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Effect of Integrated Management of Anthracnose (*Colletotrichum lindemuthianum*) on Plant and Seed Health of Common Bean in Hararghe Highlands, Ethiopia

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Abstract

Bean anthracnose, caused by *Colletotricum lindemuthianum* (Sacc. & Magn.) is an important disease affecting common bean (*Phaseolus vulgaris* L.). Information on yield losses and management options addressing both seed and soil-borne inoculum sources of this disease is lacking in Hararghe highlands which produces common bean in large areas. The present study was undertaken to evaluate the effect of integrated management of bean anthracnose through soil solarization and fungicide applications on disease development, seed health and seed yield of common bean variety Mexican-142. Field experiments were conducted at Haramaya University main campus and Hirna Research Sub-Station in 2010 main cropping season. Soil solarization was integrated with mancozeb and carbendazim seed treatments, with foliar sprays of carbendazim at the rate of 0.5 kg/ha at 10 and 20 days intervals. The experiment was arranged in 2 x 3 x 3 split-split plot design with three replications. A total of 18 treatments were evaluated. There was significant difference in the anthracnose incidence, severity, infected pods per plant, infected seeds and AUDPC among treatments. Combined effect of mancozeb seed treatment with carbendazim spray at 10 day intervals and carbendazim seed treatment and carbendazim spray at 10 day intervals have reduced severity by 46.5% and 41%, respectively at Haramaya. Interactions of solarized soil with carbendazim foliar spray frequencies at 10 days interval reduced the number of infected pods per plant by 58% at Haramaya and 38.9% at Hirna. Seed treatments, foliar sprays and soil solarization alone as well as their interactions did not significantly affect pods per plant and seeds per pod at both locations. The combinations of solarized soil + mancozeb seed treatment + carbendazim foliar spray at 10 day intervals produced seed yield of 3.8 t h^{-1} at Haramaya and 3.6 t h^{-1} at Hirna over the control. In the results concluded that, the integration of soil solarization, seed treatments and foliar spray were found to be effective in reducing bean anthracnose epidemics and increasing yield. Extensive studies are recommended for detection of seed health and management options to enhance high quality of common bean production in these regions.

Keywords: *Colletotrichum lindemuthianum*, disease severity, fungicide seed treatment, seed infection, soil solarization.

Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important food grain legume across tropical regions. Its production has been estimated at 18.43 million metrictons, which represents 32.7% of total world food grain-legume production (FAO, 2005). For many millions of households in the tropical regions, the crop is a source of food nutrients (proteins, minerals, fiber, and vitamins) and also a source of cash (Popelka *et al*., 2004). The highest production and area under beans in Africa is in the east and central Africa regions, where beans are mainly grown by resource poor farmers (Wortman *et al*., 1998; FAO, 2005). Economic significance of bean is quite considerable since it represents one of the major food and cash crops (Habtu, 1994). In Ethiopia, common bean is mainly grown in eastern, southern, south-western, and the Rift Valley areas of the country (Habtu *et al*., 1996).

Rust (*Uromyces appendiculatus* (Pers. Unger)), anthracnose (*Colletotrichum lindemuthianum* Sacc. & Magn.), common bacterial blight (*Xanthomonas campestris* pv. *phaseoli* (Smith) Dawson are the major diseases identified to cause yield reduction in Ethiopia (Habtu, 1987). Among these major diseases, anthracnose caused by *C. lindemuthianum* is the most devastating seed-borne disease of common bean (Schwartz *et al*., 1983). Infested debris and soils are among the potential sources of primary inoculum. This disease is widespread in nearly all bean growing regions of the world and often causes severe damage, which affects yield, seed quality, and market ability (Schwartz *et al*., 1983).

Significant disease development and yield losses occur if weather conditions are prolonged throughout the pod formation and pod filling stages of the crop (Peloso, 1992). The management of primary inoculum sources is key strategy in controlling bean anthracnose (Hall, 1994). Various control strategies have been advocated in an attempt to reduce losses caused by anthracnose (Zaumeyer and Thomas, 1957; Chaves, 1980; Ferraz, 1980). The use of seed treatment is an important practice for disease control in general and for anthracnose management in particular (Freeman *et al*., 1997). However, seed treatment alone could be inefficient and would often require follow-up applications of contact or systemic foliar fungicides (Koch, 1996).

Soil solarization has been identified as an environmentally sound, pesticide free, low cost method of controlling a wide variety of soil-borne fungal plant pathogens, parasitic nematodes and weeds (Katan, 1981; Barbercheck and Broembsen, 1986). Minimizing seed infections and destruction of soil-borne inoculum could lead to effective management of the disease in the growing crop and seed. In spite of such treatments, should the disease appear during the season, it can be handled through foliar application of suitable fungicides. However, there is no empirical research data locally on integrated disease management addressing both seed and soil-borne inoculum sources of bean anthracnose. Therefore, the present study was undertaken to determine the effect of integrated management of bean anthracnose through soil solarization and fungicide applications on epidemics of the disease, and their productivity of seed health as well as seed yield.

Materials and Methods

Description of the Study Sites

The study was conducted at Haramaya University experimental field in the main campus and Hirna Sub-Research Station. Haramaya is located at 9°26'N latitude, 42°30'E longitude and at an altitude of 1980 meters above sea level. The site received mean annual rainfall of 780 mm, with mean minimum and maximum temperatures of 8.25 °C and 24.4 °C, respectively. On the other hand, Hirna is located at 9°12'N latitude, 41°4'E longitude and at an altitude of 1870 meter above sea level. The site received a mean annual rainfall of 990-1010 mm with an average temperature of 24 °C.

Experimental materials and design

The bean variety Mexican-142, which is susceptible to anthracnose (Beshir, 1997), was used for both experiments; in addition, mancozeb was used for seed treatment at 3 g/kg while carbendazim was used for seed treatment at 2 g/kg and as foliar spray at 0.5 kg/ha. Transparent plastic sheet was used for soil treatment.

Table 1. List of fungicides, their respective dosage and spray frequencies

Fungicides		Dosage*	Seed treatment and spray frequencies
Trade name	Common name		
Pencozeb 80 WP	Mancozeb	3 g/Kg seeds	Seed treatment 24 hour before sowing
Bavistin DF	Carbendazim	2 g/Kg seeds	Seed treatment 24 hour before sowing
		(0.5 Kg/ha)	Every 10 days (3 sprays both at Haramaya and Hirna)
			Every 20 days (2 sprays both at Haramaya and Hirna)

*Seed treatment dosages used were based on recommendation of the manufacturers and dosage used for foliar spray was based on CIAT (1988).

Two soil solarization treatments by comparing them with control were evaluated. After ploughing the plots, the area to be solarized was leveled and made free from weeds, debris, and large clods that could raise the plastic-off ground. The soil was turned over by hand and raked smooth to provide an even surface. Transparent plastic sheeting that was 0.001inch thick was laid by hand (i.e. close to the soil), and anchored to the soil by burying the edges in trench around the treated area. The plastic was kept in place from 4th week of May to 4th week of June in 2010 for one month to allow the soil to heat to the greatest depth as possible.

Foliar spray with carbendazim (Bavistin DF) at the rate of 0.5 kg ha^{-1} (CIAT, 1988), and at three rounds of application (including control) was used as the third component of the experimental treatments. Frequencies consisted of spraying at 10 days' interval as of disease onset, spraying at 20 days' interval and no spray (Table 1). Spraying of fungicide started 42 days after sowing (DAS) at Haramaya and 50 DAS at Hirna, i.e. when the first symptom of the disease appeared. The experiments relied entirely on natural infection, because both sites are hot spot areas for the disease. Seeds were treated with mancozeb or carbendazim 24 hours before sowing and untreated seeds served as control. Planting was done on July 5, 2010 at Haramaya University and July 13, 2010 at Hirna Sub Research Station on previous plots plated with common bean to get increased disease pressure.

The treatments consisted of two soil solarization (solarized and non solarized), three foliar spray frequencies (no spray, 10 days interval, 20 days interval) and three fungicide treatments (mancozeb, carbendazim and no treatment) combined factorially in a split-split plot design with three replications at each of the experimental site. Total of 18 treatment combinations were evaluated. Main plots were assigned to soil solarization, sub-plots to frequencies of foliar sprays and sub-sub plots to seed treatments. Each sub-sub-plot (2.4 x 2) consisted of six rows, and distance between rows and between plants were 40 and 10 cm, respectively. There were 20 plants per row and the four central rows were harvested for determining yield. There were 0.8 m space between sub-sub plots, 1 m between sub-plots and 1 m between main plots.

Data Collection and Analysis

Anthracnose incidence and severity assessments were started at disease onset, 10 days' intervals at both locations. Using ten randomly pre-tagged bean plants in the four central rows, severity was rated using standard disease scales of 1- 9 (CIAT, 1987), where, 1=no visible disease symptoms and 9=more than 25% of leaf surface area with large coalescing and generally necrotic lesions resulting in defoliation. The severity grades were converted into percentage severity index (PSI) for analysis (Wheeler, 1969).

$$PSI = \frac{Sum\ of\ numerical\ ratings \times 100}{No.of\ plants\ scored\ \times maximum\ score\ on\ scale}$$

Number of infected pods per plant was determined as the average number of infected pods of ten randomly pre-tagged plants. Seed yield (tons/ha) was obtained from the four central rows of each experimental plot; it was converted into tons per hectare (after adjusting to 10% seed moisture content using moisture meter).

Seed health testing

Direct (visual) inspection to observe signs of the pathogen and agar plate incubation methods were used for seed health testing. For visual inspection method, 100 seeds were taken at random from harvested seed lots of each sub-sub plot and examined for brown discoloration visually and under stereomicroscope, and finally percentages of seeds infected by *Colletitrichum lindemuthianum* were recorded. For agar plate incubation, 100 seeds per sample were selected, dipped in 1% sodium hypochlorite solution and rinsed three times in sterilized distilled water. Then seeds were transferred to PDA plates (5 seeds per plate) and incubated at 25 °C for 10 days. The number of infected seeds were determined and at the end percentages of total infection by anthracnose were calculated (Amare, 2009).

The area under the diseases progress curve (AUDPC) from PSI was computed using the following formula (Campbell and Madden, 1990):

$$\mathbf{AUDPC} = \sum_{i=1}^{n-1} (0.5(xi + 1 + xi)(ti + 1 - ti))$$

Where n is total number of assessment times, ti is time of the i^{th} assessment in days from the first assessment date, xi is percentage of disease severity at i^{th} assessment. Since the epidemic periods of the two locations varied, AUDPC were standardized by dividing the values to the epidemic period of the respective locations (Campbell and Madden, 1990), which were 40 and 30 days at Haramaya and Hirna, respectively.

All data were subjected to analysis of variance using General Linear Model (GLM) procedure of SAS statistical version 9.2 software (SAS, 2009) except mean separation for significant interaction effects which was carried out using GenStat version 12.1 software (GenStat, 2009). Least Significant Difference (LSD) was used to separate means.

Results and Discussion

Incidence of Anthracnose

Incidence of bean anthracnose showed significant difference between solarized and non-solarized plots at 52 days after sowing (DAS) ($P<0.05$) and highly significant difference at 62, 72, 82 and 92 DAS ($P<0.01$) at Haramaya and all four successive disease assessments at Hirna ($P<0.01$). At final date (92 and 90 DAS) of disease assessment at Haramaya and Hirna, incidence reached 72.1 % and 50.7%, respectively in non-solarized soil, 60.7% and 45.6% in solarized soil. In these experiments, disease incidence in solarized soil decreased when compared with non-solarized soil. The experimental field had also been planted to bean in the previous year. Hence, there were considerable amounts of initial inoculum bean crop residue in the field. As reported by Dillard and Cobb (1993), in areas where beans are consecutively cropped, over seasonal inoculum can initiate epidemics of bean anthracnose. The primary inoculum from infested debris was relatively more damaging than other inoculum sources, causing early epidemic development and yield reduction (Fininsa and Tefera, 2002).

The effect of seed treatments on the incidence of anthracnose was highly significant ($P<0.01$) difference at 52, 62 DAS at Haramaya, 60 DAS at Hirna, and showed significant difference ($P<0.05$) 72 DAS at Haramaya, 70, 80 and 90 DAS at Hirna. At Hirna, the maximum incidence was recorded from control (53.9%), while lower levels of incidence were encountered for seed treatments with mancozeb and carbendazim, 43.3% and 47.2%, respectively at final date of incidence assessment (Table 2).

Table 2. Effect of soil solarization, seed treatment and foliar sprays on incidence of common bean anthracnose at Haramaya and Hirna during 2010 main cropping season

Treatments	Disease incidence at Haramaya DAS (%)		Disease incidence at Hirna DAS (%)	
	Initial (52)	Final (92)	Initial (60)	Final (90)
Soil solarization				
Solarized	19.6	60.7	15.9	45.6
Non-solarized	24.4	72.1	21.5	50.7
CV (%)	9.1	2.6	7.3	1.9
LSD (5%)	3.6	6.5	3.1	3.7
Foliar spray				
CFS10	18.9	63.9	16.1	45.6
CFS20	19.4	66.1	17.2	47.2
Control	27.8	72.2	22.8	51.7
CV (%)	35.9	13.0	36.1	12.4
LSD (5%)	4.4	7.9	3.8	4.4
Seed treatment				
MST	18.9	63.3	15.6	43.3
CST	22.8	66.7	17.8	47.2
Control	24.4	72.2	22.8	53.9
CV (%)	24.2	13.4	31.8	15.8
LSD (5%)	4.5	7.9	3.8	4.5

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and; DAS=Days after sowing; 20=Carbendazim foliar spray at 10 and 20 days interval; LSD=Least significant difference.

There was no significant variation in disease incidence between frequencies of carbendazim foliar sprays at 62, 72, 82 and 92 DAS dates of disease assessment at Haramaya except initial date 52 DAS (*P<0.01*), while significant differences were observed at all dates of assessment at Hirna (*P<0.01*). Lower mean incidence was calculated from carbendazim foliar sprays at 10 (16.1%) and 20 (17.2%) days' intervals at initial date of incidence assessment 60 DAS, while the control showed higher incidence (22.8%) at Hirna. Similarly, 45.6% and 47.2% incidence was obtained at 10 and 20 days spray intervals, respectively whereas, the control showed 51.7% incidence at final date of assessment (90 DAS) at Hirna (Table 2). This result agrees with Pastor-Corrales and Tu (1989), who reported that preventive spraying of foliage at flower initiation, late flowering and pod-filling with protective and systemic fungicides like maneb, zineb, benomyl, carbendazim, and fentin hydroxide have been used to control bean anthracnose. As reported by Sindhan and Bose (1981), carbendazim was effective as seed dressing and foliar sprays, and these treatments increase seed germination and seed yield, while reducing disease incidence. Study conducted by Gwary (2008) support present experiment in that sorghum anthracnose can best be managed on the early susceptible variety by integrating seed dressing treatment supplemented with foliar sprays.

Severity of Anthracnose

Percent severity index (PSI) calculated from disease severity assessed five times at Haramaya and four times at Hirna was significantly affected by soil solarization at all dates of severity assessment. Percent severity index was higher in non-solarized soil as compared to solarized soil at both locations (Table 3).

There were significant interaction effects (*P<0.01*) between levels of soil solarization and seed treatment in reducing PSI at 52, 62 72 DAS at Haramaya and non significant difference at 82, 92 DAS at Haramaya and all dates of severity assessment at Hirna (Table 3). There were significant interaction effects between soil solarization x foliar sprays (*P<0.01*) at 52, 62 and 92 DAS at Haramaya and (*P<0.05*) 70, 80 and 90 DAS at Hirna. Percentage severity index was not significantly different at the remaining dates of severity assessment at both locations. At final date of assessment, the combination of solarized soil with carbendazim sprays at 10 and 20 days intervals reduced PSI by 39.8% and 31.6%, respectively over the control at Haramaya. On the other hand, the combination of non-solarized soil with carbendazim sprays at 10 and 20 days intervals reduced PSI by 31.5% and 19.0%, respectively over the control at initial date of severity assessment

(Table 3). At Hirna during final severity assessment, the interactions of 10 and 20 days intervals spray frequencies of carbendazim with non-solarized soil showed lower PSI of 25.2% and 31.8%, respectively, than the control (35.8%) (Table 3).

Table 3. Effect of soil solarization x seed treatment, soil solarization x foliar sprays and seed treatment x foliar sprays interactions on percentage severity index (PSI) of anthracnose at Haramaya and Hirna during 2010 main cropping season

Treatments interaction		PSI at Haramaya DAS (%)		PSI at Hirna DAS (%)	
		Initial (52)	Final (92)	Initial (60)	Final (90)
Soil solarization	Seed treatment				
Solarized	MST	13.8	28.7	16.3	25.2
	CST	13.1	29.1	16.6	25.7
	US	20.7	38.5	15.6	26.2
Non-solarized	MST	13.9	33.1	20.3	29.4
	CST	14.3	34.8	20.9	31.4
	US	26.9	44.7	21.9	32.1
CV (%)		13.0	12.3	9.6	9.7
LSD at 5% for SS x ST		4.4	NS	NS	NS
Soil solarization	Foliar spray				
Solarized	CFS10	13.3	30.5	19.0	21.9
	CFS20	15.1	31.5	15.1	25.2
	UF	19.3	34.4	14.3	29.9
Non-solarized	CFS10	15.1	32.6	21.2	25.2
	CFS20	17.9	32.7	17.5	31.8
	UF	22.1	47.4	24.4	35.8
CV (%)		14.7	12.1	25.8	21.1
LSD at 5% for SS x FS		2.5	4.3	NS	14
Seed treatment	Foliar spray				
MST	CFS10	12.2	28.2	20.0	29.6
	CFS20	13.4	29.3	16.3	24.8
	UF	15.9	35.3	18.5	27.4
CST	CFS10	14.5	31.1	21.1	31.8
	CFS20	13.6	30.3	15.9	25.2
	UF	12.9	34.6	19.2	28.5
US	CFS10	15.8	35.4	19.3	31.1
	CFS20	19.8	36.7	16.7	25.6
	UF	33.2	52.8	20.4	30.7
CV (%)		13.0	12.3	9.6	9.7
LSD at 5% for ST x FS		3.6	5.3	NS	NS

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; DAS =Days after sowing; US=Untreated seed; LSD=Least significant difference; FS=Foliar spray; ST=Seed treatment; SS=Soil solarization; NS=Non significant difference

Soil solarization alone or with low dosages of a fungicide, biocide and bio-agent resulted in complete reduction of the pathogen; soil solarization integrated with applications of *T. harzianum*, carbendazim and neem was the most effective treatment (Chakraborty *et al*., 2008).

There were significant interaction effects between seed treatment x foliar sprays in reducing PSI ($P<0.01$) at Haramaya which were non significant at all dates of severity assessment at Hirna. The combination of mancozeb seed treatment with spray frequencies of carbendazim at 10 and 20 day intervals showed PSI 28.2% and 29.3%, respectively over the control (52.7%) at final date of disease assessment at Haramaya. Likewise, the interaction of carbendazim seed treatment with carbendazim spray at intervals of 10 and 20 days showed PSI of 31.1% and 30.3%, respectively on the final date of severity assessment at Haramaya (Table 5). Carbendazim foliar spray at 10 and 20 day intervals alone showed PSI levels of 35.4% and 36.7%, respectively at Haramaya during final severity assessment. Jenny (2010) reported that the seed treatment alone provide effective control for a maximum of four to six weeks after sowing, but do not provide absolute control. This study also showed that combination of seed treatment with foliar spray was more effective in reducing severity than seed treatment or foliar applications of fungicides alone.

There were significant interaction effects among soil solarization x seed treatment x foliar sprays ($P<0.01$) at 52, 72 and 82 DAS at Haramaya and non significant at the remaining dates at Haramaya and all dates disease assessment at Hirna. The interactions of solarized soil x mancozeb seed treatment x carbendazim foliar sprays at 10 and 20 days gaps reduced PSI at initial date of anthracnose disease assessment. Similarly, the interaction of carbendazim seed treatment with the same fungicide foliar sprays frequencies at 10 and 20 days intervals reduced disease severity at initial (52 DAS) date of severity assessment.

The primary inoculum from infested debris was relatively more damaging, causing early epidemic development and yield reduction, and the difference among severity levels could be influenced by concentration of inoculum harbored which survived the temperature, relative humidity, and rain during over seasoning and the location of debris could have an effect (Fininsa and Tefera, 2002). Under favorable temperature and relative humidity, the pathogen leads to reduction of the grain quality due to occurrence of the tags, besides to decrease in the productive potential of the common bean (Pastor-Corrales *et al*., 1995). Generally, variation in severity between locations might have been due to the differences in environmental factors, inoculum load and time of infection. At both study areas, the magnitude of disease severity was significantly different between levels of solarization, it was higher for non-solarized than solarized soil.

Pod Infection due to Anthracnose

Infected pods per plant varied significantly (*P<0.01*) between the levels of soil solarization both at Haramaya and Hirna. At Haramaya, non-solarized soil held recorded higher number of infected pods per plant (11.4), compared with the solarized soil (8.1). Similarly at Hirna, lower infected pods per plant were recorded from solarized soil (3.4) than non-solarized soil (4.9) (Fig. 1). There were significant interaction effects among the levels of soil solarization x foliar sprays on infected pods per plant at both locations. At Haramaya, the combination of non-solarized soil with carbendazim spray frequencies at 10 and 20 day intervals showed lower infected pods per plant of 7.9 and 9.9, respectively over the control (16.3).

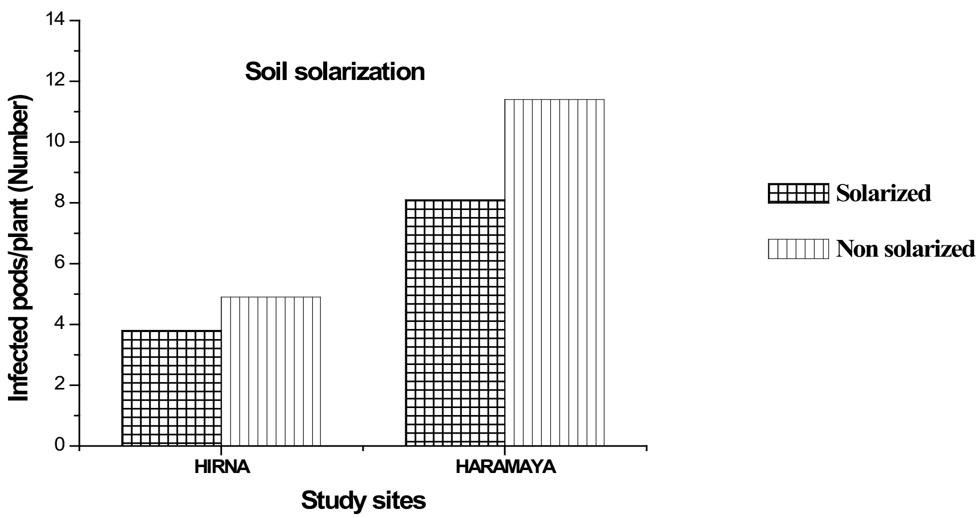

Figure 1. Infected pods per plant as affected by soil solarization at Haramaya and Hirna during 2010 main cropping season

Table 4. Effect of soil solarization x foliar sprays interaction on infected pods per plant at Haramaya and Hirna during 2010 main cropping season

Treatments interaction		Infected pods/plant (Number)	
		Haramaya	Hirna
Soil solarization	Foliar spray		
Solarized	CFS10	6.7	3.6
	CFS20	7.8	3.9
	UF	9.8	3.8
Non-solarized	CFS10	7.9	3.9
	CFS20	9.9	5.0
UF		16.3	5.9
CV (%)		18.2	18.0
LSD at 5% for SS x FS		1.81	0.81

CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; LSD=Least significant difference; No=Number; FS=Foliar spray; SS=Soil solarization

Similarly, the combination of solarized soil with carbendazim spray frequencies at 10 and 20 days interval showed infected pods per plant of 6.7 and 7.8, respectively as compared to16.3 in the control (Table 4). At Hirna, the combination of solarized soil with carbendazim foliar sprays frequencies at 10 and 20 intervals reduced infected pods per plant by 38.7% and 33.9%, respectively over the control.

Area under Disease Progress Curve and Disease Progress Rate

Interaction between soil solarization x seed treatments was highly significant (*P<0.01*) in reducing AUDPC at Haramaya and non significant at Hirna. Where, the combination of non-solarized soil with mancozeb and carbendazim seed treatments showed AUDPC of 24.3%-days and 24.7%-days, respectively over the control (36.6%-days). And combination of solarized soil with the same fungicides seed treatments showed lower AUDPC of 21.1%-days and 20.8%-days, respectively over the control (Table 5).

Significant interaction (*P*<0.01) between the levels of seed treatments and foliar sprays were observed at Haramaya and Hirna. At Haramaya, lower AUDPC was calculated from the interaction of mancozeb seed treatment with carbendazim spray frequencies at 10 and 20 days intervals of 20%-days and 22.5%-days, respectively than the control (42.7%-days). At Hirna, maximum AUDPC was obtained from untreated plots (27%-days). While, lower AUDPC was calculated from the combination of mancozeb seed treatment with carbendazim foliar spray frequency at 10 days intervals, and combinations of carbendazim seed treatment with the same fungicide foliar spray frequency at 10 days intervals. Generally, variation in anthracnose of common bean area under disease progress curve due to levels of solarization and fungicide seed treatments and foliar sprays were clearly observed and AUDPC was higher in non-solarized soil than solarized soil both at Haramaya and Hirna (Table 5). AUDPC was lower in plots treated with combination of mancozeb seed treatment and carbendazim foliar spray frequencies at 10 day intervals than other seed and foliar treated fungicides. There were no significant interaction between levels of solarization and foliar sprays in reducing AUDPC at Hirna and Haramaya.

Disease progress rate helps to determine whether disease develops in one treatment faster than the other (Jones, 1998). Interaction effects of soil solarization x seed treatment, soil solarization x foliar sprays, seed treatment x foliar sprays were significant on progress rate at Haramaya and non significant at Hirna (Table 5). The lowest progress rate was calculated from combination of carbendazim seed treatment with unsprayed foliar (0.031%-days) while, the highest progress rate was obtained from the control (0.110%-days). Generally, variation in bean anthracnose disease progress rate due to solarization, fungicides seed treatment and foliar sprays were clearly observed and rate of disease progress was higher at Haramaya than Hirna.

Effect of Soil Solarization and Fungicide Applications on Seed Health

Infected seeds played considerable role in the establishment of economically important plant disease in the field resulting in the heavy reduction of crop yield and infected seeds also have lower seed quality leading to reduced market values, poor germination and field establishment (Neergaard, 1979). Apart from this, infected seeds act as vehicle in carrying pathogens to uninfected areas within a country and from one country to the other. Interaction effects of soil solarization x seed treatment, solarization x foliar spray and solarization x seed treatment x foliar spray, no significant difference was observed in reducing seed infection both in visual inspection and agar plate incubation at both locations except combinations of soil solarization x foliar sprays at Hirna for visible infection of seed; the same was true for seed treatment x foliar sprays ($P<0.01$) in both methods of seed health detection at each location (Table 6).

Table 5. Effect of solarization x seed treatment, soil solarization x foliar sprays and seed treatment x foliar sprays interactions on area under disease progress curve (AUDPC) and Disease progress rate of bean anthracnose during 2010 main cropping season

Treatments interaction		AUDPC (%-days)		Disease progress rate (Units/day)	
		Haramaya	Hirna	Haramaya	Hirna
Soil solarization	Seed treatment				
Solarized	MST	21.1	21.2	0.042	0.053
	CST	20.8	20.7	0.095	0.051
	US	29.1	30.1	0.085	0.037
Non-solarized	MST	24.3	24.3	0.065	0.038
	CST	24.7	24.7	0.097	0.041
	US	36.6	36.7	0.098	0.061
CV (%)		8.1	7.1	23.7	29.2
LSD at 5% for SS x ST		2.4	NS	0.024	NS
Soil solarization	Foliar spray				
Solarized	CFS10	21.9	24.8	0.071	0.049
	CFS20	21.8	19.8	0.079	0.061
	UF	27.3	18.3	0.078	0.033
Non-solarized	CFS10	25.3	22.5	0.088	0.042
	CFS20	26.4	22.2	0.070	0.040
	UF	33.9	33.7	0.097	0.055
CV (%)		10.0	31.1	17.5	29.8
LSD at 5% for SS x FS		NS	NS	0.015	NS
Seed treatment	Foliar spray				
MST	CFS10	20.0	21.9	0.101	0.042
	CFS20	22.5	20.8	0.091	0.047
	UF	25.7	25.3	0.084	0.045
CST	CFS10	23.4	25.1	0.086	0.043
	CFS20	21.5	21.4	0.093	0.053
	UF	23.4	25.9	0.031	0.044
US	CFS10	27.5	23.8	0.063	0.044
	CFS20	28.4	20.9	0.066	0.051
	UF	42.7	27.0	0.110	0.052
CV (%)		8.1	7.1	23.7	29.2
LSD at 5% for ST x FS		2.8	1.3	0.028	NS

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; US=Untreated seed; LSD=Least significant difference; NS=Non significant difference; FS=Foliar spray; SS=Soil solarization

Table 6. Effect of soil solarization x foliar sprays, seed treatment x foliar spray interactions on anthracnose infection (%) of bean seed at Haramaya and Hirna during 2010 main cropping season

Treatments interaction		Haramaya		Hirna	
		Visual inspection	Agar plate Incubation	Visual inspection	Agar plate incubation
Soil solarization	Foliar spray				
Solarized	CFS10	4.7	24.4	3.8	17.8
	CFS20	8.4	30.0	6.3	27.8
	UF	11.7	34.4	8.0	31.1
Non-solarized	CFS10	9.1	43.3	7.7	40.0
	CFS20	10.3	50.0	8.1	47.8
	UF	14.7	58.9	9.6	47.9
CV (%)		22.7	21.6	20.2	31.0
LSD at 5% for SS x FS		NS	NS	1.5	NS
Seed treatment	Foliar spray				
MST	CFS10	6.5	33.3	5.3	25.0
	CFS20	7.3	38.3	4.8	40.1
	UF	9.5	41.7	7.8	35.0
CST	CFS10	5.7	33.2	5.4	28.3
	CFS20	7.5	33.5	7.3	33.2
	UF	10.7	40.0	7.8	34.0
US	CFS10	8.5	35.0	6.5	33.2
	CFS20	13.3	48.3	9.5	40.0
	UF	19.3	58.3	10.7	50.0
CV (%)		17.1	16.2	14.0	15.0
LSD at 5% for ST x FS		2.2	7.9	1.5	6.5

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; US=Untreated seed; LSD=Least significant difference; NS=Non significant difference; SS=Soil solarization; FS=Foliar sprays

Combination of solarized soil with carbendazim spray frequencies at 10 day intervals reduced visible seed infection by 60%. The combination of non-solarized soil with carbendazim spray frequencies at 10 day intervals reduced visible seed infection by 19% at Hirna (Table 6). The interaction of mancozeb seed treatment with carbendazim spray frequencies at 10 and 20 intervals reduced percentages of seed infection on agar plate incubation of seed infection by 42.8% and 34.3%, respectively over the control at Haramaya. Similarly, the combination of carbendazim seed treatment with the same fungicide spray frequencies at 10 and 20 days intervals reduced seed infection on agar plate incubation by 43.4% and 33.6%, respectively over the control at Hirna (Table 6). The relationships were evident between infection levels in the pods and seed infection, as determined by seedling grow-out in laboratory tests reported by Vechiato *et al*. (1997). These results are in line with those reported by Ravi *et al.* (1999) in that agar plate incubation was found to be the best and yielded maximum percentage of seed infection. The percentage of infected seed is an important determines factor and indicates virulence of the pathogen during the growing season since the secondary inoculum produced will be proportional to the amount of initial inoculum (Tu, 1983).Based on detection of seed-borne fungi using agar plate method, *C. lindemuthianum* was found to be the most important seed-borne pathogen and is found in high frequency with severe crop damage followed by *Phaeoisariopsis griseola,* and *Ascochyta phaseolorum* in many bean growing areas of Ethiopia (Mohammed and Somsiri, 2005).

Effect of Integrated Management of Bean Anthracnose on Seed yield

There were significant ($P<0.05$) differences in interactions among the levels of solarization x foliar sprays x seed treatments on seed yield both at Haramaya and Hirna. The combinations of non-solarized soil x mancozeb seed treatment x carbendazim spray frequencies at 10 intervals yield (3.4 t h^{-1}) over the control (1.9 t h^{-1}) at Haramaya and 3.5t h^{-1} over the control (2.3 t h^{-1}) at Hirna (Table 7). Similarly, the combinations of solarized soil x mancozeb seed treatment x carbendazim spray frequencies at 10 intervals increased the seed yield by 50% at Haramaya and 36.1% at Hirna. While, the lowest seed yields were recorded on the combinations of non-solarized soil x unsprayed foliar x seed treatments at both study sites (Table 7). Low application rates of fungicide, fumigant, or herbicide have been successfully combined with soil solarization to achieved better pest control (Hartz *et al*., 1993).

Table 7. Effect of soil solarization x foliar spray x seed treatment interactions on seed yield of common bean during 2010 main cropping season at Haramaya and Hirna

Treatments interactions			Yield (tons/ha)	
			Haramaya	Hirna
Soil solarization	Foliar spray	Seed treatment		
Solarized	CFS10	CST	3.6	3.5
	CFS10	MST	3.8	3.6
	CFS10	US	2.5	2.8
	CFS20	CST	2.9	3.1
	CFS20	MST	3.2	3.1
	CFS20	US	2.3	2.6
	UF	CST	2.6	2.9
	UF	MST	2.8	2.9
	UF	US	2.2	2.5
Non-solarized	CFS10	CST	3.2	3.2
	CFS10	MST	3.4	3.5
	CFS10	US	2.4	2.5
	CFS20	CST	2.7	2.8
	CFS20	MST	3.0	3.1
	CFS20	US	2.2	2.4
	UF	CST	2.4	2.6
	UF	MST	2.5	2.8
	UF	US	1.9	2.3
CV (%)			17.1	12.5
LSD at 5% for SS x FS x ST			0.88	0.68

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; US=Untreated seed; LSD=Least significant difference; SS=Soil solarization; FS=Foliar spray; ST=Seed treatment

However, the interaction effects of soil solarization x seed treatments as well as seed treatments x foliar sprays were non significant at both Haramaya and Hirna experimental study areas.

Conclusion

In the Hararghe highlands, bean anthracnose is an important disease that calls for better attention, for economical management using combinations of soil solarization, fungicide seed treatments with foliar sprays. Differences in epidemics occurred within each level of solarization due to fungicide applications under natural infection. Plots treated with combinations of mancozeb seed treatment and carbendazim spray frequencies at 10 days' intervals obtained the best protection in terms of disease severity, infected pods per plant AUDPC and increased seed yield at both locations. Therefore, this study contributes to integrated bean anthracnose management options using soil solarization seed treatment and foliar spray. Bean growers should be encouraged to use seed treatment and other cultural practices applicable in these areas against anthracnose when growing susceptible bean cultivars, and the use of resistant varieties and producing pathogen free seeds would be a cheap means of controlling the anthracnose disease and need to be explored.

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