Evaluation of Copper Hydroxide Bactericide for the Management of Common Bacterial Blight (*Xanthomonas axonopodis* pv. phaseoli) of Common Bean in Eastern Amhara, Ethiopia

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Abstract

Common bacterial blight constitutes a major constraint to common bean production in Ethiopia. To evaluate the efficacy of seed treatment and varying frequencies of foliar application of copper hydroxide for disease management, a field experiment was conducted at the Sirinka, Jari, and Cheffa research sites during the 2022 and 2023 growing seasons. The study employed a randomized complete block design with three replications. Eight treatments were assessed, including copper hydroxide seed treatment alone, seed treatment combined with one, two, or three foliar spray applications, and an untreated control. Data on disease severity, yield, and yield components were subjected to analysis of variance using GenStat version 18.0 software. The combined mean analysis revealed that the highest area under the disease progress curve (AUDPC) value (957) was recorded in the seed-treated plots receiving two foliar sprays, while the lowest AUDPC value (518.6) was observed in the untreated control plots. Seed yield ranged from 1408 kg.ha^{-1} in the control treatment to 2397 kg.ha^{-1} in plots treated with copper hydroxide seed treatment plus two foliar sprays. The highest marginal rate of return (2214.2%) was attained with seed treatment alone, whereas a single foliar spray application yielded a return of 102.92%. Based on these findings, it is recommended that copper hydroxide bactericide be applied as a seed treatment at a rate of 300 g.100 kg^{-1} of common bean seed at planting, supplemented with a single foliar spray at the onset of disease, as this approach provides the greatest net economic benefit compared to other treatments and the control.

Keywords: AUDPC, copper hydroxide, disease management, foliar spray, seed treatment, seed yield

Introduction

Common bean (*Phaseolus vulgaris* L.) is a globally important crop, recognized for its high commercial demand and extensive cultivation (Zewdie and Hassen, 2021). It plays a vital role in enhancing food security, nutrition, and livelihoods, particularly in developing regions (Nchanji et al., 2023; Tsegaye et al., 2024). In Ethiopia, common bean is a significant crop, occupying a production area of 311,583.58 ha with an annual output of 5.5 million tons and an average productivity of 1.8 tons.ha^{-1} (CSA, 2021).

Various biotic and abiotic factors, including low soil fertility, frequent water shortages, insect pests, and diseases, challenge common bean production in Ethiopia. Among these biotic constraints, common bacterial blight (*Xanthomonas axonopodis* pv. phaseoli) is one of the most widespread and economically important diseases affecting common bean (Chen et al., 2021). This disease causes both quantitative and qualitative yield losses worldwide (Adila et al., 2021; Terefe et al., 2024) and has been identified as a primary constraint to production in Ethiopia (Degu et al., 2020). The disease is reported to be 100% prevalent and widely distributed in the major bean-growing regions of eastern, central, and southern Ethiopia (Girma et al., 2022). It affects multiple plant parts, including leaves, stems, pods, and seeds. Early symptoms manifest as small, water-soaked lesions on leaves (Manandhar et al., 2016), with disease progression favoured by high humidity and rainfall. Yield losses attributed to common bacterial blight typically range from 10% to 45% (Fininsa, 2003; Manandhar et al., 2016), but in susceptible cultivars, losses may reach up to 70%, making it the most destructive disease of common bean (Ararsa et al., 2018; da Silva Junior et al., 2022).

The pathogen responsible for common bacterial blight is seed-borne and persists in plant debris, with seed serving as the primary inoculum source for disease dissemination (Manandhar et al., 2016). Consequently, seed treatment is a fundamental control strategy aimed at reducing initial inoculum levels (Hailu and Tontosha, 2021). Effective management of CBB requires an integrated disease management approach that combines chemical treatments such as antibiotics (e.g., streptomycin), the use of genetically resistant cultivars, certified disease-free seed, and cultural practices including crop rotation and intercropping (Ararsa et al., 2018). Cultivation of varieties with varying degrees of resistance can reduce the frequency and dosage of pesticide applications. Application of contact bactericides early in the growing season, at intervals of 7 to 10 days under cool, moist conditions, has been shown to suppress bacterial establishment (Selamawit, 2004). Hailu and Tontosha (2021) demonstrated that integrating resistant varieties with chemical seed treatment and cultural practices significantly reduced CBB incidence while improving seed yield and its components.

Foliar application of copper-based bactericides, such as copper hydroxide-101, has also proven effective in controlling CBB before disease establishment (Fininsa, 2003; Selamawit, 2004). In the Eastern Amhara Region of Ethiopia, two foliar sprays of copper hydroxide at 3.0 kg.ha⁻¹ significantly reduced CBB epidemics on common bean, leading to increased yield and yield components (Asmamaw, 2008). Given the increasing threat posed by CBB to common bean production in Ethiopia, particularly in Eastern Amhara, where it remains a major limiting factor (Asmamaw, 2008), there is a critical need to evaluate effective management strategies. However, to date, no studies have been conducted in this region to assess the management of CBB on common beans. Therefore, this study was undertaken to evaluate the efficacy of copper hydroxide bactericide applied through seed treatment and foliar spraying for managing common bacterial blight, and to identify economically viable options for controlling this disease in common beans.

Materials and Methods

Experimental Site Description

A field experiment was conducted to evaluate the use of copper hydroxide bactericide for managing common bacterial blight of Common bean at the Sirinka, Jari, and Cheffa research sites of the Sirinka Agricultural Research Center during the main cropping seasons. The altitudes of the experimental fields were 1850 and 1450 masl, located at 11° 45' 10" and 10° 50' 39" North latitude, and 39° 36' 44" and 39° 48' 46" East longitude, at Sirinka and Cheffa, respectively. The altitude of Jari location was 1690 m.a.s.l., located at 11° 21' North latitude and 39° 47' East longitude. The soils of the experimental sites are eutric vertisols (Sirinka Agricultural Research Center), which are generally suitable for common bean cultivation. Nonetheless, it is recognized for growing in various soil types throughout Ethiopia. The trial sites receive annual minimum temperatures of 13.6°C and 11.6°C, and annual maximum temperatures of 27.3°C and 30.4°C, along with rainfall of 876 mm and 850 mm, for Sirinka and Chefa, respectively. Moreover, the annual rainfall at this Jari trial site is 987.3 mm, with a minimum temperature of 14.20°C and a maximum temperature of 28.70°C.

Experimental Design and Materials

The field experiment was conducted in 2022 at Sirinka and during the 2023 primary cropping season at the Sirinka Agricultural Research Center (SARC) trial station locations of Sirinka, Jari, and Cheffa. The field experiment was structured using a completely randomized block design with three replications. The experiment consisted of eight treatments (Table 1), which included a combination of copper hydroxide (trade name: Kocide) seed treatment, seed treatment with varying copper hydroxide spray frequencies (one, two, and three times), and an untreated control. The treatment application was performed using copper hydroxide bactericide as a seed treatment at a rate of 300 g.100 kg⁻¹ of seed, mixed with 300 mL of water, and applied 10–30 minutes before planting. For foliar application, 3.0 kg.ha⁻¹ was dissolved in 300 L of water. ha⁻¹ and sprayed starting at 51 days after planting, which is the time when disease typically occurs. Treatments were repeated at 10 day intervals based on the assigned spraying frequencies. A bactericide application was done by using a knapsack sprayer for each plot. Plastic sheets were used to protect the drift effect during copper hydroxide spraying.

The plot size of the experiment was 3 m x 2 m, and plant spacing of 10 cm and 40 cm row spacing, and 0.5 m and 1 m spacing between plots and experimental blocks, respectively. There were five rows per plot, and the middle three rows with a net plot area of 4.8 m² (excluding the two border rows) were used for data collection. The experiment was conducted using the "Awash Mitin" improved variety as the planting material for all treatments. All agronomic practices, such as weeding and cultivation, were applied uniformly for all treatments in each plot.

Disease Data Collection

Disease severity was recorded by visually estimating the percentage of leaf area diseased from 10 randomly taken and pre-tagged plants in the middle three rows of each plot. The severity was scored five times every 10 days, starting from the onset of the disease, using a standard disease scale of 1–9 (CIAT, 1998). For statistical analysis, the common bacterial blight severity and the average severity of the 10 plants per plot were used. Each severity value was converted into a percentage severity index (PSI) for analysis by using the following formula (Campbell and Madden, 1990):

$$PSI = \frac{Snr}{Npr \times Msc} X\ 100\%$$

Where Snr represents the sum of the numerical ratings, Npr indicates the overall number of plants evaluated, and Msc denotes the highest score on the scale.

The area under the disease progress curve (AUDPC) was calculated for each treatment using the disease severity assessment, as outlined in the following formula (Campbell and Maddan, 1990).

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

Where:
x = disease severity at i[th] observation
n = the total number of days of disease assessed
t = the time at the ith observation (in days numbered sequentially beginning with the initial assessment)

Yield and Yield Component

Yield and yield component data, including pods per plant, seeds per pod, hundred-seed weight, and seed yield, were recorded using standard measurements.

Relative Yield Loss and Percentage Yield Increase

The relative yield loss due to common bacterial blight disease was measured as the percentage yield reduction of unsprayed plots compared with the most protected plot, using the following formula.

$$RPYL\ (\%) = \frac{YP - YT}{YP} X\ 100\%$$

Where RPYL refers to the relative percentage of yield loss, YP represents the yield from the plot with maximum protection, and YT denotes the yield from plots subjected to alternative treatments.

The percent yield increase (PYI) was calculated based on the following formula:

$$PYI = \frac{\text{seed yield of a bactericide treated plot} - \text{seed yield of control plot}}{\text{yield of control plot}} X\ 100\%$$

Cost-Benefit Analysis

A partial analysis of the cost-benefit assessment for each treatment was conducted, and the marginal rate of return was calculated by taking into account the variable costs associated with each treatment (CIMMYT, 1988). Variable costs included chemical and labor costs for chemical application. The prices of copper hydroxide (copper hydroxide) and the labor costs for chemical application were used. At the end of the production, the total gross benefit of the field was calculated based on the seed yield of common beans and the local market prices in Sirinka, Jari, and Cheffa Districts. Total input costs were obtained by summing the variable costs and the fixed production costs. A partial analysis of the costs and benefits of each treatment was performed, and the marginal rate

Table 1. Treatment combination and application methods*

No	Treatment combinations	Method of application
1	Copper hydroxide ST	Only copper hydroxide seed treatment
2	Copper hydroxide ST+ 1SF	Copper hydroxide seed treatment, sprayed once
3	Copper hydroxide ST+ 2SF	Copper hydroxide seed treatment, sprayed twice
4	Copper hydroxide ST+ 3SF	Copper hydroxide seed treatment, sprayed three times
5	Copper hydroxide 1SF	Copper hydroxide spray, once
6	Copper hydroxide 2SF	Copper hydroxide spray, twice
7	Copper hydroxide 3SF	Copper hydroxide spray, three times
8	Control	Untreated control

Notes: *the seed treatments were applied 10-30 minutes before planting, and foliar sprays were used at the onset of the disease (51 days after planting). ST = Seed treatment; SF = Spraying frequency.

of return (MRR) was calculated by factoring in the variable costs associated with each treatment. Yield and economic data were analyzed to compare the advantages of different rates and spraying methods for bactericide applications in various treatment combinations. The marginal rate of return indicates the value of the benefits gained relative to the percentage of additional costs incurred.

$$\text{MRR} = \frac{\text{MNB}}{\text{MC}} X \, 100\%$$

Where MRR is the marginal rate of return, MNB is the marginal net benefit compared to the control, and MC is the marginal cost compared to the control.

Data Analysis

Data on disease severity, AUDPC, yield, and yield component parameters were subjected to analysis of variance (ANOVA) for each dataset using GenStat version 18.0 Software (GenStat, 2015). By using Duncan's multiple range tests, the means of the treatments were separated. The linear regression model was used to predict the relationship between AUDPC and grain yield using GenStat version 18.0 Software.

Results and Discussion

Disease Assessment

The analysis of variance revealed a significant difference between treatments (p<0.05) in the percentage severity index and AUDPC at Sirinka, Jari, and Cheffa districts in the 2022 and 2023 cropping seasons. The first assessment of common bacterial blight disease was conducted 56 days after sowing (DAS) at Sirinka during the 2022 cropping season (Table 2). In 2023, the first disease symptom was observed and recorded at 51, 52, and 55 DAP at Sirinka, Jari, and Cheffa, respectively (Tables 3, 4, and 5).

Percent severity index of common bacterial blight

Copper hydroxide bactericide seed treatment with foliar sprays significantly affected (p<0.05) the percent severity index (PSI) at three locations, except for the initial assessment at Sirinka in 2022 and the second and third assessments at Sirinka and Cheffa in 2023. In 2022, at Sirinka, the highest (43.7%) and lowest (26.81%) final percentage severity index values were calculated from the untreated control plot and the copper hydroxide-treated plot with a two-times spraying frequency (Table 2). Similarly,

the highest percentage severity index of common bacterial blight on common bean (52.59%, 50.37%, and 45.19%) was found in untreated control plots at Sirinka, Jari, and Cheffa locations, respectively, during the 2023 cropping season. The lowest severity (22.44%, 20.93%, and 24.93%) was recorded for copper hydroxide-treated seeds with a one-time spraying frequency at Sirinka, Jari, and Cheffa locations, respectively, during the 2023 cropping season (Tables 3, 4, and 5).

The analysis of the overall combined mean for all locations in 2022 and 2023 revealed a significant difference (p<0.05) among treatments in the final percentage severity index. The maximum final percentage of severity index (47.96%) was recorded on the unsprayed control plot, and the minimum final percentage of severity index (24.81%) was recorded on the copper hydroxide seed treated with a one-time spray frequency of the bactericide (Table 6). The trend of the disease increases from the initial to the final assessment dates in all treatments. However, chemical seed treatment with one and two foliar spray frequencies significantly reduces the disease severity index on common bean compared to the control plot.

The present study demonstrated that copper hydroxide seed treatment, combined with foliar spray frequencies, showed promising potential in reducing the severity index of common bacterial blight in common beans. This study is similar to the one conducted by Hailu and Tontosha (2021), who reported that seed treatment and foliar spray treatment reduce the percentage severity index compared to untreated seed at the final assessment dates. It was also reported that seed treatment and foliar spray frequency can effectively control CBB when used as components of an integrated disease management strategy (Hailu and Tontosha, 2021). Previous studies by Selamawit (2004) and Tumsa (2007) noted that copper-hydroxide (Copper hydroxide-101) is commonly used as a chemical applied at various intervals to minimize the spread of bacterial cells. Hailu and Tontosha (2021) reported that applications of copper hydroxide 101 at every two-week interval can decrease the establishment of bacterial pathogens. This experiment is similar to the study conducted by Fetene and Ayalew (2016), who reported that at the final assessment dates, foliar spray intervals of two and four weeks reduced the severity index percentage by 18.0% and 17.3%, respectively, compared to the unsprayed control.

Area under the disease progress curve (AUDPC) of the common bacterial blight

Data analysis on AUDPC revealed significant

differences (p<0.05) among treatments at all locations in both 2022 and 2023. The lowest AUDPC value (590.7) and the highest area under disease progress curve (953.7) were found in the copper hydroxide seed-treated plot with three times the foliar spray frequency and in the untreated control plot, respectively, at Sirinka in the 2022 cropping season. The lowest (402.1% day) area under disease progress curve was calculated from seed treated with one-time foliar spray frequencies at Jari location, and 500 AUDPC was recorded from plots seed treated plus two-times spraying frequencies at Sirinka location (Tables 3 and 4). Additionally, the highest value of the area under the disease progress curve (1083.3, 863.9, and 927.2) was obtained from the untreated plots at Sirinka, Jari, and Cheffa locations, respectively, in 2023 (Tables 3, 4, and 5).

The overall average across all locations during the 2022 and 2023 cropping seasons revealed significant differences (p<0.05) among the treatments concerning the area under the disease progress curve (Table 6). The highest (957 days) and lowest (518.6 days) AUDPC values were calculated from untreated control and seed-treated plots, respectively, with a two-times spraying frequency of copper hydroxide bactericide (Table 6). The present study aligns with Fetene and Ayalew (2016) and Hailu and Tontosha (2021), who reported that the lowest value of the area under the disease progress curve was obtained from seed treatment with bio-bactericide, combined with a foliar spray every two weeks.

Number of pod per plant and number of seeds per pod

The analysis of variance revealed no significant differences (p<0.05) among treatments regarding seed per pod and pod per plant at Sirinka in 2022, as well as at Jari and Cheffa locations in the 2023 cropping seasons (Tables 2, 4, and 5). However, there was a significant difference among treatments on seed per pod and pod per plant at Sirinka in the 2023 cropping season (Table 3). The maximum (6.93) and minimum (4.67) seeds per pod were recorded for copper hydroxide-treated seeds with a three-times spray frequency and untreated seeds with a three-times spray frequency, respectively. Similarly, the highest (22.8) and lowest (13) pod counts per plant were obtained from copper hydroxide-treated seed with two sprays and untreated seed with one spray, respectively (Table 3).

Likewise, the overall combined means for seeds per pod did not show significant differences across treatments; however, a significant difference (p<0.05) was observed in pods per plant. Most treatments produced approximately six seeds per pod (Table 6). These results suggest that the application of copper hydroxide did not affect the number of seeds per pod in common beans. Whereas the highest and lowest pod per plant were recorded from only the copper hydroxide seed-treated and the untreated control plot, respectively (Table 6).

Table 2. Mean of yield, yield component, and disease data of common bean at Sirinka in 2022

| Treatments | Percentage severity index (PSI) | | | | Area under the disease progress curve | Seed per pod | Pod per plant | 100 seed weight | Seed yield (kg.ha⁻¹) |
	56 days after sowing	66 days after sowing	76 days after sowing	86 days after sowing					
Seed treatment	10.37	18.52	27.41	30.15	661.8	5.33	15.87	20.67	1996
Seed treatment and one spray	6.667	15.56	28.15	30.96	625.2	6.13	15.33	22.33	2779
Seed treatment and two sprays	9.63	17.04	24.07	26.81	593.3	5.53	16.17	21.67	2892
Seed treatment and three sprays	6.667	15.56	25.93	28.52	590.7	5.93	14.07	21.67	3217
One spray	9.63	18.52	29.63	32.59	692.6	5.8	17.53	21.33	2270
Two sprays	13.333	17.78	27.65	30.81	675	5.53	12.8	21.33	2434
Three sprays	11.852	17.78	26.58	29.21	648.9	5.87	18.27	20.67	2628
Control	9.63	30.48	38.22	43.7	953.7	4.47	10.1	20	1823
GM	9.72	18.9	28.45	31.6	680.16	5.58	15.02	21.21	2505.14
LSD	ns	5.17	5.81	8.05	106.58	ns	ns	1.15	799.92
CV (%)	29	15.6	11.7	14.6	8.9	13.5	26	3.1	18.2

Notes: ns= not significant at p<0.05. GM= Grand mean; LSD= List significance difference; CV= Coefficient of variation.

Hundred-seed weight of common bean

Data analysis on hundred-seed weight revealed significant differences (p<0.05) among treatments at all locations in both 2022 and 2023, except at Sirinka in the 2023 cropping season. The lowest (20) and highest (21.67) hundred-seed weights were found from the untreated control and copper hydroxide seed treated with two times of foliar spraying frequency plot, respectively, at Sirinka in the 2022 cropping season (Table 2). The highest (21.91 and 21.83 g) hundred-seed weight was calculated from copper

Table 3. Mean of yield, yield component, and disease data of common bean at Sirinka (2023)

Treatment	Percentage severity index (PSI)				Area under the disease progress curve	Seed per pod	Pod per plant	100 seed weight	Seed yield (kg.ha⁻¹)
	51 days after sowing	61 days after sowing	71 days after sowing	81 days after sowing					
Seed treatment	5.93	19.26	19.26	23.75	533.6	6.8	20.77	16.63	1061
Seed treatment and one spray	5.19	21.85	20	22.44	593.7	6.8	20.41	17.17	1272
Seed treatment and two sprays	2.96	15.56	20	25.93	500	6.8	22.8	16.77	1177
Seed treatment and three sprays	2.59	23.7	23.7	26.1	580.5	6.93	21.33	17.1	1218
One spray	9.63	27.41	43.63	43.7	983.3	5.67	13	17.17	1395
Two sprays	7.04	30.37	44.26	46.3	1006.7	5.87	14	18.2	1146
Three sprays	8.15	22.59	45.93	40.74	973.3	4.67	13.8	16.67	1022
Control	10	31.11	50.3	52.59	1083.3	4.8	13.33	16.77	1089
GM	6.44	23.98	33.39	35.19	781.81	6.04	17.43	17.06	1172.5
LSD	3.14	ns	13.43	15.79	240.94	0.97	5.19	ns	ns
CV%	27.90	28.7	23	25.6	17.6	9.20	17.00	5.3	35

Notes: ns= not significant at p<0.05. GM= Grand mean; LSD= List significance difference; CV= Coefficient of variation.

Table 4. Mean of yield, yield component, and disease data of common bean at Jari (2023)

Treatment	Percentage severity index (PSI)				Area under the disease progress curve	Seed per pod	Pod per plant	100 seed weight	Seed yield (kg.ha⁻¹)
	52 days after sowing	62 days after sowing	72 days after sowing	82 days after sowing					
Seed treatment	5.56	15.56	19.26	21.89	485.4	5.60	36.07	19.47	2396
Seed treatment and one spray	4.52	6.01	21.48	20.93	402.1	5.87	30.8	21.91	2711
Seed treatment and two sprays	4.82	8.52	20	24	429.3	6.80	31.67	21.33	2532
Seed treatment and three sprays	2.59	11.26	20.74	27.41	470	6.20	27.73	19.85	2470
One spray	12.41	20.74	28.89	47.41	795.4	5.67	22.73	19.45	1460
Two sprays	12.59	20	31.85	42.96	796.3	6.47	26.07	19.38	1800
Three sprays	7.96	21.11	24.44	36.3	676.8	6.47	24	20.17	1520
Control	11.3	22.96	32.59	50.37	863.9	6.60	25.13	19.44	1297
GM	7.72	15.77	24.91	33.91	614.9	6.21	28.03	20.13	2023.25
LSD	5.74	9.46	9.39	18.47	210.68	ns	ns	1.49	981.33
CV%	42.50	34.30	21.50	31.10	19.60	11.80	20.70	4.40	28.70

Notes: ns= not significant at p<0.05. GM= Grand mean; LSD= List significance difference; CV= Coefficient of variation.

hydroxide seed treated with one-time foliar spraying frequency at Jari and Sirinka, respectively. The lowest hundred-seed weight (19.44 and 19.5 g) was obtained from the untreated plots at Jari and Cheffa locations, respectively, in 2023 (Tables 4 and 5). The present finding agrees with Hailu and Tontosha (2021), who also report that seed treatment with foliar sprays of copper hydroxide-101 at two-week intervals significantly reduced CBB epidemics and increased yield and yield components of common beans.

The current study results are similar to those of Hailu and Tontosha (2021), who reported that seed treated with foliar spray frequencies increased relative seed yield, seed per pod, pod per plant, and hundred-seed weight compared to the control. Similarly, Ararsa et al. (2018), who reported that the interaction effect of seed treatment and chemical spray had a pronounced impact on reducing all disease parameters and increasing yield and yield components at Arsi Negele, significantly reduced all disease parameters, but only improved the pod per plant and seed per pod at Melkassa. Tumsa (2007) reported that seed treatment increased the relative seed yield and hundred-seed weight compared to the control.

Seed Yield of Common Bean

Copper hydroxide bactericide seed treatment with foliar spray frequencies showed a significant difference (p<0.05) among treatments in common bean seed yield at all locations in 2022 and 2023, except at Sirinka in the 2023 cropping season. The highest seed yield (3217 kg.ha⁻¹) was obtained from seed treated with three times foliar spray frequencies, and the lowest (1823 kg.ha⁻¹) seed yield was obtained on untreated plots (Table 2). Due to seed treatment with foliar spray and increased frequency, the mean seed yield increased by 43.75% over the untreated control at the Sirinka location in 2022 (Table 2). In 2023, the highest average seed yield (1395, 2711, and 2987 kg.ha⁻¹) was obtained from a single foliar spray frequency, while seed treated with one and two foliar spraying frequencies at Sirinka, Cheffa, and Jari locations, respectively. Additionally, the lowest seed yields (1089, 1297, and 1423 kg.ha⁻¹) were obtained from untreated plots at Sirinka, Cheffa, and Jari locations, respectively (Tables 3, 4, and 5).

Moreover, the overall mean analysis of the results revealed a significant difference (p<0.05) in common bean seed yield among the treatments (Table 6). The highest yields of 2,397 kg.ha⁻¹ were obtained in plots treated with copper hydroxide at a two-times spraying frequency. In contrast, the untreated control plot produced the lowest seed yield of 1,408 kg.ha⁻¹ (Table 6). Additional foliar sprays (three times the spraying frequency) may not yield significant benefits, resulting in diminishing returns in effectiveness. Conditions such as the growth stage (maturity) of the common bean and pest pressure may vary, affecting the efficacy of additional sprays. The present study agrees with Asmamaw (2008), who found that seed treatment and foliar application of copper hydroxide bactericide resulted in the highest seed yield of common bean compared to other treatments and

Table 5. Mean of yield, yield component, and disease data of common bean at Cheffa (2023)

Treatment	Percentage severity index (PSI)				Area under the disease progress curve	Seed per pod	Pod per plant	100 seed weight	Seed yield (kg.ha⁻¹)
	55 days after sowing	65 days after sowing	75 days after sowing	85 days after sowing					
Seed treatment	3.7(1.9)	18.89	24.77	34.81	551.8	5.87	24.83	20.17	2382
Seed treatment and one spray	3.7(1.9)	19	23.91	24.93	572.3	5.31	25.45	21.83	2514
Seed treatment and two sprays	4.4(2.1)	14.07	24.07	29.63	629.2	5.72	22.83	21.17	2987
Seed treatment and three sprays	4.1(1.6)	19.81	23.93	34.81	631.8	5.69	21.33	21.17	2475
One spray	6.7(2.6)	28.15	29.63	42.22	817.4	5.2	18.33	20.83	1697
Two sprays	5.6(2.3)	28.89	30.99	42.96	822.2	5.6	20.87	20.83	2423
Three sprays	15.6(3.8)	25.81	28.15	40	841.3	5.56	21.27	20.17	1880
Control	10.3(3.2)	27.78	37.22	45.19	927.2	5.427	17.33	19.5	1423
GM	6.75	22.8	27.83	36.82	724.15	5.55	21.53	20.71	2222.55
LSD	6.23	7.95	ns	12.94	170.59	ns	ns	1.15	829.72
CV%	27.6	19.90	24.50	20.10	13.50	7.00	22.10	3.30	21.30

Notes: ns= not significant at p<0.05. GM= Grand mean; LSD= List significance difference; CV= Coefficient of variation.

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the control check. Selamawit (2004) also reported similar results, indicating that spraying copper-based chemicals at a 5-day interval increased the yield over the control plot. The results of this study align with the work of Fetene and Ayalew (2016), who found that seed treatment and foliar spray frequencies increased the mean seed yield by 26.1% compared to the untreated control.

After a certain point, additional foliar sprays may not yield significant benefits, resulting in diminishing returns in effectiveness.

Relative Yield Loss and Percentage Yield Advantage

The analysis of relative yield loss assessment and percentage yield advantage was calculated from the average seed yield of all locations in the 2022 and 2023 cropping seasons. Yield loss was calculated for all treatments relative to the yield of the maximum protected plot, which was treated with copper hydroxide seed and sprayed twice. The yield loss result differed among plots treated with copper hydroxide. Losses were notably higher in unsprayed plots than in treated plots with copper hydroxide bactericide (Table 7). In comparison to the other plots, the lowest losses were obtained from plots of copper hydroxide seed treated with two foliar sprays. The highest relative common bean seed yield loss (41.26%) was obtained from unsprayed control plots, followed by a 28.83% yield loss from a single spraying frequency (Table 7). However, common bean seed

yield losses were reduced by all Copper hydroxide-treated treatments as compared to the unsprayed control plots. According to Tumsa's (2007) research report, the highest seed yield losses of common beans were observed in the untreated control plot.

The percentage yield advantage study was calculated from all treatments as compared with the untreated control plots. The result of the percentage yield advantage showed differences among treatments. Maximum (70.24%) yield advantage was obtained from plots seed treated with two times copper hydroxide spraying frequency, followed by 66.5 and 58.81% yield increase was found from plots of copper hydroxide seed treated with three and one times spraying frequency, respectively (Table 7). According to Fetene and Ayalew (2016), the research result showed that the maximum standard bean seed yield increment was obtained from a combination of seed treatment with foliar sprays of copper hydroxide bactericide at Haramaya and Hirna.

Linear Regression between Area under the Disease Progress Curve (*AUDPC) of Common Bacterial Blight and the Common Bean Seed Yield*

Linear regression analysis of common bean seed yield and AUDPC of common bacterial blight was used for predicting common bean seed yield loss. Because AUDPC linear regression is a more effective analytical model for indicating the relationship between yield loss and disease effects. AUDPC was considered an

Table 6. The combined means of yield, yield components, and disease parameters

Treatment	Percentage severity index (PSI)				Area under the disease progress curve	Seed per pod	Pod per plant	100 seed weight	Seed yield (kg.ha⁻¹)
	51 days after sowing	61 days after sowing	71 days after sowing	81 days after sowing					
Seed treatment	6.39	18.05	22.67	27.65	577.5	5.9	24.38	19.23	1959
Seed treatment and one spray	5.02	15.6	24.31	24.81	548.3	6.03	23	20.81	2236
Seed treatment and two sprays	5.46	13.8	22.04	26.59	518.6	6.21	23.37	20.23	2397
Seed treatment and three sprays	3.98	17.58	22.65	29.21	568.3	6.19	21.12	19.95	2345
One spray	9.58	23.7	33.1	41.48	823.4	5.58	17.9	19.7	1706
Two sprays	9.63	24.26	33.53	40.76	829.8	5.87	18.43	19.94	1951
Three sprays	10.8	21.82	32.37	36.56	779.1	5.64	19.33	19.42	1763
Control	10.3	28.08	38.49	47.96	957	5.32	16.48	18.93	1408
GM	7.66	20.36	28.65	34.4	700.25	5.84	20.5	19.78	1970.63
LSD	2.95	5.07	6.17	6.77	108.77	ns	5.54	ns	590.63
CV%	47.4	30.7	26.5	24.3	19.1	13.5	33.30	9.6	36.9

Notes: ns= not significant at p<0.05. GM= Grand mean; LSD= List significance difference; CV= Coefficient of variation.

independent variable, and common bean seed yield, considered the dependent variable, was regressed to estimate the yield loss due to common bacterial blight disease. The higher the percentage in days of AUDPC, the more susceptible. Thus, as the relative AUDPC increases, the yield decreases and approaches zero asymptotically, indicating an inverse relation between common bacterial blight disease and seed yield in common beans.

The equation of the model, Y= -1.8775X + 3285.3, indicates that for every one-unit increase in AUDPC, there is a corresponding 1.88 kg.ha^{-1} loss in common bean seed yield (Figure 1). The relationship suggested by the linear regression model indicates that 82.56% of the loss in common bean seed yield can be attributed to common bacterial blight disease.

Economic Cost-Benefit Analysis

A partial budget analysis was conducted for the management of common bacterial blight (CBB) through seed treatment and spraying frequencies of copper hydroxide bactericide application (Table 8). The result of the partial budget analysis of copper hydroxide application on the common bean field obtained the highest net benefit, resulting in a maximum seed yield compared to the unsprayed control plots. Copper hydroxide seed treatment, combined with one and two times spraying, gave the highest net benefit, marginal net benefit, and marginal rate of return as compared to unsprayed control plots. The highest net benefits (65705.5 and 65384 ETB. ha^{-1}) were obtained from plots treated with copper hydroxide seed and combined with two and one times spraying of bactericide, respectively. Minimum (44352 ETB.ha^{-1}) net benefits were obtained from the untreated control plot (Table 8). Marginal net benefits varied among combinations of seed treatment and spraying frequencies of copper hydroxide bactericide. Additionally, the marginal rate of return describes a method for comparing the costs that vary with the net benefits of all treatment combinations. The highest (2214.2 %) marginal rate of return had been obtained from only copper hydroxide seed-treated plots, followed by 102.92 % obtained from seed treated with a one-time spraying frequency of copper hydroxide bactericide. The findings of this study are supported by Admasie et al. (2025), who found that pesticide-treated plots yielded the highest net benefit and maximum marginal rate of return compared to untreated plots.

Table 7. The average relative yield loss and percentage yield advantage of all locations

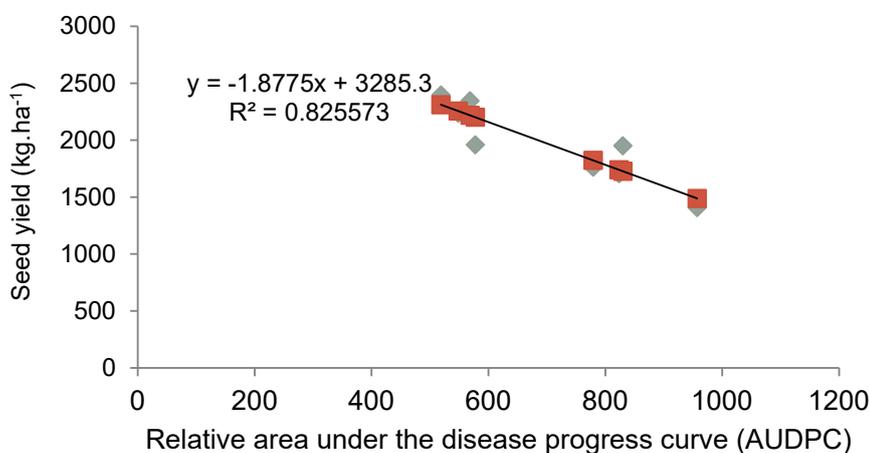| Treatments	Seed yield (kg.ha^{-1})	Relative yield loss (%)	Yield increase (%)
Seed treatment	1959	18.27	39.13
Seed treatment and one spray	2236	6.72	58.81
Seed treatment and two sprays	2397	0.00	70.24
Seed treatment and three sprays	2345	2.17	66.55
One spray	1706	28.83	21.16
Two sprays	1951	18.61	38.57
Three sprays	1763	26.45	25.21
Control	1408	41.26	0.00

Figure 1. Regression analysis of combined common bean seed yield and AUDPC of the common bacterial blight

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Table 8. Partial budget analysis of copper hydroxide bactericide for the management of common bacterial blight disease

Treatments	Seed yield (kg.ha^{-1})	Adjusted seed yield per ha	Price per kg (B.ha^{-1})	Gross benefit per ha	Marginal cost (B.ha^{-1})	Net benefit (B.ha^{-1})	Marginal net benefit (B.ha^{-1})	Marginal rate of Return (%)
Seed treatment	1408	1267.2	35	44352	0	44352	-	
Seed treatment and one spray	1959	1763.1	35	61708.5	750	60958.5	16606.5	2214.2
Seed treatment and two sprays	1706	1535.4	35	53739	4750	48989	D	
Seed treatment and three sprays	2236	2012.4	35	70434	5050	65384	4425.5	102.92
One spray	1951	1755.9	35	61456.5	9500	51956.5	D	
Two sprays	2397	2157.3	35	75505.5	9800	65705.5	321.5	6.77
Three sprays	1763	1586.7	35	55534.5	14250	41284.5	D	
Control	2345	2110.5	35	73867.5	14550	59317.5	D	

Notes: *In 2024, the average market price for common bean seed in eastern Amhara was 35 ETB.kg^{-1}, while copper hydroxide bactericide was priced at 2100 ETB.kg^{-1}.

Conclusions

The integrated application of copper hydroxide as a seed treatment, combined with varying frequencies of foliar spraying, demonstrated a significant and consistent reduction in common bacterial blight (CBB) severity, as quantified by both the percent severity index (PSI) and the area under the disease progress curve (AUDPC), across all experimental locations. The most effective disease suppression was observed in plots that received copper hydroxide seed treatment complemented by foliar sprays, indicated by the lowest final PSI value of 24.81%. The highest common bean seed yields, quantified at 2397 kg.ha^{-1} and 2345 kg.ha^{-1}, were obtained from plots that received the seed treatment in combination with two and three foliar sprays, respectively. The partial budget analysis indicated that the highest marginal rate of return (2214.2%) was obtained from copper hydroxide seed treatment plots, followed by 102.92% from seed treated with a one-time spraying frequency. Generally, from this finding, the use of copper hydroxide bactericide as seed treatment at the rate of 300 g per 100 kg seed of common bean during planting and one-time spray at the onset of the disease is suggested for end-users, as it gave relatively the highest net benefit as compared to the other treatments and untreated control plots.

Acknowledgment

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