

EPIDEMIOLOGY AND MANAGEMENT OF COMMON BACTERIAL BLIGHT ON COMMON BEAN VARIETIES (*Phaseolus vulgaris* L.) IN GUJI ZONE, SOUTHERN ETHIOPIA

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ABSTRACT: Common bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *phaseoli* is a major constraint to common bean production globally by significantly reducing both yield and seed quality. The objective of this study was to investigate the effectiveness and economic viability of integrated CBB management strategies using seed treatment, chemical control, and genetic resistance of common beans in Ethiopia. To this end, three bean varieties (KAT-B1, Awash-1, Awash-2) were subjected to different disease control factors: seed treatment with streptomycin, foliar application of copper hydroxide at two frequencies, and an untreated control. Results showed significant interactions ($p < 0.05$) between variety, seed treatment, and foliar spray frequency on disease severity (DS) and yield parameters. Awash-2, a resistant variety, exhibited the lowest DS and progression. Streptomycin seed treatment combined with two Kocide-101 sprays significantly reduced CBB severity and increased yield (36% over the control) in both susceptible and moderately resistant varieties. Economic analysis revealed that seed treatment with two foliar sprays on Awash-2 provided the highest gross field benefit (ETB93893.00) compared to the control (ETB62603.00). Therefore, treating seeds with streptomycin and applying two foliar sprays of Kocide-101 on the resistant variety Awash-2 is recommended for optimal and economically feasible control of CBB for south Ethiopia and similar agro-ecological areas.

Keywords: Economic returns, Disease severity, integrated disease management, *Xanthomonas axonopodis*

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.), a globally important legume crop, plays a vital role in food security and nutrition, particularly in developing countries. Cultivated for both its dry seeds and fresh pods, the common bean provides a rich source of protein, carbohydrates, fiber, vitamins, and minerals [1-3]. Global production reached substantial levels in 2018, with 30.4 million tons of dry seeds and 24.7 million tons of fresh pods harvested from a combined area of over 36 million hectares [4]. Ethiopia, in particular, relies heavily on common beans as a dietary staple and a source of income for smallholder farmers [5]. The country dedicates significant acreage to both white and red bean varieties, with production in 2018 reaching 148,212.84 tons and 372,766.48 tons, respectively [6]. The crop's short growth cycle provides farmers with a

valuable source of early income, while its high protein content earns it the moniker "the poor man's meat," highlighting its crucial role in combating malnutrition [7].

Despite its importance, common bean production in Ethiopia faces significant challenges, primarily from a range of devastating diseases. These diseases, including anthracnose (*Colletotrichum lindemuthianum*), root rot (*Fusarium oxysporum*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), and halo blight, have significantly reduced yields and threaten the livelihoods of farmers [8, 9, 10]. While some diseases remain localized, others, such as anthracnose, rust, angular leaf spot, and common bacterial blight, are widespread and pose a persistent threat to common bean cultivation across Ethiopia [11, 12, 13].

Common bacterial blight (CBB) is a serious threat to bean production, impacting both the yield and quality of beans globally [14]. This disease thrives in warm, humid conditions, causing significant damage to bean plants and reducing their productivity. CBB can infect various parts of the plant, including leaves, stems, pods, and seeds, ultimately leading to substantial yield losses [15, 16]. The extent of yield loss due to CBB depends on several factors, including the severity of the disease, the susceptibility of the bean cultivar, and environmental conditions. Studies have shown that CBB can cause yield losses ranging from 30% to 70% in susceptible cultivars worldwide [17]. On average, yield losses from CBB are estimated to be between 10% and 40% but can reach up to 100% under severe disease pressure, high susceptibility, and favorable environmental conditions for disease spread [18, 19]. In Ethiopia, CBB is considered one of the most destructive bean diseases, with reported yield losses of up to 22.4% in the eastern part of the country [19].

Several management strategies can be employed to mitigate the impact of CBB on bean production. These include using resistant bean varieties, treating seeds with pesticides before planting, applying bactericides to foliage, and implementing cultural control practices [20]. Among these, planting resistant cultivars is considered the most practical and cost-effective approach to managing CBB [14]. Other effective strategies involve integrating resistant varieties with chemical seed treatment and bactericide application. Despite the widespread occurrence of CBB and its impact on commonly grown bean cultivars in Ethiopia, research on resistance mechanisms and effective management strategies remains limited. There is a lack of understanding of how different bean varieties respond to the disease and a need for more empirical data to develop robust management strategies. Therefore, the objectives of this study were to: i) investigate the combined effects of bean varieties, streptomycin seed treatment, and foliar application of Kocide-101 (a copper hydroxide bactericide) spray frequencies against common bacterial blight in natural field conditions; ii) evaluate the treatments' viability from an economic standpoint in the Guji zone of southern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted during the 2021 main cropping season at the farmers' training center in the Dugda Dawa district, situated 498 kilometers south of Addis Ababa along the Addis Ababa-Moyale International Road. Dugda Dawa is geographically positioned between latitudes 5°53' - 6°27' N and longitudes 39°15' - 40°38' E. The district encompasses two distinct agro-ecological zones. This zone, spanning elevations from 800 to 1500 meters above sea level, is characterized as an arid lowland environment. It constitutes approximately 70% of the district's area. Ranging from 1500 to 2300 meters above sea level, this zone is classified as semi-arid and

comprises the remaining 30% of the district. Dugda Dawa experiences a bimodal rainfall pattern, with two distinct rainy seasons. The long rainy season, extending from March to May, brings heavier rainfall. The short rainy season, occurring from September to November, receives comparatively less rainfall. The district's annual rainfall averages around 750 mm, indicating a relatively dry climate. Temperatures in Dugda Dawa typically range from 25 to 33°C, as reported by [21].

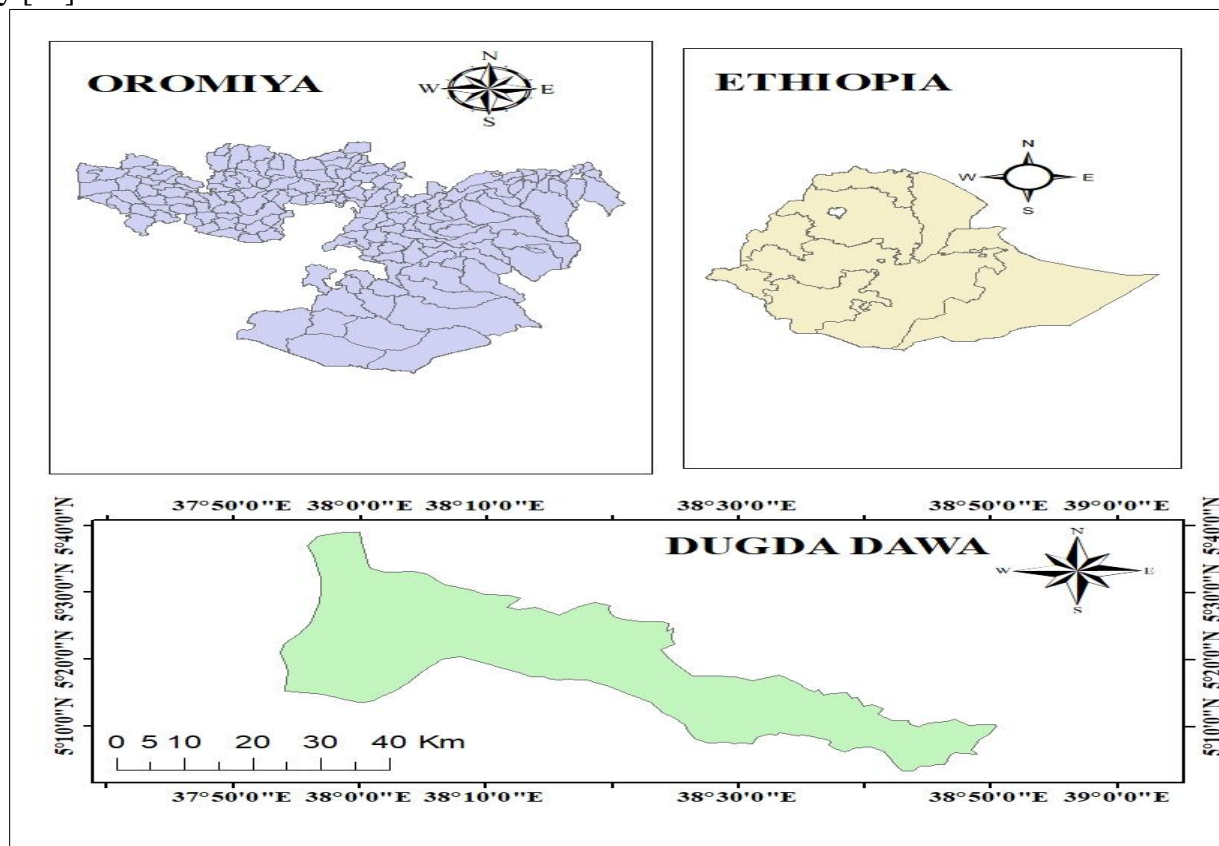


Fig. 1. Map of the study area.

Experimental Materials and Treatments

Common bean Varieties

Two CBB moderately resistant varieties of common bean, Awash-2 and Awash-1 (Exrico-23), and one susceptible variety (KAT-B1), were used as varietal components of the treatment [22].

Table 1. Description of Common bean varieties to be used for the experiment

SN	Varieties	Genotype	Year of release	Maintainer	DM	Yield (t/ha)	Reaction to CBB
1	KAT -B1	PAN-182	Early	MARC	93	2.0-2.5	S
2	Awash-1	Exrico-23	2008	MARC	90	2.0-2.4	MR
3	Awash-2	G-11239	2016	MARC	96	1.6-2.0	MR

MR = Moderately resistant; S = Susceptible; DM = Days to maturity; MARC = Melkassa Agricultural Research Center

Seed Treatment

Streptomycin, an antibiotic known to control bacterial surface contamination of seeds [23], was used as a seed treatment component. A solution was prepared following the method described by [24], where 1 g of streptomycin was dissolved in 10 liters of water. This solution was used to treat 25 kg of common bean seeds. The seeds were soaked in the solution for 3 hours and planted immediately after treatment.

Foliar Sprays

Copper hydroxide (Kocide® 101 77% WP) was used as a foliar spray at a rate of 2.31 kg/ha, as recommended by [19]. Two spray frequencies were tested: a single spray and two sprays applied 7 days apart. The foliar sprays were initiated upon the appearance of the first disease symptoms.

Experimental Design and Field Management

The experimental land used for this trial was planted with maize and sorghum in the previous seasons alternatively in order to demonstrate the performance of the newly released improved varieties to the smallholder farmers, since maize and sorghum are the major cereal crops grown in this part of the country. However, the disease (CBB) is known to be widely spread in the region and most seeds are contaminated by the pathogen. The experiment followed a 3 x 2 x 3 factorial design with three replications, arranged in a randomized complete block design. The factors included three common bean varieties (two moderately resistant and one susceptible), two seed treatment levels (streptomycin-treated and untreated), and three foliar spray frequencies (copper hydroxide applied once, twice at a 7-day interval, or not applied). This resulted in 18 treatment combinations, including a control group with untreated seeds and no foliar spray for each variety.

Each treatment combination was randomly assigned to experimental units within a block. The field trial included three replicates of each treatment. Each block had a spacing of 1.5 meters between them, while adjacent plots within a block were spaced 1 meter apart. Each plot measured 1.6 meters by 2.5 meters and consisted of four rows of bean plants, with the two central rows designated as harvestable. The rows were spaced 0.4 meters apart, and plants within each row were spaced 0.1 meters apart.

Two seeds were sown per hole and later thinned to one plant per hole 15 days after sowing to maintain a density of 100 plants per plot. Standard agronomic practices were consistently applied across all treatment plots. Weed control and cultivation were carried out manually from 15 days after planting until flowering. No fertilizers were used in any of the treatments, as the common bean is a nitrogen-fixing crop. However, it's worth noting that applying nitrogen fertilizers to common bean plants grown in nitrogen-deficient soils can enhance yield, as observed by [25].

Data to be Collected

Disease Assessment

Common bacterial blight severity was assessed at 7-day intervals starting from the initial appearance of disease symptoms [26]. To mitigate border effects, assessments were focused on ten randomly selected plants within the two central rows of each plot. Disease severity was recorded as the percentage of leaf area exhibiting symptoms. A standardized disease scale of 1-9 was employed, as described by [2]. This scale assigns a numerical rating based on the approximate percentage of infection: 1 representing 5%, 2 representing 15%, 3 representing

25%, 6 = 65%, 8 = 75%, and 9 representing 85% infection. These severity grades were then converted into a percentage severity index (PSI) (Eqn.1) for analysis using the formula proposed by [27].

$$\text{PSI} = \frac{\text{Sum of all numerical ratings} \times 100}{\text{Total no of plants rated} \times \text{Maximum rating}}$$

Eqn. 1

The disease progress rate (r) was calculated based on the linearized model [28, 29], and the calculated value was analyzed by using SAS software:

$$r = ((\text{Ln } x / (1-x)) - (\text{Ln } x_0 / (1-x_0))) / t$$

Eqn. 2

Where: r = disease progress rate, X_0 = initial disease severity, X = final disease severity, t = the duration of the epidemic, and Ln = Natural logarithm.

The area under disease progress curve (AUDPC) was computed from severity data using the formula suggested by [30].

$$\text{AUDPC} = \sum [(x_i + x_{i+1})/2] \times (t_{i+1} - t_i)$$

Eqn. 3

Where x_i is the disease severity expressed in percentage at i^{th} observation, t_i is the time (days after planting) at the i^{th} observation, and n is the total number of days the disease was assessed.

Yield and Yield Components

Data on yield and yield components were collected from ten randomly selected and tagged plants within the two central rows of each plot. For each selected plant, the following data were recorded: the number of pods per plant and the number of seeds per pod (obtained by counting seeds from three randomly selected pods per plant). Bean yield data were collected after the harvested beans reached a moisture content of 10%, as determined using a moisture tester. The weight of 100 randomly selected seeds was also measured. The percentage of relative yield loss was calculated based on the yield difference between the basic treatment (plots receiving the full treatment combination) and the lower treatments, using the formula suggested by [31].

$$\text{Relative \% yield loss} = \frac{Y_{bt} - Y_{lt}}{Y_{bt}} \times 100$$

Eqn. 4

Where, Y_{bt} = yield of basic treatment and Y_{lt} = yield from the lower treatment.

Statistical Analysis

The collected data, encompassing disease severity assessments, yield and yield components, and relative yield loss percentages, were subjected to rigorous statistical analysis. ANOVA was employed to examine the effects of bean variety, seed treatment, and foliar spray frequency on the following parameters; viz., disease parameters (percentage severity index, area under the disease progress curve, and disease progress rate), yield components (number of pods per plant, number of seeds per pod, and 100-seed weight, seed yield and relative yield loss percentage). Regression analysis, using the General Linear Model procedure in GenStat 16th

edition software, was conducted to further investigate the relationships between the variables mentioned above. When ANOVA detected significant treatment differences, mean separation tests were performed using the least significant difference method to determine the specific treatment groups that differed significantly from one another.

Economic Analysis: Partial Budget Analysis

A partial budget analysis was conducted to assess the economic viability of the integrated common bacterial blight management strategies. This analysis followed the methodology outlined by [32] and utilized prevailing market prices for inputs at the time of planting and for outputs at harvest. The key concepts and calculations involved in the partial budget analysis are detailed below:

Adjusted Yield: was calculated to account for the potential discrepancy between experimental yields and those achievable under typical farming conditions of resource poor smallholder farmers' fields (characterized by low input use such as low inorganic fertilizer application rates, low frequency of weeding and chemical applications rates less than the recommended dose and/or frequency), the average yield for each treatment was adjusted downward by 10%, as recommended by [33]. This adjustment provides a more realistic estimate of the yield farmers can expect when implementing similar treatments.

Gross Field Benefit (GFB) represents the revenue generated per hectare and was calculated by multiplying the adjusted marketable bean seed yield by the prevailing field/farm gate price received by farmers.

Total Variable Cost (TVC) encompasses all variable costs associated with each treatment, including (*Seed cost:* Seed prices for each bean variety (ETB30.00 per kilogram) were obtained from local markets and farmers' unions, and the total seed cost per hectare was calculated, *Bactericide cost:* The cost of copper hydroxide was determined (ETB1000.00 per hectare for single spray), and the total cost of spraying one hectare of beans was calculated based on the recommended spray program, *Labor cost for spraying:* Labor costs associated with the application of bactericides (800.00 per single spray including spraying equipment) were factored in, *Seed treatment cost:* seed treatment cost [ETB300.00) for a 100kg common bean seed enough for sowing one hectare at a spacing of 40cm between rows and 10cm between plants was determined). It's important to note that costs for other inputs (fertilizers) and standard production practices (land preparation, planting, weeding, harvesting) were considered consistent across treatments and, therefore, not included in the TVC calculation.

Net Income or Net Benefit (NI): referred to as NB, represents the profit earned per hectare and was calculated by subtracting the total variable cost from the total revenue, which is equivalent to the gross field benefit:

$$NB = TR - TVC$$

Eqn. 5

Marginal Rate of Return (MRR): expressed in percentages, and calculated to evaluate the profitability of each integrated CBB management option relative to the control (no treatment). MRR represents the increase in net income for every unit increase in total variable cost compared to the control:

$$\text{MRR (\%)} = \text{DNI/DIC} \times 100$$

Eqn. 6

Where, MRR = is the marginal rate of returns, DNI = difference in net income compared with control, and DIC = difference in input cost compared with control. A treatment could be considered worth to farmers when its minimum acceptable marginal rate of return (MAR) is 100% that is regarded as realistic. This condition enables to make farmer recommendations from marginal analysis [33].

RESULTS AND DISCUSSION

Impact of Variety, Seed Treatment, and Foliar Spray on Disease Parameters

This study investigated the impact of different treatments on the severity of plant diseases, focusing on two key aspects: disease severity and crop loss. The researchers examined the effects of using different bean varieties (cultivars), treating seeds with streptomycin (an antibiotic), and applying copper hydroxide (a bactericide) to the plants' leaves at various frequencies. The following sections will delve deeper into the specific results of these treatments on the disease parameters.

Disease Development

This study analyzed treatment effects on disease development through three interconnected lenses: apparent infection rate, disease severity, and area under the disease progress curve. Apparent infection rate and AUDPC are particularly insightful metrics for comparing epidemics. As explained by [34], the former helps to determine if disease progression is faster in one treatment group compared to another. The latter, AUDPC, quantifies the cumulative disease stress experienced throughout the season, serving as a potential predictor of yield.

Percent Severity Index (PSI)

The results showed a statistically significant interaction ($p < 0.01$) between bean variety and spray frequency on CBB severity, measured as Percent Severity Index (PSI), across all assessment periods (Table 1). Regular copper hydroxide application consistently reduced disease progression compared to the unsprayed control. Notably, two applications provided significantly better control than a single application at every assessment point. At the first assessment (52 days after sowing), the unsprayed KAT-B1 exhibited the highest PSI (14.66), followed by unsprayed Awash-1 (13.43) and Awash-2 (12.08). Conversely, the lowest PSI values were observed in plots with two applications of copper hydroxide: Awash-1 (9.85) and Awash-2 (8.62) (Table 1). This trend of reduced PSI in treated plots persisted throughout the subsequent assessments. Similar findings have been reported by [20].

By the final assessment (80 DAS), the mean PSI in unsprayed plots reached 20.91, 19.68, and 18.33. In contrast, treated plots showed considerably lower PSI values, ranging from 18.77 to 19.19 for KAT-B1, 16.10 to 17.70 for Awash-1, and 14.87 to 16.81 for Awash-2, depending on the spray frequency. Interestingly, the significant ($p < 0.05$) PSI reduction in the susceptible KAT-B1 suggests that copper hydroxide application might enhance the effectiveness of inherent genetic resistance. Overall, the study demonstrated that copper hydroxide 77% WP effectively controls CBB, with two applications being significantly more effective than one or no application (Table 1). Furthermore, the results highlight the influence of varietal susceptibility on

CBB severity. In agreement with the current study, [14] reported the role of genetic resistance in controlling CBB significantly.

This study further explored the combined effects of seed treatment and foliar bactericide application on CBB severity in common beans as shown in the materials and methods section. The results revealed a statistically significant interaction ($p < 0.01$) between seed treatment and spray frequency on CBB severity, measured as Percent Severity Index (PSI), across all assessment periods. Combining streptomycin seed treatment with copper hydroxide sprays consistently outperformed the untreated control (no seed treatment, no spray) in suppressing disease progression. Moreover, two bactericide applications, in conjunction with seed treatment, consistently yielded significantly lower PSI values compared to a single application or the untreated control at all assessment points. At the first assessment (52 DAS), the untreated control group exhibited the highest PSI (14.18), followed by the seed-treated, unsprayed group (12.60) and the untreated group with one spray application (12.16). The lowest PSI values were observed in groups receiving both seed treatment and bactericide applications; which was 9.37 for one spray and 8.48 for two sprays (Table 1). This trend of reduced PSI in groups receiving combined treatment persisted throughout the study, which is in agreement with the reports of [20].

By the final assessment (80 DAS), the mean PSI in the untreated control and seed-treated, unsprayed groups reached 20.43 and 18.85, respectively. In contrast, groups receiving both seed treatment and bactericide applications showed considerably lower PSI values, ranging from 17.99 to 18.41 for one spray and 15.17 to 17.38 for two sprays. Remarkably, the combined treatment approach effectively reduced the final PSI from 20.43 in the untreated control group to 14.18 in the group receiving both seed treatment and foliar sprays. These findings underscore the synergistic effect of combining streptomycin seed treatment with copper hydroxide 77% WP sprays in effectively managing CBB in common beans. The study highlights the importance of integrated disease management strategies for maximizing disease control.

The result of the interaction effect of streptomycin seed treatment with common bean varieties showed a statistically significant interaction ($p < 0.01$) between bean variety and streptomycin seed treatment on CBB severity index across all disease evaluation periods. Streptomycin treatment consistently reduced the progression of CBB in all bean varieties compared to the untreated control group. At the first disease assessment (52 days after sowing), untreated KAT-B1 exhibited the highest CBB severity index (13.94%), followed by treated KAT-B1 (12.81%) and untreated Awash-1 (12.72%). Among all treatments, Awash-1 and Awash-2 treated with streptomycin showed the lowest CBB severity indices, 10.43% and 9.41% respectively. This trend of reduced disease severity in treated seeds compared to untreated seeds within the same variety persisted throughout the second, third, and fourth assessment rounds. The contribution of genetic resistance has been elucidated by the works of [35], where similar results have been reported to the current finding. It has to be noted that frequent use of antibiotics for seed treatment to control common bean blight in haricot beans carries the risk of antibiotic resistance development in the bacterial pathogen, making future treatments less effective. Additionally, it can harm beneficial microorganisms in the soil, disrupting the ecosystem and potentially weakening the plants' ability to resist other diseases [36].

Table 1. Interactive Effects of Variety and Bactericide Application Frequency on Common Bacterial Blight Severity in Common Bean.

Components:		CBB Percent Severity Index (PSI)					AUDPC (%-days)
Variety x Foliar Spray		52DAS	59DAS	66DAS	73DAS	80DAS	
KAT-B1	Unsprayed	14.66 ^a	16.41 ^a	17.91 ^a	19.41 ^a	20.91 ^a	508.50 ^a
	1-time spray	12.94 ^c	14.69 ^c	16.19 ^c	17.69 ^c	19.19 ^c	460.30 ^c
	2-time spray	12.52 ^d	14.27 ^d	15.77 ^d	17.27 ^d	18.77 ^d	448.60 ^d
Awash-1	Unsprayed	13.43 ^b	15.18 ^b	16.68 ^b	18.18 ^b	19.68 ^b	474.10 ^b
	1-time spray	11.45 ^f	13.20 ^f	14.70 ^f	16.20 ^f	17.70 ^f	418.60 ^f
	2-time spray	9.85 ^h	11.60 ^h	13.10 ^h	14.60 ^h	16.10 ^h	373.80 ^h
Awash-2	Unsprayed	12.08 ^e	13.83 ^e	15.33 ^e	16.83 ^e	18.33 ^e	436.20 ^e
	1-time spray	10.55 ^g	12.30 ^g	13.81 ^g	15.31 ^g	16.81 ^g	393.50 ^g
	2-time spray	8.62 ⁱ	10.37 ⁱ	11.87 ⁱ	13.37 ⁱ	14.87 ⁱ	339.40 ⁱ
CV (%)		2.9	2.6	2.3	2.1	1.9	2.3
LSD (5%)		0.4070	0.4070	0.4070	0.4070	0.4070	11.40
Seed TRT x Foliar spray							
Untreated	Unsprayed	14.18 ^a	15.93 ^a	17.43 ^a	18.93 ^a	20.43 ^a	495.10 ^a
	1-time spray	12.16 ^c	13.91 ^c	15.41 ^c	16.91 ^c	18.41 ^c	438.60 ^c
	2-time spray	11.74 ^d	13.49 ^d	14.99 ^d	16.49 ^d	17.99 ^d	426.80 ^d
Treated	Unsprayed	12.60 ^b	14.35 ^b	15.85 ^b	17.35 ^b	18.85 ^b	450.80 ^b
	1-time spray	11.13 ^e	12.88 ^e	14.38 ^e	15.88 ^e	17.38 ^e	409.80 ^e
	2-time spray	8.92 ^f	10.67 ^f	12.17 ^f	13.67 ^f	15.17 ^f	347.70 ^f
CV (%)		2.9	2.6	2.3	2.1	1.9	2.3
LSD (5%)		0.3323	0.3323	0.3323	0.3323	0.3323	9.30
Seed TRT x Variety							
Untreated	KAT-B1	13.94 ^a	15.69 ^a	17.19 ^a	18.69 ^a	20.19 ^a	488.30 ^a
	Awash-1	12.72 ^b	14.47 ^b	15.97 ^b	17.47 ^b	18.97 ^b	454.30 ^b
	Awash-2	11.43 ^c	13.18 ^c	14.68 ^c	16.18 ^c	17.68 ^c	417.90 ^c
Treated	KAT-B1	12.81 ^b	14.56 ^b	16.06 ^b	17.56 ^b	19.06 ^b	456.60 ^b
	Awash-1	10.43 ^d	12.18 ^d	13.68 ^d	15.18 ^d	16.68 ^d	390.10 ^d
	Awash-2	9.41 ^e	11.16 ^e	12.66 ^e	14.16 ^e	15.66 ^e	361.50 ^e
CV (%)		2.9	2.6	2.3	2.1	1.9	2.3
LSD (5%)		0.3323	0.3323	0.3323	0.3323	0.3323	9.30

Mean within a column followed by the same letters are not significantly different from each other according to LSD at 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation and AUDPC = Area under disease progress curve.

The study investigated the effectiveness of streptomycin seed treatment in controlling Common Bacterial Blight in different common bean varieties (Table 2). The results showed a statistically significant interaction ($p < 0.01$) between bean variety and streptomycin seed treatment on CBB severity index across all disease evaluation periods. Streptomycin treatment consistently reduced the progression of CBB in all bean varieties compared to the untreated control group. This effect was particularly noticeable in the highly susceptible variety KAT-B1. At the first disease assessment (52 days after sowing), untreated KAT-B1 exhibited the highest

CBB severity index (13.94%), followed by treated KAT-B1 (12.81%) and untreated Awash-1 (12.72%). Among all treatments, Awash-1 and Awash-2 treated with streptomycin showed the lowest CBB severity indices, 10.43%, and 9.41% respectively. This trend of reduced disease severity in treated seeds compared to untreated seeds within the same variety persisted throughout the second, third, and fourth assessment rounds. The findings of [36] also confirmed the effective control of CBB using seed treatment along with foliar application of chemicals.

Table 2. Interactive Impact of Variety, Seed Treatment, and Bactericide application frequency on Common Bacterial Blight Severity in Common Bean.

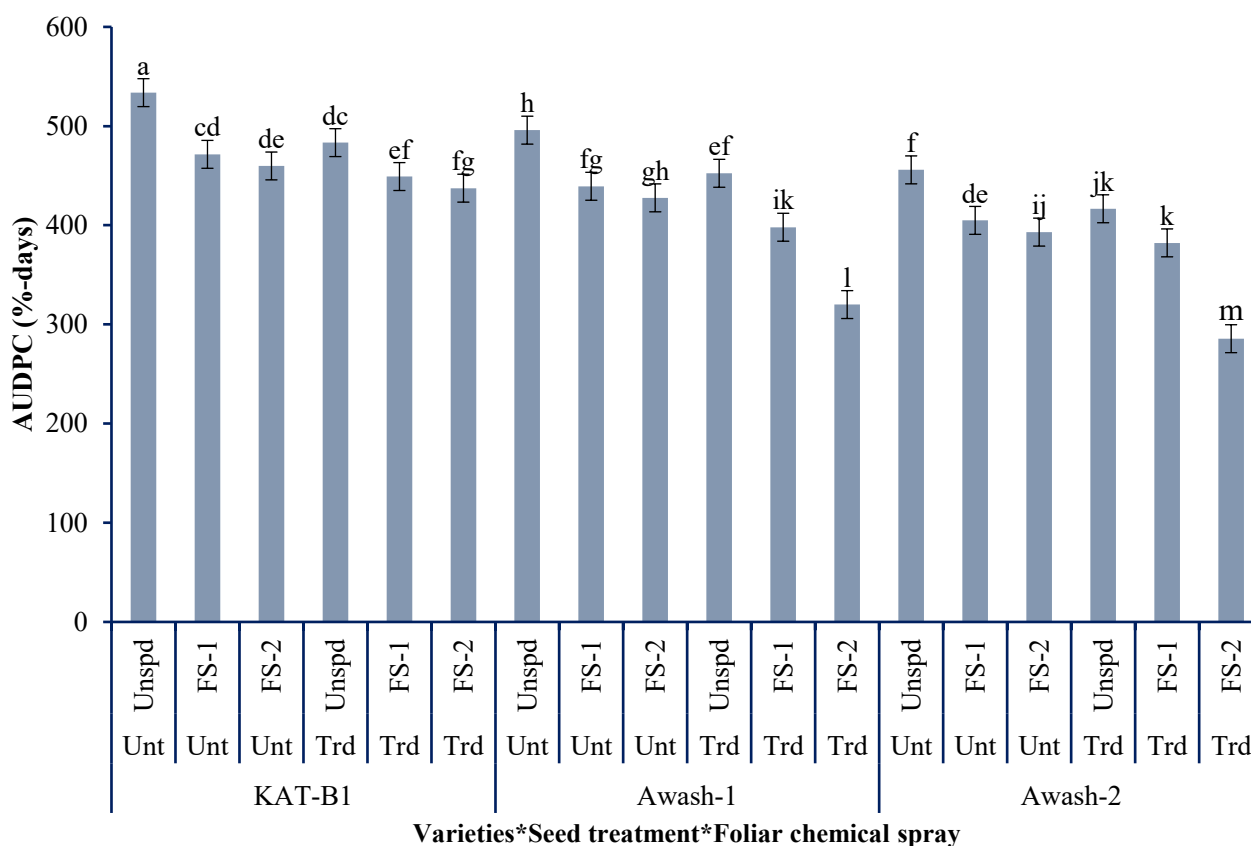
CBB percent severity index (PSI)								
Variety	Seed TRT	Foliar spray	52DAS	59DAS	66DAS	73DAS	80DAS	DPR(r)
KAT-B1	Untreated	Unsprayed	15.56 ^a	17.31 ^a	18.81 ^a	20.31 ^a	21.81 ^a	0.0072 ^a
		1-time spray	13.34 ^{cd}	15.09 ^{cd}	16.59 ^{cd}	18.09 ^{cd}	19.59 ^{cd}	0.0048 ^{c-e}
		2-time spray	12.92 ^{de}	14.67 ^{de}	16.17 ^{de}	17.67 ^{de}	19.17 ^{de}	0.0046 ^{c-f}
	Treated	Unsprayed	13.76 ^{bc}	15.51 ^{bc}	17.01 ^b ^c	18.51 ^{bc}	20.01 ^{bc}	0.0049 ^{cd}
		1-time spray	12.54 ^{ef}	14.29 ^{ef}	15.79 ^{ef}	17.29 ^{ef}	18.79 ^{ef}	0.0051 ^c
		2-time spray	12.12 ^{fg}	13.87 ^{fg}	15.37 ^{fg}	16.87 ^{fg}	18.37 ^{fg}	0.0042 ^{f-i}
Awash-1	Untreated	Unsprayed	14.21 ^b	15.96 ^b	17.46 ^b	18.96 ^b	20.46 ^b	0.0063 ^b
		1-time spray	12.19 ^{fg}	13.94 ^{fg}	15.44 ^{fg}	16.94 ^{fg}	18.44 ^{fg}	0.0044 ^{e-h}
		2-time spray	11.77 ^{gh}	13.52 ^{gh}	15.02 ^{gh}	16.52 ^{gh}	18.02 ^{gh}	0.0045 ^{d-g}
	Treated	Unsprayed	12.66 ^{ef}	14.41 ^{ef}	15.91 ^{ef}	17.41 ^{ef}	18.91 ^{ef}	0.0048 ^{cd}
		1-time spray	10.71 ^{jk}	12.46 ^{jk}	13.96 ^{jk}	15.46 ^{jk}	16.96 ^{jk}	0.0042 ^{f-i}
		2-time spray	7.93 ^l	9.68 ^l	11.18 ^l	12.68 ^l	14.18 ^l	0.0039 ^{ij}
Awash-2	Untreated	Unsprayed	12.78 ^{de}	14.53 ^{de}	16.03 ^{de}	17.53 ^{de}	19.03 ^{de}	0.0044 ^{e,h}
		1-time spray	10.96 ^{ij}	12.71 ^{ij}	14.21 ^{ij}	15.71 ^{ij}	17.21 ^{ij}	0.0041 ^{g-j}
		2-time spray	10.54 ^{jk}	12.29 ^{jk}	13.79 ^{jk}	15.29 ^{jk}	16.79 ^{jk}	0.0042 ^{f-i}
	Treated	Unsprayed	11.77 ^{gh}	13.13 ^{hi}	14.63 ^{hi}	16.13 ^{hi}	17.63 ^{hi}	0.0043 ^{f-i}
		1-time spray	10.15 ^k	11.90 ^k	13.40 ^k	14.90 ^k	16.40 ^k	0.0040 ^{h-j}
		2-time spray	6.70 ^m	8.45 ^m	9.95 ^m	11.45 ^m	12.95 ^m	0.0036 ^j
CV (%)			2.9	2.6	2.3	2.1	1.9	6.1
LSD (5%)			0.57	0.57	0.57	0.57	0.57	0.00046

Means within a column followed by the same letters are not significantly different from each other according to LSD at 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation and DPR = Disease Progress Rate.

Area under disease progress curve (AUDPC)

This study analyzed the Area Under the Disease Progress Curve to assess the combined effects of common bean variety, streptomycin seed treatment, and copper hydroxide foliar spray timing on Common Bacterial Blight progression (Figure 2). The results revealed a significant three-way interaction ($p < 0.01$) between these factors on AUDPC values. The highest AUDPC value (533.7% days), indicating greater disease progression, was observed in untreated KAT-B1 plots without foliar spray. This was followed by untreated Awash-1 (495.9% days) and Awash-2 (455.8% days) plots without foliar spray. Conversely, the lowest AUDPC values were recorded in plots with treated Awash-1 seeds and two-time copper hydroxide sprays (320% days) and treated Awash-2 seeds with two-time sprays (285.6% days). These findings highlight the superior efficacy of integrated disease management strategies over single-tactic approaches. While previous studies, such as those conducted by Arsi Negele and Melkassa [37], demonstrated the effectiveness of foliar bactericide treatments in reducing disease severity, AUDPC, and disease progression, which emphasized the enhanced impact of combining

bactericide sprays with seed treatment. The study concludes that integrating streptomycin seed treatment with a two-time copper hydroxide foliar spray application significantly reduces CBB progression, ultimately improving yield and minimizing yield losses. This integrated approach proves to be the most effective strategy for bean growers to manage CBB and ensure sustainable bean production. Similar views has been endorsed by [20, 36]



Bars with the same letter(s) are not significantly different at $p < 0.01$

Fig. 2. Combined effects of variety, seed treatment, and bactericide application frequency on common bacterial blight progression in common bean.

Analysis of Progress Rate (r)

The analysis revealed a significant three-way interaction ($p < 0.01$) between these factors (Table 2). The apparent CBB infection rate ranged from 0.0036 to 0.0072 units/day across various treatment combinations. The fastest disease progression rate (0.0072 units/day) was observed in untreated KAT-B1 plots without foliar spray. This was followed by untreated Awash-1 (0.0063 units/day) and Awash-2 (0.0044 units/day) plots without foliar spray. Conversely, the slowest disease progression rates were recorded in plots with treated Awash-1 seeds and two-time copper hydroxide sprays (0.0039 units/day) and treated Awash-2 seeds with two-time sprays (0.0036 units/day) (Table 2). Notably, all bean varieties subjected to streptomycin seed treatment and two times application of copper hydroxide foliar sprays consistently exhibited lower CBB progress rates when assessed at 73 days after sowing

compared to other treatment combinations. While foliar spraying alone effectively reduced the CBB progress rate compared to untreated and unsprayed plots, the combination of seed treatment and foliar spray demonstrated a significantly greater reduction in disease progression compared to seed treatment alone (Table 2). These findings underscore the importance of integrated disease management strategies in effectively mitigating CBB progression in common bean cultivation. This finding is in agreement with [35] who reported the necessity of integrated management of CBB disease in common bean through genetic resistance and chemical applications.

Common Bacterial Blight (CBB) Progress Curve on Bean

This study observed the disease progression of Common Bacterial Blight in three bean varieties (KAT-B1, Awash-1, and Awash-2) during the 2021 cropping season in the Dugda Dawa district. Despite an early onset of CBB at 50 days after planting, likely delayed by dry weather during the planting season, the disease severity consistently increased throughout the study period for all varieties (Figure 3). However, the rate of disease progression differed significantly among the varieties. Awash-1 and Awash-2, both moderately resistant varieties, exhibited slower infection rates initially and reached terminal severity levels of 17.82 PSI and 16.196 PSI, respectively. In contrast, the susceptible variety KAT-B1 showed a rapid increase in disease severity, peaking at 19.62 PSI by the end of the growing season. These findings highlight the significant influence of genetic resistance on CBB progression in different bean varieties. While all varieties experienced an increase in disease severity over time, the moderately resistant varieties displayed slower progression and lower terminal severity compared to the susceptible variety. The resistance of CBB in common bean is polygenic with low to moderately high heritability values. Such types of resistance is affected by environmental conditions (climate and edaphic factors), number of QTL present in the host plant and disease pressure. Several researchers reported that resistance to CBB is controlled mostly by one major large effect allele and additional minor small effect alleles [8,9]. Though breeding for quantitative resistance is challenging it is known to be durable. This finding is in conformity with the works of [19, 20, 35, 36] who reported comparable results that there was significant variation among common bean varieties and visible differences in disease progress curves.

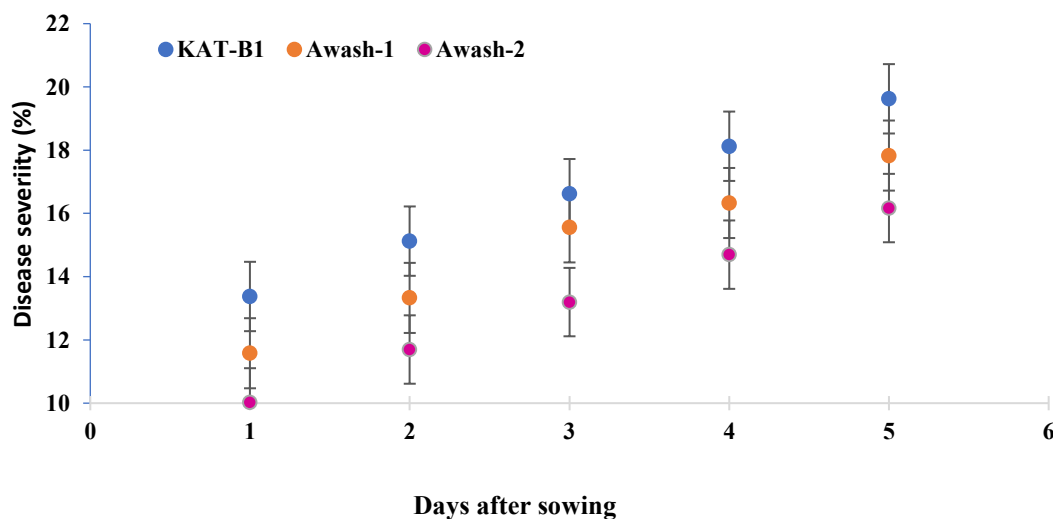


Fig. 3. The disease progress curve for CBB was recorded five times on the hybrid common bean varieties at Dugda Dawa district 2021 main cropping season.

Impact of Variety, Seed Treatment, and Foliar Spray on Bean Yield

Number of Pods per Plant (PPP)

The study revealed a significant interaction effect between bean variety and seed treatment on pods per bean plant (Table 3). Treating seeds with streptomycin generally led to a higher pod per bean plant compared to untreated seeds, but the extent of this effect varied among varieties. Awash-2, when treated with streptomycin, exhibited the highest PPP (18.48), followed closely by Awash-1 with streptomycin treatment (18.28). In contrast, the KAT-B1 variety showed a less pronounced response to seed treatment, with treated seeds yielding 10.19 pods per plant compared to 8.94 for untreated seeds.

Combining seed treatment with foliar spray applications further enhanced the number of pods per plant (Table 3). The highest number of pods per plant (15.97) was achieved by treating seeds with streptomycin and applying the copper hydroxide spray twice. While the interaction between bean variety and foliar spray frequency did not reach statistical significance though there were notable trends (Table 3). Both Awash-1 (17.83) and Awash-2 (18.15) varieties, when sprayed with copper hydroxide during pod setting, tended to produce a higher number of pods per plant compared to the unsprayed KAT-B1 variety (8.75). This suggests that certain varieties, like Awash-1 and Awash-2, might benefit more from foliar spray applications in terms of the number of pods per plant.

The study also found a significant three-way interaction effect of variety, seed treatment, and foliar spray timing on pods per bean plant (Table 3). This highlights the complex interplay between these factors in determining bean yield. Awash-2, when treated with streptomycin and sprayed twice with copper hydroxide, achieved the highest number of pods per plant (18.67). In contrast, untreated KAT-B1 seeds without any foliar spray resulted in the lowest pods per plant (8.13). These findings underscore the importance of considering variety, seed treatment, and foliar spray practices holistically to optimize bean yield. The optimal combination of these factors appears to be variety-specific, emphasizing the need for tailored management strategies. This result could be a good example for integrated pest management practices as indicated by [20].

Number of Seeds per Pod (SPP)

The study found a significant interaction effect between bean variety and seed treatment on seed per pod (SPP) (Table 3). While treating seeds with streptomycin generally increased seed per pod compared to untreated seeds, the magnitude of this effect varied depending on the bean variety. Awash-2, when treated with streptomycin, yielded the highest SPP (5.22), while Awash-1, also treated with streptomycin, had a slightly lower SPP (5.21). In contrast, the KAT-B1 variety showed minimal response to seed treatment, with both untreated and treated seeds producing similarly low number of seeds per pod (5.01 and 5.06, respectively).

The combination of seed treatment and foliar spray frequency also significantly impacted number of seeds per pod. Treating seeds with streptomycin and applying the copper hydroxide spray twice resulted in the highest SPP (5.25) (Table 3). The Awash-2 variety, when sprayed

with copper hydroxide during pod setting, tended to produce a higher seed per pod (5.20) compared to the unsprayed KAT-B1 variety (5.05). This suggests that certain varieties, like Awash-2, might benefit more from foliar spray applications in terms of seeds per pod.

The most striking finding was the significant three-way interaction effect of variety, seed treatment, and foliar spray timing on seeds per pod (Table 3). This highlights the complex interplay between these factors in determining bean yield. For instance, the Awash-2 variety, when treated with streptomycin and sprayed twice with copper hydroxide, achieved the highest seed per pod (5.40). Conversely, untreated KAT-B1 seeds, without any foliar spray, resulted in the lowest seeds per pod (4.76). These results underscored the importance of considering variety, seed treatment, and foliar spray practices in an integrated manner to optimize bean yield. The optimal combination of these factors appears to vary depending on the specific bean variety, highlighting the need for tailored management strategies.

Number of Discolored Seed (DCS)

The study highlights a significant ($p < 0.05$) interaction between bean variety and seed treatment on DCS. Untreated seeds consistently resulted in a higher DCS across all varieties (Table 3). Specifically, untreated KAT-B1 exhibited the highest DCS (18.96%), followed by untreated Awash-1 (17.69%) and Awash-2 (17.48%). Seed treatment with streptomycin effectively reduced DCS, with treated KAT-B1, Awash-1, and Awash-2 showing 9.52%, 6.19%, and 6.12% DCS, respectively. This underscores the efficacy of streptomycin seed treatment in mitigating seed discoloration, regardless of the variety. The study further reveals a synergistic effect of seed treatment and foliar spray on DCS (Table 3). Combining streptomycin seed treatment with two applications of copper hydroxide spray resulted in the lowest DCS (1.53%). Conversely, untreated seeds without copper hydroxide spray yielded the highest DCS, ranging from 19.37% to 20.04%. This emphasizes the additive benefit of integrating both seed treatment and foliar spray in minimizing seed discoloration.

Table 3. Influence of Variety, Seed Treatment, and Bactericide Timing on Bean Yield Components and Disease Progression in Dugda Dawa

Variety	Seed TRT	Foliar spray	PPP	DCS	SPP
KAT-B1	Untreated	Unsprayed	8.13 ^m	20.53 ^a	4.76 ^j
		1-time spray	9.30 ^l	19.87 ^b	5.16 ^{c-e}
		2-time spray	9.40 ^l	16.33 ^d	5.06 ^{d-g}
	Treated	Unsprayed	9.37 ^l	14.53 ^e	5.13 ^{d-f}
		1-time spray	10.53 ^k	9.44 ^g	5.03 ^{e-h}
		2-time spray	10.67 ^k	4.60 ⁱ	5.06 ^{d-g}
Awash-1	Untreated	Unsprayed	15.20 ⁱ	20.00 ^b	4.96 ^{g-i}
		1-time spray	16.80 ^h	19.20 ^c	5.20 ^{b-d}
		2-time spray	17.43 ^f	14.00 ^f	5.00 ^{f-i}
	Treated	Unsprayed	17.83 ^d	9.43 ^g	5.16 ^{c-e}
		1-time spray	18.43 ^b	9.15 ^{gh}	5.20 ^{b-d}
		2-time spray	18.57 ^{ab}	0.00 ⁱ	5.33 ^{ab}
Awash-2	Untreated	Unsprayed	14.90 ^j	19.73 ^b	4.90 ^{h-j}
		1-time spray	17.00 ^g	18.90 ^c	5.10 ^{d-g}
		2-time spray	17.63 ^e	13.80 ^f	5.30 ^{a-c}
	Treated	Unsprayed	18.10 ^c	9.32 ^{gh}	4.86 ^{ij}
		1-time spray	18.67 ^a	9.04 ^h	5.40 ^a
		2-time spray	18.67 ^a	0.00 ⁱ	5.40 ^a
CV (%)			0.8	1.5	1.8
LSD (5%)			0.185	0.32	0.1505

Mean within a column followed by the same letters are not significantly different from each other according to LSD at 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation, DCS=Discolored seeds, DPR=Disease progress rate (r), SPP=Seeds per pod.

Seed Yield, Hundred Seed Weight, and Relative Yield Loss

Seed Yield (t/ha)

The mean performance of grain yield due to the interaction effects of bean variety (Awash-1, Awash-2, and KAT-B1), seed treatment with streptomycin, and foliar spray applications of copper hydroxide 77% WP at different frequencies is presented in Table 4. The results revealed a complex interplay between these factors. Analyzing the two-way interactions, the researchers found that both seed treatment and foliar spray timing significantly ($p < 0.05$) influenced seed yield. Awash-2, when treated only with streptomycin, demonstrated the highest average yield (3.553 t/ha) (Table 4). Similarly, two applications of the copper hydroxide spray resulted in a higher average yield (3.503 t/ha) compared to other spray frequencies.

Further analysis of the three-way interaction effects provided a more nuanced understanding. Awash-2, when treated with streptomycin and subjected to two copper hydroxide sprays, achieved the highest yield (3.835 t/ha). Conversely, untreated Awash-1 seeds in unsprayed plots yielded the lowest among the Awash varieties (2.220 t/ha). The most susceptible variety, KAT-B1, produced the lowest overall yield (2.008 t/ha) when seeds were left untreated, and no foliar spray was applied (Table 4). Similar outcomes have been reported by [19, 38]

These findings highlight the importance of integrated disease management strategies. Seed treatment with streptomycin consistently demonstrated its effectiveness in enhancing yield, aligning with the observations of [39]. Similarly, the study corroborated the findings of [37], who reported yield increases of up to 0.95 t/ha with a combination of chemical spray and seed treatment. The positive impact of streptomycin seed treatment, especially when combined with copper hydroxide sprays, in controlling common bacterial blight and improving yield components, resonates with the research conducted by [40] and [41]. The study underscores that achieving optimal bean yield requires a multifaceted approach. Selecting disease-resistant varieties like Awash-2, coupled with appropriate seed treatment and timely foliar chemical applications, can significantly mitigate yield losses caused by diseases like CBB. These findings provide valuable insights for farmers and agricultural experts seeking to optimize bean production in regions prone to CBB outbreaks.

Hundred Seed Weight (g)

The weight of a hundred seeds, a key indicator of seed size and potential yield, was significantly influenced by a three-way interaction between variety, seed treatment, and foliar chemical spray, as shown in Table 4. This complex interaction suggests that the impact of each factor on hundred seed weight is dependent on the levels of the other two factors. Among the tested varieties, Awash-2 consistently produced heavier seeds. The highest mean hundred seed weight of 28.5g was recorded for Awash-2 under a specific combination of seed treatment and foliar spray. A slightly lower hundred seed weight of 28.33g was observed in Awash-2 under a different treatment combination. In contrast, the KAT-B1 variety consistently yielded the smallest mean hundred seed weight of 24.83g, irrespective of the treatment combinations. This

finding highlights the importance of considering all three factors; variety, seed treatment, and foliar spray when aiming to optimize hundred seed weight. Further investigation into the specific treatment combinations that resulted in the highest hundred seed weight for Awash-2 could provide valuable insights for maximizing yield potential. The effect of integrated control of CBB also demonstrated significant improvements in components of yield and seed yield of common bean as reported by [19, 36].

Relative Yield Loss

The impact of the main effects of treatments on the yield loss has been detailed in Table 4. The results revealed significant two-way interactions between these factors, highlighting their combined influence on seed yield (Table 4). The interaction between variety and seed treatment significantly ($p < 0.05$) affected relative yield loss. Untreated plots across all varieties experienced substantially higher yield losses compared to their treated counterparts. Specifically, KAT-B1 without streptomycin treatment exhibited the highest mean relative yield loss at 18.96%, followed by Awash-1 (17.69%) and Awash-2 (17.48%) without treatment. In contrast, streptomycin treatment consistently reduced yield loss across all varieties, with KAT-B1, Awash-1, and Awash-2 showing losses of 9.52%, 6.19%, and 6.12% respectively. This finding underscores the effectiveness of streptomycin seed treatment in mitigating yield losses, regardless of the bean variety. The same trend has been observed with foliar sprays of copper fungicide on the bean varieties, where sprayed varieties generally showed reduced seed yield loss compared to the control treatment, and more reduced loss observed with increased frequency of spray. The result showed that unsprayed plots of KAT-B1 suffered the highest mean relative yield loss (17.53%), followed by Awash-1 (14.65%) and Awash-2 (14.52%). Notably, Awash-1 and Awash-2 then sprayed twice with copper hydroxide 77% WP, exhibited the lowest relative yield losses of 7.00% and 6.90% respectively (Table 4). This finding is in agreement with the works of [19, 36] who reported comparable results with the current investigation. Though we noticed significant achievements of chemical control for CBB has been obtained and reported by several scholars we should be aware that repeated use of copper-based bactericides to control bacterial blight in common beans raises significant environmental and ecotoxicological concerns. These include copper accumulation in soil, potential phytotoxicity to crops, and impacts on non-target organisms like beneficial microbes and aquatic life. Additionally, excessive copper use can contribute to the development of copper-resistant bacterial strains, hindering future control efforts.

Despite the overall effectiveness of the combined treatment, varietal differences in response were observed. KAT-B1, even with the treatment, experienced a substantial yield loss of 20.53% compared to the "maximum protection" benchmark (Table 4). This suggests a potentially higher susceptibility of KAT-B1 to CBB, necessitating further investigation into additional protective measures. The study's findings align with previous research by [37], who also reported significant reductions in relative yield losses when treatments were applied compared to untreated plots. Their study, conducted in Melkassa and Arsi Negele, demonstrated the substantial benefits of seed treatment in reducing yield losses, with even greater efficacy observed when combined with bactericide sprays. Overall, this study underscores the importance of a multi-pronged approach to managing CBB in common bean cultivation. Integrating seed treatment with appropriate foliar chemical applications can significantly minimize yield losses.

However, varietal differences in disease susceptibility should be considered when tailoring management strategies. Further research exploring the economic feasibility of different treatment combinations and their long-term impact on disease dynamics is recommended. There is no doubt that copper-based bactericides remain a vital tool in some situations like in large scale commercial production of common beans, however, in situations like the smallholder subsistence farmers that may not afford the cost of chemical bactericides and/or in organic agriculture, exploring alternative disease management strategies like using resistant bean varieties, integrated disease management, and biological control methods is crucial to minimize environmental and ecotoxicological risks.

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Variety	Seed TRT	Foliar spray	Seed yield (t/ha)	HSW (g)	Relative Yield Loss (%)
KAT-B1	Untreated	Unsprayed	2.008 ^m	25.67 ^{fg}	20.53a
		1-time spray	2.461 ^{jk}	26.33 ^{def}	20.00b
		2-time spray	2.671 ^{ij}	26.33 ^{def}	16.33d
	Treated	Unsprayed	2.671 ^{ij}	26.17 ^{ef}	14.53e
		1-time spray	2.867 ^h	25.27 ^{fg}	9.44g
		2-time spray	3.149 ^{ef}	25.33 ^{fg}	9.15gh
Awash-1	Untreated	Unsprayed	2.220 ^l	27.00 ^{cde}	19.87b
		1-time spray	2.690 ⁱ	26.17 ^{ef}	19.20c
		2-time spray	2.894 ^h	26.33 ^{def}	14.00f
	Treated	Unsprayed	2.859 ^h	26.83 ^{de}	9.43g
		1-time spray	3.298 ^d	27.33 ^{bcd}	9.04h
		2-time spray	3.459 ^c	27.00 ^{cde}	0.00j
Awash-2	Untreated	Unsprayed	2.455 ^k	24.83 ^g	19.73b
		1-time spray	2.949 ^{gh}	28.33 ^{ab}	18.90c
		2-time spray	3.271 ^{de}	28.50 ^a	13.80f
	Treated	Unsprayed	3.071 ^{fg}	28.00 ^{abc}	9.32gh
		1-time spray	3.604 ^b	24.83 ^g	4.60i
		2-time spray	3.835 ^a	25.00 ^g	0.00j
CV (%)			2.6	1.5	2.5
LSD (5%)			0.1276	3.1733	1.0891

Mean values within a column followed by the same letters are not significantly different from each other. LSD = Least Significant Difference, CV = Coefficient of Variation.

3.4. Cost-Benefit Analysis in Common Bean Bacterial Blight Management

A cost-benefit analysis for the different treatment combinations of common bacterial blight management strategies was computed in order to evaluate their feasibility for common bean cultivation. The economic performances of various treatment combinations against a baseline of untreated and unsprayed control plots were compared. The results unequivocally demonstrated the economic advantage of integrated CBB management. Across all evaluated bean varieties, integrating seed treatment with copper hydroxide foliar sprays resulted in significantly ($p < 0.05$) higher yields, leading to increased gross income and ultimately higher profitability (Table 5). Specifically, the combination of streptomycin seed treatment and two foliar applications of copper hydroxide consistently yielded the highest marginal benefits. It indicated that this particular treatment regime is economically optimal for most tested varieties. However, the study also revealed varietal differences in economic response to treatments. For instance, the

Awash-2 variety treated with the aforementioned combination achieved the highest net benefit (ETB93893 ha⁻¹), with MRR of 272% highlighting the potential for variety-specific management recommendations. According to the guidelines described in [33] a treatment is considered worth for farmers when its minimum acceptable rate of return (MAR) is 100%, which is suggested to be realistic in order to make recommendations from marginal analysis.

Beyond immediate economic gains, the study highlighted the long-term benefits of selecting varieties with desirable traits. The Awash-2 variety, besides demonstrating high profitability under the recommended treatment, also exhibited resistance to storage pests, further enhancing its economic viability. Generally, the findings of this study highlighted that the host plant resistance screening remains the cheapest mechanism of cultivar development in both developed and developing countries, like Ethiopia, but still alone could not meet the multidimensional needs of the common bean growers [42]. Overall, this cost-benefit analysis provides compelling evidence for the economic advantage of integrated CBB management in common bean production. Seed treatment combined with strategically timed copper hydroxide sprays significantly improves yield and profitability. However, optimizing management strategies should consider varietal differences in response to treatments. The study underscores the importance of selecting varieties that not only exhibit disease resistance but also possess desirable traits like storage pest resistance, contributing to long-term economic sustainability.

Table 5. Cost-benefit analysis of common bean production as influenced by Common bacterial blight management options at Dugda Dawa district in 2021 main cropping season.

Seed treatment	Foliar spray	Seed yield (t/ha)	Adj. yield	GFB	TVC	NB	MNC	MNB	MRR%
KAT-B1									
Untreated	No spray	2.008	1.707	51204	0	51204	0	0	
	1-time spray	2.461	2.092	62756	1800	60956	1800	9752	541.8
	2-times spray	2.671	2.270	68111	3600	64511	1800	3555	197.5
Treated	no spray	2.671	2.270	68111	300	67811	-1800	3300	-183.3
	1-time spray	2.867	2.437	73109	2100	71009	1800	3198	177.7
	2-times spray	3.149	2.677	80300	3900	76400	1800	5391	299.5
Awash-1									
Untreated	No spray	2.22	1.887	56610	0	56610	0	0	
	1-time spray	2.69	2.287	68595	1800	66795	1800	10185	565.8
	2-times spray	2.894	2.460	73797	3600	70197	1800	3402	189.0
Treated	no spray	2.859	2.430	72905	300	72605	-1800	2408	-133.8
	1-time spray	3.298	2.803	84099	2100	81999	1800	9395	521.9
	2-times spray	3.459	2.940	88205	3900	84305	1800	2306	128.1
Awsh-2									
Untreated	No spray	2.455	2.087	62603	0	62603	0	0	
	1-time spray	2.949	2.507	75200	1800	73400	1800	10797	599.8
	2-times spray	3.271	2.780	83411	3600	79811	1800	6411	356.2
Treated	no spray	3.071	2.610	78311	300	78011	-1800	-1800	100.0

1-time spray	3.604	3.063	91902	2100	89802	1800	11792	655.1
2-times spray	3.835	3.260	97793	3900	93893	1800	4091	227.3

GFB = gross field benefit, TVC = total variable cost, NB = net benefit, MNC = Marginal net cost., MNB = Marginal net benefit, MRR% = marginal rate of returns.

CONCLUSION

The field experiment showed significant variation in disease parameters under different treatment conditions, particularly with regard to variety, seed treatment, and copper hydroxide spray frequencies. The moderately resistant bean variety, Awash-2, exhibited the lowest disease severity index, disease progression rate, and area under the disease progress curve. Combining streptomycin-treated seeds with two copper hydroxide sprays resulted in a significant reduction in common bacterial blight (CBB) severity. Additionally, applying these treatments to the susceptible variety, KAT-B1, resulted in notable improvements in yield.

In general, the study demonstrated the potential for managing CBB through a combination of bean varieties, streptomycin seed treatment, and timely foliar sprays. The Awash-2 variety, in particular, showed promise in its resistance to CBB. Furthermore, economic analyses showed that using seeds of the Awash-2 variety, treated with streptomycin and spraying of copper hydroxide two times at 7-day interval, may be more economically viable than the widespread use of multiple applications of bactericides. Future research should focus on testing and sustaining these outcomes in different seasons and agro-ecologies, as well as exploring the integration of host resistance with other cultural practices. Additionally, further studies on seed treatment with different bactericides, as well as testing of efficacy, application rates, and frequencies, are necessary to develop an integrated CBB management strategy for sustainable common bean production.

With regard to the safety of the environment, we should be aware of the drawbacks of repeated use of copper-based foliar sprays and antibiotics for seed treatment to control common bacterial blight (CBB) in common bean. In the long run, such practices could raise environmental and ecotoxicological concerns due to potential copper accumulation in soil and antibiotic resistance. Copper, a heavy metal, can persist in the soil, impacting soil fertility and potentially harming soil microbes, earthworms, and aquatic organisms. Antibiotic overuse can lead to the emergence of resistant bacterial strains, reducing treatment efficacy and potentially impacting human health.

Future Research Directions

Under Ethiopian current conditions, most of the haricot bean is produced by smallholder farmers, who are resource-poor farmers. These farmers usually could not afford the cost of chemical bactericides. Besides, the use of bactericides in farm fields has several harmful effects on the environment. Therefore, breeding for disease-resistant bean cultivars should be the major strategy for controlling CBB in common bean. Such varietal development strategies require the knowledge of the population structures of both the host plant and the pathogen, including their interaction effects. This can be done by the collection and characterization of germplasm and

Xap isolates from all regions of the country. Genetic diversity analysis studies could exploit both morphological and molecular (DNA) methods for both organisms. Similarly, the conventional and modern breeding approaches could be employed for variety development.

Hence, backcross breeding coupled with molecular marker-assisted selection approaches might be considered as one of the best strategies in managing this disease. This breeding strategy allows to deployment of multiple QTL/genes in one of the agronomically superior or preferred improved common bean varieties that ultimately enables to achievement high level of field resistance with the use of genetic resistance alone.

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Conflict of interest. Authors declare that there is no conflict of interest among them

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