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Chapter

Challenges, Progress and Prospects for Sustainable Management of Soilborne Diseases of Cowpea

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Abstract

Cowpea [*Vigna unguiculata* L. (Walp.)], is an important legume crop widely grown in the tropics. Biotic and abiotic stresses cause significant yield reduction in cowpea. In this chapter, we provide a synthesis of information on the damage/economic importance of soilborne diseases of cowpea and present options that can be used to manage these diseases. The aim is to demonstrate that a wide array of control options are available for potential use within an integrated disease management (IDM) framework. Reviewed literature indicated presence of several sources of resistance to *fusarium* wilt (FW) and charcoal rot but few sources for stem rots, collar rot and damping-off. Major resistant genes and quantitative trait loci (QTL) were identified for FW and charcoal rot and these may be exploited in marker assisted selection (MAS). Cultural practices such as crop rotation and compositing were found to be effective against soilborne diseases, however, there is lack of knowledge regarding their adoption. Similarly, several botanicals were found to be effective against several soilborne fungal diseases but these studies were limited to controlled environments necessitating the need for large scale field trials. Several effective microbial control agents (MBCAs) and fungicides exist and can be incorporated in IDM.

Keywords: cowpea, disease management, fungi, host resistance, soilborne

1. Introduction

Cowpea, *Vigna unguiculata* L. (Walp.) is a multipurpose legume providing food for humans and feed/fodder for livestock and also a key source of income for farmers and grain traders especially in the tropical environments [1]. Ecologically, cowpea improves the productivity and sustainability of farming systems especially through its ability to fix substantial amounts of nitrogen from the atmosphere [1, 2]. While the name cowpea is the most popular worldwide especially among the English-speaking regions, it is known by a wide range of names. For instance, in the Francophone countries, the name 'niébé' is often used. In the USA, cowpea is popularly referred to as 'blackeye beans', 'blackeye peas', and 'southern peas' while in India and Brazil, it is referred to as 'lobia' and 'caupi', respectively [1, 2]. Common local names include

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'seub' and 'niao' in Senegal, 'wake' in Nigeria, and 'lubahilu' in the Sudan [1, 2]. The species *V. unguiculata* includes cultivated forms (*Vigna unguiculata* ssp. *Unguiculata* var. *unguiculata*), wild annual forms (ssp. *Unguiculata* var. *spontanea*) and wild perennial subspecies [3]. Cultivated cowpea, subspecies *Unguiculata* is divided into five cultivar-groups (Cv-gr.) based on pod and seed characteristics; Cv-gr. *Unguiculata*, Cv-gr. *Biflora*, Cv-gr. *Sesquipedalis*, Cv-gr. *Textilis* and Cv-gr. *Melanophthalmus* [4]. Cv-gr. *Unguiculata* is the largest and comprises of both medium and large seeded grain and forage cowpea types of African origin. Cv-gr. *Melanophthalmus* includes 'blackeye pea'-type cowpeas which is characterised by white flowers/white seeds and thin seed coats [4, 5]. Cv-gr. *Textilis* is a rare form of cowpea mainly grown in West Africa for fibre extracted from its long peduncles [5, 6]. Cv-gr. *Sesquipedalis* (yard long bean, long bean, asparagus bean and snake bean) is commonly grown in Asia for its long (40–100 cm) green, fleshy and wrinkled pods that are often used as 'snap beans' [4, 5]. Cv-gr. *Biflora* is characterised by thick seed testa and erect pods.

Cowpea is consumed in several forms; for instance, in south-eastern USA, Asia and Caribbean, fresh seeds and green pods are mostly consumed while in many parts of Africa and Asia, dry grains are mainly consumed in addition to fresh or dry leaves (as side dish or part of the stew), thus providing significant nutritional value [7–9]. Although leaves are consumed, cowpea is mainly grown for consumption of grains as they are rich in proteins, carbohydrates as well as minerals. The nutrient composition both in grain and leaves is highly variable depending on the environment and genotype under consideration. In an evaluation of 1541 cowpea accessions for grain nutrient composition by [10], protein content ranged from 17.5 to 32.5%, Fe content from 33.6 to 79.5 mg/kg, Zn ranged from 22.1 to 58.0 mg/kg, Ca from 310 to 1395 mg/kg, Mg from 1515 to 2500 mg/kg, K ranged from 11,400 to 18,450 mg/kg and P from 3450 to 6750 mg/kg. Weng et al. also reported a wide range (22.8–28.9%) of seed protein content among the 173 cowpea genotypes [11]. A similar study of 15 genotypes by [12] showed that moisture content ranged from 12.28 to 13.35%, total carbohydrates from 49.37 to 55.74%, crude ash from 2.99 to 3.34%, crude lipids from 0.13 to 0.81%, crude protein from 23.37 to 29.70% and crude fibers from 1.40 to 4.34%. Cowpea samples recorded highest percentage of essential amino acids (60.71%) and non-essential amino acids (39.29%). The mineral content ranged from 1.97 to 2.69 mg/100 g for calcium, 3.23 to 3.90 mg/100 g for magnesium, 205.53 to 223.30 mg/100 g for sodium, 0.80 to 1.23 mg/100 g for zinc, 1071.15 to 1152.62 mg/100 g for potassium and 0.62 to 1.06 mg/100 g for phosphorus. Cowpea has shown great potential for production of fermented yoghurt-like food products with improved bioavailability of nutrients [13, 14]. Cowpea is rich in phenolic acids such as benzoic and cinnamic acid derivatives that are associated with antioxidant properties [15]. In addition, cowpea has a high proportion of polyunsaturated fatty acids (40.1–78.3% of total fats) [16] and these are associated with several healthy benefits.

While cowpea is cultivated globally, most of the production occurs in the developing countries. Recent estimates show that West Africa accounts for over 80% of the total world production [17]. The leading cowpea producing countries in Africa include: Nigeria, Niger, Burkina Faso and Ethiopia with production of 3,576,361, 2,386,735, 652,454 and 374,332 tonnes, respectively. The estimated acreage, production and average yield of cowpea from the selected major producing countries of cowpea are presented in **Table 1**.

Despite the importance of cowpea, abiotic and biotic constraints are major yield limiting factors especially in the developing countries where most of the production takes place. Water availability is the most significant abiotic constraint for yield in cowpea despite the fact that the crop is inherently drought tolerant [9]. Cowpea diseases caused by various pathogens (fungi, bacteria, viruses, nematodes

Rank	Country	Acreage (Ha)	Quantity (t)	Yield (hg/Ha)
1	Nigeria	4,303,005	3,576,361	8311
2	Niger	5,725,433	2,386,735	4169
3	Burkina Faso	1,354,100	652,454	4818
4	Ethiopia	220,037	374,332	17,012
5	Kenya	298,120	246,870	8281
6	Mali	454,274	215,436	4742
7	Cameroon	244,058	215,016	8810
8	Ghana	149,102	202,735	13,597
9	Senegal	290,677	184,137	6335
10	Sudan	339,780	161,000	4738
11	Tanzania	112,657	127,884	11,352
12	Myanmar	122,637	108,021	8308
13	Mozambique	331,424	90,461	2729
14	DRC	175,418	76,292	4349
15	Yemen	26,062	66,190	25,397
16	Malawi	97,825	41,656	4258
17	Madagascar	34,122	31,069	9105
18	Haiti	42,145	30,741	7294
19	Peru	15,794	21,539	13,637
20	China	14,503	14,696	10,133
21	Uganda	33,350	12,697	3807
22	USA	5220	11,750	22,510

Source: FAOSTAT [17].

Table 1.
Top cowpea producing countries in the world.

and parasitic plants) constitute one of the important biotic constraints to cowpea production in all regions where the crop is cultivated [18]. These diseases can infect cowpea at different stages such as during emergence, vegetative and reproductive stages causing substantial plant damage hence leading to yield loss or complete production failure [19]. While there have been some extensive reviews on shoot and pod diseases of cowpea [20], as well as soilborne diseases [21], this manuscript provides an updated synthesis of the economic importance of major soilborne fungal diseases in the world and the available options for their sustainable management. This present review covers past efforts, achievements and gaps in the management of soilborne fungal diseases of cowpea. The management approaches focused on include: resistance breeding/host resistance or pre-breeding, cultural practices, fungicides, microbial biocontrol agents (MBCAs) and use of botanicals.

2. Damage caused by soilborne fungal diseases

Soilborne fungal diseases of cowpea are widespread globally and constitute a major constraint to production especially in the tropical and subtropic environments. Southern blight also referred to as basal stem disease or stem rot, damping-off, collar rot or seedling blight, *Fusarium* wilt, and charcoal or dry root rot are the prevalent soilborne fungal diseases of cowpea. Notably, Southern blight or stem rot is caused by *Sclerotium rolfsii*, damping off is caused by *Pythium* sp., while collar rot or seedling blight is incited by *Rhizoctonia solani* [22–27]. Among these pathogens, *Sclerotium rolfsii* is identified as the main disease-causing pathogen while the others are referred to as minor pathogens [24–26]. Southern blight is characterised by initial stem decay of plants in the top 2 cm of the soil, general wilting and yellowing of plants followed by drying of foliage and plant death [28]. In advanced stages of infection, the stems exhibit tan to brown sclerotial bodies and white mycelial growth on the epidermis of the stem at the soil surface. Non-germinated diseased seeds have a brown blotchy colour or a soft rot and often disintegrate when touched. Germinated seedlings may fail to emerge above the soil line and are characterized by water-soaked lesions girdling the hypocotyl. Emerged seedlings have necrotic tap roots with few lateral roots while infected hypocotyls above the soil surface have light brown lesions [29]. While the disease is widely recognised as important, there are limited studies aimed at assessing its economic impact. Fery and Dukes reported yield losses of up to 53% in susceptible cultivars mainly due to reduction in the number of pods per plant [28]. Similarly, Thies et al. [30] reported significant seedling losses and reductions in seed weight/seed number as a result of *Rhophitulus solani* infection.

Charcoal rot or dry root rot caused by *Macrophomina phaseolina* [31] is another serious constraint to cowpea production especially in the drier savannas and Sahel [18]. Yield loss of up to 10% due to charcoal rot has been reported in the Sahelian zone of West Africa [32]. For instance, in Niger and Senegal alone, charcoal rot was estimated to cause yield loss of up to 30,000 tons of grain valued at USD146 million [32]. *Fusarium* wilt (FW) caused by *Fusarium oxysporum* f.sp. *tracheiphilum* (*Fot*) is associated with characteristic symptoms such as chlorosis, wilting and stunting at seedling or flowering stage or and/or early pod development resulting in plant mortality with significant yield losses [33–36]. Significant yield losses ranging from 35 to 65% or total loss due to *fusarium* wilt alone or in combination with nematode infestation were reported [33–36]. In Brazil, yield losses of 8.3–86.5% due to wilt were also reported [37].

3. Management approaches for soilborne diseases of cowpea

Effective management of soilborne fungal diseases requires use of a number of approaches which can be grouped into four categories: (1) host resistance or use of tolerant varieties, (2) adoption of best cropping practices, (3) seed treatments and (4) protection of seedlings [38]. However, none of these approaches is effective when used alone thus necessitating the need for their combination within the framework of integrated disease management (IDM) approach if sustainability is to be achieved.

3.1 Utilization of host resistance

Host resistance is the most effective, economical and environmentally friendly approach for managing soilborne fungal diseases of cowpea. This approach mainly involves deployment of resistant and/or tolerant plant varieties, which support lower pathogen populations or better tolerate injury; and the integration of such varieties with other approaches within the IDM framework. In this section we provide a synthesis of available information about genetic resources for resistance, genetics of resistance, identification of markers associated with disease resistance and their potential for use in breeding programs.

3.1.1 Genetic resources for resistance to soilborne diseases

Several screening studies have been conducted both under the field and greenhouse conditions to identify sources of resistance against major soilborne fungal diseases of cowpea. Majority of the studies have targeted resistance to *fusarium* wilt (FW) and charcoal rot while screening trials for southern blight, stem rots, collar rot and damping-off have been limited, hence more studies are needed on these aspects.

Oyekan reported resistance to FW in TVu109-2, 347, 984, 1000 and 1016-1 cowpea varieties under both field and greenhouse conditions [39]. Five cowpea cultivars with resistance to three FW races (1, 2 and 3) were identified in another study [40]. The cultivars were: Magnolia, Iron PI293520, Iron TVu 990, Iron TVu 1072 and Iron TVu 1611. Roberts et al. identified CB3, CB46, 7964 and 8517 as having resistance to FW [36]. Similarly, Hall et al. [2] reported varieties CB3 and 7977 as sources of resistance to FW. Moreover, CB 46 and CB 88 were reported to have resistance only against race 3 of FW while CB27 and CB50 gave resistance against both race 3 and race 4 of FW [41, 42]. Following screenhouse/greenhouse studies, four FW resistant cowpea genotypes namely: Asontem, Danila, IT89KD-88 and NE 70 were identified [43, 44]. Other genotypes that could be used as resistance donors for FW are: TVu 134, TVu 410, TVu 901-1 and MNCO1-649F-2-1 [45, 46]. Genotypes TVu 134, TVu 410 and TVu 901-1 share the same resistance gene [45, 46]. Wu et al. reported 10 highly resistant genotypes to FW. These were: Fei 8, CB46, IT93K_503_1, UCR5040, Zhijiang dwarf No. 1, Jiacaidou, Heiziyacao, Fan, Zhuyan long bean and Qiyezai [47] representing the Chinese asparagus bean, and the African cowpea.

For resistance to southern blight/basal stem disease, cowpea genotypes: CO-4, Brown Crowder, Carolina Cream, L-25, IT89-KD-374, IT86-D-715 and IT99K-1122 were identified [28, 48–50, 57]. According to Adandonon [24] Sèwé, Kpodji, Kumassi and Cameroon cowpea genotypes showed resistance to both stem rots and damping off under field conditions. The potential sources of resistance to charcoal rot include: IT04K-217-5, Komsare, Gaoua local-2, 58-57, Kaya local and SP369A profil-39B [51, 52]. Singh and Lodha found moderate resistance to charcoal rot in 26/4/1, V 16, K 39, 25/8/2 and CO3 genotypes [53]. In field experiments conducted over 3 years, IT98K-499-39, Suvita 2, IT93K-503-1 and Mouride were found to be highly resistant to charcoal rot [54]. Cowpea cultivar Caloona was reported to be resistant to *Phytopthora vignae*, the causal agent for Phytopthora root rot or foot rot [55]. Under field conditions, the genotype IT86D-326-2 was found to be moderately resistant to damping-off and stem rots caused by *S. rolfsii* [26].

3.1.2 Inheritance of resistance to soilborne diseases

Most studies on inheritance of resistance to soilborne fungal pathogens of cowpea have relied on Mendelian genetics. These studies have mainly focused on FW resistance with few studies on charcoal rot and southern blight. Inheritance studies focusing on other pathogens such as *Pythium* sp. and *Rhizoctonia solani* are largely missing in literature. Literature on genetic inheritance of resistance to FW suggests that it is controlled by a single dominant gene [46]. Resistance to race 1, 2 and 3 was reported to be controlled by a single dominant gene [45, 56]. Dominant monogenic inheritance makes it possible to effectively use backcrossing for transfer of resistance to susceptible backgrounds [46]. However, additive gene effects were also reported to control resistance [44]. For southern blight, resistance is conditioned by single dominant genes which are non-allelic in two resistant genotypes namely: Carolina Cream and Brown Crowder [57]. Inheritance to charcoal rot was found to be controlled by additive gene action and thus quantitative in nature [54, 58]. Resistance to *P. vignae* (race 2) in cultivar Caloona is controlled by a single dominant gene [55, 59] and it is expressed throughout the life of the plant in all tissues [55].

3.1.3 Identification of resistant loci and markers for resistance to soilborne pathogens

Efforts to identify resistant loci and development or deployment of molecular markers in breeding for resistance to soil-borne fungal diseases in cowpea have been restricted mainly to FW and charcoal rot. Little or no progress has been made on markers used or developed for other pathogens. For instance, a single SSR marker (C13-16) that can discriminate between resistant and susceptible genotypes for FW resistance was identified [45]. This marker can easily be used in low resourced laboratories in several developing countries [45]. Two independent loci (QTLs), *Fot4-1* and *Fot4-2*, which confer resistance to FW race 4 were identified in three cowpea RIL populations derived from three crosses: IT93K-503-1 × CB46, CB27 × 24-125B-1 and CB27 × IT82E-18/Big Buff. Locus *Fot4-1* was located on linkage group 5 while *Fot4-2* was located on linkage group 3 [34]. *Fot4-1* was derived from an African breeding line, IT93K-503-1 and *Fot4-2* was derived from a US blackeye dry grain cultivar, CB27 [34]. While the locations of *Fot4-1* and *Fot4-2* were identified, generation of tightly linked markers is yet to be done. For resistance to FW race 3, Pottorff et al. [33] identified a single QTL (*Fot3-1*) from a RIL population derived from CB27 × 24-125B-1 cross. The *Fot3-1* locus is located on linkage group 1. Four SNP markers, 1_1107, 1_0860, 1_1484 and 1_0911 linked to *Fot3-1* locus were identified making transfer of FW resistance into susceptible cultivars through MAS more likely [33]. Using a genome wide association study, 17 SNPs associated with FW resistance were reported [47]. The 17 SNPs were: 1_0075, 1_1111, 1_1147, 1_0251, 1_0895, 1_0691, 1_0897, 1_0298, 1_0410, 1_0857, 1_0981, 1_1369, 1_0330, 1_1062, 1_0629, 1_0318 and 1_1504. SNP 1_0981 was used to design a PCR primer (1_0981CAPS-F: 5′-AAGTTGCAGAGCACCACAGA-3′ and 1_0981CAPS-R: 5′-TAAAAGGACCACTGCACACG-3′) to distinguish between resistant and susceptible lines due to its strong association with FW resistance [47]. This primer set can readily be used in marker assisted selection. QTL analysis of a RIL population derived from a cross between IT93K-503-1 and CB46 revealed nine QTLs: *Mac-1*, *Mac-2*, *Mac-3*, *Mac-4*, *Mac-5*, *Mac-6*, *Mac-7*, *Mac-8* and *Mac-9* against charcoal rot and these QTLs were associated with eight SNP markers: 1_0709, 1_0853, 1_0604, 1_0201, 1_0079, 1_0804, 1_0678 and 1_0030, respectively [54].

3.2 Adoption of good agronomic practices

Agronomic practices that can delay or discourage the survival and development of pathogens can play a role in the management of soilborne fungal diseases. This is because many of the pathogens are relatively weak requiring a favourable environment for infection to occur [38]. Several agronomic practices that modify the growing environment such as seedbed preparation, soil pH management, planting dates, seed rate, plant density, soil fertility and moisture management, cropping systems (crop sequence and intercropping, cover crops), and soil solarisation have been reported as efficient in the control of soilborne pathogens [38]. However, few studies have been carried out on management of cowpea soilborne fungal diseases.

For instance, rotation of cowpea with a gramineous/cereal crop such as fonio (*Digitaria exilis*) and millet (*Pennisetum glaucum*) leads to rapid reduction of microsclerotia of *Modiolula phaseolina* in soils [32, 60]. Fonio and millet planted continuously for 3 years significantly reduced microsclerotia densities in soils at a rate of

81% after the second year; 86% after the third year under fonio and 56 and 66% for the second and third year under millet, respectively [32, 60]. Composting heavily *M. phaseolina* infected cowpea residues raises temperature (52–60°C) leading to complete destruction of *M. phaseolina* microsclerotia [32, 61]. Addition of six tonnes of compost alone or supplemented with 50 kg NPK ha^{-1} gave 28–45% lower area under disease progress curves (AUDPC) with a 43–66% higher cowpea production. Furthermore, addition of compost combined with *C. rosea* in planting holes sharply reduced AUDPC (up to 4-fold) and increased the grain yield 2–5-fold [32, 61].

Combined use of solarization and organic soil amendments is highly effective in controlling soilborne fungal pathogens [32, 61, 62]. For instance, there was a 78 or 96% reduction in charcoal rot disease severity, when millet residues or paunch amendments were applied in combination with solarization, respectively. Soaking of seed in an antioxidant, spermine (SP) at 10 mg L^{-1} before planting followed by foliar application of potassium (K) as potassium chloride (KCl) at 2% and zinc (Zn) as zinc sulphate $ZnSO_4$ at 0.01% gave the highest germination percentage and lowest incidence of damping-off disease at 96.34 and 3.66%, respectively [63]. The same treatments (SP + K + Zn) also significantly reduced the incidence of charcoal rot by up to 83.30% [63].

3.3 Role of microbial biocontrol agents (MBCAs) against soilborne fungal diseases

The pathogens causing soil-borne diseases such as *R. solani*, *Pythium* spp., *Fusarium* spp., *S. rolfsii*, and *M. phaseolina* on cowpea either survive in soil or are introduced from seeds therefore both seed treatment and soil application of MBCAs or chemicals are recommended. In particular, management of soilborne pathogens of cowpea through MBCAs is more effective. Application of beneficial microbes for the control of plant diseases can be successfully used particular within the framework of an IDM system due to their manifold mode of actions (**Figure 1**). The use

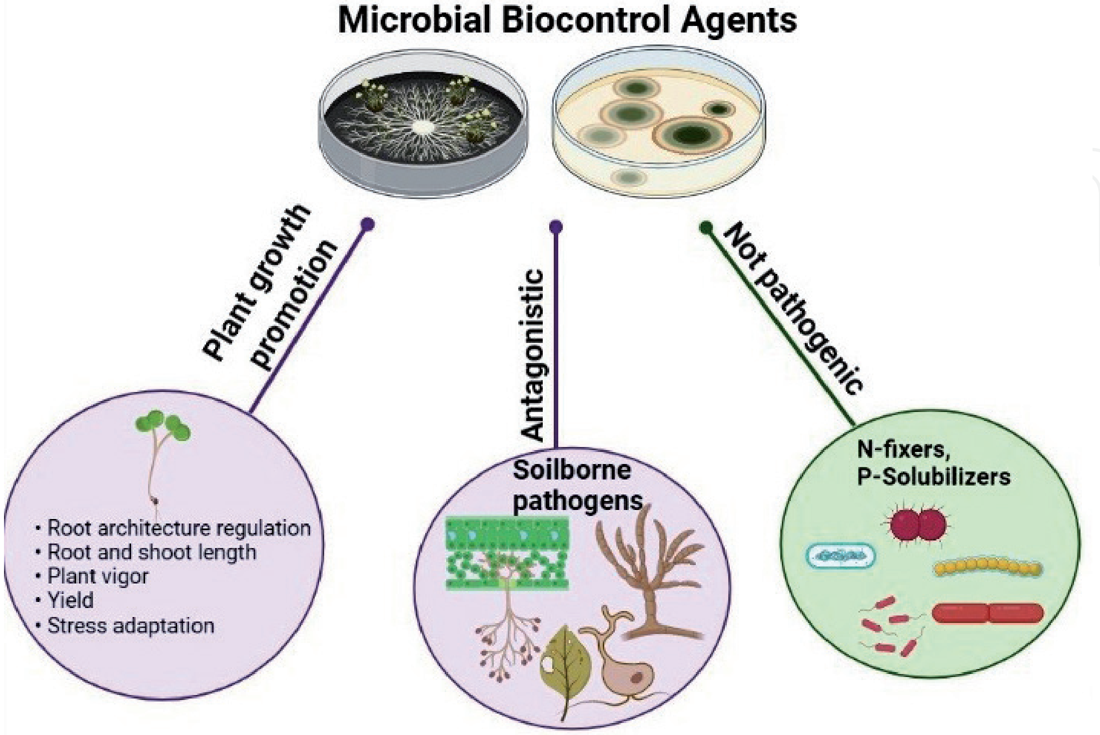

Figure 1.
Showing manifold performance of microbial biocontrol agents (MBCAs).

of MBCAs with other management practices such as cultural practices, cover crops and organic amendments is known to be less harmful than chemical fungicides in the management of soilborne diseases [64].

The beneficial microbes that have been frequently used for the control of soil-borne diseases of cowpea include: *Trichoderma* species, *Pseudomonas* species and *Bacillus* species [65, 66]. *Bacillus* species have been used against root rot and postharvest diseases [67, 68]. In a study by [69], *Bacillus firmus* coated cowpea seeds when sown in soil amended with radish compost had lower mortality at 3–4% induced by *Modiolula phaseolina* compared to non-amended soils (13.8–20.5%). Cowpea seeds treated using *Trichoderma* strain Kd 63, and soil sprinkle with *Trichoderma* IITA 508 (5 g/L, 10^9 colony forming units (CFU)/g) exhibited higher control of stem rot caused by *S. rolfsii* [70]. Besides, Adandonon et al. [70] found that seed treatment with *Moringa* followed by soil sprinkle application of *Trichoderma* resulted in 94 and 70% stem rot control under greenhouse and field conditions, respectively with significant increase in seed yield.

Application of *Trichoderma* species with organic amendments increased the population and efficacy of *Trichoderma* as well as increased defense response in host species and seed yield [71, 72]. In India, Singh et al. [73] used six organic substrates for multiplication and efficacy testing of *T. harzianum* against collar rot disease caused by *Rhophitulus solani*. They found that of the six substrates, *T. harzianum* multiplied in spent mushroom compost contained the highest population density (15×10^7 CFU/g) up to 240 DAI and exhibited potential efficacy against collar rot. The treated plants showed reduced seedling mortality, enhanced shoot and root length, number of leaves as well increased seed yield. Similar results were reported by El-Mohamedy et al. [74] in greenhouse experiments. They reported that soil amendment with *T. harzianum* multiplied on sugar cane bagasse (10% w/w) of soil reduced root rot incidences by 73.9, 73.9 and 78.6% caused by *R. solani*, *F. solani* and *M. phaseolina* at pre-emergence stage, respectively. The management of soil-borne pathogens through soil amended with organic materials including MBCAs may be attributed to: (i) increasing efficacy of native microbes resulting in suppression of pathogens through competition or specific inhibition, (ii) releasing degradation compounds viz., ammonia, carbon dioxides, saponins, nitrites or enzymes which are generally lethal to the pathogens, (iii) inducing defense mechanisms of hosts and (iv) glucanase and cellulose being prevalent in the soil at a high concentration as a result of cellulose and lignin biodegradation [75]. Besides, the efficiency of *Trichoderma* may be also due to the presence of several volatile and non-volatile antifungal metabolites, a combination of competition and mycoparasitism [75, 76]. Both *Trichoderma* species and bacterial agents produce many mycolytic enzymes, thus playing a key role in the degradation of cell wall of target pathogens [77].

In recent times, bio-priming as a seed treatment that integrates the biological aspects of disease management has been used as an alternative method for mitigating many seed and soil-borne pathogens, and it has emerged as another alternative to chemical fungicides. Also, seed coating with MBCAs is the most efficient treatment for mitigating root rot diseases as shown by many researchers [78, 79]. In this regard, bio-coated cowpea seeds with *Bacillus* species demonstrated a significant ($P < 0.05$) increase in shoot and root length, seed germination and leaf area with increased seed yield [80]. In addition, the bacterium was found as potential antagonists against *M. phaseolina*, *R. solani*, *F. oxysporum*, *F. solani* and *S. rolfsii*. It was also reported [81] that priming of seed with *T. harzianum* at a rate of 4 g/kg of seed along with the application of vermi-compost with 20% neem cake (w/w) mixed with antagonists significantly controlled root and collar rot resulting in increased yield of cowpea.

One of the requirements for execution of MBCAs are the development of suitable formulation and delivery systems [82]. Fabrication procedures for these agents are dependent on enough and efficient biomass formation, which must be carried out carefully in order to retain viability at the end of processing and deployment. Seed treatment with different formulations of *T. koningii* and *T. harzianum* containing 6.8×10^7, 2.0×10^{10} and 1.0×10^7 CFUs/ml significantly controlled dry root rot in cowpea as higher plant survival was reported in treatment plots compared to control plots [83]. In another trial conducted by [84], it was observed that some strains of *P. fluorescence*, *B. subtilis* and *Trichoderma* spp. were found to be potential antagonists in control of FW caused by *F. solani* in chickpea which evidenced that these MBCAs have cross bio-efficacy against the same pathogens of different hosts. Besides, during application of MBCAs, ventilation and drainage of the field should be maintained to avoid high relative humidity, which favours germination of pathogen spores [85].

More recently, biofilms based on MBCAs have been used for the control of many soilborne diseases. In particular, these biofilms are microbial communities adhering to the biotic and abiotic surface, and they are fixed in the organic matrix of biological origin that provides structure and stability to the microbial community. Due to multi-layers of microbial cells, these biofilms play a major role in plant-microbe interaction. For example, seed treatment with *T. harzianum* and *Bacillus* biofilm-based formulations have shown potential disease control caused by *R. solani* and *Pythium aphanidermatum* with only 0–14% disease incidence and increased yield 44–48 g/plant compared to controls [86]. Moreover, the rhizosphere soil of cowpea plants applied with biofilms formulations showed higher propagules of *T. harzianum*. These results are in agreement with earlier researchers who also reported an increase in population of beneficial microbes after application in soil [87–89].

In addition to *Trichoderma*, *Pseudomonas* and *Bacillus*, other MBCAs have also been reported as effective agents against soilborne diseases of cowpea. For example, Hamed et al. [90] reported that *T. asperellum*, *T. roseum* and *Chaetomium globosum* also possessed efficient antagonistic activity against FW and stem rot pathogens, but less than *Trichoderma* species. Some other MBCAs have been found effective against soilborne pathogens of other crops. For instance, the arbuscular mycorrhizal fungus (AMF), *Glomus clarum* has been found to be effective against *R. solani* by reducing the mortality in bean plants [91]. Soil drenched with AMF (*Glomus deserticola* and *Gigaspora gigantean*) before planting and inoculation of *M. phaseolina*, after 10 days of germination, the crop showed higher growth parameters. However, simultaneous treatments of *Gnypeta deserticola*, *G. gigantea* and *M. phaseolina* were the most effective for both growth parameters and reduction of charcoal rot disease severity [92]. Amendments such as soil application of biochar have been reported to improve soil carbon sequestration, soil fertility and plant growth, especially when combined with organic compounds such as compost. This in turn improved plant vigor and the ability of plants to resist pathogen attack [93]. For instance, soil amended with 15% compost was 71.4% effective in controlling damping-off while combination of 15% compost + *mycorrhizae* and 3% w/w biochar + *mycorrhizae* showed 61 and 73.3% efficacy against damping-off [93]. *In vitro* studies conducted also showed that PDA amended with 15% compost reduced *R. solani* mycelial growth by 54% while no mycelial growth occurred on PDA amended with 3% w/v biochar [93].

In addition, research has demonstrated that besides diseases control, MBCAs also increased nitrogen fixation ability. For instance, *B. subtilis* and *T. longibrachiatum* had no negative effects on the nitrogen fixing ability of *Bradyrhizobium* [94]. The application of antagonists in soil through seed treatment and soil application decreased sclerotia germination of *S. rolfsii* which resulted in decreased disease incidence and increased nitrogen fixation ability by *Bradyrhizobium*. Likewise, in beans and soybean, *Bacillus-Rhizobium* inoculants have been used to control root rot caused by *F. solani* [95]. Therefore, more investigation is required to see the effect of *Bacillus-Rhizobium* combination on soilborne diseases of cowpea.

3.4 Role of botanicals against soilborne fungal diseases

The fungicidal properties of aromatic and medicinal plants have been recognized since prehistoric times. Worldwide, plant based natural chemicals and their application for plant protection is one of the focus areas of research. Earlier, plant extracts of many medicinal plants such as neem (*Azadirachta indica*) [96] and garlic (*Allium sativum*) [97] have been used for control of many soilborne fungi. A study by [70] reported that application of *Moringa* extract at a concentration of 15 kg leaves/10 L of water (w/v), exhibited the highest stem rot control in cowpea. In another study, application of *Acacia nilotica* and *Prosopis juliflora* extracts with compost reduced charcoal rot incidence in cowpea by exhibiting <5.8% disease incidence with 28.3% increase in seed yield [98]. Using *P. juliflora* also controlled root infecting fungi (*R. solani*, *Fusarium* spp. and *M. phaseolina*) of cowpea [99]. Through soil amendment method, leaves, stem and flower powder at the rate of 0.1, 1.0 and 5% w/w suppressed the disease incidence and enhanced growth parameters like weight, shoot and root length, leaf area and number of nodules per plant. Soil amended with *Aerva javanica* leaf powder at 1%w/w was effective against several root fungi; *Fusarium* spp., *R. solani* and *M. phaseolina* [100]. In another study by Dawar et al. [101], it was reported that leaves, stem, bark and fruit powder of *Eucalyptus* species have the potential to reduce the infection of root infecting fungi viz., *Fusarium* sp., *R. solani* and *M. phaseolina* in mung bean and chick pea. Therefore, the efficacy of *Eucalyptus* species needs to be tested against soilborne pathogens of cowpea. These results suggest that in resource-deficient farming systems, certain on-farm wastes can be effectively utilized for managing soilborne pathogens, as well as for enhancing crop productivity.

In another study by Dawar et al. [102], charcoal and root rot of cowpea was controlled by seed coating with *Paecilomyces variotii* followed by soil drenching with *Datura alba* Nees extract. Another species of *Datura*, that is, *D. fastulosa* was also reported to be effective against charcoal rot in a pot experiment [103]. The efficacy of *D. alba* reported in this study may be due to presence of some compounds such as 6*B*-tigloxytropane-a-ol, tigloidine (3*B*-tigloyloxytropane), tropine, hyoscyamine, apoatropine and scopolamine present in *Datura* species [104]. Besides, Zainab et al. [105] reported that seed powder of *Adenanthera pavonina*, *A. indica*, *Leucaena leucocephala* and *Eucalyptus* spp. controlled root rot diseases at 0.1 and 1% w/w concentration and extract of *Avicennia marina* (5% w/w) has been found to suppress the growth of charcoal rot fungus in beans [106]. Similar results were reported by [107] who controlled several root rot fungi through seed treatments with *Trichoderma* + leaf extract.

In addition to control of root rot diseases, plant extracts are reported to increase seed germination through decreasing disease incidences [108]. For example, soil application of 1–3% dry leaf biomass of *A. indica* with *T. harzianum* efficiently decreased (20–25%) disease incidence caused by *M phaseolina* in cowpea with improved plant growth attributes [109]. Although extracts of *A. indica* and *Garcinia cola* have shown 77 and 92% inhibition activity against damping-off pathogen, *P. aphanidermatum* [110], they have not been tested under field conditions. Therefore, further experiments are required to validate their efficacy under field conditions.

Besides plant extracts, essential oils extracted from higher plants has also been found effective against some soilborne pathogens. For example, essential oils from wild oregano and black cumin applied at the concentration of 0.16 μl/cm^3 of air have been found effective against *M. phaseolina* and *S. sclerotiorum* under *in vitro* conditions. Similarly, Alice et al. [111] and Kazmi et al. [112] revealed that neem oil was effective against *M. phaseolina*, cinnamon bark and lemongrass essential oils were effective against *R. solani* at 5 mg/paper disc [113]. In addition to essential oils, their chemical constituents such as *trans*-cinnamaldehyde, neral, geranial, salicylaldehyde and hydrocinnamaldehyde have also shown 100% inhibition of growth of *R. solani* at 2.5 mg/paper disc in a laboratory study [113]. However, literature on field efficacy is lacking and therefore, necessitates further investigation in this domain. Since these are only observations of *in vitro* experiments, these investigations should be continued under field conditions as well in order to get more reliable data on prospects of using essential oils in the management of soilborne diseases of cowpea with the aim of keeping the environment and consumer's health safe. The efficacy of different plants extracts reported may be due to the presence of several constituents, that is, tannins, saponins, alkaloids, glycoalkaloids, alkenyl phenols, flavonoids, terpenoids, sesquiterpenes lactones and phorbol esters [114]. The active ingredients identified in these plants can be used for the development of next-generation fungicides.

3.5 Synthetic fungicides for management of soilborne fungal diseases

Most of the pathogens causing root rot diseases in cowpea are soilborne. Therefore, seed treatment prior to sowing is important followed by soil drenching. In integrated disease management, fungicides are an important component for disease management. The majority of systemic fungicides need to be applied before the occurrence of disease or at the appearance of the first symptoms to be effective. Fungicides have 'curative' properties, that is, they are active against those pathogens that have already infected the plant, tend to have a higher risk of pathogens developing resistance to the fungicide. In Benin, the only registered fungicide used on cowpea is Super-Homai 70% PM (active ingredient: methylthiophanate 35%, thiram 20% and diazinon 15%) (SPV, Benin). Unfortunately, there has been a problem regarding the efficacy of this product against pathogens [79].

Control of fungal soilborne diseases of cowpea is achieved by several fungicides. Combined application of carbendazim and mancozeb at the rate of 2 g/L as soil drenching, controlled 14.28% collar rot disease, while 57.4% disease incidence was reported in control plots [86]. Seed soaking with potassium sorbate (9%) or sodium benzoate (20 mM) followed by their foliar spray efficiently reduced root rot incidence caused by *F. solani* and *R. solani* [115]. It was found that Dithane (M-45) gave best control against *R. solani*, *F. oxysporum* and *F. solani* when compared with Benomyl 85 and Bavistin 87% [100]. These results were confirmed by the observations of [116] who reported that these fungicides were effective against root rot diseases of blackgram. Likewise, mancozeb, copper oxychloride, carbendazim and metalaxyl have been used for control of *F. solani* in other arable crops [117, 118]. Treating seeds with broad-spectrum fungicides also helps in controlling other soilborne/seedborne fungi and the decay of seeds. For example, carbendazim (0.2%) and etaconazole (0.1%) have been used for control of *M. phaseolina* in chickpea via application through seed treatment and soil drenching [119]. Similarly, fosetyl-Al, metalaxyl, propamocarb-hydrochloride, and azoxystrobin were used against *Pythium* spp. [120] and azoxystrobine fungicides have been widely used against *R. solani* in other crops [121]. These fungicides can be evaluated against *Pythium* species, *R. solani* and *M. phaseolina* isolated from cowpea for their further application against the cowpea pathosystem.

Furthermore, there has been investigations on the sensitivity of isolated *M. phaseolina* to fungicides under *in vitro* conditions and the efficacy of fungicide application to seed and soil to reduce the population of microsclerotia [111]. Relatedly, Adekunle et al. [83] reported that seeds treated with benomyl at 0.5 g a.i/50 g resulted in 95% plant survival against charcoal rot pathogen. However, control of *M. phaseolina* through chemical fungicides is still complex and neither profitable nor advisable [122]. Although, various studies have reported the efficacy of fungicides against soilborne pathogens of cowpea, they are pathogen-specific and their regular use may cause fungicide resistance. Therefore, more systemic fungicides should be screened against soilborne pathogens of cowpea in order to get more potential fungicides. Furthermore, to reduce the fungicide resistance problems, their mixed application in seed treatment or fungicide rotation strategies should be recommended. Nevertheless, it is very essential to highlight that continuous use of fungicides has a harmful impact on beneficial soil microbial communities, leading to poor soil fertility with reduced productivity [123]. The use of MBCAs in conjunction with fungicides may be one of the strategies for the management of soilborne diseases of cowpea.

3.6 Role of micronutrients and herbicides against soilborne pathogens

Improved plant nutrition through well-balanced fertilization particularly for micronutrients is critical in management of soilborne diseases [38]. A study by [124] reported that amending soil with manganese at a rate of 10 μg/g of soil as $MnSO_4.H_2O$ reduced the severity of root rots caused by *R. solani* and *R. batiticola* by 42.7 and 42%, respectively. Similarly, soil application of herbicide, Basalin 50% E.C (fluchloralin [*N*-(2-chloroethyl]-2,6-dinitro-*N*-propyl-4-trifluoromethylaniline) at a 5 μl a.i/kg soil significantly reduced incidence of seedling mortality (post-emergence damping-off caused by *R. solani*) compared to 63% in untreated controls [125]. *In vitro* studies involving the same herbicides, Fluchloralin and Lasso 50% E.C (alachlor [2-chloro-2′-6′-diethyl-*N*-(methoxymethyl] acetamide) at rates of 10 μl a.i/L at pH 8 inhibited mycelial growth of *R. solani* by 37–38% [125]. Both herbicides reduced damping-off in potted plants kept at 30°C.

4. Challenges and future prospects

Over 95% of the global cowpea production [17] occurs in the least developed countries by resource constrained smallholder farmers with limited knowledge on integrated pest and disease management options. Several cowpea genotypes with resistance or tolerance to several soilborne diseases were identified in many studies conducted in a few locations. This has hindered their widespread use because of adaptability/suitability to a restricted range of geographical conditions. Therefore, variety screening/evaluation should be conducted in diverse geographies across years when developing cowpea lines with disease resistance. Breeding for durable resistance to most soilborne fungal pathogens is still a challenge in many breeding programs due to pathogen diversity and monogenic nature of host resistance [23, 25, 26, 45]. Correct identification of causal pathogens/agents associated with soilborne diseases using rapid and reliable diagnostic assays is therefore needed.

Marker assisted selection (MAS) offers a great opportunity to improve efficiency in selecting progenies with desirable traits. This is because through MAS, selection for resistance can be carried out even in the absence of disease and at early stages of plant development [126]. Use of markers in breeding for resistance to soilborne fungal pathogens in cowpea is however lacking although a few markers were identified.

In many cowpea producing countries, many MBCAs have been experimentally tested and several are commercially available. However, their use or application is still on a very small scale. This is partly because of lack of sensitization of farmers who assume that a crop cannot be grown successfully without application of synthetic fungicides [127]. Creativity and appropriate guidance through proper extension advice is therefore needed to cause mind-set change among farmers who are still inclined to using synthetic pesticides. Many botanicals and bio-based products were evaluated in controlled environments in many studies but their effectiveness under field conditions is not yet fully known. Also, the application rates of some botanicals are unusually high [70] thus additional studies on refining their efficacy are needed.

Globally, resistance to synthetic fungicides is increasingly becoming a big problem. This problem is likely to worsen in many African countries where over 95% of the cowpea cultivation takes place due to laxity in application of fungicide regulations coupled with poor extension services to educate farmers. For instance, there is limited or lack of national, regional or international policies to guide enforcement of sustainable solutions/practices [127]. Unknowingly, majority of farmers think that registered pesticides are safe for the environment and for man, so there is no incentive for them to change. Also, farmers rarely rotate fungicides with different modes of action due to limited knowledge and extension on IDM [128].

Environmental factors such as soil moisture and temperature that greatly contribute to disease development in the field were reported to have an effect on the level of disease development [38]. For instance, initial inoculum load and soil moisture were the main factors responsible for incidence of damping-off and stem rots in cowpea [26]. A good understanding of all key predisposing factors that trigger development of soil-borne diseases is therefore needed.

5. Conclusions

Soilborne fungal diseases poses a major challenge to production of cowpea globally thus necessitating the need for sustainable management approaches that enhance production while also preserving the environment. Stem rot, damping-off, collar rot, *fusarium* wilt and charcoal rot are the main cowpea soilborne diseases. Several management options both chemical (such as synthetic fungicides) and non-chemical (cultural, physical, host-plant resistance and biological) have been researched on by several investigators. Adoption of an integrated disease management framework is the most effective option to sustainably manage these diseases. Described literature revealed that cowpea genotypes with resistance to FW and charcoal rot have been identified and only a few for stem rots, collar rot and damping-off by evaluating cowpea genotypes under natural/artificial conditions. Some of the identified sources of resistance were specific to few strains/races of the pathogen and regions where they were tested. Therefore, evaluation of resistant genotypes for these diseases at multi-locations in a coordinated approach would help in deploying host resistance at a larger scale. Reviewed literature showed that most of the genetic studies focused on *fusarium* wilt resistance and to a small extent charcoal rot and southern blight. Resistance to FW is conditioned by a single dominant gene making it easier to effectively use backcrossing for transfer of resistance to susceptible backgrounds. However, such resistance is most often less durable and thus can easily be broken down. Reviewed literature also showed that molecular markers are available for FW and charcoal rot, however, there is need for their validation before they are widely deployed in breeding programs. More effort is required to develop the molecular markers for other soilborne diseases.

Use of cultural or agronomic practices such as rotation of cowpea with cereal crops (fonio and millet), application of compost and synthetic fertilizers (NPK) was shown to reduce infestation by charcoal rot. However, there is a knowledge gap regarding how much of these practices have been adopted by farmers to manage soilborne fungal diseases in cowpea.

Several studies reported the efficacy of synthetic fungicides against soilborne pathogens of cowpea however, most of these fungicides are pathogen-specific and their regular use may cause fungicide resistance. Therefore, more systemic fungicides should be screened. Furthermore, to reduce the fungicide resistance problems, their mixed application in seed treatment or fungicide rotation strategies should be recommended. However, continuous use of fungicides has a harmful impact on beneficial soil microbial communities, leading to poor soil fertility with reduced productivity.

Concerning the use of MBCAs, several beneficial microbes (*Trichoderma*, Pseudomonas and Bacillus) have been frequently used for the control of soil-borne diseases of cowpea either as seed dresser or soil application. However, their effective use requires the development of suitable formulation and delivery systems. Similarly, several botanicals or plant-based products have been extensively evaluated in the control of soilborne fungal diseases of cowpea but few have been adopted or reached the market due to lack of large-scale field trials. Concerted and well-coordinated efforts among various stakeholders are therefore needed to evaluate prospective MBCAs, and botanical products in fields at multi-locations and commercialization of superior products.

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Conflict of interest

The authors declare that they have no conflict of interest.

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