Effect of Integrating Variety, Seed Treatment, and Foliar Fungicide Spray Timing on Managing Common Bean Anthracnose at Bako, Western Ethiopia

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Abstract: Bean anthracnose [*Colletotrichum lindemuthianum* (Sacc. And Magn.) Lams.-Scrib] is one of the major diseases of common bean (*Phaseolus vulgaris* L.), and causes huge yield losses in western Ethiopia. The research was conducted at Bako during 2014 main cropping season with the objectives to: 1) assess the efficacy of seed treatment and foliar fungicide spray timing; 2) determine the effect of integrated use of common bean varieties, seed treatment and foliar fungicide spray timing on anthracnose severity, yield and yield components; and 3) assess the economic feasibility of the treatments. The treatments consisted of three bean varieties (Awash Melka, Awash-1 and Mexican 142), two levels of seed treatment (thiram-treated at the rate of 5 g kg^{-1} seed and non-treated) and four foliar spray timing with tebuconazole at the rate of 350 ml ha^{-1} (at the fifth trifoliate, flowering, pod setting stages and unsprayed control). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. Disease parameters were assessed from 18 pre-tagged plants per plot; yield components were assessed from ten randomly pre-tagged plants; seed yields were recorded from plants in the three central rows in each plot. Variety, seed treatment, and foliar spray timing interacted significantly ($p \leq 0.05$) to influence foliage and pod disease severity index, area under the disease progress curve (AUDPC), infected pod per plant and seed yield. Awash-1, without seed treatment and without foliar spray, showed the highest (86.0%) foliage severity and the highest (71.32%) pod severity with calculated AUDPC values of 2771.19 and 1150.25%-days for leaf and pod, respectively. Mexican 142 from treated-seed and sprayed with tebuconazole at the fifth trifoliate stage produced the highest (2354.074 kg ha^{-1}) seed yield, followed by Awash-1 (2239.76 kg ha^{-1}) from non-treated seed and sprayed starting at the flowering stage. The highest marginal rates of return of 3071 and 2568% were calculated for Awash-1 without seed treatments but sprayed at flowering and pod setting, respectively, followed by Awash Melka (1962%) that was sown without seed treatment but sprayed at the flowering stage. Therefore, Awash-1 and Awash Melka without seed treatment and spraying with tebuconazole at the flowering stage resulted in the optimum yields of the crop, indicating that these treatments could be practiced as the most effective management measures against common bean anthracnose for sustainable production of the crop in the study area and elsewhere with similar agroecologies.

Keywords: Area under the disease-progress curve (AUDPC); [*Colletotrichum lindemuthianum* (Sacc. and Magnus) Lams.-Scrib]; *Phaseolus vulgaris* L.; foliar spray timing seed treatment

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is an important legume crop in the daily diet of more than 300 million of the world's population (Hadi *et al*., 2006). It has been rated as the second most important source of human dietary protein and the third most important source of calories of all agricultural commodities produced in eastern Africa (Pachico, 1993). Common bean production in the Central Rift Valley of Ethiopia contributes to about 60% of the total common bean production in the country (Aleligne, 1990). Common bean is grown usually as mixed varieties in most of southern, eastern, and western parts of the country (Mohammed and Somsiri, 2005).

The yields of common beans are about three times as high in developed countries, such as USA and Canada, compared to the developing countries (Porch *et al*., 2013). The national average yield of common bean in Ethiopia is low and it was estimated at 1.41 t ha^{-1} in 2015/2016 cropping season (CSA, 2016); seed yields of improved varieties on research fields in Ethiopia ranged from 2.5 to 3.0 t ha^{-1} (EPPA, 2004). There are various production constraints that contribute to the low yields of common bean in the country. Diseases are known to be the major factors that, directly or indirectly, affect the production of the crop. The major diseases that are currently threatening common bean production in Ethiopia include anthracnose [*Colletotrichum lindemuthianum* (Sacc. And Magnus) Lams.-Scrib], rust (*Uromyces appendiculatus* F. Strauss), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), halo blight (*Pseudomonas syringae* pv. *phaseolicola*), angular leaf spot

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(*Phaeoisariopsis griseola* Sacc. Ferr), Ascochyta blight (*Ascochyta phaseolorum* Sacc.) and bean common mosaic virus. Anthracnose, rust, angular leaf spot and common bacterial blight are more important than other common bean diseases and are widely distributed, while the rest are much more restricted in specific growing areas in their distribution (Habtu, 1987; Habtu and Abiy, 1995; Habtu *et al*., 1996; Odogwu *et al*., 2016).

Bean anthracnose is the most serious disease of common bean in the cool weathers in Latin America and Africa. In these parts of the world, the field losses ranged from 90 to 100% due to seedling, leaf, stem and pod infection under climatic conditions favorable to the disease (Nyvall, 1989; Padder and Sharma, 2017). The infected seeds are the most important means of dissemination *of Colletotrichum lindemuthianum (C. lindemuthianum)*, which explains its worldwide distribution (Allen *et al*., 1996). The crop is vulnerable to the pathogen at all stages of growth, from seedling to maturity, depending on the prevailing environmental conditions that favor initiation and further development of the pathogen. The disease causes an estimated common bean yield loss of 63-100% in Ethiopia (Tesfaye, 1997; Kutangi *et al.,* 2010; Amin *et al*., 2014), but there is variation from one region to another. For instance, 42.4% yield loss was reported for Haramaya district (Amin *et al*., 2013) and 11.9% for Bako area from infection of free seeds and 20% from infected seeds (Mohammed and Somsiri, 2005). Also the planting value of harvested seed is reduced due to decreased germination and poor quality (Singh and Schwartz, 2010).

Management strategies used to minimize seed-borne infection due to *C. lindemuthianum* in the seed production fields include cultural, host resistance, biological, and chemical protection methods. Although the infected seeds are the most important means of dissemination *of C. lindemuthianum* (Allen *et al*., 1996), the pathogen affects the crop at all stages of growth. Therefore, it is necessary to understand the interaction between common bean and the pathogen at different developmental stages of the crop to design sustainable disease management strategies. Moreover, integrated disease management is the most recommended option for such diseases in which infection due to the fact that pathogen occurs starting from the seed to all growth stages of the crop, and due to the high diversity of the pathogen (Allen *et al*., 1996). However, integrating host resistance, seed treatment and foliar application of fungicides at different growth stages of the crop was not studied well in Ethiopia. Therefore, this study was conducted with the objectives to elucidating the effect of integrating common bean variety, seed treatment, and foliar fungicide spray timing on the severity of common bean anthracnose and yield and yield components of the crop as well as to assess the economic feasibility of the different treatment combinations.

2. Materials and Methods

2.1. Description of the Study Site

The study was conducted at Bako Agricultural Research Center (BARC) in western Ethiopia during the 2014 main cropping season. Bako Agricultural Research Center (BARC) has warm, humid climate with 54 years mean minimum, maximum and average temperatures of 13.3, 28.0 and 20.6 ^{o}C, respectively, and 48 years mean relative humidity of 63.55% (BARC, 2014). The averages of seven days interval rainfall and temperature during the production period are depicted hereunder (Figure 1).

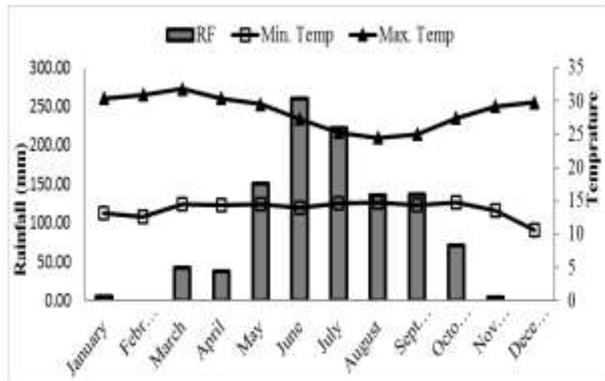

Figure 1. Weather data of Bako during 2014 cropping season

a. Experimental Materials

i. Common bean varieties

The three Malkasa Agricultural Research Center released white seed-canning type common bean varieties, namely Mexican 142, Awash 1 and Awash Melka, released in 1973, 1990 and 1998/99, respectively, were used in this experiment. The varieties have been recognized to possess different susceptibility levels, viz. Mexican 142 is moderately susceptible, and Awash-1 and Awash Melka are susceptible and tolerant, respectively, for the disease anthracnose caused by *C. lindemuthianum* (Sacc. and Magnus) Lams.- (Kutangi, *et al.,* 2010; BARC, 2013).

ii. Fungicides

The fungicide used in seed treatment is a protective fungicide, commonly known as thiram 75 WP and chemically known as tetramethyl thiuram disulfide. The broad spectrum systemic fungicide Tebuconazole 430 SC, commonly known as Orius 25 EW, was used for foliar spray to manage common bean anthracnose.

b. Treatments and Experimental Design

The treatments consisted of four spray application timing of foliar fungicide (Tebuconazole, syn. Folicur) at the rate of 350 ml ha^{-1} (at the fifth trifoliate, flowering, pod setting stages and unsprayed control), two rates of seed treatment with the fungicide Thiram (thiram-treated at the rate of 5 g kg^{-1} seed and non-treated) and three common bean varieties (Mexican 142, Awash-1 and Awash Melka). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. The treatments were assigned to each plot randomly. The experimental area was divided into 24 plots and each plot had size of 4 m x 2 m (=8 m^2) with five rows each at the spacing of 40 cm apart and 10 cm between plants. The plots and adjacent replications were spaced at the distances of 1.0 and 1.5 m, respectively. Recommended amount of 100 kg ha^{-1} diammonium phosphate (DAP) fertilizer (consisting of 46 kg P_2O_5 and 18 kg N ha^{-1}) was applied once at planting.

2.4. Seed Treatment

The seeds of all common bean varieties (Mexican 142, Awash-1 and Awash Melka) were treated with the systemic fungicide Tebuconazole at the rate of 5 g kg^{-1} seed 24 hours before sowing. The untreated seeds from all common bean varieties served as control or check treatments.

2.5. Tebuconazole Foliar Fungicide Application

Tebuconazole 430 SC (Orius 25 EW) was applied at a rate of 350 ml ha^{-1} with water spray volume of 100 L ha^{-1} at different growth stages of the crop, i.e. from vegetative stage (5th trifoliate stage), flowering (1st flower stage) to the beginning of pod setting using a knapsack sprayer having 20 liters capacity. Control (check) plots were sprayed with pure water in the same manner with that of fungicide sprayed plots to prevent differences among plots due to variation in moisture. The fungicide-sprayed plots were treated three times at a 10-day interval starting from the above mentioned growth stage of the crop onwards. The timing of application of the fungicide spray varied according to the growth stage of the crop varieties from the 5th trifoliate stage to the start of pod setting. Fungicide drift between and among the treatments were prevented by covering the plots with plastic sheets.

2.6. Data Collection

The first fungicide spray was applied 46 days after sowing. Seven days after the start of fungicide spraying, anthracnose severity assessment was started. Anthracnose severity was assessed from 18 pre-tagged plants of from three central rows in each plot every week. Evaluation of disease severity was performed using a 1 to 9 grade disease scale proposed by Schoonhoven and Pastor-Corrales (1987), where:

1 = leaf with no visible symptoms;
2 = few isolated small lesions on mid-veins in the lower leaf surfaces;
3 = a higher frequency of small lesions on mid-veins in the lower leaf surfaces;
4 = lesions in the mid-vein and occasionally in secondary leaf veins;
5 = many small lesions scattered on mid- and secondary veins;
6 = many small lesions as described in grade 5 in the lower and upper leaf surface;
7 = large lesions scattered over the leaf blade;
8 = many large, coalesced lesions accompanied by tissue breakdown and chlorotic or abscised leaf; and
9 = severely diseased or dead leaf.

Then the anthracnose severity grades were converted, for further analyses into percentage severity index (PSI) using the formula developed by Wheeler (1969) as follows:

$$PSI = \frac{\text{sum of numerical rating} \times 100}{\text{No. of plants scored} \times \text{maximum score on scale}} \quad (1)$$

The area under disease progress curve (AUDPC) and growth curve models were developed for the disease progress data. AUDPC-values were calculated for each plot using the formula stated by Campbell and Madden (1990).

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5(x_{i+1} + x_i)(t_{i+1} - t_i) \cdots (2)$$

Where: n = represents the total number of assessment times, t_i is the time of the ith assessment in days from the first assessment date, and x_i is percentage of disease severity at ith assessment.

Disease progress in time was studied by recording the severity of anthracnose at a 7-day interval right from appearance of first disease symptoms till the maturity of the crop in different varieties and treatments. Therefore, disease progress rate was calculated for each plot using the following formula (Van der Plank, 1963):

$$DPR = ln[\frac{y}{(1-y)}] \quad (3)$$

Where: DPR = Disease progress rate, and Y = Disease severity

Yield and yield component data, including number of pods per plant, number of infected pods per plant, number of seeds per pod, hundred seed weight and seed yield (kg ha^{-1}) were measured from the three middle rows. The number of pods per plant was determined as the average number of pods from ten randomly pre-tagged plants and the number of infected pods per plant was determined from the same plants as the average number of anthracnose-infected pods. The average number of seeds per pod was counted at harvest time from ten randomly pre-tagged plants, in ten randomly taken pods per plant. The seeds were sun-dried and weighed. Hundred seeds having the symptom of anthracnose infection were weighed and registered separately for all treatments. The weights of hundred seeds were measured from seeds randomly taken from the total seeds harvested from each plot. The seed yield per hectare in kilogram was estimated from seed yields of each plot (after adjusting to 10% seed moisture content) obtained from the three central rows.

2.7. Data Analysis

All the disease, yield and yield component data were subjected to analysis of variance (ANOVA) using general linear model (GLM) procedure of SAS statistical version 9.2 software (SAS, 2009). The least significant difference (LSD) test was used to separate differences in treatment means of main factor effects where significant variation was observed at 5% probability level. Lsmeans for significantly different interaction effects were separated by SAS model *PLGLM800* (P=0.05) using Duncan's Multiple Range Test (DMRT).

The cost and benefit of each treatment was estimated from the marginal rate of return (MRR) that was computed by considering the variable cost available in the respective treatment. Variable costs included chemical costs and labor expenses for application of fungicides both for seed and foliar treatment. The yield and economic data were collected to compare advantages of seed treatment and foliar application in different treatments. Economic data encompassed input cost that varied, including cost for chemicals and labour during production time. Based on the data obtained, cost-benefit analysis was performed using partial budget analysis, which is a method of organizing data and information about the cost and benefits of various agricultural alternatives (CIMMYT, 1988). Before marginal analyses were carried out, dominance analysis was conducted for the treatments. A dominance analysis was thus carried out by first listing the treatments in order of increasing costs that varied. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that varied is dominated and it was eliminated from further consideration (CIMMYT, 1988).

3. Results and Discussion

3.1. Bean Leaf Anthracnose Severity

Anthracnose disease appeared on bean leaves 46 days after sowing. Consistent with this observation, Hirpha and Salvaraji (2016) reported that the disease appeared 48 days after sowing common bean at Ambo. The interaction effect of seed treatment with foliar fungicide spray times indicated that plots without any fungicide treatment had high PSI throughout the disease assessment periods that ranged from 27.89% at initial assessment to 66.17% at terminal disease assessment period. In a similar study, Amin *et al.* (2013) reported that seed treatment with mancozeb followed by carbendazim foliar spray, and seed treatment with carbendazim followed by foliar spray with carbendazim significantly reduced bean anthracnose severity (Table 1).

The integrated effect of variety, seed treatment and foliar spray time generally exhibited significant ($p \leq 0.05$) difference in PSI all over the disease assessment periods (Table 2, 3). All varieties, regardless of seed treatment, sprayed at the third leaf stage of the crop exhibited lower disease severity till 74 days after planting (DAS); however, they were infected by anthracnose after these days. The highest (38.8-86%) significant percentage severity index (PSI) was recorded for Awash-1 variety without seed treatment, followed by no-foliar fungicide spray at all disease assessment periods. The combined treatment effect on all common bean varieties, and with and/or without seed treatment but sprayed at flowering stage showed the lowest PSI at the final disease assessment period (Table 3).

3.2. Anthracnose Severity on Pod

The percent severity index (PSI) of pods was significantly ($P \leq 0.05$) affected by integrated anthracnose management (Tables 2 and 4). Significant ($P \leq 0.01$) variation was observed on pod percent severity index due to variety * seed treatment * foliar application time at all disease assessment periods (Table 4). Plots sown with seed-treated Awash Melka variety and sprayed with the fungicide at flowering stage of the crop resulted in significantly the lowest (20.9%) PSI in comparison to non-treated seeds of Awash-1 without foliar spray, which exhibited the highest (71.3%) pod PSI. Seed treatment and foliar spray at flowering stage resulted in 68, 53 and 37% pod severity reduction over the control plots, i.e. non-treated seeds and without foliar spray on each of Awash-1, Awash Melka and Mexican 142, respectively. Control plots of Awash-1 variety showed higher pod PSI than the other varieties at all assessment periods; however, PSI was lower for Awash Melka variety than for the other two varieties.

Table 1. The effect of common bean varieties integrated with foliar fungicide spray times on percentage severity index and AUDPC at Bako in 2014 main cropping season.

Treatment component (Variety x Foliar spray time)		Anthracnose percent severity index (PSI, %)						AUDPC(%-days)
		53 DAS	60 DAS	67 DAS	74 DAS	81 DAS	88 DAS	
Variety:	Foliar spray:							
Awash Melka	5th trifoliate	19.564	19.564	19.564C	22.826 F	31.236 EF	34.475 D	603.858 FG
	Flowering	20.864	22.130	22.301C	22.568 F	23.075 G	23.639 F	514.558 FG
	Pod setting	23.001	27.817	29.771B	32.156 DE	33.210 EF	33.463 D	908.848 DE
	Control	25.570	33.263	35.900B	49.216 B	55.964 B	63.062 B	1674.383 B
Awash-1	5th trifoliate	20.174	20.174	21.619C	29.716 E	35.839 DE	42.399 C	795.782 EF
	Flowering	20.013	20.264	20.687C	21.628 F	22.840 G	24.753 EF	476.389 G
	Pod setting	25.207	33.087	34.697B	36.783 CD	42.067 CD	42.362 C	1248.765 C
	Control	29.676	38.117	49.125A	56.834 A	65.537 A	71.702 A	2071.193 A
Mexican 142	5th trifoliate	20.275	20.549	20.726C	23.141 F	27.823 FG	31.314 DE	573.971 FG
	Flowering	20.275	21.478	22.559C	23.050 F	24.487 G	26.072 EF	537.963 FG
	Pod setting	26.169	33.211	34.455B	41.062 C	45.791 C	47.466 C	1360.391 C
	Control	21.644	27.403	31.266B	35.638 CD	40.817 CD	45.881 C	1113.735 CD
LSD (0.05)		Ns	Ns	6.235	5.342	6.280	7.088	296.620
SE(±)		1.745	2.249	2.190	1.877	2.206	2.490	104.199
Seed treatment:	Foliar spray:							
Treated	5th trifoliate	20.062	20.184 D	21.029C	26.935 C	31.740 D	35.507 C	678.395 C
	Flowering	20.338	21.079 D	21.702C	22.275 D	22.906 E	23.666 D	494.753 C
	Pod setting	25.611	33.229AB	34.252B	36.969 B	40.137 C	40.984 C	1223.800 B
	Control	23.368	27.388 C	31.131B	40.616 B	46.332 B	54.260 B	1290.775 B
Untreated	5th trifoliate	19.947	20.007 D	20.244C	23.520 CD	31.526 D	36.618 C	637.346 C
	Flowering	20.430	21.503 D	21.996C	22.556 CD	24.029 E	25.977 D	524.520 C
	Pod setting	23.974	29.514BC	31.696B	36.365 B	40.575 C	41.210 C	1121.536 B
	Control	27.893	38.468 A	46.396A	53.843 A	61.880 A	66.170 A	1948.765 A
LSD (0.05)		Ns	5.227	5.091	4.362	5.127	5.787	242.189
SE(±)		1.425	1.836	1.788	1.532	1.801	2.033	85.078

Note: Means followed by the same or no letter within a column are not significantly different from each other at 0.05 probability level, DMRT test.

Table 2. Mean squares from analysis of variance for disease parameters of bean anthracnose as influenced by variety, seed treatment and foliar fungicide spray time.

Source	DF	Foliage PSI		DPR		Pod PSI		Foliage AUDPC
		53 DAS	88 DAS	60 DAS	88 DAS	67 DAS	88 DAS	
Model	25	51.639**	666.053 Ns	0.00202**	0.00075**	2182.58**	97114.93**	856224.40**
Variety (A)	2	20.567 Ns	412.740 Ns	0.00007 Ns	0.00056**	2661.17**	145442.83**	454624.48**
Seed treatment (B)	1	9.229 Ns	272.314 Ns	0.00146 Ns	0.00043**	555.56 Ns	180505.14**	333472.22*
Foliar spray time (C)	3	153.564**	3927.266 Ns	0.01184**	0.00463**	1172.86**	466359.58**	4626224.11**
Rap	2	27.700 Ns	53.886 Ns	0.00011 Ns	0.00006 Ns	12587.99**	8253.96 Ns	111647.97 Ns
A x B	2	40.069 Ns	147.976*	0.00007 Ns	0.00007 Ns	550.99**	97430.62**	178710.21 Ns
A x C	6	31.362 Ns	376.596**	0.00029 Ns	0.00041**	294.92 Ns	24083.90**	452835.87**
B x C	3	31.695 Ns	131.943**	0.00250**	0.00009*	727.04**	9577.74 Ns	557813.01**
A x B x C	6	60.188**	118.769*	0.00064 Ns	0.00004 Ns	12.003 Ns	28799.64**	218840.96**
Error	46	18.268	37.196	0.00041	0.00002	137.250	5546.630	65144.56
Total	71							
Mean		22.700	40.550	0.0262	0.0245	23.457	584.639	989.986
R^2		60.570	90.680	72.29	94.76	89.63	90.490	87.72

Note: *= significant at p≤0.05; ** = highly significant p≤0.01; Ns: non-significant; PSI= percentage severity index; DPR= disease progress rate and AUDPC= area under disease progress curve.

Table 3. Interaction effect of variety x seed treatment x foliar fungicide spray time on anthracnose percentage severity index at different anthracnose assessment periods on foliage at Bako in 2014 main cropping season.

Variety	Seed treatment	Foliar	Leaf severity index (%)						AUDPC
			53 DAS	60 DAS	67 DAS	74 DAS	81 DAS	88 DAS	(%-days)
Awash Melka	Treated	Trifoliate	19.657 C	19.657 G	19.657 H	25.464 G-J	32.453	35.762 F-I	648.87 FG
		Flower	21.1670 BC	22.345 FG	22.516 D-H	22.701 IJ	22.701	23.363 L	517.80 FG
		Pod	23.142 BC	27.966 C-G	29.499 B-G	31.366 E-H	32.435	32.940 H-L	900.21 D-F
		Non	27.490 B	34.153 BC	36.562 B	48.679 B	52.938	64.837 B	1668.62B
	Untreated	Trifoliate	19.471 C	19.471 G	19.471 H	20.189 J	30.020	33.188 H-L	558.85 FG
		Flower	20.560 BC	21.915 FG	22.086 E-H	22.434 IJ	23.450	23.914 KL	511.32 FG
		Pod	22.861 BC	27.667 C-G	30.043 B-F	32.946 EFG	33.985	33.985 G-K	917.49 D-F
		Non	23.650 BC	32.374 BCD	35.237 B	49.752 B	58.991	61.288 BC	1680.14 B
Mexican 142	Treated	Trifoliate	19.838 C	20.204 FG	20.382 H	22.687 IJ	26.957	27.885 I-L	536.52 FG
		Flower	19.657 C	20.200 FG	21.420 F-H	21.594 IJ	22.791	23.428 L	472.43 G
		Pod	27.342 B	37.304 B	37.777 B	43.819 BC	49.079	50.877 DE	1540.43 BC
		Non	22.068 BC	23.053 EFG	26.174 C-H	29.232 F-I	34.028	40.540 F-H	832.51 E-G
	Untreated	Trifoliate	20.712 BC	20.893 FG	21.071 GH	23.594 IJ	28.689	34.744 G-J	611.42 FG
		Flower	20.893 BC	22.756 EFG	23.697 D-H	24.507 HIJ	26.184	28.715 I-L	603.50 FG
		Pod	24.995 BC	29.118 B-F	31.13 BCD	38.304 CDE	42.503	44.055 EFG	1180.35C-E
		Non	21.220 BC	31.752 B-E	36.358 B	42.044 BCD	47.605	51.222 CDE	1394.96 BC
Awash-1	Treated	Trifoliate	20.691 BC	20.691 FG	23.049 D-H	32.656 EFG	35.809	42.875 E-H	849.79 D-G
		Flower	20.189 C	20.691 FG	21.169 GH	22.531 IJ	23.227	24.206 KL	494.03 FG
		Pod	26.349 BC	34.418 BC	35.481 B	35.722 DEF	38.898	39.135 FGH	1230.76 C-E
		Non	20.545 BC	24.957 D-G	30.657 B-E	43.936 BC	52.030	57.404 BCD	1371.19 BC
	Untreated	Trifoliate	19.657 C	19.657 G	20.189 H	26.776 G-J	35.868	41.923 E-H	741.77 FG
		Flower	19.838 C	19.838 G	20.204 H	20.726 J	22.452	25.301 JKL	458.75 G
		Pod	24.065 BC	31.757 B-E	33.914 BC	37.844 CDE	45.236	45.590 EF	1266.77B-D
		Non	38.808 A	51.277 A	67.593 A	69.733 A	79.044	86.001 A	2771.19 A
SE(±)			2.468	3.180	3.097	2.654	3.120	3.521	147.36
LSD (0.05)			7.025	9.053	8.817	7.555	Ns	10.024	419.484

Note: Means followed by the same or no letter within a column are not significantly different from each other at 0.05 probability level, DMRT test

3.3. Area under Disease Progress Curve (AUDPC)

Interaction of variety * foliar spray, and seed treatment * foliar spray showed significant foliage AUDPC (Tables 1). However, the interaction effect of variety * seed treatment showed no significant difference. Awash-1 sprayed at flowering showed the lowest (476.389%-days) foliage AUDPC of all the other variety * foliar spray interactions. However, the highest AUDPC of 2071.193 and 1674.383%-days were observed on the foliage of control plots of Awash-1, and Awash Melka, respectively. This current result agrees with the findings of Mohammed and Somsiri (2005) who reported that the foliage AUDPC value was higher for the variety Awash-1 than Mexican 142. AUDPC was also significantly different among common bean varieties based on their reaction to the disease, in which the susceptible variety produced the highest foliage AUDPC, while the values were the lowest in resistant varieties (Sharma *et al*., 2008). Hirpha and Selvaraj (2016) also indicated that foliar fungicide application reduced AUDPC value on every variety.

Foliage AUDPC calculated for plots from untreated seeds and not receiving any foliar fungicide sprays showed significantly ($p \leq 0.05$) highest (1948.765%-days) values of all the rest seed treatment and foliar fungicide spray combinations. However, the lowest 494.753 and 524.52%-days foliage AUDPC values were calculated from plots sown with seeds treated and sprayed at flowering, and untreated seeds but sprayed at flowering, respectively. Similar to the results of the current study, Amin *et al.* (2013) reported that interaction of seed treatment with foliar fungicide sprays significantly differed in foliage AUDPC values; generally plots from treated-seeds and followed by spray with foliar fungicide had significantly reduced foliage AUDPC values.

The combined effect of variety *seed treatment* foliar spray time showed highly significant ($P \leq 0.01$) difference in the area under disease progress curve (Table 2). The lowest most significant foliage AUDPC value (458.745%-days) was calculated from plots of the variety Awash-1, without seed treatment and sprayed at flowering, followed by AUDPC values of 472.428 and 494.033%-days that resulted from plots sown with treated-seeds of Mexican 142 and Awash-1, respectively, and both sprayed at flowering (Table 3). The highest foliage AUDPC value (2771.193%-days) was calculated from data recorded from non-seed treated and unsprayed Awash-1, followed by AUDPC value (1680.144%-days) on Awash Melka, without seed treatment and unsprayed plots.

The three-way interaction effects of variety, seed treatment, and foliar fungicide spray showed significant differences on pod AUDPC values (Table 2 and 3). Significantly the highest pod AUDPC value (1150.25%-days) was calculated from plots sown with non-treated seeds of Awash-1 without foliar spray, followed by AUDPC value (919.45%-days) on plots sown with non-treated seeds of Mexican 142 without foliar spray. However, the lowest pod AUDPC value (435.06%-days) was calculated from plots sown with treated seeds of Awash Melka and sprayed at flowering of the crop variety (Table 3). Thus, integrated disease management options, rather than using a single component strategy alone, proved to be a more effective disease management option for sustainable bean production than using a single tactic alone.

3.4. Anthracnose Progress Rate on Common Bean Varieties

The interaction effect of variety with foliar fungicide spray, and seed treatment with foliar fungicide spray were significant from 67 DAS assessment period onwards; however, the interaction effect of seed treatment with foliar fungicide spray was not significantly ($P \leq 0.05$) different at 60 DAS (Table 2). The interaction effect of variety * seed treatment, and variety * seed treatment * foliar spray were not significant. Variety with foliar fungicide spray interaction resulted in significantly higher (0.0643 units-day^{-1}) anthracnose progress rate on Awash-1 variety at 67 DAS than the interaction effect of the same variety without foliar spray. Awash Melka variety sprayed at fifth trifoliate stage till 67 DAS and Awash-1 at 60 DAS did not show any increase in disease progress rate (Figure 2).

The analysis of variance revealed the occurrence of higher disease progress rates, i.e. 0.0584, 0.0471 and 0.0310 units-day^{-1} at the final disease assessment period on the control plots of Awash-1, Awash Melka and Mexican 142 varieties, respectively, than the treated plots of each variety. The maximum protected plot of Awash Melka sprayed at flowering reduced anthracnose progress rate 11 times more than the plots under natural condition (non-sprayed control plots), while the maximum protected plots of Awash-1 and Mexican 142 varieties sprayed with tebuconazole at flowering reduced disease progress rate seven and three times, respectively, more than the plots of the same varieties under natural conditions, i.e. without any treatment (Figure 4). Generally, anthracnose progress rates at 74 DAS disease assessment period onwards were lower on all bean varieties sprayed with tebuconazole at flowering stages than the disease progress rates of all the interactions due to other treatment combinations (Figure 3).

Seed treatment and foliar fungicide spray at flowering significantly reduced anthracnose progress rate eight times more than the anthracnose progress rate on plots sown with treated-seeds but without foliar fungicide spray, while foliar spray alone reduced anthracnose progress rate six times more than plots sown from non-treated seeds and unsprayed with tebuconazole. Similar to the results of this study, Amin *et al.* (2013) reported that disease progress rate was significantly affected by seed treatment and foliar fungicide spray interaction at Haramaya.

Table 4. Interaction effect of varieties, seed treatment and foliar spray times on pod percentage severity index (PSI) and AUDPC at Bako in 2014 main cropping season.

Seed treatment	Foliar	Pod anthracnose severity index (%)				AUDPC
		67 DAS	74 DAS	81 DAS	88 DAS	(%-days)
Awash Melka:						
Treated	Trifoliate	19.47 G	19.47 G	22.28 IJ	22.59 IJ	439.44 J
	Flower	19.84 G	20.89 FG	20.89 J	20.89 J	435.06 J
	Pod	20.90 FG	21.24 FG	22.20 IJ	22.20 J	454.88 J
	Non	25.03 CDE	37.48 BC	39.12 B-E	39.37 CD	761.71 CDE
Untreated	Trifoliate	19.47 G	19.47 B	21.54 J	22.53 IJ	434.06 J
	Flower	19.47 G	21.58 FG	24.21 HIJ	24.51 G-J	474.50 IJ
	Pod	20.55 FG	21.26 FG	22.30 IJ	22.30 IJ	454.91 J
	Non	21.54E FG	30.81 D	33.09 D-G	33.38 DE	639.53 EFG
Mexican 142:						
Treated	Trifoliate	19.47 G	21.22 FG	24.17 HIJ	24.74 F-J	472.45 IJ
	Flower	19.47 G	19.84 G	21.61 J	22.30 IJ	436.34 J
	Pod	25.46 CD	26.65 DEF	30.34 F-I	30.34 E-G	594.24 F-I
	Non	23.88 DEF	29.15 DE	31.53 E-H	31.53 EF	618.61 FGH
Untreated	Trifoliate	19.47 G	21.57 FG	26.96 G-J	29.76 E-H	512.04 HIJ
	Flower	20.53 FG	22.87 FG	26.77 G-J	27.05 E-J	513.97 HIJ
	Pod	22.44 D-G	24.75 EFG	27.08 G-J	27.34 E-J	536.96 G-J
	Non	33.88 B	44.34 A	46.30 B	47.54 B	919.45 B
Awash-1:						
Treated	Trifoliate	19.84 G	20.53 G	22.86 IJ	26.36 F-J	465.40 J
	Flower	19.47 G	20.85 G	21.91 J	22.28 IJ	445.44 J
	Pod	19.47 G	21.22 FG	22.56 IJ	22.90 HIJ	454.76 J
	Non	27.81 C	37.21 BC	45.35 BC	46.06 BC	836.48 BC
Untreated	Trifoliate	20.56 FG	32.30 CD	37.33 C-F	42.45 BC	707.90 DEF
	Flower	20.56 FG	20.56 G	24.61 HIJ	29.23 E-I	490.42 IJ
	Pod	25.86 CD	37.48 BC	40.84BCD	41.08 BC	782.53 CD
	Non	41.09 A	42.04 AB	66.08 A	71.32 A	1150.25 A
LSD (0.05)		3.655	5.847	7.976	6.935	122.403
SE(±)		1.284	2.054	2.802	2.436	42.999

Note: According to DMRT, means followed by the same letter(s) within a column are not significantly different at 5% probability level.

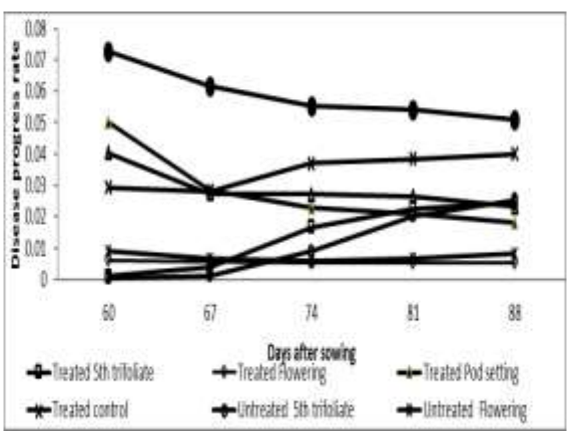

Figure 2. Interaction effect of seed treatment with foliar fungicide spray on anthracnose progress rate at Bako in 2014 main cropping season.

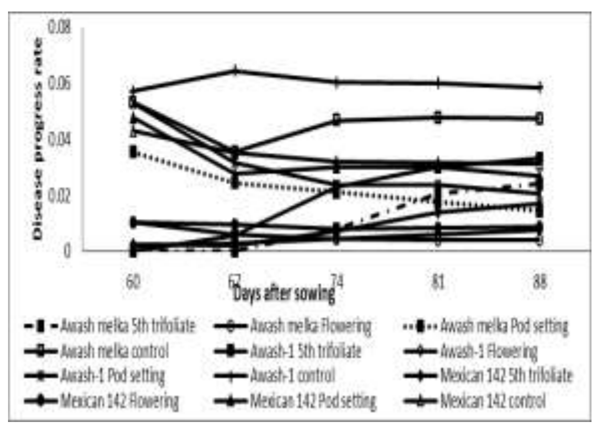

Figure 3. Interaction effect of variety with foliar fungicide spray on anthracnose progress rate at Bako during 2014 main cropping season.

3.5. Effect of Variety, Seed Treatment, Foliar Spray and Their Interaction on Yield and Yield Components

3.5.1. Pod per Plant, Infected Pod per Plant, and Seed per Pod

Main effects of variety, seed treatment and foliar fungicide spray showed highly significant ($P \leq 0.01$) differences on the number of pods per plant and infected seed per pod. However, pod infection per plant was significantly ($P \leq 0.01$) affected by variety and foliar fungicide spray (Table 5).

The highest (16.958) mean number of pods per plant was observed for the variety Awash-1, while Awash Melka and Mexican 142 produced lower pod number than Awash-1, i.e. 13.542 and 14.875 pods per plant, respectively. Also, plots sown with treated-seeds produced significantly higher (17.056) pod mean number per plant than plots sown with untreated seeds. Plots sprayed with foliar fungicide at the fifth trifoliate stage gave significantly higher number of pods per plant than the control plots, followed by plots sprayed at flowering stage (Figure 4). Similar to this result, Amin *et al.* (2014) reported that the number of pods per plant was significantly different from foliar fungicide-sprayed plots and plots sown with bioagent-treated-seeds along with non-spray fungicide. But, contrary to this finding, Amin *et al.* (2013) reported that the number of pods per plant was non-significant and did not differ from plots sown with treated-and untreated-seeds, and foliar sprayed and non-sprayed plots.

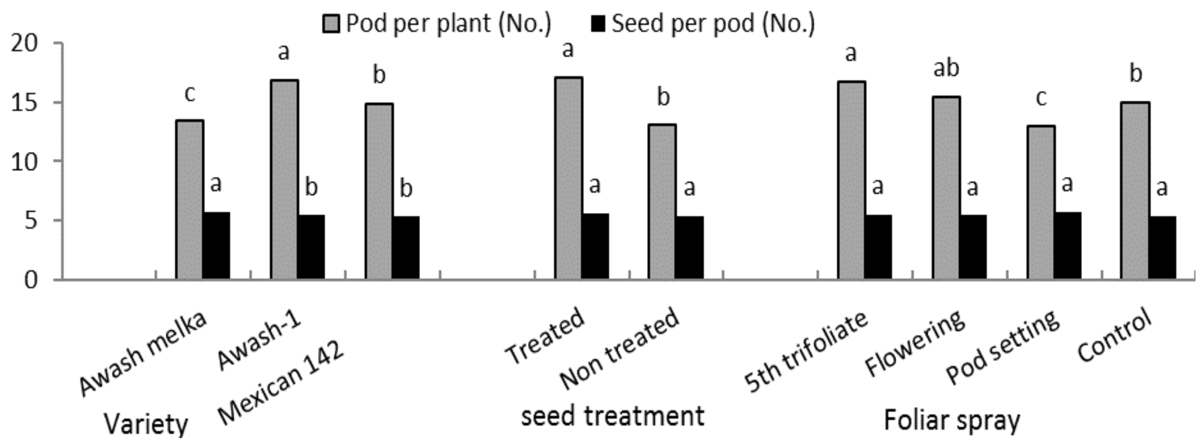

Figure 4. Effect of variety, seed treatment and foliar spray on number of pods per plant and number of seeds per pod at Bako in 2014 main cropping season.

Note: According to DMRT, means followed by the same letter(s) within a similar colored graphs are not significantly different at 5% probability level.

Table 5. Mean squares of common bean morphological and yield related data parameters as influenced by integrated anthracnose management options at Bako in 2014 main cropping season.

Source	DF	Mean squares (MS) values		
		IP	NSP	PP
Model	25	1330.118**	0.298*	32.640**
Variety (A)	2	2329.542**	1.120**	73.789**
Seed treatment (B)	1	130.681 Ns	0.405 Ns	288.400**
Foliar spray (C)	3	6796.125**	0.323 Ns	43.858**
Rep	2	32.042 Ns	0.058 Ns	0.691 Ns
A x B	2	433.681**	0.238 Ns	1.934 Ns
A x C	6	433.986**	0.332 Ns	29.659**
B x C	3	132.384 Ns	0.141 Ns	15.937*
A x B x C	6	690.384**	0.139 Ns	2.907 Ns
Error	46	77.998	0.163	4.494
Total	71			
R^2		90.26	49.9	79.788
Mean		31.625	5.500	15.054

Note: DF = Degree of freedom; IP = infected pod per plant; NSP = Number of seeds per pod and PP = pod per plant; ** Highly significant at $p \leq 0.01$; * Significant at $p \leq 0.05$; Ns= non-significant.

Plots sown with treated-seeds of Awash Melka variety and sprayed with tebuconazole at flowering stage reduced pod infection by more than 93, 93 and 94% over the plots sown with untreated seeds and unsprayed Awash-1 and Mexican varieties and treated-seeds and non-sprayed Awash Melka varieties, respectively. (Tables 5 and 7).

Pod infection significantly ($p \leq 0.05$) varied among common bean varieties even without any fungicide treatment. In this connection, Awash Melka variety without any seed treatment showed lower (38.67%) pod infection, while 75 and 71.3% pod infections were recorded for the varieties Awash-1 and Mexican 142 plots, respectively, that did not receive any fungicide treatment. Pod infection on the susceptible common bean variety ranged from 45.60 to 55.95% during favorable environment for pathogens to cause disease development (Hanan *et al.*, 2009).

3.5.2. Effect of Integrated Anthracnose Management Options on Hundred Seed Weight of Infection-Free and Infected-Seeds

Combined effect of common bean variety with foliar fungicide spray significantly affected hundred infected-seed weight; however, combined effect of variety with thiram seed treatment, foliar fungicide spray with seed treatment, and integrated effects of variety with seed treatment with foliar fungicide spray resulted in non-significant difference in weights of hundred infected-seeds (Table 6). The result indicated that Awash-1 variety without foliar fungicide spray significantly lowered (10.9 g) 100 infected seed weight. However, the infected seeds of the variety Awash Melka sprayed at pod setting and Mexican 142 variety sprayed at flowering showed higher hundred seed weight than that of Awash-1 (Table 6).

3.5.3. Effect of Integrated Anthracnose Management Options on Seed Yield

The two-way interaction of variety with seed treatment, variety with foliar spray, and seed treatment with foliar spray showed a significant difference in bean seed yield (Table 6). Plots sown with treated seeds of Awash Melka produced the highest significant seed yield (1912.750 kg ha^{-1}) of all treatments.

Similarly, the highest, i.e. average seed yields (2096.493 and 2071.486 kg ha^{-1},) were obtained from bean plots sown with treated and untreated seeds and sprayed at flowering stage, respectively, whereas plots sown with non-treated seeds and non-sprayed with fungicide showed significantly lower (1049.354 kg ha^{-1}) average seed yield, followed by the seed yield (1419.920 kg ha^{-1}) from plots sown with treated-seeds and non-sprayed plots (Table 6). Consistent with the results of this study, Amin *et al.* (2013) reported that the combined effect of benlate (benomyl) as a seed treatment and difenoconazole (Score 250 EC) effectively reduced anthracnose severity and increased the yield per plot.

Mexican 142 sprayed at the fifth trifoliate stage, and Awash-1 and Awash Melka sprayed at the flowering stage produced the highest respective seed yields of 2226.770, 2197.88 and 2149.62 kg ha^{-1} of all other treatment combinations of variety with foliar fungicide sprays. On the contrary, Awash-1 without foliar fungicide spray produced the lowest (948.32 kg ha^{-1}) seed yield. Foliar fungicide spray at flowering stage increased seed yield of Awash-1 variety by 56% over the unsprayed (control) plots (Table 6).

Three-way interactions of variety, seed treatment and foliar spray significantly differed in seed yield among the treatment combinations (Table 7). The seed yield obtained from plots sown with treated seeds of Mexican 142 variety and sprayed at the trifoliate stage was the highest (2354.07 kg ha^{-1}), followed by 2156, 2239.76 and 2175.99 kg ha^{-1} seed yields of Awash-1 sown with treated and non-treated seeds and sprayed at flowering stage, and Awash Melka without seed treatment and sprayed at flowering stage, respectively. Foliar spray at flowering stage alone increased seed yield by more than 67% for Awash-1 variety over the control plots of the same variety (Table 7). The minimum seed yield advancement by 38% was recorded from Awash-1 plots sown with seed-treated but without foliar fungicide spray as compared with its own control plots of the three-way interaction combinations.

Table 6. Two-way interaction effect of common bean varieties, seed treatment and foliar fungicide spray time on yield and yield related parameters at Bako in 2014 main cropping season.

Components:		Pod per plant (No.)	100 infected seed wt (g)	Yield (kgha^{-1})
Seed treatment x Variety:				
Seed treatment:	Variety:			
Treated	Awash Melka	15.258	14.796	1912.750 A
	Awash-1	19.233	12.834	1598.607 C
	Mexican 142	16.675	13.013	1793.011 B
Untreated	Awash Melka	11.575	13.769	1680.616 C
	Awash-1	14.575	12.696	1595.708 C
	Mexican 142	13.008	12.692	1606.930 C
LSD (0.05)		NS	NS	101.289
SE (±)		0.601	0.414	35.582
	Seed treatment x Foliar spray			
Seed treatment:	Foliar spray:			
Treated	5th trifoliate	19.111 A	13.463	1945.010 B
	Flowering	18.611 A	14.896	2096.493 A
	Pod setting	14.289 BC	13.400	1611.066 D
	Control	16.211 B	12.433	1419.920 E
Untreated	5th trifoliate	14.444 BC	13.457	1765.225 C
	Flowering	12.244 DE	13.907	2071.486 A
	Pod setting	11.722 E	13.176	1624.940 D
	Control	13.800 CD	11.670	1049.354 F
LSD (0.05)		2.011	NS	116.958
SE (±)		0.707	0.477	41.086
	Variety x Foliar Spray			
Variety	Foliar spray			
Awash Melka	5th trifoliate	13.383 DE	14.418 AB	1845.490 BC
	Flowering	14.267 CD	14.488 AB	2149.616 A
	Pod setting	11.467 EF	15.338 A	1810.926 BC
	Control	14.550 CD	12.886 BCD	1380.701 DE
Awash-1	5th trifoliate	19.333 A	12.269 CDE	1493.092 D
	Flowering	16.533 BC	15.221 A	2197.883 A
	Pod setting	17.467 AB	12.671 CD	1749.335 C
	Control	14.283 CD	10.899 E	948.319 F
Mexican 142	5th trifoliate	17.617 AB	13.693 ABC	2226.770 A
	Flowering	15.483 BCD	13.495 BCD	1904.471 B
	Pod setting	10.083 F	11.854 DE	1293.748 E
	Control	16.183 BC	12.369 CDE	1374.891 DE
LSD (0.05)		2.464	1.665	143.244
SE (±)		0.865	0.585	50.320

Note: Means followed by the same or no letter (s) in the same column are not significantly different from each other at p≤0.05, DMRT

Table 7. Interaction effects of common bean variety, seed treatment and foliar fungicide spray time on infected pod per plant and seed yield at Bako in 2014 main cropping season.

Variety	Seed treatment	Foliar spray	Infected pod per plant (%)	Seed yield (kg ha^{-1})
Awash Melka	Treated	Trifoliate	13.000 HI	1918.983DEF
		Flower	4.333 I	2123.245 BCD
		Pod	9.333 HI	2035.057 BCD
		Non	73.000 A	1573.716 HI
	Untreated	Trifoliate	23.333 E-H	1771.998 FGH
		Flower	9.667 HI	2175.986 ABC
		Pod	9.333 HI	1586.794 GHI
		Non	38.667 D	1187.686 M
Mexican 142	Treated	Trifoliate	28.667 D-G	2354.074 A
		Flower	23.000 E-H	2010.231 CDE
		Pod	14.000 HI	1298.336 J-M
		Non	31.000 DEF	1509.400 IJ
	Untreated	Trifoliate	30.000 DEF	2099.465 BCD
		Flower	21.667 E-H	1798.711 EFG
		Pod	21.667 E-H	1289.160 KLM
		Non	71.333 AB	1240.383 LM
Awash-1	Treated	Trifoliate	58.333 BC	1561.973 HI
		Flower	33.667 DE	2156.003 ABC
		Pod	18.000 F-I	1499.805 IJK
		Non	57.000 C	1176.645 M
	Untreated	Trifoliate	58.000 BC	1424.212 I-L
		Flower	15.000 GHI	2239.762 AB
		Pod	22.000 E-H	1998.865 CDE
		Non	75.000 A	719.992 N
LSD (0.05)			14.515	202.578
SE(±)			5.099	71.163

Note: Means followed by different letters within the same column are significantly different from each other and without letters are not significant at $p \leq 0.05$, DMRT.

3.6. Cost-Benefit Analysis in Bean Anthracnose Management

Partial budget analysis of marginal cost and marginal benefit depicted the highest (ETB 32,775.67 ha^{-1}) marginal benefit from Mexican 142 plots sown with treated-seed and foliar fungicide-spray at the fifth trifoliate stage. However, Awash-1 and Awash Melka varieties sown without seed treatment and sprayed with tebuconazole at flowering stage resulted in the highest marginal benefits of ETB 31,562.57 and 30,644.20 ha^{-1}, respectively. In addition, the marginal rates of return were calculated for the significant treatments under dominant analysis for comparison of the treatment cost/benefit of the treatments (Table 8).

For the variety Awash-1, plots sown with untreated seeds and sprayed with fungicide at flowering stage exhibited that for every one ETB incurred or invested on foliar fungicide spray at this stage additional ETB 30.72 was obtained in return, followed by ETB 25.69 from plots without seed treatment and sprayed with fungicide at pod setting. Generally, Awash-1 without seed treatment and with foliar fungicide spray at flowering stage resulted in a higher marginal rate of return than the other two common bean varieties, i.e. Awash Melka and Mexican 142. Similar to the findings of this study, Hirpha and Selvaraji (2016) indicted that Awash-1 sprayed with fungicide had high marginal rate of return. On the other hand, sowing seeds after treating with the fungicide resulted in lower rates of return than sowing without treatment because additional costs were incurred for the purchase of fungicide for seed treatment (Table 8).

Table 8. Cost-benefit analysis of common bean production as influenced by anthracnose management options at Bako in 2014 main cropping season.

Seed treatment	Foliar spray	Seed yield (kg ha^{-1})	Adj. seed yield (kg ha^{-1})	Gross return (ETB ha^{-1})	Marginal cost (ETB ha^{-1})	Marginal benefit (ETB ha^{-1})	MRR (%)
Awash Melka							
Treated	Trifoliate	1918.98	1727.085	27633.4	1123.00	26510.36	---
	Flowering	2123.25	1910.921	30574.7	1123.00	29451.73	---
	pod setting	2035.06	1831.551	29304.8	1123.00	28181.82	---
	None	1573.72	1416.344	22661.5	433.00	22228.51	1183.79
Untreated	Trifoliate	1772.00	1594.798	25516.8	690.00	24826.77	1119.43
	Flowering	2175.99	1958.387	31334.2	690.00	30644.20	1962.54
	pod setting	1586.79	1428.115	22849.8	690.00	22159.83	---
	None	1187.69	1068.917	17102.7	0.00	17102.68	0.00
Mexican 142							
Treated	Trifoliate	2354.07	2118.667	33898.7	1123.00	32775.67	1328.06
	Flowering	2010.23	1809.208	28947.3	1123.00	27824.33	---
	pod setting	1298.34	1168.502	18696.0	1123.00	17573.04	---
	None	1509.40	1358.460	21735.4	433.00	21302.36	794.65
Untreated	Trifoliate	2099.47	1889.519	30232.3	690.00	29542.30	1692.87
	Flowering	1798.71	1618.840	25901.4	690.00	25211.44	1065.21
	pod setting	1289.16	1160.244	18563.9	690.00	17873.90	---
	None	1240.38	1116.345	17861.5	0.00	17861.52	0.00
Awash-1							
Treated	Trifoliate	1561.97	1405.776	22492.4	1123.00	21369.41	---
	Flowering	2156.00	1940.403	31046.4	1123.00	29923.44	---
	pod setting	1499.81	1349.825	21597.2	1123.00	20474.19	---
	None	1176.65	1058.981	16943.7	433.00	16510.69	1418.66
Untreated	Trifoliate	1424.21	1281.791	20508.7	690.00	19818.65	1369.68
	Flowering	2239.76	2015.786	32252.6	690.00	31562.57	3071.69
	pod setting	1998.87	1798.979	28783.7	690.00	28093.66	2568.95
	None	719.99	647.9928	10367.9	0.00	10367.88	0.00

Note: Numbers written in columns of marginal rate of return (MRR) were treatments that showed significant differences in dominance analysis; average market price of bean ETB 16 kg-1

4. Conclusions

The results of this study demonstrated that seed treatment and foliar spray of common bean plants with the contact fungixide Thiram at the rate of 5 g kg^{-1} at flowering stage significantly reduced foliage anthracnose percent severity index (PSI) by 54.26, 61.88 and 71.85% over the respective control plots of all three varieties tested (i.e., sown with non-treated seed without any earlier foliar sprays). The results revealed that Mexican 142 common bean variety sown from treated-seed and sprayed with tebuconazole at the fifth trifoliate stage produced the highest (2354.074 kg ha^{-1}) seed yield, followed by seed yield (2239.76 kg ha^{-1}) of the variety Awash-1 sown from non-treated seed and sprayed at flowering stage. The economic analysis of the seed treatment with thiram at the rate of 5 g kg^{-1} seed indicated the highest (3071%) marginal rate of return (MRR) from the variety Awash-1, followed by the same variety with MRR of 2568% without seed treatments but sprayed at flowering and pod setting stages, respectively, as well as Awash Melka (1962%) MRR without seed treatment but sprayed at flowering stage. Awash-1 without seed treatment but sprayed at pod setting gave 2568% MRR, but 13% of the seeds had blemishes on their surfaces due to anthracnose resulting in low seed quality. Therefore, Awash-1 and Awash Melka without seed treatment but with a foliar spray treatment with tebuconazole at the rate of 350 ml ha^{-1} at the water spray volume of 100 L ha^{-1} at flowering stage that resulted in optimum yield and economic benefits of the crop are recommended as options for the management of common bean anthracnose. This implies that common bean farmers in the study area can enhance the productivity of common bean with the integrated cultivation of Awash-1 and Awash Melka common bean varieties with the spray of the fungicide at the aforementioned rate. Similarly, further research into seed treatment with different fungicides, testing the efficacies of more fungicides, application rates and frequencies in multi-locations over seasons is desirable to design a consolidated integrated bean anthracnose management options for sustainable common bean production in the study area and elsewhere that have similar agroecologies. Future research should focus also on breeding for resistance by transferring resistance genes into improved market-type elite common bean varieties.

5. Acknowledgements

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