit local farmers in terms of sustainability (Ishida et al. 1998). In addition, their assessments of past projects revealed that most of the capital-based technologies had not lasted beyond the project duration, with the farmers reverting to their indigenous systems (Ishida et al. 1998). Therefore, it is necessary to apply new technologies and varieties that farmers can adapt to their ecological environment and socio-economic conditions. High priority needs to be given to filling these gaps and achieving optimal social implementation.

To overcome these difficulties, Muranaka designed a community-based dissemination scheme, Accelerated dissemination system of improved cowpea varieties via empowered communities in Burkina Faso (AVEC-BF). The central concept of the scheme is the "packaging" of different activities and application to a limited local area. Ishikawa conducted and extended this into a large-scale dissemination scheme (Ishikawa et al. 2015, Ishikawa et al 2017a, Ishikawa 2018). Based on the project, five new varieties were selected by farmers. These varieties were formally registered/released in Burkina Faso in 2013 (IITA press release 2013, IITA the Bulletin 2013a). The extra-early maturing and high-yielding variety, IT99K-573-2-1, was named "Yiisi yande" in the Moore language (a local language of Burkina Faso) meaning "escape from shame" by farmers who participated in FPVS. Fortunately, these results were quickly taken up by the government of Burkina Faso. These varieties were applied to the project of West Africa Agricultural Productivity Program (WAAPP)/Programme de Productivite Agricole en Afrique de l'Ouest (PPAAO) supported by the World Bank, which enhanced social implementation in the country (IITA the Bulletin 2013b). The dissemination rate of improved varieties increased dramatically by up to 72% around the target regions to reach around 22,934 individual cowpea farmers. In addition, the implementation cost was kept low (Ishikawa et al. 2017a), and all benefits of production were given back to the farmers. These results demonstrate that the rapid dissemination of a new cowpea variety is indeed possible when it fulfils the farmers' preferences, farmers can access the seeds of the said variety, and the farmers' skills are sufficient to adopt the new variety.

The bridge on the gaps: Prospects of breeding and research for cowpea

The necessity of high-throughput evaluation for extensive genetic resources and new breeding materials is becoming increasingly useful. Resources developed from cowpea IT97K-499-35 include a whole-genome shotgun (WGS) assembly, a bacterial artificial chromosome (BAC) physical map, and assembled sequences from 4355 BACs (Muñoz-Amartiain et al. 2017). In particular, the bottleneck in phenotyping and applying remote sensing technologies to crop monitoring and evaluation, which has drawn intense interest over the past decade (Furbank & Tester 2011), is now successfully addressed by combining novel technologies such as non-invasive imaging, spectroscopy, image analysis, robotics, and high-performance computing. There is a need for continued cowpea breeding activities utilising new technologies to ultimately create high-yielding varieties with resistance to multiple pests.

Ishikawa et al. (2017b) developed a model to calibrate the nitrogen content in a single seed using Fourier transform infrared spectroscopy (FTIR). Using this technique, breeders were able to evaluate the nitrogen content (protein content) of the seed within 20 s per seed. Moreover, this technique is non-destructive; therefore, it is very useful for the cowpea, in that seed numbers and breeding lines can be saved and breeders can plant the same seed after evaluation. This spectroscopy could also be applied to other physiological analyses. For example, Iseki (IITA HQ, JIRCAS visiting scientist 2016-present) et al. (2020) applied this technique for intra-plant variation analysis. This technique could pave the way for developing other methods to evaluate and enrich the nutritional profile of the cowpea. This would be a much-desired outcome because the cowpea is an incredible source of many health-promoting functional components, minerals, and B-group vitamins (Mudryj et al 2012, Liyanage et al 2014, Jayathilake et al 2018); enhancing not only the yield but also the nutritional value would be highly beneficial.

Although these technical developments and basic research may take time, it will lead to the development of new agri-business opportunities. IITA strongly supports such ventures through its Business Incubation Platform (IITA BIP, IITA annual report 2013, 2016), and IITA youth agripreneurs (IYA, IITA annual report 2013, 2016). For example, Asanuma (IITA HQ, 1979–1983, a board member of IITA from 2018 to present) worked for the isolation and analysis of rhizobia of soybean and cowpea in the 1980s (IITA annual report 1980, 1982, Ayanaba et al. 1983, Asanuma et al. 1985). Based on these studies, the rhizobial inoculation technique underwent much advancement and the rhizobium strain is currently manufactured as "NoduMax" *via* IITA BIP (IITA annual report 2014). In another revolutionary example, Nakayama (IITA HQ, 1989–1991, food technologist and tofu expert, JICA) developed a procedure for making tofu (Nakayama & Osho 1996, IITA annual report 1998). As a result, soybean production has increased up to 3.5 million tons in the recent years, and tofu ("*awara*" or "*k'waidak'wai*") is disseminated to West Africa widely, generating a new business opportunity (Nakamura 2011). If the population increase continues and more young people move to urban areas, agricultural production will become stagnant. There is thus an urgent need for agriculture to remain attractive and profitable, with the demonstration of successful examples such as the above.

On the other hand, the most persistent challenge to the expanded production and consumption of cowpea is closing the "yield gap". Although the annual potential yield of the improved cowpea variety is between 2,000 and 3,000 kg/ha (IITA annual report 1974, CSIR 2010), the current global average yield is only 450-650 kg/ha (Table 3, Abate et al 2011). To overcome these issues, rapid delivery of the developed varieties and technologies to the end-users (small-scale farmers) is crucial. As mentioned above, IITA has already started several efforts *via* the Partnerships for delivery (P4D) strategy (IITA annual report 2016, 2017), and has started advocating unification of international collaboration research for development and dissemination. In this regard, IITA leads several mega-initiatives such as Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) program through a grant from USAID as part of the US government's Feed the Future initiative, and African Development Bank Group initiative including the "Africa Feeding Africa" and the Technologies for African Agricultural Transformation (TAAT) programs. These mega-initiatives have a critical strategy for transforming agriculture on the continent with the goal of ensuring that Africa will be able to feed itself through agriculture (IITA special issue 2017). Hereafter, we expect to enhance the cooperative framework between international and national research institutes and dissemination agencies and integrate individual projects and achievements *via* the One-CGIAR strategy.

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Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection

Accession number/Cultivar name	Feature trait	Remarks	Reference
Aloka (TVu174665)	Drought tolerant	White seed (speakle), brown eye	Singh et al. 2002 EDITS-Cowpea database
Dan Ila (TVu17466)	Drought tolerant	White seed, brown eye	IITA Cowpea database Singh et al. 2002
IT00K-1263 (TVu17211)	Drought tolerant	Brown seed, dark brown eye Evaluation in Mozambique	IITA Cowpea database IITA annual report 2010
IT00K-901-5 (TVu17213)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT03K-316-1 (TVu17234)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT03K-378-4 (TVu17186)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT04K-227-4 (TVU17193)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT84S-2246 (TVu17816)	Drought tolerant	Brown seed, dark brown eye Evaluation in seedling state	Watanabe 1998
IT89KD-245 (TVu-16498)	Drought tolerant	High yielding, Striga resistance	Singh et al. 2002
IT89KD-288 (TVu-16722)	Drought tolerant		Singh et al. 2002
IT89KD-349 (TVu-17811)	Drought tolerant		Singh et al. 2002
IT90K-59-2	Drought tolerant		Singh et al. 2002
IT97K-1069-6 (TVu-17310)	Drought tolerant	Evaluation in Mozambique	IITA Cowpea database IITA annual report 2010
IT97K-1075-7	Drought tolerant		IITA annual report 2001
IT97K-390-2 (TVu-17315)	Drought tolerant	Evaluation in Mozambique	IITA Cowpea database IITA annual report 2010
IT97K-499-35 (TVu-17317)	Drought tolerant	Evaluation in Mozambique	IITA Cowpea database IITA annual report 2010
IT97K-499-39	Drought tolerant		IITA annual report 2001
IT97K-568-18 (TVu-17802)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT97K-634	Drought tolerant		IITA annual report 2001
IT97K-819-118 (TVu-17318)	Drought tolerant		IITA Cowpea database IITA annual report 2010
IT97K-819-154	Drought tolerant		Singh et al. 2002
IT98D-1399 (TVu-17453)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT98K-128-3 (TVu-17455)	Drought tolerant	Evaluation in Mozambique	IITA Cowpea database IITA annual report 2010
IT98K-131-2 (TVu-17456)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT98K-412-13	Drought tolerant	Evaluation in Nigeria	IITA annual report 2010
IT98K-452-1	Drought tolerant		Singh et al. 2002
IT98K-491-4 (TVu-17797)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT98K-506-1 (TVu-17326)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT99K-377-1 (TVu-17339)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT98K-573-1-1 (TVu-17328)	Drought tolerant	White seed, back eye, Striga resistance Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
IT99K-7-21-2-2 (TVu-17348)	Drought tolerant	Evaluation in Nigeria	IITA Cowpea database IITA annual report 2010
Kanannado (TVu803)	Drought tolerant		Singh et al. 2002

(Continued on next page)

Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection (Continued)

Accession number/Cultivar name	Feature trait	Remarks	Reference
Suvita 2 (Golom local, TVu15553)	Drought tolerant	Cream seed, dark brown eye Evaluation in seedling state	Watanabe 1998 IITA Cowpea database
Tvu-11979	Drought tolerant	Evaluation in seedling state	Watanabe & Terao 1998
Tvu-11982	Drought tolerant	Brown seed, dark brown eye Evaluation in seedling state	Watanabe 1998
Tvu-11986	Drought tolerant	Evaluation in seedling state	Watanabe & Terao 1998
Tvu-12348	Drought tolerant	Evaluation in seedling state	Watanabe & Terao 1998
Tvu-12349	Drought tolerant		Singh et al. 2002
Tvu-124914	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-13464	Drought tolerant		Singh et al. 2002
Tvu-1362	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-1469	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-14910	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-14915	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-2365	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-3752 (WEEDY)	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-433	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-4632	Drought tolerant	Dark brown seed, black eye Evaluation in seedling state	Watanabe 1998 EDITS-Cowpea database
Tvu-7144	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-7841	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-8256	Drought tolerant	Purple mottled seed	IITA Cowpea database Singh et al. 2002
Tvu-8885	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-9157	Drought tolerant	Evaluation in seedling state	Watanabe 1998
Tvu-9178	Drought tolerant	Evaluation in seedling state	Watanabe 1998
VITA7 (TVx289-4G)	Drought tolerant	Evaluation in Nigeria	IITA annual report 1985
IT88D-643-1 (TVu-17410)	Heat tolerant		IITA annual report 2001
IT88D-867-11 (TVu-17411)	Heat tolerant		IITA annual report 2001
IT99K-1058	Heat tolerant		IITA annual report 2001
IT99K-1059	Heat tolerant		IITA annual report 2001
IT99K-1060	Heat tolerant		IITA annual report 2001
Tvu-4552	Heat tolerant		IITA annual report 2001
B301 (TVu13950)	Early maturing	Brown seed, Striga resistance	Ishikawa et al. 2019
IT00K-1148	Early maturing	Brown seed	Ishikawa et al. 2019
IT00K-1150	Early maturing		Abaidoo et al. 2017
IT00K-1217 (TVu-17362)	Early maturing		Abaidoo et al. 2017
IT00K-898-5	Early maturing		Abaidoo et al. 2017
IT82D-849 (TVu-15560)	Early maturing	Striga resistance	IITA Cowpea database Abaidoo et al. 2017
IT85D-3428 (TVu-15790)	Early maturing		Abaidoo et al. 2017
IT85D-3428-4 (TVu-16481)	Early maturing		Abaidoo et al. 2017
IT85D-3516-2 (TVu-16476)	Early maturing		Abaidoo et al. 2017
IT85F-1002 (TVu-15763)	Early maturing		Abaidoo et al. 2017
IT85F-1992 (TVu-15775)	Early maturing		Abaidoo et al. 2017
IT85F-958 (TVu-16497)	Early maturing		Abaidoo et al. 2017
IT86D-1008 (TVu-15777)	Early maturing		Abaidoo et al. 2017
IT86D-1065 (TVu-15770)	Early maturing		Abaidoo et al. 2017

Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection (Continued)

Accession number/Cultivar name	Feature trait	Remarks	Reference
IT86D-1073 (TVu-15825)	Early maturing		Abaidoo et al. 2017
IT86D-345 (TVu-15789)	Early maturing		Abaidoo et al. 2017
IT89KD-374 (TVu-16502)	Early maturing		Singh et al. 2002
IT90K-372-1-2	Early maturing	White seed, Striga resistance (evaluation at Burkina Faso)	Ishikawa et al. 2019
IT92KD-279-3	Early maturing		Abaidoo et al. 2017
IT93K-2045-29 (TVu-17293)	Early maturing		Abaidoo et al. 2017
IT93K-509-16 (TVu-17302)	Early maturing		Abaidoo et al. 2017
IT93K-513-2	Early maturing	IPM good practical performance	Asante et al. 2001 Abaidoo et al. 2017
IT93K-734	Early maturing		Abaidoo et al. 2017
IT93KZ-4-5-6-1-5	Early maturing		Abaidoo et al. 2017
IT94K-410-2	Early maturing		Abaidoo et al. 2017
IT94K-437-1	Early maturing		Abaidoo et al. 2017
IT95K-1088-4	Early maturing		Abaidoo et al. 2017
IT95K-1384	Early maturing		Abaidoo et al. 2017
IT95K-1491	Early maturing		Abaidoo et al. 2017
IT95K-181-9	Early maturing		Abaidoo et al. 2017
IT95K-207-22	Early maturing		Abaidoo et al. 2017
IT95M-190	Early maturing		Abaidoo et al. 2017
IT96D-618	Early maturing		Abaidoo et al. 2017
IT96D-711	Early maturing		Singh et al. 2002 Abaidoo et al. 2017
IT96D-738	Early maturing		Abaidoo et al. 2017
IT96D-774	Early maturing		Abaidoo et al. 2017
IT97-819-180	Early maturing		Singh et al. 2002
IT97K-1042-3	Early maturing	Multiple virus resistance and tolerance	Ogunsola et al. 2010 Abaidoo et al. 2017
IT97K-1069-6 (TVu-17310)	Early maturing		Abaidoo et al. 2017
IT97K-1075-7	Early maturing		Singh et al. 2002 Abaidoo et al. 2017
IT97K-1101-5 (TVu-17311)	Early maturing		Abaidoo et al. 2017
IT97K-497-2 (TVu-17446)	Early maturing		Singh et al. 2002
IT97K-499-35 (TVu-17317)	Early maturing		Abaidoo et al. 2017
IT97K-499-38 (TVu-17447)	Early maturing		Abaidoo et al. 2017
IT97K-499-39	Early maturing	Striga resistance, genotyping	Abaidoo et al. 2017
IT97K-499-8	Early maturing		Singh et al. 2002 Abaidoo et al. 2017
IT97K-508-2	Early maturing		Singh et al. 2002
IT97K-569-9	Early maturing		Abaidoo et al. 2017
IT97K-608-14	Early maturing		Singh et al. 2002
IT97K-818-35	Early maturing	Alectra resistance	Abaidoo et al. 2017
IT97K-819-170	Early maturing		Singh et al. 2002 Abaidoo et al. 2017
IT97K-819-180	Early maturing		Singh et al. 2002 Abaidoo et al. 2017
IT97K-825-3 (TVu-17319)	Early maturing		Abaidoo et al. 2017
IT97K-837-8 (TVu-17452)	Early maturing		Abaidoo et al. 2017
IT98K-1111-1	Early maturing		Abaidoo et al. 2017

Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection (Continued)

Accession number/Cultivar name	Feature trait	Remarks	Reference
IT98K-1399	Early maturing	drought tolerant	Abaidoo et al. 2017
IT98K-166-4 (TVu-17798)	Early maturing		Abaidoo et al. 2017
IT98K-409-4 (TVu-17325)	Early maturing	White seed, Striga resistance	IITA Cowpea database Ishikawa et al. 2019
IT98K-498-1	Early maturing		Abaidoo et al. 2017
IT98K-503-1 (TVu-17326)	Early maturing	White seed, Striga resistance (Niger)	IITA Cowpea database Ishikawa et al. 2019
IT98K-506-1	Early maturing	White color, black eye	Abaidoo et al. 2017 EDITS-Cowpea database
IT98K-589-2	Early maturing		Abaidoo et al. 2017
IT99K-1060 (TVu-17333)	Early maturing		IITA Cowpea database Abaidoo et al. 2017
IT99K-494-6	Early maturing	Alectra resistance	Abaidoo et al. 2017
IT99K-529-1 (TVu-17344)	Early maturing		IITA Cowpea database Abaidoo et al. 2017
TVu-1047 (CLAY K713)	Early maturing		IITA Cowpea database Abaidoo et al. 2017
TVu-11424	Early maturing	Dark brown seed	Abaidoo et al. 2017
TVu-12449	Early maturing		Abaidoo et al. 2017
TVu-1272	Early maturing		Abaidoo et al. 2017
TVu-1332	Early maturing		Abaidoo et al. 2017
TVu-1987	Early maturing		Abaidoo et al. 2017
TVu-4630	Early maturing		Abaidoo et al. 2017
TVu-7676	Early maturing		Abaidoo et al. 2017
TVu-8337	Early maturing		Abaidoo et al. 2017
TVu-10366	Early maturing	Light brown seed, brown eye	EDITS-Cowpea data base
TVu-1037	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-10466	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-10513 (TVX 5882 - O4E (FROM GLIP))	Early maturing	White seed, back eye	IITA Cowpea database EDITS-Cowpea data base
TVu-12873	Early maturing	Light brown seed, black eye	EDITS-Cowpea data base
TVu-13388 (Kvu 71)	Early maturing	Dark brown seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-14248	Early maturing	Red seed, black eye	EDITS-Cowpea data base
TVu-14253	Early maturing	Dark brown seed, dark brown eye	EDITS-Cowpea data base
TVu-14272	Early maturing	Brown seed, dark brown eye	EDITS-Cowpea data base
TVu-1429	Early maturing	Black seed, dark brown eye	EDITS-Cowpea data base
TVu-14759	Early maturing	Light brown seed, dark brown eye	EDITS-Cowpea data base
TVu-14890	Early maturing	Light brown seed, dark brown eye	EDITS-Cowpea data base
TVu-15114	Early maturing	Cream (light brown) seed, black eye	EDITS-Cowpea data base
TVu-15500 (KVx-60-K26-2)	Early maturing	White seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-15661 (IT86D-1038)	Early maturing	Light brown seed, brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-15775 (IT85F-1992)	Early maturing	Crean (white) seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-15995	Early maturing	Cream (white) seed, dark brown eye	EDITS-Cowpea data base
TVu-16403 (DAMADAMI)	Early maturing	Brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-16521 (GIN89-30)	Early maturing	Light brown seed, black eye	IITA Cowpea database EDITS-Cowpea data base

Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection (Continued)

Accession number/Cultivar name	Feature trait	Remarks	Reference
TVu-1656	Early maturing	Light brown seed, dark brown eye	EDITS-Cowpea data base
TVu-1886 (LUBIYA)	Early maturing	Black seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-2168	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-2252 (POLON LEEMA)	Early maturing	Brown seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-2845	Early maturing	White seed, dark brown eye	EDITS-Cowpea data base
TVu-3107	Early maturing	Cream (white) seed, dark brown eye	EDITS-Cowpea data base
TVu-3428	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-3947	Early maturing	Brown seed, dark brown eye	EDITS-Cowpea data base
TVu-43	Early maturing	Black seed, black eye	EDITS-Cowpea data base
TVu-4316	Early maturing	Black seed, black eye	EDITS-Cowpea data base
TVu-441	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-4535 (IF H144-1)	Early maturing	Brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-6641 (GUINEA PEA)	Early maturing	Light brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-6744	Early maturing	Dark brown seed, dark brown eye	EDITS-Cowpea data base
TVu-7719	Early maturing	Light brown seed, black eye	EDITS-Cowpea data base
TVu-7778	Early maturing	Brown seed, dark brown eye	EDITS-Cowpea data base
TVu-7971	Early maturing	Dark brown seed, black eye	EDITS-Cowpea data base
TVu-8 (C 1)	Early maturing	Cream seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-849 (FORTY DAYS)	Early maturing	Dark brown seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-8671	Early maturing	Dark brown seed, dark brown eye	EDITS-Cowpea data base
TVu-8775 (POLON ME)	Early maturing	White color, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-8877 (KLOUEKANME NO.4)	Early maturing	Black seed, black eye	EDITS-Cowpea data base
TVu-9259	Early maturing	White seed, brown eye	EDITS-Cowpea data base
TVu-9357	Early maturing	Red seed, black eye	EDITS-Cowpea data base
TVu-9391 (LAKHPET NO.1)	Early maturing	White seed, brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-9474 (MANSURA RED EYE 11)	Early maturing	Cream seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-9848 (NYEZANI NO.2)	Early maturing	Light brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-9866 (LUNZU NO.1)	Early maturing	Dark brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVx 1999-02E	Early maturing		Abaidoo et al. 2017
TVx 2724-01F (TVu-13067)	Early maturing		Abaidoo et al. 2017
TVx 3380-042E	Early maturing		Abaidoo et al. 2017
IT00K-1217 (TVu-17362)	Extra-early maturing	White seed, Striga resistance (Niger)	IITA Cowpea database Ishikawa et al. 2019
IT00K-901-5 (TVu-17213)	Extra-early maturing	White seed	IITA Cowpea database Ishikawa et al. 2019
IT82D-752 (TVu-17260)	Extra-early maturing	Tan seed color	IITA Cowpea database Singh 2014
IT82D-889 (TVu-17263)	Extra-early maturing	Red seed color	IITA Cowpea database Singh 2014
IT82D789 (TVu-13680)	Extra-early maturing	Light brown seed color	IITA Cowpea database Singh 2014

Table S1. Typical cultivar of drought or heat tolerant / eary maturing cowpeas in IITA collection (Continued)

Accession number/Cultivar name	Feature trait	Remarks	Reference
IT82E-16 (TVu-13674)	Extra-early maturing	Red seed color	IITA Cowpea database Singh 2014
IT82E-18 (TVu-13675)	Extra-early maturing	Tan seed color	IITA Cowpea database Singh 2014
IT82E-32 (TVu-13676)	Extra-early maturing	Red seed color	IITA Cowpea database Singh 2014
IT82E-60 (TVu-13678)	Extra-early maturing	White color, black eye	IITA Cowpea database Singh 2014
IT82E-9	Extra-early maturing	Black color	Singh 2014
IT83S-818 (TVu-14185)	Extra-early maturing	White color, black eye	IITA Cowpea database Singh 2014
IT93K-452-1 (SAMPEA8)	Extra-early maturing	White seed, black eye IPM good practical performance	Ishikawa et al 2019 Asante et al. 2001
IT95K-627-34	Extra-early maturing		Singh et al. 2002
IT97K-1042-3 (TVu-17444)	Extra-early maturing	Red seed color	IITA Cowpea database Singh 2014
IT98K-1111-1 (TVu-17321)	Extra-early maturing	White color, black eye	IITA Cowpea database Singh 2014
IT98K-205-8	Extra-early maturing	White seed, black eye, Striga resistance	IITA Cowpea database Ishikawa et al. 2019
IT98K-463-7	Extra-early maturing		Singh et al. 2002
IT99K-573-2-1	Extra-early maturing	White seed, black eye, high yielding, Striga resistance	IITA Cowpea database Ishikawa et al. 2019
TVu-12968 (APC 890)	Extra-early maturing	Cream seed, black eye	IITA Cowpea database EDITS-Cowpea data base
TVu-13939	Extra-early maturing	Cream (white) seed, dark brown eye	EDITS-Cowpea data base
TVu-15687 (IT86D-719)	Extra-early maturing	Cream seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-1609 (PS87Z-26)	Extra-early maturing	Brown seed, brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-16504 (IT90K-77)	Extra-early maturing	Brown seed, dark brown eye	IITA Cowpea database EDITS-Cowpea data base
TVu-2723	Extra-early maturing	Cream seed, black eye	EDITS-Cowpea data base
TVu-2968	Extra-early maturing	Brown seed, black eye	EDITS-Cowpea data base
TVu-7755	Extra-early maturing	Brown seed, brown eye	EDITS-Cowpea data base

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Table S2. Typical resistant cowpea varieties for the key insect pests and diseases in the West Africa savannah

Resistant variety	Remarks	Reference
Aphids *(Aphis croccivora)*		
Tvu-36, Tvu-408, Tvu-410, Tvu-2740, Tvu-3417, Tvu-3509, Tvu-2896	Resistant	Singh et al. (1982), Jackai & Singh (1988)
Tvu-26, Tvu-62, Tvu-801, Tvu-3000	Resistant	Singh et al. (1982, 1984)
IT83S-728-5, IT84S-2246-4, IT85D-3577, IT87S-1394, KVx-426-1	Resistant	Jackai & Adalla (1997)
Mandya local, P-912, P-1475, Tvu-2740	Resistant	Jayappa & Lingappa (1988)
Dan lla, IT98K-131-2, IT98K-1092-1	Resistant	Babura & Mustapha (2012)
Tvu-308, Tvu-9944, IT84S-2246-4, Tvu-9930	Resistant	Ofuya (1993, 1997), Togola et al. (2017)
Tvu-2740, TVNu-1158, IT97K-556-6	Tolerant	Souleymane et al. (2013)
KVx-145-27-6, KVx-165-14-1, KVx-146-27-4, KVx-146-1, KVx-295-2-124-99	Resistant / tolerant	Dabiré et al. (2012)
Leafhopper *(Empoasca spp)*		
Tvu-59, Tvu-123, VITA-1, VITA-3, Tvu-123, TVu-662, TVu-1190	Resistant	Oyewale & Bamaiyi (2013), Singh et al. (1984)
Thirips *(Megalurothirips sjostedti)*		
Tvu-1509	Monderately resistant	Singh (1977), Salifu et al. (1988)
TVx-3236	Resistant	Rösingh (1980)
IT82D-716, IT84S-2246, IT90K-59, IT90K-76	Monderately resistant / Resistant	Singh et al. (1997)
IT90K-277-2, IT91K-180	Low damage or larger number of pods	Alabi et al. (2003)
ITH98-20, TVu1509	Lower number of thrips populations	Abudulai et al. (2006)
ITH98-47	Lower yield loss	Abudulai et al. (2006)
Tvu-2870, TVx-3236	Monderately resistant	Singh et al. (1982, 1984)
IT820-716, Sanzi	Resistant	CTA (1991), Omo-Ikerodah et al. (2008)
KVx-404-8-1, KVx165-14-1, KVx404-3J, KVx-404-2J, Moussa local	Resistant	Dabiré et al. (2012)
Pod borer *(Maruca vitrata)*		
Tvu-946, Tvu-4557 (VITA-5)	Monderately resistant	Jackai (1981), Singh et al. (1982)
TVNu-72, TVNu-73	Resistant	Jackai & Oghiakhe (1989)
VITA-4, Ife Brown	Resistant to peduncle damage	Singh & Taylor (1978)
Tvu-1, TVx3890010F, VICAM-1/SP	Resistant	Jackai (1982)
VITA-1, Kamboinse local	Resistant	Macfoy et al. (1983)
IT82E-32, IT82E-77, IT82E-18, TVx-1843-1C, Tvu-72-59-25, ER 7	Less susceptible	Marfo (1985)
IT93K-452-1	Lowest incidence of larvae in flower	Yusuf (2005)
IT86D-719	Lowest pod damage	Yusuf (2005)
TVNu-64, TVNu-77, Tvnu-84, TVNu-87, TVNu-96, TVNu-100, TVNu-133, TVNu-290, TVNu-405, TVNu-410, TVNu-412, TVNu-433, TVN-u-459	Resistant / highly resistant	Jackai et al. (1996)
Pod sucking bug *(Clavigralla tomentosicollis)*		
Tvu-1, Tvu-1890, Tvu-3164, Tvu-3198, Tvu-3199	Monderately resistant	Jackai & Singh (1988)
Tvu-3354, Tvu-3355	Highly resistant for yield	Olatunde (2000)
Tvu-3372	Monderately resistant	Olatunde (2000)
TVNu-151, TVNu-72	Resistant	Koona et al. (2002)
IT86D-716	Resistant	Dabiré et al. (2012)
Bruchids *(Callosobruchus maculatus)*		
Tvu-2027, Tvu-11952, Tvu-11953	Monderately resistant	Singh & Singh (1990), Edde & Amatobi (2000)
Tvu-4200	Resistant	Jackai & Singh (1988)
IT81D-994	Monderately resistant	Amusa et al. (2013)

(Continued on next page)

Table S2. Typical resistant cowpea varieties for the key insect pests and diseases in the West Africa savannah (Continued)

Resistant variety	Remarks	Reference
IT04K-334-2, IT04K-343-1, IT06K-141, IT99K-216-48-1, IT99K494-6, IT99K-529-2	Resistant	Azeez & Pitan (2014)
IT81D-985, IT84S-2246, KVx-426-2, KN-1, KVx-426-9, KVx-30G-246-2-5K	Resistant	Dabiré et al. (2012)
Anthracnose, brown blotch, Cercospora leaf spot and bacterial pustule and blight		
IT81D-994, IT82E-16, IT82E-18, IT82D-889, IT86D-719, IT90K-59-2, IT90K-277-2, IT97K-556-4, IT98K-205-8		Singh (2014)
Septoria leaf spot		
IT81D-994, IT90K-82-2, IT97K-556-4, IT97K-499-35		Singh (2014)
Scab		
TVx-3236, IT84S-2246-4, IT90K-59, IT90K-76		Singh (2014)
False smut		
IT84D-666, IT97K-556-4		Singh (2014)
Cowpea mosaic, cowpea Aphid borne mosaic, backyey cowpea mosaic, cowpea mottle, cowpea cucumber mosaic		
IT83D-889, IT83S-818, IT85F-867-5, IT86D-880, IT90K-277-2, IT97K-556-4, IT98K-205-8		Singh (2014)
Powdery mildew		
IT97K-556-4		Singh (2014)
Root-knot nematode		
IT84S-2246-4, IT89D-288, IT89KD-391, IT90K-59		Singh (2014)
Striga and Alectra (parasite weeds)		
IT98K-205-8, IT99K-573-2-1	Evaluation at Niger, Burkina Faso	Muranaka et al. (2010), Ishikawa et al. (2019)
IT90K-372-1-2, IT99K-494-6, KVx-771-10	Evaluation at Burkina Faso	Ishikawa et al. (2019)
IT90K-59, IT90K-82-2, IT97K-499-35		Singh (2014)
IT82D-849, Suvita-2, IT81D-994, IT88D-867-11, IT90K-76, TVu-1271, TVu-1272, TVu-1330, TVu-4642, TVu-8337, TVu-9238, TVu-11788, TVu-12415, TVu-12432, TVu-12470, TVu-13035	Striga resistant	Singh et al. (1997)
TVu-9238, TVu-11788, TVu-12415, TVu-12432, TVu-12470	Alectra resistant	Singh et al. (1997)

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