



Research article

Management of *Fusarium Solani* (Root Rot of Common Bean) Using Disparate Methodologies

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A B S T R A C T

Common bean is frequently infected by several pathogens, which reduce its yield (20–100%) and product quality. Three sub-trials were employed to proffer solutions to the infection of beans by *Fusarium solani*. All three sub-trials (botanical, chemical, and bio-control) were set up using the completely randomized design, with each treatment replicated thrice *in vitro*. The results of applying synthetic fungicides (i.e., metalaxyl, metalaxyl+copper, and metalaxyl+carboxin) revealed that all the fungicides were significantly different ($P \leq 0.05$) compared with the control. Metalaxyl (single agent) was significantly ($P \leq 0.05$) less effective compared to combined formulations with metaxyl and other agents. The best treatment was Metalaxyl+Copper (100% concentration), followed by Metalaxyl+Copper (50% concentration), then Metalaxyl+Carboxin (100% concentration), Metalaxyl+Carboxin (50% concentration) in descending order of performance. All the plant extracts (Silk cotton (*Ceiba pentandra*), Tamarind (*Tamarindus indica*), wild cardamom (*Sulettaria surculosa*), and Eucalyptus (*Eucalyptus globulus*)) were significantly different ($P \leq 0.05$) compared with the control. The highest control of this pathogen was attained using Eucalyptus (100% concentration), followed by Eucalyptus (50% concentration), Cardamom (100% concentration), Cardamom (50% concentration), Silk cotton (100% concentration), Tamarind (100% concentration), Tamarind (50% concentration), and finally Silk cotton (50% concentration). The inhibitory efficacy of *Trichoderma* isolates shows that they were significantly different ($P \leq 0.05$) compared with the control. *Trichoderma harzianum* isolates AIM22 and *Trichoderma hamatum* isolate ZXPB provided the best control, followed by *Trichoderma harzianum* isolate AIBN, and finally *Trichoderma viride* isolate AIBK. In conclusion, these botanical, chemical, and bio-control agents revealed their potency in managing *Fusarium solani*.

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1. INTRODUCTION

Stenglein et al. (2003). FAO (2007), Drost (2010), and Gupta and Singh (2020) stated that common bean (*Phaseolus vulgaris* L.) is an important source of plant protein globally. Muedi and Fourie (2014) and Broughton et al. (2003) empathetically argued that common bean is one of the chief legumes consumed by man, and 30% of the crop is produced by resource-poor, small-scale farmers in Latin America and Africa. Pamela et al. (2014) expounded that this crop is the second most important source of dietary fiber for humans and the third most important source of calories in Eastern and Southern Africa. Muedi and Fourie (2014) maintained that dry beans are among the most affordable high-protein sources globally.

Drost (2010) elaborated that the common bean includes many varieties and may be referred to as bush beans, dry beans, dwarf beans, field beans, snap beans, garden beans, haricot beans, kidney beans, pole beans or string beans, pinto beans, black beans, navy beans, French beans, small red beans, etc.

The common bean comprises seed-pulse and green vegetable produce, which may be eaten fresh or cooked. Abueleliwa et al. (2022) explicated that beans can be prepared differently (i.e., boiling, frying, and baking). Beans are used in many traditional dishes worldwide; alternatively, they are preserved by drying or canning.

However, Muedi and Fourie (2014), Pamela et al. (2014), Gupta and Singh (2020), and Daba (2022) indicated that beans are infected by several fungi, bacteria, and viruses, which reduce the yield and the quality of this desirable produce. Singh and Schwartz (2022) elucidated that diseases cause severe yield losses (20–100%) and reduce the quality of common bean globally. The *F. solani* is cosmopolitan and can yield losses of 6-53% or more (Abawi, 1989).

Nonetheless, various fungicides are routinely utilized in southern Africa to control bean rust. The application of tebuconazole resulted in tripling the yield of beans even under severe disease conditions (Liebenberg & Pretorius, 2010). Picinini and Fernandez (2000) pointed out that in other regions of Africa, fungicides (i.e., tebuconazole,

mancozeb, and benomyl) are regularly applied against angular leaf spot disease of beans.

Muedi and Fourie (2014) and Schwartz (2016) recounted that pesticides should be applied early enough. They emphasized that ‘once the bacterial symptoms are already visible, it is already too late for the chemicals to be effective, and it will only control the spreading of the disease’ to new plants or tissues.

Muthomi et al. (2017) lamented that using synthetic pesticides in bean production has been detrimental to the marketing of Kenyan snap bean pods due to the presence of chemical residues, which do not meet the stringent regulations by importers. Obes-Corrêa et al. (2014) narrated that there is a positive potential of bio-control using *Bacillus subtilis* to manage plant fungal and bacterial diseases (i.e., bacterial wilt, *Fusarium* wilt, charcoal rot, and angular leaf spot) of dry beans.

Sikora et al. (2018) recommended the use of seed treatment or soil drench application of fungicides containing metalaxyl (as active ingredient) to control *Pythium* spp. or those containing pentachloronitrobenzene (PCNB) to control *Rhizoctonia* root rot disease. However, they stated categorically that fungicides have no lethal effect against *Fusarium* root rot disease caused by *F. solani*.

In the tropics, research on the management of diseases of common bean is erratic, inadequate, and rudimentary. Employing alternative, environmentally friendly methods to control this pathogen could produce wholesome, clean, and sound produce. Based on the foregoing discourse, this study was carried out to document the diseases that infect beans and proffer practical solutions (i.e., botanical, bio-control, and chemical agents) to control *F. solani* associated with the production of common beans.

2. METHOD

2.1. Site of the Study

The study was carried out in the Plant Pathology Laboratory of the Crop Science Department, Alex Ekwueme Federal University, Ndufu-Alike, located in the environs of Abakaliki municipality (6.069°N by 8.199°E at 57 m above sea level). The site is in Nigeria's semi-humid, derived savannah ecological zone with well-drained, iron-rich, highly leached loamy soils. However, beans prefer

fertile, well-drained soil with a pH between 6.0 and 6.75 (Drost, 2010). Thus, we can see a recipe for bean disease epidemics.

The main occupation of the inhabitants of the south-eastern region of Nigeria, West Africa, and Africa at large is subsistence farming. Yams, maize, beans, cocoyams, sweet potatoes, and many other tropical crops are cultivated in Ebonyi State. The climatic pattern in the region is tropical, as seen in Figure 1 for succinctness and lucidity. Based on this chart, the mean monthly relative humidity is above 70% all year round, the maximum monthly temperature is above 28°C, and it rains heavily for more than seven months. This is a harbinger of severe plant diseases like root rots.

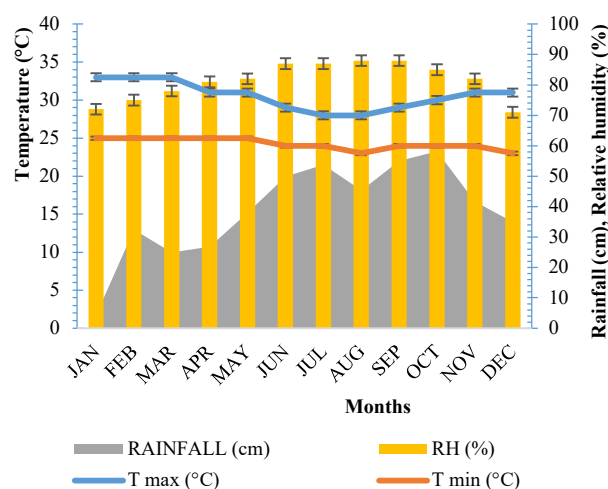


Figure 1. Monthly temperature, rainfall, and relative humidity for Ebonyi State, Nigeria.

Sources: As compiled from 35-year climate trends: www.Meteoblue.com Weather 2006-2020. www.Climate-data.org. www.Timeanddate.com 1999-2020. Compiled by this author.

2.2. Isolation, identification, and sub-culturing of *F. solani* associated with common beans

The isolates of *F. solani* encountered were obtained from infected common beans (*Phaseolus vulgaris* L.) sourced from local bean farms in Plateau State (at 08°24'N by 10°38'E with altitude of 1280 m above sea level), from Kaduna State (at 10°31'35" N by 7°26'19" E with altitude of 626 m above sea level), and from Ebonyi State (at 6°15'0" N and 8°4'60" E with altitude of 130 m above sea level) of Nigeria. This pathogen was isolated from all three altitudes (low, mid, and high altitude). This pathogen was selected for this study based on its frequency of occurrence and the importance of the global disease. Work will continue on the other, less frequently recovered pathogens of common beans.

Different fungi isolates were isolated using Acetate Differential Agar® (Difco, USA) enriched with dextrose (ADAD), and the cultures were purified using potato dextrose agar (PDA) (Lifesave Biotech, USA). The media were autoclaved for 15 minutes at 121 °C and 15 psi. Each medium was allowed to cool to approximately 45 °C, then 50 mg/L streptomycin sulphate was added to the conical flasks. The content of the conical flask was swirled around to mix without creating bubbles (Dhingra & Sinclair, 2005; Ndifon et al., 2018). The fungus was identified using microscopy (i.e., an Olympus 100 compound microscope) and fungi identification keys (Barnett & Hunter, 1999).

2.3. Preparation of the Plant Extracts

The plant extracts used for bioassay were selected based on their indigenous medicinal uses. The plant materials included extracts of silk cotton bark, tropical almond leaves, native cardamom seeds, and eucalyptus resin. The plant tissues were weighed at 333.3 g bark or leaves or 163.5 g seeds/resin per liter of sterile distilled water to give the 100% full-strength concentration.

The plant tissues were washed in distilled water and surface sterilized for 10 minutes using 1% sodium hypochlorite solution. Silk cotton utilized is *Ceiba pentandra*, and Tamarind is *Tamarindus indica*. Wild cardamom utilized is *Suaeda frutescens* (syn. *Elettaria surculosa*), and Eucalyptus used is *Eucalyptus globulus*.

Each plant tissue was rinsed thrice using sterile distilled water, chopped into small pieces, and blended using an electric blender (Warrington blender; England). Each plant extract was allowed to stand for 72 hours before it was filtered (using Whatman No. 1 filter paper) into sterilized conical flasks. The plant extracts were used at 0.0, 50, and 100%. The 50% concentration was obtained by diluting the full-strength extract using sterile distilled water.

2.4. Experimental Layout

2.4.1. Sub-trial 1. Assessment of the inhibitory efficacy of plant extracts to control *F. solani* in vitro

The experiment was laid out using a completely randomized design. The nine treatments included plant extracts from silk cotton bark, tropical almond (tamarind) bark, native cardamom seeds, eucalyptus bark (each at 50% and 100% concentrations), and a plant extract-free control. The plant extracts were prepared as discussed above. Each treatment was replicated three times. Potato dextrose agar was poured at 15 ml per Petri dish and allowed to set in the laminar air flow system (Dhingra &

Sinclair, 2005). The inoculation was carried out using a 2-mm disc of mycelium excised (using a sterilized cork borer) from the fungi colony placed at the edge of the Petri dish.

2.4.2. Sub-trial 2. Assessment of the inhibitory efficacy of synthetic fungicides applied against *F. solani* in vitro

The experiment was laid out using a completely randomized design. The nine treatment sets comprised two rates of metalaxyl, metalaxyl + copper, metalaxyl + carboxin (each at 50 and 100% concentrations), and a negative control. Each treatment was replicated three times. The quantities utilized were 2.5 g/L of metalaxyl, copper, and carboxin, while combined chemical treatments were composed at 0.5:0.5 of 2.5 g/L. Potato dextrose agar was poured at 15 ml per Petri dish and set in the air-flow hood (Dhingra & Sinclair, 2005). The inoculation was carried out using a 2-mm disc excised (using a sterilized cork borer) from the colony of the fungi, which was placed at one edge of the Petri dish.

Carboxin (Synonyms: carboxine; carbathiin; vitavax; fenoxan) is an anilide systemic fungicide from the oxathiin class of chemical agents. Metalaxyl is a systemic acylalanine (phenylamide) fungicide with systemic function. Its chemical name is methyl N-(methoxyacetyl)-N-(2,6-xylyl)-DL-alaninate. Metalaxyl has a protective and curative mode of action.

2.4.3. Sub-trial 3. Assessment of the inhibitory efficacy of *Trichoderma* isolates applied against *F. solani* in vitro

The experiment was laid out using a completely randomized design. The five treatment sets consisted of *Trichoderma viride* isolate AIBK, *Trichoderma harzianum* isolate AIBN, *Trichoderma hamatum* isolate ZXPB, *Trichoderma harzianum* isolate AIM22, and a control. Each treatment was replicated three times. Potato dextrose agar was poured at 15 ml per Petri dish and set in the air flow hood (Dhingra & Sinclair, 2005). Two lines were ruled under each petri dish at right angles to each other (i.e., to ensure the full diameter will be used for inoculation) using a permanent marker. The fungal inoculants comprised 2-mm disks of 9-day-old *Trichoderma* species and *F. solani* cultures. Each bio-control agent and pathogen was placed at the edge of the Petri dish (on the same diameter line) using a flamed inoculating loop.

2.5. Data collection and analysis

The Petri dishes were incubated on the laboratory bench, and data on the radial growth (cm) were measured using a transparent rule (i.e., at 24-hour intervals) till each trial was

terminated. The radius of the fungal colony was measured using a transparent ruler at 24-hour intervals starting from day 1 through day 5. The percentage inhibition was calculated using the following equation 1 (Ndifon, 2022b):

$$PI\% = ((C - T) / C) \times 100 \quad (1)$$

Where,

PI = % inhibition of growth of the fungus

C = Perpendicular* radius of fungal colony in the control plate

T = Perpendicular radius of fungal colony in treated plate

*perpendicular refers to 'right angle' through the center of the Petri dish.

The data were subjected to analysis of variance, and the means were separated using Tukey's HSD test ($P \leq 0.05$). Genstat Discovery 2nd Edition and IBM Statistical Package for Social Sciences (SPSS) version 23 were used to process the data.

3. RESULTS AND DISCUSSION

The results of the sub-trial on inhibiting the growth of *F. solani* using synthetic fungicides are presented in Table 1. The results revealed that all the fungicides were effective and significantly different ($P \leq 0.05$) compared with the control. The results showed that the pathogen was controlled most effectively with combinations of fungicides. When Metalaxyl was applied singly, it produced good results that were significantly different ($P \leq 0.05$) compared to the control. Metalaxyl (single agent) was significantly ($P \leq 0.05$) less effective than when it was combined with other agents.

The best treatment was Metalaxyl + Copper 100% followed by Metalaxyl + Copper 50%, Metalaxyl + Carboxin 100%, and Metalaxyl + Carboxin 50% in descending order of preference at 48 hours after inoculation (HAI) through 144 HAI. The performance of the agrochemicals was consistent and persistent.

Likewise, the results of the inhibitory efficacy of plant extracts applied against *F. solani* are presented in Table 2. The results revealed that all the plant extracts were effective and significantly different ($P \leq 0.05$) compared with the control from 24 HAI through 96 HAI. The results showed that Eucalyptus 100% resin plant extracts controlled the pathogen most effectively. The half rate of Eucalyptus plant extract was also very good at managing the pathogen.

This trend was followed by Cardamom 100% then Cardamom 50%. Silk cotton 100% was an excellent treatment against the pathogen after Eucalyptus and Cardamom. The half rate of Silk cotton was the least effective treatment against the pathogen. However, Silk

cotton 50% was significantly different compared with the control. Tamarind 100% was the subsequent treatment, which performed slightly less than Silk cotton 100%. Tamarind 100% was significantly different ($P \leq 0.05$) compared with Tamarind 50% which followed it in terms of high quality of control of the pathogen.

The results of inhibiting the pathogen using *Trichoderma* isolates are presented in Table 3. The performance of the isolates and species of *Trichoderma* was significantly different ($P \leq 0.05$) compared with the control throughout the sub-trial period. *Trichoderma harzianum* isolate AIM22 and *Trichoderma hamatum* isolate ZXPB provided the best pathogen control from 24 through 72 HAI. *Trichoderma harzianum* isolates AIBN, the next most preferred bio-control agent, and was technically on par with the best bio-control agents used. The bio-control agents were at par with the control during the first 48 HAI, but at 72 HAI, the trend was more evident. *Trichoderma viride* isolate AIBK was the least effective bio-control agent, but it performed significantly better than the control.

Table 1. Inhibitory efficacy of chemical fungicides applied against *F. solani* in vitro

Synthetic fungicide treatments	Radial growth (cm) of the pathogen after inoculation at		
	48 hours	96 hours	144 hours
Metalaxyl + Copper 100%	0.17a	0.27a	1.47a
Metalaxyl + Copper 50%	1.10ab	1.83b	2.83ab
Metalaxyl + Carboxin 100%	1.57ab	3.33bc	4.17bc
Metalaxyl + Carboxin 50%	2.10b	4.00c	5.37cd
Metalaxyl 100%	2.20b	3.53c	5.33cd
Metalaxyl 50%	2.50b	4.23c	6.70de
Control	5.07c	8.17d	9.00e
S.D.	1.555	2.359	2.463
S.E.	0.339	0.514	0.537

Means followed by the same letter(s) in a column are statistically similar based on Tukey's HSD ($P \leq 0.05$)

Table 2. Inhibitory efficacy of plant extracts applied against pathogen *F. solani* in vitro

Botanicals	Radial growth (cm) of the pathogen after inoculation at			
	24 hours	48 hours	72 hours	96 hours
Eucalyptus 100%	0.00a	0.13a	0.13a	0.27a
Eucalyptus 50%	0.43a	0.43a	0.77ab	1.00a
Cardamom 100%	0.53ab	1.00ab	1.33bc	2.17b
Cardamom 50%	0.87ab	1.60bcd	2.17cd	3.00bc

Silkcotton 100%	0.73ab	1.37a-d	2.53de	3.40c
Tamarind 100%	0.83ab	1.67bcd	2.27cd	3.27c
Tamarind 50%	1.10b	2.17cd	3.33ef	4.53d
Silkcotton 50%	1.27b	2.67d	3.67f	4.50d
Control	3.23c	5.07e	6.67g	8.17e
S.D.	0.929	1.465	1.868	2.229
S.E.	0.179	0.282	0.359	0.429

Means followed by the same letter(s) in a column are statistically similar based on Tukey's HSD ($P \leq 0.05$)

Table 3: Inhibitory efficacy of *Trichoderma* isolates applied against *F. solani* in vitro

Biocontrol agents	Radial growth (cm) of the pathogen after inoculation		
	24 hours	48 hours	72 hours
<i>Trichoderma harzianum</i> AIM22	1.63a	3.27a	3.87a
<i>Trichoderma hamatum</i> ZXPB	1.33 a	2.80a	4.10a
<i>Trichoderma harzianum</i> AIBN	1.60a	3.40ab	4.67ab
<i>Trichoderma viride</i> AIBK	1.57a	3.33ab	5.50bc
Control	3.23b	5.07b	6.67c
S.D.	0.801	0.978	1.133
S.E.	0.207	0.253	0.293

Means followed by the same letter(s) in a column are statistically similar based on Tukey's HSD ($P \leq 0.05$)

Bean farmers can use the verdicts of this study on a case-by-case basis. However, the integrated disease management principle is the final goal of any crop protection endeavor, no matter how long the research goes on. This midway issue report will add more stuff to the farmers' arsenal. Trutmann et al. (2008) reiterated that bean farmers routinely engage various strategies, including manipulating sowing density and time of sowing, choice of soil, use of crop varieties, crop variety and species mixtures for specific conditions, foliage reduction, staking, and selective weeding to produce wholesome produce.

G.R.G.C. (Grain Research and Growers Corporation) (2018) also pointed out that disease management is essential for successful bean production to avoid yield and quality reduction. They lamented that debauched experience with disease epidemics and the effort required to manage disease has led some growers to discontinue growing beans. Schwartz (2016) emphasized that bacterial pathogens of dry and snap beans can only be managed by carefully implementing integrated crop production strategies. These diseases cannot be eliminated. Elimination of pathogens is technically not advisable based

on economics and ecology. These approaches reduce or delay disease severity during the critical vegetative and reproductive plant growth periods. These proposals fully agree with this study's goal to give farmers a free choice of management measures against pathogens.

This study showed that applying metalaxyl, copper, and carboxine against bean diseases is rare. When applied singly or concomitantly, these synthetic agents were highly effective against this pathogen. G.R.G.C. (2018) agrees with the findings of this study by concurring that the registered fungicides for beans are mancozeb, carbendazim, chlorothalonil, copper, metiram, procymidone, and tebuconazole (available in the USA under permit (PER13752)). Sikora et al. (2018) stated categorically that fungicides have no lethal effect against *Fusarium* root rot disease caused by *F. solani*, which contradicts the current study's findings.

Thus, G.R.G.C. (2018) recommended that it is best to alternate carbendazim with either chlorothalonil or mancozeb, which aligns with the composition of the treatments used in this sub-trial. Using chemical mixtures will reduce labour demands, reduce the development of resistance by pathogens, and may allow for the use of lower quantities of pesticides.

Disease control by applying agrochemicals like Thiram, PCNB, Benomyl (0.56 kg/ha), Captafol (4.7l/ha), and Busan 30A reduces *Fusarium solani* (*Fusarium* root-rot) severity on hypocotyls and roots of young seedlings (Abawi, 1989). This corroborated the findings of the current study.

Likewise, Sikora et al. (2018) buttressed that the most effective methods employed to control bean anthracnose include using disease-free seed, rotating crops, and following a fungicide spray program (i.e., apply a fungicide with the active ingredient chlorothalonil) initiated through a disease scouting program. Use of fungicides containing sulfur to control powdery mildew was highly solicited.

Stenglein *et al.* (2003) projected that every 10% increase in angular leaf spot severity results in 7.9% yield loss. However, they lamented that fungicide application in common bean production is exceptionally uncommon; thus, this present sub-trial may aid in providing more useful fungicides to bean farmers.

Common bacterial blight and bacterial wilt are only partially controlled by copper fungicides, so applying the pesticide as a preventive agent gives acceptable control. Nonetheless, various fungicides are routinely used in southern Africa to control bean rust (Liebenberg & Pretorius, 2010).

Using tebuconazole resulted in tripling of the yield of beans even under severe disease conditions (Liebenberg & Pretorius, 2010). Picinini and Fernandez (2000) pointed out that in other regions of Africa, fungicides (i.e., tebuconazole, mancozeb, and benomyl) are regularly applied against angular leaf spot disease of beans.

Muedi and Fourie (2014) recounted that pesticides should be applied early enough. They emphasized that 'once the bacterial symptoms are already visible, it is already too late for the chemicals to be effective, and it will only control the spreading of the disease' to new plants or tissues. Common bacterial blight and bacterial wilt are only partially controlled by copper fungicides, so applying the pesticide as a preventive agent gives acceptable control.

Schwartz (2016) agreed that when pathogens have become established and disease symptoms are evident, copper sprays can help reduce the pathogen's spread to healthy foliage and pods. However, the bacteria inside lesions are not affected by this copper treatment.

Drost (2010) pointed out that the *Alternaria* leaf spot on bean leaves and pods can be managed with foliar fungicide application. Drost also bemoaned that there is no true immunity to white mold disease in any bean variety, which corroborates the aim of this study to proffer diverse effective means to manage pathogens of beans. As was pointed out, this can help reduce the buildup of disease resistance.

Muthomi et al. (2017) lamented that using synthetic pesticides in bean production has been detrimental to the marketing of Kenyan snap bean pods due to the presence of chemical residues, which do not meet the stringent regulations by importers. Therefore, we advise farmers to apply bio-control and botanicals and utilize chemical controls cautiously or less often.

Paparu *et al.* (2014) observed that attendant infection by causal agents of angular leaf spot and rust resulted in more than 50% snap bean yield loss in fields. Concomitant infection by two or more pathogens may synergistically affect crop yield (de Jesus Junior, 2001).

Drost (2010) stated that bacterial blight (*Xanthomonas campestris* (syn. *Xanthomonas axonopodis*)) may be managed using appropriate protective copper-based fungicide before the appearance of symptoms. When managing diseases, one can unintentionally offset the balance of nature. Thus, using copper against this fungus pathogen was necessary to confirm the efficacy of copper-based fungicides against fungi, as it has been shown that it also controls bacteria.

For eons, copper has been used against fungi, including powdery mildews on grapevine. The present study filled this gap and showed that single-agent metalaxyl was less effective than combined agents.

Beans seem to be left to fight against pathogens as best as possible. The choice of control agents is minimal. Regrettably, very little work has been done on bio-control and botanical agents against pathogens in producing beans.

Muthomi et al. (2017) set up field experiments using *Trichoderma* spp., *Paecilomyces* spp., and plant extracts (sourced from turmeric, garlic, ginger, and lemon), which were applied weekly as foliar sprays against populations of whiteflies and thrips infesting beans.

Eventually, these plant extracts attained up to 58% and 41% control of whiteflies and thrips, respectively. While *Trichoderma* spp. Moreover, *Paecilomyces* spp. had a corresponding 30% and 18% reduction in whitefly and thrips populations, respectively. The findings of this current study have also shown that bio-control and botanical agents may be profitably applied against fungi associated with beans.

Pamela et al. (2014) expatriated that angular leaf spot and rust are important diseases of common beans (*Phaseolus vulgaris* L.) in the tropics, causing yield losses of up to 100%. They emphasized that in 2010, the incidence and severity of angular leaf spot in Uganda ranged between 40-99% and 21-80% respectively. Furthermore, the incidence and severity of rust ranged between 37-69% and 24-44% respectively. This rust may result in an estimated yield loss of 191,400 metric tons per annum in Africa (Wortmann et al., 1998).

Due to climate vagaries and growing population pressure, Africa cannot afford this monumental food waste. Thus, this current research is timely and can help reduce this yield loss. The current trial is only a drop in the ocean. Bean production is taxing, considering the array of severe yield-reducing fungi, bacteria, viruses, nematodes, and infecting beans.

Harveson et al. (2010) and Botelho et al. (2013) stated that white mold is one of the most important diseases of beans in temperate areas, which can result in more than 90% yield loss. In the USA, Brazil, and the Philippines, *Rhizoctonia* root rot causes 5 to 10% yield loss or more. Hagedorn and Inglis (1986) conveyed that yield loss due to angular leaf spot disease may range from 10% to 50% globally, especially in the tropics and subtropics. This shows that urgent action should be taken to ensure that we still have these palatable beans on our tables and that bean farmers can stay in business.

4. CONCLUSIONS

Bean production is plagued by many diseases globally; however, minimal research has been conducted to submit solutions to these yield-squandering pathogens. This study utilized three sub-trials to provide sound recommendations for bean farmers on combating the pathogens they face. Applying synthetic agrochemicals (metalaxyl, metalaxyl + copper, metalaxyl + carboxin) at two rates proved highly effective against *F. solani*. Likewise, the sub-trial utilizing plant extracts (from eucalyptus, silk cotton, tamarind, and cardamom) proved very effective against the pathogen. Using four biocontrol *Trichoderma* isolates (*T. hamatum*, two *T. harzianum* isolates, and *T. viride*) against this pathogen proved highly effective. The pathogen was subdued by all levels of the chemicals, botanicals, and biocontrol agents; thus, these control agents are recommended.

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