

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

## 4,800

Open access books available

## 122,000

International authors and editors

## 135M

Downloads

Our authors are among the

## 154

Countries delivered to

## TOP 1%

most cited scientists

## 12.2%

Contributors from top 500 universities

**WEB OF SCIENCE™**Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.

For more information visit [www.intechopen.com](http://www.intechopen.com)

## Chapter

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

*Ana Maria Figueira Gomes, Nascimento Nhantumbo, Manuela Ferreira-Pinto, Rafael Massinga, José C. Ramalho and Ana Ribeiro-Barros*

## 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 constraints and opportunities to establish and run successful and effective cowpea production and breeding 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<sub>2</sub> 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<sub>2</sub>-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
<i>Aphis craccivora</i> Koch (Homoptera: Aphididae)	Leaves, flowers and pods	Key	[23–25]
<i>Empoasca dolichi</i> Paoli (Homoptera: Cicadellidae)	Leaves	Sporadic	[26]
<i>Ophiomyia phaseoli</i> (Tryon) (Diptera: Agromyzidae)	Stem	Sporadic	[27]
<i>Amsacta moorei</i> (Butler) (Lepidoptera: Arctiidae)	Leaves	Sporadic	[28]
<i>Megalurothrips sjostedti</i> (Trybom) (Thysanoptera: Thripidae)	Floral structures	Key	[24, 29]
<i>Maruca vitrata</i> (Fab.) (Lepidoptera: Pyralidae)	Stem, flowers, pods	Key	[24, 29]
<i>Clavigralla tomentosicollis</i> Stal (Hemiptera: Coreidae)	Pods	Key	[24, 29]
<i>Riptortus dentipes</i> (Fab.) (Hemiptera: Alydidae)	Pods	Sporadic	[28]
<i>Nezara viridula</i> Linnaeus (Hemiptera: Pentatomidae)	Pods	Sporadic	[28]
<i>Callosobruchus</i> 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 Development (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 scantily 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 phenotypic 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  $\times$  Environment  $\times$  Management (G  $\times$  E  $\times$  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 breeding 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.

## Acknowledgements

The authors acknowledge the support of Fundação para a Ciência e a Tecnologia (FCT), Portugal, through grant SFRH/BD/113952/2015 and research units UID/AGR/04129/2013 (LEAF) and UID/GEO/04035/2013 (GeoBioTec), and the Dutch Organization for Internationalization in Education (NUFFIC), through the project NICHE-MOZ-151.

## Author details

Ana Maria Figueira Gomes<sup>1,2</sup>, Nascimento Nhantumbo<sup>2</sup>, Manuela Ferreira-Pinto<sup>3</sup>, Rafael Massinga<sup>2</sup>, José C. Ramalho<sup>3,4</sup> and Ana Ribeiro-Barros<sup>3,4\*</sup>

1 TropiKMan Doctorate Programme, Nova School of Business and Economics, Universidade NOVA de Lisboa, Portugal

2 Divisão de Agricultura, Instituto Superior Politécnico de Manica (DivAG-ISPM), Moçambique

3 Plant Stress and Biodiversity Lab, Linking Landscape, Environment, LEAF, Instituto Superior de Agronomia (ISA), Universidade de Lisboa, Portugal

4 GeoBioTec, Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, Portugal

\*Address all correspondence to: [aribeiro@isa.ulisboa.pt](mailto:aribeiro@isa.ulisboa.pt)

## IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 



## References

- [1] Boukar O, Belko N, Chamarthi S, Togola A, Batiemo J, Owusu E, et al. Cowpea (*Vigna unguiculata*): Genetics, genomics and breeding. *Plant Breeding*. 2018;0:1-10. DOI: 10.1111/pbr.12589
- [2] Bashir M, Ahmad Z, Ghafoor A. Cowpea aphid-borne mosaic potyvirus: A review. *International Journal of Pest Management*. 2002;48:155-168. DOI: 10.1080/09670870110118722
- [3] Peoples M, Brockwell J, Herridge D, Rochester I, Alves B, Urquiaga S, et al. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis*. 2009;48:1-17. DOI: 10.1007/BF03179980
- [4] Herridge DF, Peoples MB, Boddey RM. Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil*. 2008;311:1-18. DOI: 10.1007/s11104-008-9668-3
- [5] Bacci ML. *A Concise History of World Population*. West Sussex: John Wiley & Sons; 2017. p. 300. DOI: 10.1002/9781119406822
- [6] Long SP, Marshall-Colon A, Zhu XG. Meeting the global food demand of the future by engineering crop photosynthesis and yield potential. *Cell*. 2015;161:56-66. DOI: 10.1016/j.cell.2015.03.019
- [7] Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, et al. *Climate change 2014: Mitigation of climate change*. In: *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 2014. p. 1435. Available from: [https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc\\_wg3\\_ar5\\_full.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf) [Accessed: February 5, 2019]
- [8] Ribeiro-Barros AI, Moura IM, Ramalho JC, Máguas-Hanson C, Ribeiro NS. The potential of tree and shrub legumes in agroforestry systems. In: Amanullah, editor. *Nitrogen in Agriculture—Updates*. Rijeka, Croatia: InTech; 2018. Available from <https://www.intechopen.com/books/nitrogen-in-agriculture-updates/the-potential-of-tree-and-shrub-legumes-in-agroforestry-systems> [Accessed: February 5, 2019]
- [9] CSIRO. *State of the Climate*. 2018. Available from: <https://www.csiro.au/en/Showcase/state-of-the-climate> [Accessed: February 5, 2019]
- [10] United Nations. *Sustainable Development Goals*. 2015. Available from: <https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf> [Accessed: February 5, 2019]
- [11] Timko M, Singh BB. Cowpea, a multifunctional legume. In: Moore PH, Ming R, editors. *Genomics of Tropical Plants*. New York: Springer; 2008. pp. 227-258. DOI: 10.1007/978-0-387-71219-2\_10
- [12] Goncalves A, Goufo P, Barros A, Domínguez-Perles R, Trindade H, Rosa EA, et al. Cowpea (*Vigna unguiculata* L. Walp), a renewed multipurpose crop for a more sustainable agri-food system: Nutritional advantages and constraints. *Journal of the Science of Food and Agriculture*. 2016;96:2941-2951. DOI: 10.1002/jsfa.7644
- [13] Ohler TA, Nielsen SS, Mitchell CA. Varying plant density and harvest time to optimize cowpea leaf yield and nutrient content. *Horticultural Science*. 1996;31:193-197

- [14] Singh U, Singh B. Tropical grain legumes as important human foods. *Economic Botany*. 1992;**46**:310-321
- [15] Schönfeldt HC, Gibson HN. Dietary protein quality and malnutrition in Africa. *British Journal of Nutrition*. 2012;**108**:69-76. DOI: 10.1017/S0007114512002553
- [16] Jayathilake C, Visvanathan R, Deen A, Bangamuwage R, Jayawardana BC, Nammi S, et al. Cowpea: An overview on its nutritional facts and health benefits. *Journal of the Science of Food and Agriculture*. 2018;**98**:4793-4806. DOI: 10.1002/jsfa.9074
- [17] Boukar O, Massawe F, Muranaka S, Franco J, Maziya-Dixon B, Singh B, et al. Evaluation of cowpea germplasm lines for protein and mineral concentrations in grains. *Plant Genetic Resources*. 2011;**9**:515-522. DOI: 10.1017/s1479262111000815
- [18] Zahran HH. *Rhizobium*-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology and Molecular Biology Reviews*. 1999;**63**:968-989
- [19] Quin FM. Introduction. In: Singh BB, Mohan Raj DR, Dashiell KE, Jackai LEN, editors. *Advances in Cowpea Research*. International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS); 1997. pp. ix-xv
- [20] Carsky RJ, Vanlauwe B, Lyasse O. Cowpea rotation as a resource management technology for cereal-based systems in the savannas of West Africa. In: Fatokum CA, Tarawali SA, Singh BB, Kormawa PM, Tamò M, editors. *Challenges and Opportunities for Enhancing Sustainable Cowpea Production*. International Institute of Tropical Agriculture (IITA); 2002. pp. 252-266
- [21] Fatokum CA, Tarawali SA, Singh BB, Kormawa PM. Challenges and Opportunities for Enhancing Sustainable Cowpea Production. International Institute of Tropical Agriculture (IITA); 2002. p. 433
- [22] Bado V, Bationo A, Cescas M. Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa). *Biology and Fertility of Soils*. 2006;**43**:171-176. DOI: 10.1007/s00374-006-0076-7
- [23] Omoigui L, Ekeuro GC, Kamara AY, Bello LL, Timko MP, Ogunwolu GO. New sources of aphids [*Aphis craccivora* (Koch)] resistance in cowpea germplasm using phenotypic and molecular marker approaches. *Euphytica*. 2017;**213**:178. DOI: 10.1007/s10681-017-1962-9
- [24] Abudulai M, Kusi F, Seini SS, Seidu A, Nboyine JA, Larbi A. Effects of planting date, cultivar and insecticide spray application for the management of insect pests of cowpea in northern Ghana. *Crop Protection*. 2017;**100**:168-176. DOI: 10.1016/j.cropro.2017.07.005
- [25] Souleymane A, Aken'Ova M, Fatokun C, Alabi Y. Screening for resistance to cowpea aphid (*Aphis craccivora* Koch) in wild and cultivated cowpea (*Vigna unguiculata* L. Walp.) accessions. *International Journal of Science, Environment and Technology*. 2013;**2**:611-621
- [26] Parh IA. The effects of *Empoasca dolichi* Paoli (Hemiptera: Cicadellidae) on the performance and yield of two cowpea cultivars. *Bulletin of Entomological Research*. 1983;**73**:25-32. DOI: 10.1017/S0007485300013766
- [27] Singh SR, Allen DJ. Cowpea Pests and Diseases. International Institute

- of Tropical Agriculture (IITA); 1978. Available from: [http://newint.iita.org/wp-content/uploads/2016/06/COWPEA\\_PESTS\\_AND\\_DISEASES.pdf](http://newint.iita.org/wp-content/uploads/2016/06/COWPEA_PESTS_AND_DISEASES.pdf) [Accessed: February 5, 2019]
- [28] Singh BB, Mohan-Raj D, Dashiell K, Jackai L, editors. *Advances in Cowpea Research*. Ibadan: International Institute of Tropical Agriculture (IITA); 1997. p. 375
- [29] Asante SK, Tamò T, Jackai LEN. Integrated management of cowpea insect pests using elite cultivars, date of planting and minimum insecticide application. *African Crop Science Journal*. 2001;**9**:655-666. DOI: 10.4314/acsj.v9i4.27587
- [30] Bamaiyi LJ, Onu I, Amatobi CI, Dike MC. Effect of *Callosobruchus maculatus* infestation on nutritional loss on stored cowpea grains. *Archives of Phytopathology and Plant Protection*. 2006;**39**:119-127. DOI: 10.1080/03235400500180743
- [31] Kébé K, Alvarez N, Espíndola A, Justyl F, Olivieri I, Sembène M. Insights into the genetic structure of the cowpea pest *Callosobruchus maculatus* in Africa. *Journal of Pest Science*. 2016;**89**:449-458. DOI: 10.1007/s10340-015-0688-5
- [32] Umeozor OC. Effect of the infection of *Callosobruchus maculatus* (fab.) on the weight loss of sored cowpea (*Vigna unguiculata* (L.) Walp). *Journal of Applied Science and Environmental Management*. 2005;**9**:169-172. Available from: <http://www.bioline.org.br/pdf?ja05032> [Accessed: February 4, 2019]
- [33] Annan B, Schafers G, Twingey W. Impact of density of *Aphids craccivora* (Aphididae) on growth and yield of susceptible and resistant cowpea cultivars. *Annals of Applied Biology*. 1996;**128**:183-193. DOI: 10.1111/j.1744-7348.1996.tb07315.x
- [34] Dugje LO, Omoigui LO, Ekeleme F, Kamara AY, Ajeigbe H. *Farmers' Guide to Cowpea Production in West Africa*. International Institute of Tropical Agriculture (IITA); 2009. p. 19. DOI: 10.13140/2.1.1597.5361
- [35] Ujagir R, Byrne O. Insect pests and their management. In: Erskine W, Muehlbaue FJ, Sarker A, Sharma B, editors. *The Lentil: Botany, Production and Uses*. Wallingford: CABI; 2009. pp. 282-305. Available from: <http://nsdl.niscair.res.in/jspui/bitstream/123456789/493/1/revised%20insect%20pest%20and%20their%20management.pdf> [Accessed: February 5, 2019]
- [36] Bett B, Gollash S, Moore A, James W, Armatrong J, Walsh T, et al. Transgenic cowpeas (*Vigna unguiculata* L. Walp) expressing *Bacillus thuringiensis* Vip3Ba protein are protected against the Maruca pod borer (*Maruca vitrata*). *Plant Cell, Tissue and Organ Culture*. 2017;**131**:335-345. DOI: 10.1007/s11240-017-1287-3
- [37] Abutu A. Brighter Days for African Farmers—As Pod-Borer Resistant Cowpea Edge Towards Commercialisation. 2017. Available from: <https://aatfnews.aatf-africa.org/?p=669> [Accessed: February 5, 2019]
- [38] Klopez. Is Genetically Modified Cowpea Safe? 2009. Available from: <http://r4dreview.iita.org/index.php/2009/03/08/640/> [Accessed: February 5, 2019]
- [39] ACB. GM and Seed Industry Eye Africa's Lucrative Cowpea Seed Markets: The Political Economy of Cowpea in Nigeria, Burkina Faso, Ghana and Malawi. 2015. 38 p. Available from: <https://acbio.org.za/wp-content/uploads/2015/07/GM-Cowpea-report.pdf> [Accessed: February 5, 2019]
- [40] News Ghana. Farmers Opt for GM Cowpea. 2017. Available from: <http://b4fa.org/farmers-opt-gm-cowpea/> [Accessed: February 5, 2019]

- [41] Williams RJ. Diseases of cowpea (*Vigna unguiculata* (L.) Walp.) in Nigeria. *International Journal of Pest Management*. 1975;21:253-267. DOI: 10.1080/09670877509411407
- [42] Baker TA, Nielsen SS, Shade RE, Singh BB. Physical and chemical attributes of cowpea lines resistant and susceptible to *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of Stored Products Research*. 1989;25:1-8. DOI: 10.1016/0022-474X(89)90002-7
- [43] Cruz LP, de Sá LFR, Santos LA, Gravina GA, Carvalho AO, Fernandes KVS, et al. Evaluation of resistance in different cowpea cultivars to *Callosobruchus maculatus* infestation 2015. *Journal of Pest Science*. 2016;89:117-128. DOI: 10.1007/s10340-015-0657-z
- [44] Aboagye D, Darko JO, Banadda N. Comparative study of hermetic and non-hermetic storage on quality of cowpea in Ghana. *Chemical and Biological Technologies in Agriculture*. 2017;4:10. DOI: 10.1186/s40538-017-0091-y
- [45] Baoua IB, Bakoye O, Amadou L, Murdock LL, Baributsa D. Performance of PICS bags under extreme conditions in the Sahel zone of Niger. *Journal of Stored Products Research*. 2018;76:96-101. DOI: 10.1016/j.jspr.2018.01.007
- [46] Baributsa D, Baoua IB, Bakoye ON, Amadou L, Murdock LL. PICS bags safely store unshelled and shelled groundnuts in Niger. *Journal of Stored Products Research*. 2017;72:54-58. DOI: 10.1016/j.jspr.2017.03.007
- [47] Agbicodo EM, Fatokun CA, Bandyopadhyay R, Wydra K, Diop NN, Muchero W, et al. Identification of markers associated with bacterial blight resistance loci in cowpea [*Vigna unguiculata* (L.) Walp.]. *Euphytica*. 2010;175:215-226. DOI: 10.1007/s10681-010-0164-5
- [48] Olowe T, Dina SO, Oladiran AO, Olunuga BA. The control of weed, pest and disease complexes in cowpea (*Vigna unguiculata* (L.) Walp.) by the application of pesticides singly and in combination. *Crop Protection*. 1987;6:222-225. DOI: 10.1016/0261-2194(87)90042-1
- [49] Adegbite AA, Amusa NA. The major economic field diseases of cowpea in the humid agro-ecologies of South-Western Nigeria. *Archives of Phytopathology and Plant Protection*. 2010;43:1608-1618
- [50] Thottappilly G, Rossel HW. Virus diseases of cowpea in tropical Africa. *Tropical Pest Management*. 1992;38:337-348. DOI: 10.1080/09670879209371724
- [51] Varma A. Sunn-Hemp mosaic virus. In: Van Regenmortel MHV, Fraenkel-Conrat H, editors. *The Plant Viruses: The Rod-Shaped Plant Viruses*. New York: Springer; 1986. pp. 249-266. DOI: 10.1007/978-1-4684-7026-0\_13
- [52] Silver S, Quan S, Deom CM. Completion of the nucleotide sequence of sunn-hemp mosaic virus: A tobamovirus pathogenic to legumes. *Virus Genes*. 1996;13:83-85. DOI: 10.1007/BF00576982
- [53] Odedara O, Kumar L. Incidence and diversity of viruses in cowpeas and weeds in the unmanaged farming systems of savanna zones in Nigeria. *Archives of Phytopathology and Plant Protection*. 2016;50:1-12. DOI: 10.1080/03235408.2016.1241203
- [54] Shoyinka SA, Thottappilly G, Adebayo GG, Anno-Nyako FO. Survey on cowpea virus incidence and distribution in Nigeria. *International Journal of Pest Management*. 1997;43:127-132. DOI: 10.1080/096708797228816
- [55] Mukoye B, Mangeni B, Were H, Ndong'a M, Akech W. Occurrence

- and biological characterization of cowpea aphid-borne mosaic virus infecting legumes in Western Kenya. In: Proceedings of the First Pan-African Congress on Knowledge Generation and Dissemination; 3-6 December 2017; Kenya. 2018
- [56] Sarkar SC, Wang E, Wu S, Lei Z. Application of trap cropping as companion plants for the management of agricultural pests: A review. *Insects*. 2018;**9**:128. DOI: 10.3390/insects9040128
- [57] Farooq M, Jabran K, Cheema ZA, Wahid A, Siddique KH. The role of allelopathy in agricultural pest management. *Pest Management Science*. 2011;**67**:493-506. DOI: 10.1002/ps.2091
- [58] Ben-Issa R, Gomez L, Gautier H. Companion plants for aphid pest management. *Insects*. 2017;**8**:112. DOI: 10.3390/insects8040112
- [59] Lehoczky E, Nelima MO, Szabó R, Szalai A, Nagy P. Allelopathic effect of *Bromus* spp. and *Lolium* spp. shoot extracts on some crops. *Communications in Agricultural and Applied Biological Sciences*. 2011;**76**:537-544
- [60] Sing G, Sekhon HS. Integrated weed management in Pigeonpea [*Cajanus cajan* (L.) Millsp.]. *World Journal of Agricultural Sciences*. 2013;**9**:86-91. DOI: 10.5829/idosi.wjas.2013.9.1.27213
- [61] Yadav T, Chopra NK, Yadav MR, Kumar R, Rathore DK, Soni PG, et al. Weed management in cowpea—A review. *International Journal of Current Microbiology and Applied Sciences*. 2017;**6**:1373-1385. DOI: 10.20546/ijcmas.2017.602.156
- [62] Muranaka S, Fatokun C, Boukar OO. Stability of *Striga gesnerioides* resistance mechanism in cowpea under high-infestation level, low soil fertility and drought stresses. *Journal of Food, Agriculture and Environment*. 2011;**9**:313-318. Available from: <https://cgspace.cgiar.org/handle/10568/42029>
- [63] Lado A, Umar SF, Usman YS, Kwalle KA. Efficacy of *Parkia biglobosa* fruit powder on the control of *Striga* in cowpea cropping systems in the Sudan-Savanna, Nigeria. *Heliyon*. 2018;**4**:e00733. DOI: 10.1016/j.heliyon.2018.e00733
- [64] Gbègbèlègbè SD, Lowenberg-DeBoer J, Adeoti R, Lusk J, Coulibaly O. The estimated *ex ante* economic impact of Bt cowpea in Niger, Benin and northern Nigeria. *Agricultural Economics*. 2015;**46**:563-577. DOI: 10.1111/agec.12182
- [65] Singh SK, Kakani VG, Surabhi GK, Reddy KR. Cowpea (*Vigna unguiculata* [L.] Walp.) genotypes response to multiple abiotic stresses. *Journal of Photochemistry and Photobiology*. 2010;**100**:135-146. DOI: 10.1016/j.jphotobiol.2010.05.013
- [66] Craufurd PQ, Bojang M, Wheeler TR, Summerfield RJ. Heat tolerance in cowpea: Effect of timing and duration of heat stress. *Annals of Applied Biology*. 1998;**133**:257-267. Available from: <https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1744-7348.1998.tb05826.x> [Accessed: February 4, 2019]
- [67] Iwuagwu M, Ogbonnaya CI, Onyike NB. Physiological response of cowpea [*Vigna unguiculata* (L.) Walp] to drought: The osmotic adjustment resistance strategy. *Academic Journal of Science*. 2017;**7**:329-344. Available from: [file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge\\_8wekyb3d8bbwe/TempState/Downloads/MaryO.Iwuagwueta%20\(1\).pdf](file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge_8wekyb3d8bbwe/TempState/Downloads/MaryO.Iwuagwueta%20(1).pdf) [Accessed: February 4, 2019]
- [68] Hall AE, Cisse N, Thiaw S, Elawad HOA, Ehlers JD, Ismail AM,

et al. Development of cowpea cultivars and germplasm by the bean/cowpea CRSP. *Field Crops Research*. 2003;**82**:103-134. DOI: 10.1016/S0378-4290(03)00033-9

[69] Ibrahim AR, Kiari SA, Mensah B, Akromah R. Water stress and water use efficiency in cowpea [*Vigna unguiculata* (L.) Walp.] under controlled environment. *International Journal of Agricultural Science Research*. 2013;**2**:191-199. Available from: [file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge\\_8wekyb3d8bbwe/TempState/Downloads/WaterUseEffBioetMoi%20\(1\).pdf](file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge_8wekyb3d8bbwe/TempState/Downloads/WaterUseEffBioetMoi%20(1).pdf) [Accessed: February 4, 2019]

[70] Jemo M, Sulieman S, Bekkaoui F, Olomide OAK, Hashem A, Abd Allah EF, et al. Comparative analysis of the combined effects of different water and phosphate levels on growth and biological nitrogen fixation of nine cowpea varieties. *Frontiers in Plant Science*. 2017;**8**:2111. DOI: 10.3389/fpls.2017.02111

[71] Agbicodo EM, Fatokun S, Muranaka R, Visser RG, Van Der Linden CGS. Breeding drought tolerant cowpea: Constraints, accomplishments, and future prospects. *Euphytica*. 2009;**167**:353-370. DOI: 10.1007/s10681-009-9893-8

[72] Adejumo TO, Florini DA, Ikotun T. Screening of cowpea cultivars for resistance to leaf smut. *Crop Protection*. 2001;**20**:303-309. DOI: 10.1016/S0261-2194(00)00155-1

[73] Adipala E, Takan JP, Mukalere Z. Preliminary evaluation of cowpea lines for resistance to zonate leaf spots and bacterial blight. *East African Agricultural and Forestry Journal*. 1995;**61**:55-61. DOI: 10.4314/eaafj.v61i1.46792

[74] Asare-bediako E, Vera EA, Aaron AT. Phenotypic and serological

evaluation of cowpea (*Vigna unguiculata* L. Walp) genotypes for resistance to viral infection under field conditions. *Journal of Plant Breeding and Crop Science*. 2018;**10**:169-177

[75] Kareem K, Adegbite AA, Ayoola OT, Olayinka RB, Oloyede-Kamiyo QO. Evaluation of cowpea genotypes for infection by two aphid-borne viruses. *World Rural Observations*. 2016;**8**:80-88. Available from: [http://www.sciencepub.net/rural/rural080416/13\\_31328wro080416\\_80\\_88.pdf](http://www.sciencepub.net/rural/rural080416/13_31328wro080416_80_88.pdf) [Accessed: February 4, 2019]

[76] Taiwo KA. The potential of cowpea as human food in Nigeria. *Food Reviews International*. 1998;**14**:351-370. DOI: 10.1080/87559129809541168

[77] Singh B. Cowpea Breeding at IITA: Highlights of Advances and Impacts. *International Institute of Tropical Agriculture (IITA)*; 2018. 4 p. Available from: [file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge\\_8wekyb3d8bbwe/TempState/Downloads/COWPEA\\_BREEDING\\_AT\\_IITA\\_HIGHLIGHTS\\_OF\\_ADVANCES\\_AND%20\(1\).pdf](file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge_8wekyb3d8bbwe/TempState/Downloads/COWPEA_BREEDING_AT_IITA_HIGHLIGHTS_OF_ADVANCES_AND%20(1).pdf) [Accessed: February 4, 2019]

[78] Karapanos I, Papandreou A, Skouloudi M, Makrogianni D, Fernández JA, Rosa E, et al. Cowpea fresh pods—A new legume for the market: Assessment of their quality and dietary characteristics of 37 cowpea accessions grown in southern Europe. *Journal of Science and Food Agriculture*. 2017;**97**:4343-4352. DOI: 10.1002/jsfa.8418

[79] Pottorff M, Ehlers JD, Fatokun C, Roberts PA, Close TJ. Leaf morphology in cowpea [*Vigna unguiculata* (L.) Walp]: QTL analysis, physical mapping and identifying a candidate gene using synteny with model legume species. *BMC Genomics*. 2012;**13**:234. DOI: 10.1186/1471-2164-13-234

- [80] Boukar O, Fatokun CA, Roberts PA, Abberton M, Huynh BL, Close TJ, et al. Cowpea. In: Ron D, editor. Handbook of Plant Breeding. New York: Springer; 2015. pp. 219-250. DOI: 10.1007/978-1-4939-2797-5\_7
- [81] Georges F, Ray H. Genome editing of crops: A renewed opportunity for food security. *GM Crops & Food*. 2017;**8**:1-12. DOI: 10.1080/21645698.2016.1270489
- [82] Poiré R, Chochois V, Sirault XR, Vogel JP, Watt M, Furbank RT. Digital imaging approaches for phenotyping whole plant nitrogen and phosphorus response in *Brachypodium distachyon*. *Journal of Integrative Plant Biology*. 2014;**56**:781-796. DOI: 10.1111/jipb.12198
- [83] Akdemir D, Sanchez JI, Jannink JL. Optimization of genomic selection training populations with a genetic algorithm. *Genetics, Selection, Evolution*. 2015;**47**:38. DOI: 10.1186/s12711-015-0116-6
- [84] Crain J, Mondal S, Rutkoski J, Singh RP, Poland J. Combining high-throughput phenotyping and genomic information to increase prediction and selection accuracy in wheat breeding. *The Plant Genome*. 2018;**11**:170043. DOI: 10.3835/plantgenome2017.05.0043
- [85] Guo G, Zhao F, Wang Y, Zhang Y, Du L, Su G. Comparison of single-trait and multiple-trait genomic prediction models. *BMC Genetics*. 2014;**15**:30. DOI: 10.1186/1471-2156-15-30
- [86] Hammer G, Messina C, van Oosterom E, Chapman S, Singh V, Borrell A, et al. Molecular breeding for complex adaptive traits: How integrating crop ecophysiology and modelling can enhance efficiency. In: Yin X, Struik P, editors. *Crop Systems Biology*. Cham: Springer; 2016. pp. 147-162. DOI: 10.1007/978-3-319-20562-5\_7
- [87] Hammer G. Molecular breeding for complex adaptive traits-can crop ecophysiology and modelling ease the pain? *International Sugar Journal*. 2014;**116**:64-68. Available from: file:///C:/Users/aribeiro/AppData/Local/Packages/Microsoft.MicrosoftEdge\_8wekyb3d8bbwe/TempState/Downloads/HammerIntSugarJ2014%20(1).pdf [Accessed: February 4, 2019]
- [88] Lado B, Vásquez D, Quincke M, Silva P, Aguilar I, Gutiérrez L. Resource allocation optimization with multi-trait genomic prediction for bread wheat (*Triticum aestivum* L.) baking quality. *Theoretical and Applied Genetics*. 2018;**131**:2719-2731. DOI: 10.1007/s00122-018-3186-3
- [89] Van Eeuwijk FA, Bustos-Korts D, Millet EJ, Boer MP, Kruijer W, Thompson A, et al. Modelling strategies for assessing and increasing the effectiveness of new phenotyping techniques in plant breeding. *Plant Science*. 2018. DOI: 10.1016/j.plantsci.2018.06.018. In press
- [90] Watson A, Ghosh S, Williams MJ, Cuddy WS, Simmonds J, Rey MD, et al. Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature Plants*. 2018;**4**:23-29. DOI: 10.1038/s41477-017-0083-8
- [91] O'Connor DJ, Wright GC, Dieters MJ, George DL, Hunter MN, Tatnell JR, et al. Development and application of speed breeding technologies in a commercial peanut breeding program. *Peanut Science*. 2013;**40**:107-114. DOI: 10.3146/PS12-12.1