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Article *in* Frontiers in Agronomy · August 2023

DOI: 10.3389/fagro.2023.1220387

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frontiers | Frontiers in Agronomy

TYPE Review
PUBLISHED 21 August 2023
DOI 10.3389/fagro.2023.1220387

OPEN ACCESS

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RECEIVED 10 May 2023
ACCEPTED 04 August 2023
PUBLISHED 21 August 2023

CITATION
Togola A, Datinon B, Laouali A, Traoré F, Agboton C, Ongom PO, Ojo JA, Pittendrigh B, Boukar O and Tamò M (2023) Recent advances in cowpea IPM in West Africa.
Front. Agron. 5:1220387.
doi: 10.3389/fagro.2023.1220387

Recent advances in cowpea IPM in West Africa

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Cowpea is an important and climate-resilient grain legume for human and livestock nutrition worldwide. Its grains represent a valuable source of protein for rural families in Sub-Saharan Africa while its haulms offer nutritious fodder for livestock, especially, in the Sahel regions. Cowpea production, unfortunately, faces substantial challenges of field and storage insect pests which can cause up to 100% losses. The use of synthetic pesticides, although providing farmers with a good level of pest control, has underscored the critical need for the development of integrated pest management (IPM) alternatives, due to their detrimental effects on humans, animals and the environment. This review examines recent advances in West Africa in cowpea IPM approaches, highlighting research on host plant resistance, biological control, biopesticides, good cultural practices, and on-farm participatory research and training undertaken to support sustainable cowpea production. Numerous IPM options have been developed, tested and validated for combating cowpea insect problems in West Africa by research institutions and disseminated through farmer field schools (FFS), field demonstrations, training sessions, and community-based education. Reviewing these environmentally safer and scalable IPM innovations will provide cowpea stakeholders with insights into workable, sustainable solutions for minimizing crop pest problems, reducing reliance on harmful pesticides and ultimately ensuring the long-term viability of cowpea production and its contribution to food security.

KEYWORDS

cowpea, host plant resistance, biological control, crop production, *Vigna unguiculata*, insect pests

Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most important grain legumes for human and livestock nutrition. In West Africa, it is widely cultivated by smallholder farmers, significantly contributing to affordable healthy diets for rural families and income generation crops for both women and men farmers. Cowpea grains and leaves have high protein content, up to 32% and 43%, respectively (Boukar et al., 2019a; Nielsen et al., 1993) and provide micro-nutrients (Fe, Zn), vitamins (Desire et al., 2021; Mekonnen et al., 2022), and other essential minerals for human nutrition (Voster et al., 2007) while its biomass (haulms) provides nutritious fodder for ruminants in the Sahel regions of West Africa. Because of its hardiness, it can grow on marginal lands and under extreme weather conditions, making cowpea one of the most climate-resilient crops in the region. Despite its importance, cowpea production is continuously challenged by many biotic stresses, of which insects represent the most economically significant group (Agunbiade et al., 2013; Togola et al., 2017; Togola et al., 2020). They represent the most challenging threat to cowpea production and productivity (Souleymane et al., 2013; Mekonnen et al., 2022) as they can induce up to 100% yield losses in cases of severe infestations, especially if no control measure is taken (Dugje et al., 2009; Togola et al., 2017; Dhakal et al., 2019; Egho, 2021). Also, many insect pests affect cowpea during storage, resulting in significant losses (30-90%) after a few months of storage (Gomez, 2004). Their attacks cause damage such as reduced grain weight, mold and decreased seed germination.

About twenty insect species are economically important and regularly occur worldwide in cowpea-producing areas (Oyewale and Bamaiyi, 2013). The most widespread and damaging species in West Africa are the legume pod borer, *Maruca vitrata* Fabricius (Lepidoptera: Crambidae), the cowpea aphid, *Aphis craccivora* Koch (Homoptera: Aphididae), the flower bud thrips, *Megalurothrips sjostedti* Trybom (Thysanoptera: Thripidae), the pod sucking bugs, *Clavigralla tomentosicollis* Stål (Hemiptera: Coreidae), and the cowpea weevil *Callosobruchus maculatus* Fabricius (Coleoptera: Chrysomelidae) (Oyewale and Bamaiyi, 2013; Togola et al., 2017; Tamò et al., 2019; Togola et al., 2020).

Over the years, cowpea farmers have resorted to the use of synthetic insecticides for pest management, mainly because - in the short term – they can continue to provide reasonable control for most of the pest problems, with the added advantage of providing immediate plant health improvement which can be easily discerned by low-literate farmers (Singh et al., 1990). However, the inappropriate application of synthetic pesticides is unfortunately linked to several human, animal and environmental health hazards. In the long term, their prolonged misuse severely impacts non-target organisms such as pollinators and biological control agents and can favor the development of insecticide resistance in the target insect pests (Tamò et al., 2019). Therefore, deploying cowpea integrated pest management (IPM) is the most environmentally friendly, cost-effective and sustainable solution for controlling cowpea insects. During past and recent decades, several IPM technologies were developed, tested and validated by research institutions to tackle insect problems in cowpea in several West African countries. This review intends to provide insight into recent advances in cowpea IPM in West Africa to support farmers' efforts in the sub-region. The review will highlight research on various IPM options, including host plant resistance, biological control, use of biopesticides and good cultural practices. It will also demonstrate the importance of the Economic threshold (ET) and Economic Injury Level (EIL) as decision-making tools for pest control. Finally, it will give an overview of on-farm participatory research and training (including gender aspects) towards developing, testing and validating IPM approaches and applications to support improved and sustainable cowpea production in West Africa.

Recent research on host plant resistance for managing cowpea insects

During the last decades of the 21st century, efforts have been made to develop eco-friendly integrated pest management (IPM) options in cowpea agro-systems and make them available to smallholder farmers across West Africa. Among these options, varietal resistance has been one of the research focuses on increasing cowpea productivity while expanding the genetic resistance of the crop to insect pests, especially in Sub-Saharan Africa (SSA), where accessibility and affordability of suitable agro-chemicals remain an issue (Badiane et al., 2014; Boukar et al., 2019a). Current approaches in host plant resistance are guided by crop–pest interactions, pest ecology, and the availability of novel resistance genes (Srinivasan et al., 2021). Identifying and deploying host-plant-resistant cultivars to manage insect pests can minimize dependence on environmentally toxic chemicals that resource-poor farmers cannot handle (Dormatey et al., 2015). Moreover, developing and releasing insect-resistant cultivars enable farmers to grow cowpea more profitably and enhance their health as they will no longer need to handle potentially toxic synthetic insecticides. Therefore, breeding for insect resistance is one of the most effective methods that can sustain the production and productivity of the cowpea for extended periods.

In the last decades, scientists from multiple disciplines (entomology, plant pathology, conventional and molecular breeding, and agronomy) have made significant progress in the identification or development of hundreds of tolerant/resistant lines not only through field, laboratory and screen house screening but also through genetic improvement and biotechnology applications to mitigate insect pests' effects on cowpea production and value-chain (Boukar and Fatokun, 2009). Significant progress was made in the past years in identifying and developing cowpea lines with resistance to important insect pests in West Africa, as shown in Table 1. Singh et al. (1997) reported several improved cowpea varieties with combined resistance to aphids, thrips and bruchids. In 2020, three accessions of the International Institute of Tropical Agriculture (IITA) mini core collection, namely TVu6464, TVu1583, and TVu15445, were identified as resistant to *A. craccivora* compared to the susceptible TVx3236. These resistant lines and the resistant check TVu801 had a low sucrose level in stems and leaves and a high level of kaempferol and quercetin compounds (Togola et al., 2020). Earlier, some studies found the cowpea wild relative, TVNu1158, as resistant to aphids in the seedling stage (Souleymane et al., 2013; Boukar et al., 2020).

To establish effective breeding strategies for aphid resistance, genetic studies have also been conducted to elucidate the nature of resistance inheritance in cowpea. For instance, a single dominant gene designated as *Rac1* and *Rac2* has been implicated in

10.3389/fagro.2023.1220387

TABLE 1 Non-exhaustive list of cowpea cultivars resistant to key insect pests.

Names of cultivar	Target insect pest	References
TVx-3236	*M. sjostedti* tolerance	Boukar et al. (2019b)
IT84S-2246-4	*C. maculatus* tolerance Nematode tolerance *A. craccivora* resistance	Boukar et al. (2019b)
VITA-5	Field tolerance to leafhopper	Boukar et al. (2019b)
IT81D-994	*C. maculatus* tolerance	Boukar et al. (2019b)
TVu801, TVu15445, TVu6464, TVu1583	*A. craccivora* resistance	Togola et al. (2020)
TVu8631, TVu16368, TVu8671, TVu7325	*M. sjostedti* resistance	Togola et al. (2019)
Sanzisabinli	*M. sjostedti* resistance	Abudulai et al. (2006)
KVx900-38, KVx907-34, KVx907-40, KVx908-1, KVx908-32, KVx910-2, KVx912-6	Resistant to *C. tomentosicollis*	Ba et al. (2008)
IT81D-994	Moderately resistant to *C. maculatus*	Amusa et al. (2013)
DAN' ILA; IT98K– 131 – 2; IT98K–1092– 1	Resistant to *A. craccivora*	Babura and Mustapha (2012)
IT04K-334-2, IT04K-343-1, IT06K-141, IT99K-216-48-1, IT99K-494-6, IT99K-529-2	Resistant to *C. maculatus*	Azeez and Pitan (2014)
IT07K-243-1-10, Nontchè-Wagbèhamin, Kplobè-Wewe, Kpegnikoun, Kpodjiguegue, IT86D-88	Resistant to *M. sjostedti*	Agbahoungba et al. (2021)
Moussa local, TVu1509, TVx3236, Sewe and Sanzibanili.	Resistant to *M. sjostedti*	Alabi et al. (2004)
IT 82D-716, IT 84S-2246-4, IT 84S-2231-15, IT 84S-275-9B, IT 81D-1020, IT 81D 1137, IT 81D-994, TVu2027; TVNu181 *Vigna racemosa* Hulch and Dalziel,	Resistant to *C. maculatus*	Lattanzio et al. (2005)
WC66*5Tb, WC36, TVU13677 IT84S2246-4	Resistant to *C. maculatus*	Kpoviessi et al. (2021a); Kpoviessi et al. (2021b)
TVu11953	Resistant to *C. maculatus*	Amusa et al. (2019)
IT86D-716	Resistant to *C. tomentosicollis*	Dabire-Binso et al. (2010)
Sampea 8 (IT93K-452-1)	Moderately resistant to thrips	Dormatey et al. (2015)
SARC1-57-2	Resistant to *A. craccivora*	Kusi et al. (2020); Mofokeng and Gerrano (2021)
TVNu1158	Resistant to *A. craccivora*	(Souleymane et al., 2013; Boukar et al., 2020)
Erusu	Resistant to *A. craccivora*	Mofokeng and Gerrano (2021)
Berret	Resistant to *A. craccivora*	Mofokeng and Gerrano (2021)
Modupe	Resistant to *A. craccivora*	Mofokeng and Gerrano (2021)
IT97K-556-6	Resistant to *A. craccivora*	Ouédraogo et al. (2018)
NGB001178; NGB001055	Resistant to *A. craccivora*	Nwosu et al. (2019)
TVu6464, TVu1583, TVu15445, Tvu801	Resistant to *A. craccivora*	Togola et al. (2020)
TVu6824 and TVNu 1307	Resistant to *M. sjostedti*	Toyinbo et al. (2021)
CIPEA82672, Suivita2	Resistant to *M. sjostedti*	Doumbia et al. (2019)
TVNu72, TVNu73	Resistant to *M. vitrata* and to *C. tomentosicollis*	Boukar et al. (2020); Jackai and Oghiakhe (1989)

controlling resistance to aphids in cowpea (Pathak, 1988; Boateng, 2015). Ombakho et al. (1987) studied aphid resistance in F_1 and F_2 generations of cowpea (TVu310, ICV10 and ICV11). They reported that Ac1 indicated the resistant gene in TVu310 and ICV 10, while the resistant gene in ICV11 was *Ac2*. The authors noted that plant reactions to insect attacks might depend on plant genotype, insect biotypes and environmental factors. The sources of aphid resistance identified in wild and cultivated cowpea lines are being used as parents in the breeding program of IITA, where they were crossed with some elite lines to improve their resistance to aphids. A set of

210 recombinant inbred lines (RILs) produced from the cross between the resistant TVNu1158 and some improved breeding lines by IITA cowpea breeders afforded a genetic-linkage map of cowpea consisting of 17,739 SNP markers (Boukar et al., 2019a). Hundreds of cowpea accessions were tested in many other research centers to establish their resistance to aphids.

Similar efforts were made to identify sources of resistance to *M. sjostedti*. In 2019, a study identified four mini-core accessions, TVu8631, TVu16368, TVu8671 and TVu7325, as resistant to *M. sjostedti* (Togola et al., 2019). Earlier studies reported the resistance of the local variety "Sanzisabinli" (abbreviated as Sanzi) to *M. sjostedti* (Abudulai et al., 2006). Cowpea varieties Moussa local, TVu1509, TVx3236, Sewe and Sanzibanili were reported as resistant to *M. sjostedti* (Alabi et al., 2004). Also, IT93K-452-1, an IITA-released cowpea variety in Nigeria, was found to be resistant to the flower bud thrips (Dormatey et al., 2015). In addition, IT07K-243-1-10, Nontchè-Wagbèhamin, Kplobè-Wewe, Kpegnikoun, Kpodjiguegue, Moussa, IT86D-888 were found to be highly resistant to flower bud thrips by Agbahoungba et al. (2021). Toyinbo et al. (2021) found high resistance to flower bud thrips in TVu6824, a cultivated line, and TVNu1307, a wild line of the dekindtiana subspecies. In Burkina Faso, eleven (11) varieties, including Donsin local, KVx404-8-1, KVx745-11P, Moussa local, Nafi, NS-Farakoba, NS1, Pobe local, Sanzi, TVu1509 and TVx3236 were identified as resistant to flowers thrips (Sidibe, 2020).

The cowpea genotypes TVu13677, WC36, and WC66*5T were identified as resistant to the cowpea bruchid *C. maculatus* (Kpoviessi et al., 2021b). Earlier, a study conducted in Benin by Kpoviessi et al. (2019) revealed accessions IT06K-123-1, ALEGI*SECOW3B, IT86D-1038, WC35B, IT86D-1033, TOUMKALAM, KPLOBEROUGE, WC66*NE50, IT06K-270, IT84S-2246-4, WC36, and TVu1471 to be resistant to *C. maculatus*. Doumma et al. (2011) found two local ecotypes, 044-84 and 063-84, as resistant to *C. maculatus* by inhibiting the post-embryonic development of this specie and causing 42 and 49% of larval mortality, respectively, compared to the most sensible ecotypes and resulting to a significant reduction of *C. maculatus* population.

Cowpea genotype IT86D-716 was reported by Dabire-Binso et al. (2010) as resistant to the pod bug *C. tomentosicollis* due to cyanogenic heterosides, flavonoids, tannins and trypsin inhibitors present in the pods. Boukar et al. (2020) reported two *Vigna vexillata* accessions (TVNu72 and TVNu73) as having good resistance against *M. vitrata* and *C. tomentosicollis* due to the trichomes present on the pods. Metabolomic studies discovered leaf atomatine and a non-elucidated phenolic compound as possible defensive metabolites associated with thrips resistance (Mouden and Leiss, 2021). The synthesis of sticky, resinous compounds like acyl sugars is another characteristic of glandular trichomes. Recent efforts are being put towards developing new breeding lines with insect pests resistance genes to address the major constraints to production while also considering consumer preferences (Boukar et al., 2019b). To facilitate breeding for insect pests resistance in cowpea, advances have been made in molecular discoveries. For instance, six candidate genes (Vigun08g132300, Vigun08g158000, Vigun06g053700, Vigun02g131000, Vigun01g234900 and Vigun01g201900) associated with the resistance traits to bruchid were identified in UCR Mini-core (Miesho et al., 2019).

Advances in biotechnology, such as marker-assisted selection, have accelerated the research in host plant resistance to cowpea insect pests (Jackai and Adalla, 1997). The recent development of genomic resources will support the implementation of molecular breeding to complement conventional breeding and enhance genetic gain (Boukar et al., 2019a). Huynh et al. (2015) identified one major and one minor quantitative trait loci (QTLs) for aphid resistance using a recombinant inbred lines (RILs) population evaluated in the field during two main crop seasons in a 'hotspot' location of the Central Valley of California. The QTLs were consistently mapped on linkage groups 1 and 7, respectively, with favorable alleles from genotype IT97K-556-6. The major QTL was reported as dominant based on a validation test in a separate F_2 population. SNP markers flanking each QTL were positioned in physical coatings carrying genes involved in plant defense based on synteny with related legumes. These markers have been deployed in IITA forward breeding for aphid resistance. Due to multiple aphid biotypes, the continued molecular discovery of genes associated with the diverse biotypes is required to facilitate the development of durable resistance to this insect.

As part of the recent advancements in biotechnology, efforts were made to introduce foreign genes into cowpea to improve their resistance to many biotic stresses. Several genes, such as *α-amylase inhibitor 1* (against bruchids) and *Cry1Ab* and *Cry1Ac* (against *M. vitrata*), were successfully introduced into commercially important cultivars (Badiane et al., 2014). According to Mohammed et al. (2014) and Srinivasan et al. (2021), the *Cry1Ab* confers high resistance to *M. vitrata* in transgenic cowpea. Genetically modified (GM) cowpea is being developed in some research stations in West Africa (ACB, 2015). Ghana, Burkina Faso and Nigeria are the countries where national scientists performed field evaluations (Addae et al., 2020). The first GM insect-resistant cowpea variety [SAMPEA 20-T, Pod Borer Resistant (PBR) Cowpea] has recently been approved for commercialization in Nigeria (Crop Biotech Update, 2019; Boukar et al., 2020). One limitation of the transgenic cowpea is the poor expression of the Bt genes in higher eukaryotes (Bett et al., 2017). Another limitation is the selectivity properties of the Bt genes that target mostly Lepidopteran species than other groups of insects (Togola et al., 2017).

Gene pyramiding is being explored by IITA, along with its collaborating national agricultural research systems (NARS) and advanced research institutes (ARIs), to develop highly desired cultivars combining resistance genes to different insect pests to be expanded in SSA (Boukar and Fatokun, 2009; Togola et al., 2017). Advanced biotechnology methods and tools are being explored to accelerate the breeding process. Many studies have identified quantitative traits loci (QTLs) associated with resistance to insects and other biotic stresses in cowpea (Ongom et al., 2021). Using metabolomic markers demonstrates the possibility of HPR screening for cowpea insect pests.

Breeding for induced HPR offers an entirely different path from breeding for conventional HPR, and this path has to be investigated further. All these achievements highlight the significant recent advance in improving cowpea resistance to insect pests. However, efforts should be made to obtain insect-resistant cowpea varieties with farmer-preferred traits and make them available to end users in West Africa. Also, although host plant resistance can be used as a principal control method, it must be integrated with other methods to achieve stable insect pests suppression. For instance, integrating insect-resistant cultivars with cultural management can be a powerful tool in managing insect pests.

Similarly, the use of host plant resistance with biological control tactics may be synergistic in their effects on decreasing populations of insect pests (Smith et al., 1993). The use of resistant varieties procures positive effects on natural enemies by minimizing the use of toxic insecticides. In cowpea agroecosystems, resistant varieties can be important IPM components for better-managing insect pests. Ba et al. (2008) succeeded in an effective integrated pest management strategy against pod sucking bug (*C. tomentosicollis*), flower thrips (*M. sjostedti*) and pod borers (*M. vitrata*) when combining cowpea-resistant varieties and application of neem seed extract.

Recent applications of biopesticides and biological control in managing cowpea insects

Integrated pest management (IPM) is a broad-based approach that integrates a wide range of practices, including pest control tactics such as host plant resistance, cultural practices, deployment of parasitoids, use of biopesticides, etc, for controlling pests. IPM aims to reduce insect populations below the economic injury level. Moreover, it emphasizes the growth of healthy crops with the least possible disruption to agroecosystems while encouraging natural pest control mechanisms. Nowadays, many researchers and farmers emphasize using biological agents or natural substances to control pests while securing the health of producers and consumers. In this regard, formulations based on plant substrates in powders, volatile oils, non-volatile oils and extracts have been used recently in some West African countries as promising and safe alternatives to chemical insecticides for controlling cowpea field insects as well as protecting stored seeds against insects. A biopesticide made using neem (*Azadirachta indica*) called "TopBio" has been commercially produced in Benin and was recently disseminated in rural zones for farmers' use in Niger. Also, some biorationals, such as *Beauveria bassiana* (an entomopathogenic fungus) and MaviMNPV (a Multiple Nucleopolyhedrovirus), are used as biological pesticides with potential broad-spectrum activity.

These biopesticides can be combined with other products to create synergies in controlling field insect pests (Sokame et al., 2015; Srinivasan et al., 2021). For example, MaviMNPV was introduced into Benin by IITA and was reported to be effective in controlling *M. vitrata*, causing mortality of 88% of the larva and resulting in up to 34% cowpea yield gain in Benin, Burkina Faso, Niger, and Nigeria. The yield gain was reported to be increased further when the MaviMNPV was combined with botanicals (Srinivasan et al., 2021). In Nigeria, the insecticidal activity of the substrates of *Artemisia annua* L., *Azadirachta indica* and *Ocimum gratissimum* was evaluated against bruchids; their effectiveness proved higher than the untreated control (Brisibe et al., 2011).

Other studies conducted in Nigeria by Yakubu et al. (2012) reported that eucalyptus, guava, lemongrass leaves, and orange and grape peels could adequately control the seed-eating beetle stored on cowpea. In Burkina Faso the extract from six plants species (*Boscia senegalensis* Lamarck; *Cleome viscosa* L.; *Hyptis spicigera* Lam; *Hyptis suaveolens* L. Poit.; *Ocimum canun* Sims; and *Lippia multiflora* Moldenk) as crushed leaves and essential oils were active against eggs, larvae, and adults of *C. maculatus* (Sanon et al., 2018). However, the level of effectiveness varied according to the plant species and the doses. Nowadays, many developed biopesticides are used in several West African countries while acting as effective and safe control strategies. Another important IPM component is the deployment of macro agents including predators, parasitic wasps and nematodes for pest control. Common predators of insect pests include praying mantis, spiders, earwigs, true bugs, ladybird beetles, ground beetles, lacewings, and hoverfly larvae (Ndakidemi et al., 2016). Introducing or conserving these predators in cowpea fields can provide effective and sustainable control of insects such as aphids, thrips, and lepidopterans by preying on their eggs, larvae, and adults and reduce the need for chemical insecticides (Mweke et al., 2020; Otieno et al., 2020). They can be used as part of the IPM program to maximize insect pests control efforts with no adverse effect on animals, humans or the environment. Table 2 shows a list of hymenopteran parasitoids and entomopathogenic organisms attacking the pod borer *M. vitrata* in West Africa as reported by Tamò et al. (2012).

Furthermore, in the last decade the egg parasitoid *Phanerotoma syleptae* Zettel (Hymenoptera: Braconidae) was introduced into Benin from Asia to control *M. vitrata* (Srinivasan et al., 2014). Recently, the parasitoids *Liragathis javana* Bhat and Gupta (Hymenoptera: Braconidae) and *P. syleptae* were introduced in Nigeria, Burkina Faso, Niger, Mali, and Ghana through the efforts of the IITA Benin station. The objective behind this introduction was to regulate the population of *M. vitrata*. As a result, a remarkable reduction of up to 86% in the *M. vitrata* population was observed across various pilot-release areas in West Africa (Srinivasan et al., 2022; Tamò et al., 2022).

These researches showed the potential of biological control as a vital component of the Integrated Pest Management of cowpea insect pests in West Africa. According to Tamò et al. (2017), biological-control-based interventions are becoming an attractive and essential activity for cowpea pest management in West Africa.

Advances in cultural practices for managing cowpea insect pests

Several cultural practices are important in managing cowpea insects and increasing yield. Many of these practices have been developed, tested and used by cowpea growers in West Africa. Among the common cultural practices, planting date, plant density and intercropping, crop rotation and field sanitation represent the most effective.

TABLE 2 Hymenopteran parasitoids and entomopathogenic organisms attacking the pod borer *M. vitrata* in West Africa (Tamò et al., 2012).

Natural enemies	Order/class	Family	Status	Stage attacked
Parasitoids	*Order*			
Trichogrammatoidea eldanae	Hymenoptera	Trichogrammatidae	Indigenous	E
Tretrastichus sp	Hymenoptera	Eulophidae	Indigenous	P
Apanteles taragamae	Hymenoptera	Braconidae	Introduced	L
Bassus bruesi	Hymenoptera	Braconidae	Indigenous	L
Bracon sp.	Hymenoptera	Braconidae	Indigenous	L
Braunsia sp.	Hymenoptera	Braconidae	Indigenous	L
Braunsia kriegeri	Hymenoptera	Braconidae	Indigenous	L
Dolichogenidea	Hymenoptera	Braconidae	Indigenous	L
Phanerotoma sp.	Hymenoptera	Braconidae	Indigenous	E-L
Phanerotoma leucobasis	Hymenoptera	Braconidae	Indigenous	E-L
Pristomerus sp.	Hymenoptera	Braconidae	Indigenous	L
Testudobracon sp	Hymenoptera	Braconidae	Indigenous	L
Aplomya metallica	Diptera	Tachinidae	Indigenous	L
Cadurcia sp.	Diptera	Tachinidae	Indigenous	L
Nemorilla maculosa	Diptera	Tachinidae	Introduced	L
Pseudopetichaeta laevis	Diptera	Tachinidae	Indigenous	L
Thecocarcelia incedens	Diptera	Tachinidae	Indigenous	L
Thelairosoma palposum	Diptera	Tachinidae	Indigenous	L
Entomopathogens	***Class***			
Beauveria bassiana	Sordariomycetes	Cordycipitaceae	Indigenous	L
Metarhizium anisopliae	Sordariomycetes	Clavicipitaceae	indigenous	L
Baculoviridae	Naldaviricetes	Baculoviridae		
MaviMNPV	Naldaviricetes	Baculoviridae	Introduced	L

E, egg; L, larva; P, pupa; A, adult stage.

Several studies have reported the influence of plant density on insects population and damage in cowpea fields. Lower plant densities resulting from wide row spacing often suffer from insects pressure and lead to low yields of cowpea. In contrast, a high plant population density (close spacing) of cowpea reduces diseases and insect damage (Mohdnoor, 1980) without affecting grain yields (Ezedinma, 1974). In Uganda, studies have demonstrated the role of high plant density in decreasing aphid infestation (Karungi et al., 2000a; Karungi et al., 1999). According to Pettersson et al. (1998), denser plants provide greater soil cover and reduce the strength of the visual contrasts between the ground and plants to aphids. Studies on other crops also have demonstrated the negative impact of close spacing on aphid infestation (Latigo-Ogenga et al., 1993).

On the contrary, the close spacing of cowpea was reported to attract more flower thrips, legume pod borers, and pod-sucking bugs than the sparsely spaced cowpea (Adipala et al., 2000). Karungi et al. (2000b) stated that close spacing eases host colonization since it makes it easier for the insect to find the next host. According to Karungi et al. (2000a), close spacing combined with early planting and minimum insecticide application achieved better cowpea grain yield than the unsprayed control plots. Farrell (1976) found that close spacing of mono-crop cowpea reduced losses caused by aphid viral disease transmission.

Appropriate crop planting dates is one of the good agronomic practices for controlling insect pests in cowpea field. Kamara et al. (2010) identified planting dates as vital to IPM practices. Farmers in the dry savannahs manipulate cowpea planting dates to avoid insect pests and disease attacks. According to Pedigo et al. (2021), adjusting planting dates can cause asynchrony between crops and insect pests. Similarly, Adipala et al. (2000) stated that the temporal desynchronization between the host plant development and insect population buildup creates a situation that allows the host to escape substantial damage to the crop. The effectiveness of insect management through planting dates depends on various factors, including the population dynamic of pests, the cycle of cowpea variety, the climatic region, the cropping system, etc. Kamara et al. (2018) reported that early cowpea planting predisposes the crop to insect pests and disease pressure. Therefore, they found that high yields and good-quality seeds are obtained when cowpeas are planted late, so the crop matures in dry weather.

In contrast, an earlier study conducted by IITA (1982) in Nigeria reported a higher grain yield of cowpea planted early compared to late planting due to a low population of insect. Similarly, a study made by Karungi et al. (2000b) stated that early planting reduces levels of infestation by some cowpea insects such as aphid, thrips and pod-sucking bugs and prevent subsequent buildup of their population during the cropping season but it increases *M. vitrata* infestation. Perrin and Ezueh (1978) also found that cowpea planted in June in southern Nigeria suffered more significant damage by *Cydia ptychora* Meyrick (Lepidoptera: Tortricidae) than those planted earlier or much later in the dry season. Planting date also affects the use of insecticide for controlling insect pests in cowpea (Kamara et al., 2018). Therefore, in Nigeria, Kamara et al. (2010) found that early and medium-maturing cowpea varieties should be planted in mid-August and sprayed twice, while the late-maturing indeterminate varieties should be planted in early August and sprayed thrice.

Another critical component of cultural practice for insect management is the cropping system. In West Africa, cowpea is traditionally intercropped with other food crops such as maize, pearl millet, sorghum and cassava (Kamara et al., 2018). In Uganda and elsewhere in the tropics, cowpea is grown in intercrops with maize, sorghum, finger millet, cassava and greengram (Obuo et al., 1998). Cowpea-cereal intercropping has several advantages, including land use efficiency, improved cereal yields, increased soil fertility and reduced insect incidence (Lithourgidis et al., 2011). According to Ezueh (1991), a significant advantage expected from intercropping is that it provides a less favorable habitat for some major insect pests than when cowpea is grown as a sole crop. This hypothesis corroborates the statement of Root (1973) and Andow and Risch (1985), who reported that predation on herbivores increases in diverse plant assemblages (polyculture) than in simplified plant assemblages (monoculture). Tahvanainen and Root (1972) demonstrated that with an increase in vegetation diversity within an agroecosystem, there is usually a corresponding decrease in insect pests' density, which generally leads to system stability. Aphids and thrips were consistently lower in the cowpea/sorghum intercrop than in the cowpea/greengram. At the same time, legume pod borers and pod-sucking bug infestations were significantly higher in the cowpea/sorghum mixture than in the cowpea/greengram cropping systems (Adipala et al., 2000). The factors that reduce aphid and thrips infestation in the cowpea/sorghum intercrop apparently favor legume pod borers and pod-sucking bug infestations. Adipala et al. (2000) concluded that insect pests' profile should be considered when selecting components of intercrops for insect management purposes.

Practice such as crop rotation helps to break pest life cycles, disrupts its habitat and food sources, and reduces the buildup of its populations. According to Kebede and Bekeko (2020) cowpea-cereal rotation is an important cropping system that reduces weed, insect and disease pressure. Similarly Kumar et al. (2020) reported that crop rotations diminish the prevalence of insect pests, pathogens, diseases, and weeds in the field while reducing their effects on crops.

Other common cultural practice such as field sanitation through removing crop residues and weeds enables the elimination of potential pest alternative hosts and prevent the buildup of insect population between cropping seasons. Takim and Uddin (2010) reported that weeding leads to a substantial reduction in insect pests of cowpea.

An important component of cowpea IPM is the regular field monitoring and surveillance to record the EIL and the ET. They are used as decision-making tools for determining when appropriate control measures should be taken to prevent economic losses caused by insect pests (Jackai and Adalla, 1997). Other aspects of IPM such as the practice of good hygiene, the use of hermetic storage and the use of triple bagging with PICS bags, are common methods for the management of storage insect pests. Figure 1 summarizes the major component of the IPM pyramid as reported by Karlsson Green et al. (2020).

Validating and scaling out IPM packages on-farm through participatory research, training and gender inclusion

Research institutes in West Africa developed several integrated pest management (IPM) technologies to reduce the losses due to insect pests and minimize the risk of hazardous chemicals. They were tested and disseminated through farmer field schools (FFS), field demonstrations, various training sessions and ICT tools (e.g., SAWBO videos). Also, diverse community-based education approaches were conducted to address agricultural constraints and encourage the adoption of IPM technologies to boost cowpea production in West African countries, e.g., by actively involving women farmers and youth in various IPM validation and upscaling

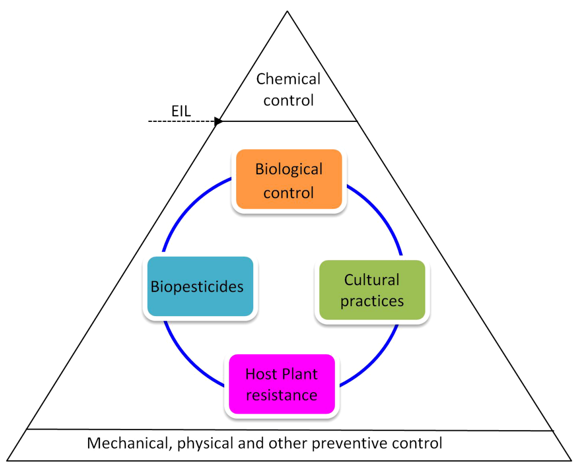

FIGURE 1
The IPM pyramid showing the major measures for insect pest control (a slightly modified pyramid from Karlsson Green et al., 2020).

activities. In Burkina Faso and Mali, 412 farmers, including 40% women, were trained on cowpea IPM in Farmer Field schools which led to a drastic reduction in the use of second-generation pesticides (Settle and Garba, 2011).

In Niger, thirty Farmer's field schools were established from 2013 to 2014 involving 600 farmers to address the cowpea production constraints. It was found that the neem seed's aqueous extracts reduced cowpea infestation by *C. tomentosicollis*, *A. craccivora*, *M. vitrata* and increased cowpea yield by 258% (Rabé et al., 2017a). The production system combined with the improved varieties, sowing date, plant density, and organic and mineral fertilizer application increased cowpea yield by 113% (Rabé et al., 2017b). Three years later, the evaluation of these FFS recorded an adoption rate of 74.9% for improved varieties, 20% for organic fertilizer and 7.4% for Neem seeds' biopesticides (Rabé et al., 2017a). Fifteen (15) farmer field schools, 28 field demonstrations, and three community-based neem production industries were established in Niger in 2020. These activities trained over 370 farmers in producing IPM and neem tea bag biopesticide (USAID, 2021). Also, in 2021 a total of 868 cowpea farmers, including 140 women, were sensitized on the scope of biological control against pests and trained on the risk of second-generation pesticide exposure and the beneficial effect of biopesticide in Niger (USAID, 2021).

Field demonstrations were conducted to compare the efficacy of three biopesticides against major cowpea insect pests in twenty-nine villages during the 2014 and 2015 cropping seasons in the Zinder region of Niger. The treatments of aqueous neem seed extracts at the dose of 5%, the neem oil and the synthetic TopBio + Virus mixture generated a yield of 1.3 to 19.9 times higher than that of control treatments (Harouna et al., 2019). The availability of technologies in a given geographical area is one of the prerequisites for its adoption by the targeted population. Therefore, in Niger, hundreds of women farmers were trained and established ten neem-based biopesticide community industries (NBCI) in the cowpea growing zones. Groups of women manage all ten NBCIs and include 30% youth. The 3384 neem tea bags produced in 2020 can spray an estimated 84.5 ha of cowpea fields (RECA (National Network of the Chamber of Agriculture of Niger), 2020).

Along with these efforts, various innovation platforms brought progress in cowpea production. In 2019 in Northern Ghana, a study conducted by ICRISAT and IITA in seven large cowpea production districts indicated that efforts by the comprehensive agricultural training program CATP increased the adoption of improved cowpea varieties, productivity, and cowpea income (Martey et al., 2021). A previous study from Northern Ghana reported that 250 participants, including 80 women farmers, were trained on IPM approaches through Farmer Field Fora (FFF) from 2010 to 2011 (Abudulai et al., 2016), whereby 80% of the trained farmers improved their knowledge and skills in IPM control methods.

In Mali, an innovation platform to improve the production and distribution of cowpea varieties was established in 2016. The platform activities organized 25 training sessions about different components of the cowpea value chain for 1097 farmers and 299 demonstrations involving 2934 producers and 12193 consumers (Kouyate et al., 2021). Another innovation platform established in Nigeria with the participation of researchers, NGOs, farmers, extension agents, and private and public sectors led to rapid adoption and use of newly released cowpea varieties by farmers as a result of increased awareness through media and communication tools and strategies during the implementation of the Tropical Legume Phase three TLIII project (Iorlamen et al., 2021).

To improve the coverage of IPM technologies and their wide-scale dissemination, various programs have started to use ICT tools to reach different target groups. The most prominent effort comes from Scientific Animations Without Borders (SAWBO), which has developed animated videos demonstrating IPM approaches. The videos have been translated into several African languages and are accessible online through the SAWBO video library and YouTube. In addition, some animations are broadcasted on TV and can reach thousands of people, including farmers. In Benin, 70% of the interviewed farmers who watched the SAWBO neem video (SAWBO, 2017) appreciated localized animated educational videos as an appropriate way to disseminate information compared to the traditional extension training approaches (Bello-Bravo et al., 2018).

Conclusions and perspectives

Cowpea is a staple crop playing an essential and strategic role in human and livestock nutrition in many parts of the World, especially in Africa and SSA West Africa. Unfortunately, African farmers continue to face numerous production constraints, among which field and storage insects pest are responsible for severe yield losses. Adequate attention must be given to addressing these pests that hamper the quantity and quality of harvested cowpea in SSA, judiciously using second-generation pesticides and implementing alternative control strategies to minimize, augment, or replace second-generation pesticides where possible. In this regard, there is a continued need for the research community to develop integrated pest management (IPM) strategies to help achieve these goals. Over the past several decades, significant progress has been made to develop, test and validate IPM options as holistic management solutions for cowpea insects. In this regard, IITA and partners, including NARES and universities, have developed and disseminated cowpea resistant/tolerant lines to key insect pests. Numerous of these cultivars were made available for use by farmers or by breeders for genetic improvement purposes to support cowpea production and productivity in SAA.

Additionally, biopesticides, including plant-based substrates and biorationals, have been developed in several West African countries as effective tools in the toolkit for strategies to control the insects of cowpeas. Other options like manipulation of planting date, plant density, and use of intercropping systems were recognized as the most common and effective cultural practices against cowpea insects. Various knowledge platforms, including farmer field schools, field demonstrations, training sessions, videos/animations and TIC tools, were used to facilitate farmers' adoption of the IPM technologies. It will be critical for the donor-research-extension community to facilitate the necessary support, research, and scalable insect control strategies to provide cowpea farmers with the solutions they need to minimize insect pests' problems on their crops.

Author contributions

AT, corresponding author, wrote and reviewed the manuscript, BD wrote sections of the manuscript, AL wrote sections of the manuscript, FT wrote sections of the manuscript, CA wrote sections of the manuscript, JO wrote sections of the manuscript, PO reviewed the manuscript, BP wrote, edited and reviewed the manuscript, OB reviewed the manuscript, MT conceived the idea of the manuscript initially, edited and reviewed it. All authors contributed to the article and approved the submitted version.

Funding

The authors appreciate funding support from the Bill and Melinda Gates Foundation (BMGF) through the Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA) project, Grant# OPP1198373.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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