Chapter

Breeding Elite Cowpea [*Vigna unguiculata* (L.) Walp] Varieties for Improved Food Security and Income in Africa: Opportunities and Challenges

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Abstract

Cowpea, *Vigna unguiculata* (L.) Walp, is among the most important grain legumes in Africa. Its nutritional value and biological nitrogen fixation (BNF) potential coupled with a high plasticity to environmental conditions places this legume in a unique position in Sub-Saharan Africa (SSA) in the context of food and nutritional security. However, cowpea yield and BNF contribution to agricultural systems in this sub-continent is far behind the average global values. The inability to run effective breeding programs to timely generate and deliver high yielding, nutritious and climate smart cowpea varieties, coupled with poor crop husbandry practices has been in the forefront of the current situation. In this chapter, the main constrains and opportunities to establish and run successful and effective cowpea production and breading programs in SSA are discussed. The discussion is built around the argument that SSA can benefit from its rich collection of landraces, as well as from high-throughput methodologies to assist the screening and the development of adapted, high yielding and nutritious varieties.

Keywords: cowpea, breeding, food security, Africa

1. Introduction

Cowpea, *Vigna unguiculata,* is a legume crop widely regarded as the "poor men's meat", due to the high protein contents in leaves, pods and grains [1]. Besides that, cowpea presents high plasticity which allows it to thrive under a wide range of environmental conditions [2]. These characteristics, together with its biological nitrogen fixation (BNF) capacity in symbiosis with rhizobia bacteria, make cowpea an important crop to rural households from Sub-Saharan Africa (SSA), whose diet is mainly based on carbohydrate rich crops and agricultural systems are largely deficient. Despite the fact that SSA is among the main cowpea producers and primary consumers, its yield and BNF return is the lowest when compared with the rest of the world [3, 4]. In consequence, the sub-continent's production is far from satisfying the internal demand.

With the exponential growth of the world's population, which is anticipated to be *ca*. 10 billion by 2050 [5], 60% of which in Africa, the demand for food in the continent is anticipated to grow by as much as 400% [6]. Taking into consideration the current scenarios of climate changes and the predictions for the middle of this century, *i.e.*, a high probability for the occurrence of temperature and CO_2 increases, coupled with altered rainfall patterns and soil salinity [7–9], the impact of population growth on food and nutritional security will be further exacerbated. Given this reality, the design and promotion of climate-smart food systems will be mandatory to achieve most of the United Nations Sustainable Development Goals [10]. Thus, accelerating the development and implementation of a nutrition-sensitive agricultural research and development agenda, particularly in making the breeding programs in SSA more responsive to its nutritional and agro-ecological context will be more relevant than ever. In this chapter the main cowpea production constraints in SSA are discussed, bringing forward the major challenges and opportunities to breed elite cowpea varieties towards self-sufficiency and competitiveness in the global arena.

2. Cowpea in sub-Saharan Africa

2.1 Importance and potential contribution to better diets and food security

In most developing countries from SSA cowpea is the most accessible nutritional source [11]. The leaves for instance, are more nutrient-dense than many other leaf vegetables [12, 13]. Cowpea is also a source of minerals and vitamins [14]. High lysine content of grain proteins plays a key role in balancing cereals and cassava-based diets, typical of most African countries [15]. Additionally, low fat and high carbohydrate contents make cowpea a balanced food source [16]. An analysis of 1541 cowpea germplasm lines [17] revealed that on average cowpea has 25% protein and *ca.* 38 mg Zn/kg, 53 mg Fe/kg, 1.9 g Mg/kg, 0.825 g Ca/kg, 5 g P/kg, and 15 g K/kg. Cowpea plays also an important role in soil nutrient cycling [18] as a result of its capacity to establish N_2-fixing root-nodule symbiosis with rhizobia bacteria. In modern agriculture systems, cowpea can contribute with 70–350 kg nitrogen per ha through biological nitrogen fixation (BNF) [19]. Thus, it is an important resource management technology in cereal-based systems leading to *ca.* three-fold yield increases of unfertilized maize [20–22].

2.2 Biotic stress: pests, diseases and weeds

One of the reasons associated with the low cowpea yields in SSA is the impact of several pests (**Table 1**). Aphids (*Aphis craccivora* Koh) are among the main pests affecting cowpea production, particularly at the seedling stage [23]. However, the impact can be minimized through the use of tolerant cultivars coupled with proper agronomic management procedures [33]. Another major threat to cowpea is posed by post flowering and podding pests, such as the flower thrips (*Megalurothrips sjostedti* Trybom), the legume pod borer (*Maruca vitrata* Fab.) and pod sucking bugs from the Hemiptera order, of which *Clavigralla tomentosicollis* Stal is the most important in tropical Africa [34]. In severely infested fields, post flowering pests can lead up to 70–80% yield loss [35]. Several measures have been used to minimize the impact of these pests, including pesticides, genetically modified (GM) varieties, as well as integrated pest management (IPM) practices [36].

Species (order: family)	Plant part attacked	Importance	Reference
Aphis craccivora Koch (Homoptera: Aphididae)	Leaves, flowers and pods	Key	[23–25]
Empoasca dolichi Paoli (Homoptera: Cicadelidae)	Leaves	Sporadic	[26]
Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae)	Stem	Sporadic	[27]
Amsacta moorei (Butler) (Lepidoptera: Arctiidae)	Leaves	Sporadic	[28]
Megalurothrips sjostedti (Trybom) (Thysanoptera: Thripidae)	Floral structures	Key	[24, 29]
Maruca vitrata (Fab.) (Lepidoptera: Pyralidae)	Stem, flowers, pods	Key	[24, 29]
Clavigralla tomentosicollis Stal (Hemiptera: Coreidae)	Pods	Key	[24, 29]
Riptortus dentipes (Fab.) (Hemiptera: Alydidae)	Pods	Sporadic	[28]
Nezara viridula Linnaeus (Hemiptera: Pentatomidae)	Pods	Sporadic	[28]
Callosobruchus spp. (Coleoptera: Bruchidae)	Seeds (storage)	Key	[30–32]

Table 1.
Major field and storage pests of cowpea: Attacked plant parts and importance.

The first GM pod borer resistant (PBR) cowpea was introduced in Nigeria in 2011 [37–39], and then expanded to Burkina Faso [39], Ghana [40], and Malawi [39]. However, results are still preliminary and most countries with on-going trials are yet to release GM-PBR cowpea, pending the evidence on GM cowpea performance, as well as the legal issues, such as competition with non-GM landraces, and assess of smallholder farmers to transgenic seeds [39]. Therefore, the GM option needs to be part of a feasible integrated IPM package that can easily meet local farmers' needs and capacities while offering an easily accessible solution.

Callosobruchus maculatus (Fab.), a cosmopolitan storage pest, is one of the most important off-the field pests affecting African cowpea producers mainly due to poor post-harvest storage conditions [30]. The attack normally leads to weight loss, decreased retail and nutritional value and reduced seed germination rate [27, 41]. So far, chemical control coupled with the use of resistant varieties have offered the best response to resource endowed smallholder cowpea producers across SSA, which also use grain hardness as a key selection trait to reduce storage losses [42–44]. More recently, hermetic grain storage technologies have been promoted [44–46]. However, these technologies are yet to reach most resource poor farmers.

Besides pests, cowpea is also susceptible to several fungal, bacterial and viral diseases. Bacterial blight caused by *Xanthomonas axonopodis* (Smith) is the most damaging bacterial disease [47]. This seed-borne disease can lead to almost 60% seedling mortality and can survive on crop residues [27]. Therefore, the use of healthy seeds and resistant varieties is the best option to control the disease [48] . On the other hand, cowpea anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. & Magn.) is the leading fungal disease, mainly during cool and wet weather [41]. Yield losses of 30–50% have been reported in highly susceptible lines grown in monocrops where the disease attack is most severe and the agent spreads easily [49].

Viruses have been even more problematic than fungal and bacterial diseases, thus needing particular attention [41, 50]. In total, eight major viral diseases were reported to affect cowpea in SSA. These can be divided in four groups based on the main propagation agent. Three are beetle-transmitted, namely, the cowpea yellow mosaic virus (CYMV), cowpea mottle virus (CMV) and southern bean mosaic virus (SBMV); two aphid-borne viruses namely, the cowpea aphid-borne mosaic potyvirus (CABMV) and cucumber mosaic cucumovirus (CMV); and two whitefly-transmitted viruses namely, cowpea golden mosaic virus (CGMV) and cowpea mild-mottle carlavirus (CPMMV). The eighth disease, whose agent is unknown to date, is the sunn-hemp mosaic virus (SHMV) [51], a tobamovirus that attacks several legume species [52]. Of the eight viruses, CABMV is the most problematic. In Nigeria, Oderara and Kumar [53] and Shoyinka and collaborators [54] analyzed 315 and 649 cowpea lines, respectively, and found that CABMV had high incidence across all sampled agroecological regions with up to 64% yield losses. Recently, Mukoye and collaborators [55] reported yield losses ranging from 10–100% in Western Kenya. The use of clean seeds and resistant varieties are the most cost-effective practices to control viruses [55], but recent research has shown promising results with IPM and the use of plant extracts in controlling the transmission agents, *i.e.*, pests [56]. The use of allelopathic effects, a technology that has gained prominent use to manage field pests in Asia and Latin America [57–59] is also another alternative to be explored in Africa. Trap cropping [56], a well-known strategy to manage insect pest through diversification of the plant strata to stimulate the population of natural enemies is also a practice to be massified.

Weeds also present a serious problem to cowpea mainly during crop establishment when more attention towards weed control is required [60]. At this stage severe competition for light, nutrient and space are responsible for considerable reduction in crop yield [61]. The parasitic weeds, *Striga gesnerioides* (Willd.) Vatke ex Engl. and *Alectra vogelii* Benth. are the major limitations to cowpea production in Africa, particularly in the dry savannas of West and Central Africa, *i.e.,* Sudan, Sahel and Guinea and portions of eastern and southern Africa [11, 62]. In total, yield losses between 73 and 100% by *S. gesnerioides* infestations have been reported in Africa [63]. Breeding efforts to transfer the *Bt*-gene to cowpea as a way to reduce the incidence of striga are ongoing with an *ex ante* economic impact assessment in West and Central Africa estimated in $1.2, $3.1 and $8.4 billion dollars in Benin, Niger and Nigeria respectively [64]. However, no Bt-cowpea has been available commercially in the region so far.

2.3 Abiotic stress: Water, nutrients and heat

Abiotic factors, such as, high temperature, drought and soil fertility are of upmost importance to plant development. Environmental stressors can lead to considerable cowpea yield losses in most SSA rain-fed agricultural systems. In the African dry savannas, characterized by hot days with high temperatures (above 35°C) spread across a short growing season, flower abortion and infertility due to poor pollen development is a common cause of yield reduction [11]. Singh and collaborators [65], observed that cowpea plants exposed to temperatures of 30–38°C, from 8 days after emergency to maturity, had a limited vegetative growth and reproductive potential. However, heat tolerant genotypes were able to retain flower production with a greater pod set [66].

Cowpea is frequently considered as a drought tolerant crop, linked also to the nitrogen fixing capacity of symbiotic rhizobia bacteria. However, in SSA where most systems are rain-fed, drought caused mainly by deficit of rainfall for long time periods has been a major threat to cowpea production [67, 68]. Ibrahim and collaborators [69] reported significant decreases in biomass production and water use efficiency (WUE) in six Ghanaian varieties subjected to water stress. Additionally, Fatokun and collaborators [1] observed that drought delayed the flowering process in 12 days and consequently the grain yield in *ca.* 70%. This might be explained by the decrease in leaf area and the concomitant photosynthetic rate and stomatal conductance [67].

One solution is the use of water efficient varieties coupled with better crop husbandry practices. The on-going efforts to screen and breed for drought tolerance and water efficient varieties, attaining more grain per drop, are essential in the African context where the crop is mostly cultivated under rainfed conditions and frequently exposed to intermittent droughts [68]. Thus, the use of well adapted early maturity cultivars seems to be one of the best solutions for smallholder cowpea producers to escape the effects of late season droughts [11].

Soil nutrient imbalances, particularly phosphorous (P) and nitrogen (N) have deserved less attention in cowpea research, despite the BNF potential to improve nutrient cycling and yields in African low external input agricultural systems [18]. According to Jemo and collaborators [70], BNF was significantly reduced in soils with low P levels and limited water supply. The same authors observed that as the level of P increased there was a significant reduction of water-deficit associated damages on BNF potential. Research has also demonstrated that supplying non-nodulated cowpea varieties with small nitrogen doses, promoted branching and increased crop yield [1].

3. Cowpea breeding programs in SSA: History, challenges and opportunities

Worldwide, cowpea breeding programs have targeted qualitative and quantitative traits to enhance the crop productive performance. The primordial breeding programs (1960–1980's) in SSA focused on high grain yield and seed quality, maturity time (extra-early, early and late), light sensitivity (photo-insensitive), growth habit (erect), intercrop fitting, lodging, and pest and disease resistance [1]. This was done mainly through a conventional breeding pipeline that included mainly germplasm collection, evaluation, maintenance and screening for desired traits mostly in Nigeria, Senegal, Uganda and Tanzania. Nowadays, breeding for drought tolerance [71, 72] and pest and disease resistance [73–76] have deserved major attention where the use of genomic tools is slowly gaining space. The International Institute of Tropical Agriculture (IITA) in Nigeria, and its international partners have played a key role in cowpea research and breeding initiatives. The Semi-Arid Food Grains Research and Development (SAFGRAD) project in the 1980's and more recently the Tropical Legumes project (2007–2018) and the CGIAR Cowpea Genomics Initiative (2005) marked a new step in cowpea breeding in SSA. Despite this, the number of varieties released in SSA is still small and there are more promising breeding lines than officially released varieties. In total, 80 IITA supported cowpea varieties were released, 24 of which during the past decade in 13 out of 54 African countries.

Despite the referred efforts, there are several constraints to cowpea breeding programs in SSA, which can be attributed to several factors, namely:

I. Poor investments in agricultural Research and Develop- ment (R&D) at national level and departmentalization of breeding programs: IITA and National Agricultural Research Systems (NARS) have been in the forefront of much breeding efforts in SSA, but the involvement of the regional agricultural universities (AUs) is not consolidate. In fact, only in Nigeria, Senegal, Uganda, Ghana, Tanzania and Kenya university-based research has been reported [1]. In addition to that, R&D in private sector is practically inexistent in SSA. Therefore, the region would benefit from a collaborative approach between international and regional R&D institutions (including AUs) and NARS, promoting the internationalization of the local R&D systems regarding scientific and technical work and publications, and engaging competitive funding raising.

II. Nutrition-sensitive trait selection for improved dietary quality: interest in cowpea's nutrition quality in Africa is an old issue [76], but it has been overlooked over the years. However, with the continent's nutrition agenda becoming increasingly important, a targeted breeding agenda on the nutritional quality of the crop is needed [12, 77]. Contrarily to Africa, the production of varieties with high dietary quality has deserved much attention in Europe and Asia [78, 79]. Currently, screening segregating populations for traits such as Fe, Zn, Cu and Mo content is in progress [80]. Such efforts are essential to improve the crop's contribution to local diets, as well as for the establishment of nutrition sensitive food systems. Special attention should be also given to fresh leaves and pods rather than solely focusing on dry pods and grain as it has happened so far. Increasing protein and mineral content, the latter also through biofortification, needs to be on top of the agenda.

III. Breeding approach: most breeding programs in Africa rely on open environment conventional breeding technics centered mostly on single trait selection methods. However, in the developing world, molecular characterization of germplasm, based in modern genomics and molecular marker-assisted selection [1] and genetic engineering [80, 81] coupled with digital imaging in high-throughput phenotyping [82], historical data [83, 84] and model-assisted selection [84–87] have revolutionized crop breeding programs. Such approach facilitated molecular, morpho-agronomic, physiological and biochemical characterization of cowpea germplasm to identify the best performing genotypes [88]. This integrative screening and selection approach represents a clear shift from single-trait to multiple-trait selection [85], something that is scantly done in African screening programs. By doing multiple-trait selection, the effectiveness and efficiency of breeding programs have been significantly improved in Europe, America and Australia, where significant investments in research infrastructure and human resource training has been made [89]. Model assisted breeding has proved to be fundamental in helping underpin prediction of likely phenotypical consequences of trait and genetic variations in targeted environments [86]. Furthermore, the agricultural production simulator (APSIM) has been successfully used in phenotyping and evaluating Genotype × Environment × Management (G × E × M) effects on drought adaptation. The growing interest in genotype-to-phenotype (G2P) models which predict phenotypic traits as a function of genotypic and environmental inputs is currently helping to enhance phenotype screening [89]. Additionally, the use of speed breeding chambers (SBC) [90], is also a recent and important advance in breeding programs. Such facilities allowed breeders to achieve up to six generations per year from spring wheat, durum wheat, barley, pea, chickpea and groundnuts, instead of one to three generations per year usually possible under field conditions and glasshouse, respectively [91].

IV. Improve cross-country coordination mechanisms and systematization of existing information: over the last decades several projects involving cowpea landraces screening and the assessment of their genetic diversity have been conducted in Africa [77]. However, the knowledge generated from this research is scattered all over the region and needs to be systematized and made available to aid current and future breading programs. For that to happen, cross-country coordination mechanisms and collaborative research opportunities need to be improved.

4. Conclusion

With an increasing world population, there is an urgent need to re-structure the R&D agenda in SSA towards the development of elite crop varieties that are more likely to successfully cope with future climate conditions. Cowpea, despite its high plasticity to survive in harsh environments, will not be an exception. The crop's importance in SSA as a food crop, animal feed and nutrient cycling agent makes it a candidate crop for future improvement and to operationalize the continents' nutrition agenda. For that, coordinate R&D efforts should be made at the regional level, in order to: (i) address the best production and breeding practices, through a wide screening of landraces towards the identification of the best performing genotypes (yield and nutritional quality) under limiting environmental conditions; (ii) identify multiple breeding traits and molecular tools for marker-assisted selection; and (iii) develop fast and reliable methods for variety certification, linked to important investment in R&D facilities and advanced training of human resources.

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