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Association of common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) epidemics with agro ecological factors in Southwestern Ethiopia

W. Adila[1*], H. Terefe[1] and A. Bekele[2]

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ABSTRACT

Common bacterial blight, caused by *Xanthomonas axonopodis* pv. *phaseoli*, is an economically important disease of common bean and causes significant yield losses in Ethiopia. A field survey was conducted to understand the spatial distribution, relative importance and association of common bacterial blight epidemics with agro-ecological factors in low and mid-land areas of Southwestern, Ethiopia, during the 2018-19 cropping season. A total 85 bean fields were assessed in four common bean growing districts. High diseases incidence and severity was recorded at Debub Ari (77.6 and 52.7%, respectively) while the lowest was from Male (38.5 and 28.0%, respectively). The associations between disease parameters and agro-ecological factors were analyzed using multiple logistic regression models. Agronomic practices including NPS fertilization, preceding crop, weed management and plant population had highly significant ($P<0.0001$) association with both disease incidence and severity. Also, altitude, seed source and cropping system significantly ($P<0.05$) influenced disease severity while cropping pattern showed significant ($P<0.05$) association with disease incidence in the reduced model. Higher mean disease severity (≥40%) had high probability of association with district, absence of NPS fertilization, poor weed management practice, and preceding crops, than their counter parts. Adequate NPS fertilization increases growth performance of the crop in turn decreases disease intensity, weed serve as alternate host for incoming inoculum and previous crops were source for inocula as well as crop rotation used as reduce inoculum load. Therefore, the present study showed that the disease is a major production constraint of common bean, and suggested proper nutrient and weed management practices, and crop rotation to reduce common bacterial blight in the study areas.

Keywords: CBB, *Xanthomonas axonopodis*, Incidence, Severity, Ethiopia.

[1]*School of Plant Sciences, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia.*
[2]*Southern Agricultural Research Institute, SARI, P.O. Box 06, Hawassa, Ethiopia.*

*Corresponding author's email: wondadila@gmail.com (Wondimu Adila)

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Introduction

Common bean (*Phaseolus vulgaris* L.) is the world's second most important pulse after soybean (Parades *et al.*, 2009) and constitutes a significant part of human diet in Ethiopia (EPPA, 2004). Worldwide, about 22.8 million metric tons of dry beans were produced and annually India alone produces more than 4 million metric tons (FAOSTAT, 2014). The crop has been cultivated as main food crop particularly in Southern and Eastern parts of Ethiopia, where it is widely intercropped with maize and sorghum to improve farmers' income (Fininsa, 2003).

Production of the crop is indispensable in the country to enrich the stable cereal crop with sufficient and quality protein in order to overcome the problem of malnutrition (Tadesse *et al.*, 2009). Thus, it is cultivated in a wide range of agro-ecologies and farming systems including well-watered and drought-stressed areas (Asrat *et al.*, 2009). Common beans were covering on 0.29 million ha of area and the production obtained was 0.48 million tons of the grain production. Similarly, it covered 98.32 thousand ha of land with productivity of 1.62 t ha^{-1} of grain yield in Southern Ethiopia (CSA, 2018). However, productivity is even below the national average 1.69 ton ha^{-1} (CSA, 2018). Low productivity is attributed to both abiotic and biotic constraints such as soil fertility status, recurrent water stress, insect pests and diseases, which are considered as the principal factors in Africa (Katungi *et al.*, 2010; Belete and Bastas, 2017).

Among major diseases, Common Bacterial Blight (CBB), caused by *Xanthomonas axonopodis* pv. *phaseoli*, is very important in warmer agro-ecologies of Ethiopia, including the Southwestern Ethiopia, where common beans are widely grown (Kimit *et al.*, 2009; Gurmu, 2013). Wind, rain splash, irrigation and infected seed are main dispersal factors for pathogen (Fininsa and Tefera, 2001). A yield loss of 30-70% was caused by CBB on susceptible cultivars worldwide (Karavina *et al.*, 2011) and up to 22.4% yield reduction was reported in eastern part of Ethiopia (Fininsa, 2003), which could be more than this figure in recent years.

Different production practices and variation in climatic conditions is thought to influence disease occurrence, epidemics development and damage to the crops under field conditions (Mwangombe *et al.*, 2007). The effects of various management practices like cropping system on disease prevalence and intensity was reported (Fernandez *et al.*, 2011). However, understanding of environmental, cultural and epidemiological factors still plays a vital role in development of management options, such as resistant varieties (Singh and Schwartz, 2010). Thus, understanding the association of disease parameters with cropping systems, crop and weed management practices and other environmental factors will help to identify the most important variables and to develop an integrated and sustainable management options (Zewde *et al.*, 2007).

However, information on disease occurrence, importance, intensity and effects of different agronomic practices, environmental variables and other biophysical factors on common bacterial blight of common bean are not quantified in Southwestern, Ethiopia. Thus, survey studies are found useful to gain insights into the occurrence, distribution and relative importance of plant diseases (Fininsa and Yuen, 2001). Therefore, this paper targets (1) to assess CBB distribution and its importance in Southwestern Ethiopia and (2) to determine association between disease intensity with different agro-ecological factors in the study areas.

Materials and Methods

The survey areas

Field survey was conducted over four major common bean producing districts, namely Bena-Tsemay, Debub Ari and Male from South Omo and Arba Minch Zuria from Gamo Zone, Ethiopia. The field survey was conducted during July to October in 2018 main cropping season. The districts were selected purposively as the disease was frequently reported and severe in those districts. The altitude range of Southern Omo is from 375-3500 m.a.s.l. and it is located at 4°43'N-6°46'N and 35°79'E-36°06'E (Fig. 1). The average annual rainfall ranges from 400-1600 mm and average minimum and maximum temperature of 10.1 and 27.5°C, respectively (Yoseph et *al.*, 2014). The overall agro-ecological characteristics of the surveyed districts are presented in Table 1.

Table 1. Characteristic feature of surveyed districts in Southwestern Ethiopia.

District	Altitude (m.a.s.l)	Latitude	Longitude	Rainfall (mm)	Mean T° (°C) [a]
Arba Minch Zuria	1153-1232	5°88.08"-6°13.44"	37°24.10'-36°47.53"	81.0-94.7	16.7-31.9
Bena-Tsemay	1359-1503	5°65.99"-5°70.68"	36°61.9-36°72.87"	31.2-90.8	16.2-28.9
Debub Ari	1414-1807	5°72.19"-5°81.90"	36°54.95'-36°62.28"	104.4-126.4	13.5-28.6
Male	1308-1355	5°72.06"-5°77.07"	36°62.28"-36°76.32"	-	15.4-29.5

[a] *Average minimum and maximum temperature (°C) for four consecutive growing months (July-October).*
Source: National Meteorology Agency, Hawassa branch

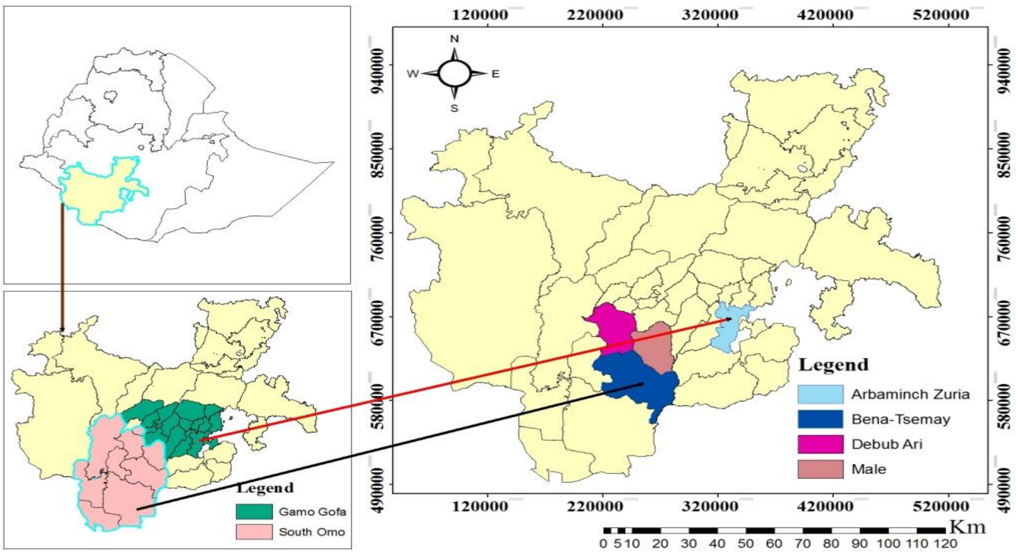

Fig. 1. Map of surveyed districts in SNNPR.

Sampling and sample unit

Group discussions were held with development agents and different stakeholders who are closely working with farmers to have a broader understanding of the production potential and route in the survey of districts, farmers association (FAs) and fields. Formal survey guides were prepared to collect required information from the farmers, which were administered through personal interviews. Districts were selected purposively and simple stratified sampling was used to separate FAs based on elevation difference (low, medium and high). Five FAs were selected randomly from established strata for each district. Fields were randomly selected at intervals of 5 to 10 km along the main and feeder accessible rural roads. Selection of fields per FAs was depending on FAs bean production potentials. In this regard, a total of 85 bean fields were assessed across surveyed districts. Plant samples exhibiting typical symptoms of CBB disease was assessed systematically for each field and representative samples were pressed and brought to Haramaya University Plant Pathology Laboratory for pathogen identity confirmation and confirmed as *Xanthomonas axonopodis* pv. *phaseoli*.

Geographical and agronomic data collection

Global Positioning System (GPS) instrument was used to determine the coordinates (latitude and longitude) and altitude of each field upon spot visit. GPS based survey sheet was prepared to collect information on disease status from each farm. Additionally, data like variety, cropping systems (sole or intercropping), planting date, weed density, fertilizer usage, planting pattern (row or broadcast), crop growth stage (flowering, pod filling and early maturity), plant density and previous crops were collected to determine their relationship with the magnitude of the disease. Information on previous crop, variety type and planting date were obtained from growers through interviews. The plant and weed population were assessed using 1 m^2 quadrat set by "X" fashion throwing five quadrats within 10 m apart per field. The mean plant and weed population densities were obtained by averaging the number of population in the five quadrats for analysis.

Disease assessment

Disease assessment usually involves the measurement and quantification of the amount of plant disease. It is also a primary significance in the study and analysis of plant disease epidemics. Thus, common bean farms were evaluated for disease prevalence, incidence and severity. Common bacterial blight prevalence was determined on presence and absence of the disease in the inspected districts. Disease incidence was determined from five quadrats of 1m^2 in each assessed fields across districts where as disease severity was scored from randomly taken 10 plants per quadrat by using standard scoring scales. Details of each parameter are presented in the following sections.

Disease prevalence

Proportion or percentage of sampling areas in which a disease is present and determined as:

$$\text{Disease prevalence (\%)} = \frac{\text{Number of fields showing CBB symptoms}}{\text{Total number of fields visited}} \times 100$$

Disease incidence

Common bacterial blight incidence was assessed by counting the number of plants showing typical CBB symptoms within five quadrats per field and incidence per farm was computed using the following formula:

$$\text{Incidence (\%)} = \frac{\text{Total number of plant infected per quadrat}}{\text{Total number of plants observed per quadrat}} \times 100$$

Disease severity

Disease severity was rated on 10 randomly selected plants per quadrat in each field using a 1-9 scoring scale of CIAT (1987). The severity grades obtained were converted into percentage severity index (PSI) based on (Wheeler, 1969) for analysis as follows:

$$\text{PSI (\%)} = \frac{\text{Sum of numerical ratings}}{\text{Number of plants scored x maxium score in the scale}} \times 100$$

Data analyses

Descriptive analysis was performed and descriptive parameters were used to describe the distribution and prevalence of CBB incidence and severity. Disease incidence and severity were classified into distinct groups of binomial qualitative data (Fininsa and Yuen, 2001; Sahile *et al*., 2008; Belete *et al*., 2013). Accordingly, categorization tables of the disease intensity (incidence and severity) and independent variables were built to represent the bivariate distribution of the fields (Table 2). Class boundaries were selected, so that binary variable classes were set for incidence (≤50 and >50%) and severity (<40 and ≥40) to yield binary variable for CBB. The associations of CBB disease parameters with agro-ecological factors (districts, altitudes, land preparation, NPS fertilization, plant population, weed management, cropping system, cropping pattern, seed source, previous crops sown, and crop growth stages) were analyzed using a logistic regression model (Yuen, 2006) using SAS procedure of GENMOD (SAS, 2014). The importance of the independent variables was evaluated twice in terms of their effect on disease parameters. First, the association of the single independent variables with CBB incidence and severity were tested in a single-variable model. Second, the association of all the independent variables with CBB incidence and severity were tested in a single-variable model. Selected independent variables that have significant association with the disease incidence and severity were sequentially added to a reduced multiple-variable model (Yuen, 2006). The parameter estimates and their standard errors were analyzed using the GENMOD procedure both for the single and multiple-variable models. The odds ratio was obtained by exponentiation of the parameter estimates for comparing the effect based on a reference point. A complete analysis of the deviance reduction was calculated for each variable as it was added to the reduced multiple-variable model (Yuen, 2006). The deviance, the logarithm of the ratio of two likelihoods, was used to compare the single- and multiple-variable models. The difference between the likelihood ratio tests (LRTs) was used to examine the importance of the variable and was tested against the χ^2 value (McCullagh and Nelder, 1989).

Results and Discussion

General characteristic features of surveyed fields

From a total of 85 inspected fields, about 94.11% were infested by CBB while only 5.88% bean fields were disease free. The highest (35.3%) numbers of fields were surveyed from Debub Ari district and the lowest fields assessed were from Male district, which were only 17.6%. Regarding sowing time, 60% of bean farms were sown at late July to mid-September and 40% at late September to late October. About 67% of bean fields were broadcasted and 32.9% were row planted. Common bean fields were found at three growth stages during the survey period including flowering (29.4 %), pod filling (47.06%) and early maturity (23.5%).

Major common bean genotypes noted in the study areas were local (69.41%) and Nasir (25.88%), and variety Hawassa dume took the remaining balance. Seeds of bean genotypes were obtained from three sources: extension office (29.42%), local market (32.94%) and own seed (37.65%). Most (56.47%) farmers used to apply blended NPS (19% N, 38% P_2O_5 and 7% S) inorganic fertilizer at a rate of 100 kg ha^{-1} for bean production. However, some farmers still use crop debris for soil nutrient management. With regard to cropping system, nearly 71% of inspected bean fields were sole cropped and the rest bean fields were dominantly intercropped with maize and sorghum crops. Commonly intercropped crops were maize, sorghum and rarely sunflower.

Farmers in the surveyed districts have not used chemicals to control CBB. High weed infestation was ascertained from Debub Ari and Bena-Tsemay districts. *Xanthium stramarium* was among the major weeds which could harbour *Xanthomonas axonopodis* pv. *phaseoli*. Angular leaf spot, rarely common bean mosaic virus and bean curl virus, root rot, bean rust at higher altitudes and insect pests including aphids and leafhopper were recorded during the survey periods. Of which, about 48.2% of inspected fields showed angular leaf spot and 21.2% of fields were infected with common bean mosaic and bean curl virus. Moreover, ladybird beetles were also observed in assessed farms.

Distribution, incidence and severity of common bacterial blight

Surveyed fields had shown 100%, 90%, 95% and 90% of disease prevalence in Debub Ari, Bena-Tsemay, Arba Minch Zuria and Male districts, respectively. Among districts, different levels of mean disease incidence and severity were recorded; higher mean incidence (77.6%) and severity (52.74%) were registered in Debub Ari district while lower incidence (38.50%) and severity (28.01%) were recorded in Male district (Table 2). In this regard, Fininsa (2003) reported that extended warm and humid weather enhances disease development and responsible for losses in both yield and seed quality. Similarly, Zewde *et al.* (2007) and Darkwa *et al.* (2016) noted that temperature and moisture conditions influence the rate of disease development. Altitude range of >1500 m.a.s.l. had relatively the highest mean disease incidence (Table 2) and severity while altitudes <1200 m.a.s.l. had the lowest mean disease incidence (49.8%) and severity (34.3%). Kassahun (2008) noted that bacterial growth is enhanced in low to mid altitude agro-ecologies in Ethiopia. Moreover, Perry and Pauls (2011) confirmed that common bacterial blight is most prevalent in areas where warm, wet or humid conditions facilitate the spread of the pathogen.

Pod formation to early maturity growth stages of the crop was significantly associated with CBB incidence and severity in the reduced multiple-variable model. For example, flowering growth stage reduced disease incidence and severity by 41.30 and 36.69%, respectively, compared with maturity growth stage during the survey. CBB epidemics are highly related with different crop growth stages and the crop is highly prone to infection during bean pod formation growth stage and onwards (Gudero and Terefe, 2018). This could imply that these crop growth stages are susceptible to the disease and when it coincides with favorable weather variables, the disease would be highly devastating. That is, some plants escape disease because they are susceptible to a pathogen only at particular growth stage (Agrios, 2005); or although blight symptoms sometimes appear on seedlings, symptoms are not seen during the vegetative growth stage and symptoms usually occur during the reproductive stage under field conditions (Fourie, 2002).

Intercropped field showed less disease incidence and severity in comparison with sole cropping (Table 2). About 41.31 disease severity reduction was recorded from intercropped fields as compared to sole bean cropping. This might be attributed to disturbing the movement of inocula or component crops could be used as barrier, which restrict pathogen movement, in turn reduce epidemics. Moreover, bean intercropping could reduce temperature and wind velocity, decrease crop density, decrease spread of propagules through trapping by non-host crops discussed by various researchers (Boudreau and Mundt, 1992; Fininsa and Yuen, 2001; Kassahun, 2008).

Table 2. Categorization of variables used for analyses and mean (±SE) of disease incidence and severity of common bacterial blight of common bean for different independent variables at Southwestern Ethiopia, during the 2018-19 main cropping season.

Variable	Variable class	No. of field	Common Bacterial light					
			Severity (%)		Incidence (%)		Severity (%)	Incidence (%)
			<40	≥40	≤50	>50		
District	Arbamich Zuria	20	11	9	10	10	38.88 ± 3.70	52.80 ± 5.16
	Bena-Tsemay	20	9	11	5	15	44.07 ± 4.39	62.90 ± 6.56
	Debub Ari	30	9	21	2	29	52.74 ± 3.18	77.60 ± 3.77
	Male	15	15	0	14	1	28.01± 2.02	38.50 ± 4.35
Altitude [a]	<1200	12	8	4	7	5	34.31 ± 4.20	49.80 ± 6.80
	1200-1500	62	33	29	24	37	42.50 ± 2.39	58.20 ± 3.17
	>1500	11	2	9	0	11	55.93 ± 4.17	81.40 ± 5.96
Land preparation [c]	Twice	39	16	23	11	28	47.23 ± 2.78	71.30 ± 3.51
	More than twice	46	28	18	19	27	36.80 ± 2.63	53.00 ± 4.09
Variety	Hawassa dume	4	2	2	0	4	37.80 ± 3.03	59.30 ± 2.88
	Local	59	25	34	19	40	47.50 ± 2.52	68.60 ± 4.06
	Nasir	22	18	4	14	8	30.84 ± 2.03	43.30 ± 4.11
Sowing time	Late July to Mid Sept.	51	16	35	6	45	50.00 ± 3.60	72.50 ± 3.21
	Late Sept. to Late Oct.	34	28	6	26	8	32.57 ± 2.74	48.80 ± 4.02
Cropping system [d]	Sole cropping	60	43	17	12	48	49.04 ± 2.37	69.70 ± 3.30
	Intercropping	25	23	2	9	16	28.78 ± 1.61	41.50 ± 3.18
Cropping pattern	Broadcasting	28	26	2	20	8	49.62 ± 2.33	72.00 ± 3.23
	Row planting	57	32	35	12	45	27.60 ± 1.56	39.90 ± 3.12
Plant population [e]	<20	41	30	11	23	18	33.87 ± 2.01	48.10 ± 3.26
	>20	44	12	32	8	36	52.10 ± 2.79	73.40 ± 4.02
Weed management [b]	Poor	35	35	29	3	32	55.65 ± 2.38	80.40 ± 2.84
	Intermediate	32	32	10	18	14	31.98 ± 2.33	45.00 ± 4.09
	Good	13	13	0	9	4	30.15 ± 2.84	40.50 ± 4.10
Growth stages	Flowering	25	25	4	15	10	31.90 ± 3.20	46.90 ± 5.61
	Pod filling	40	40	24	11	29	46.43 ± 2.67	65.40 ± 3.01
	Early maturity	20	20	13	5	15	50.39 ± 4.20	79.90 ± 6.09
NPS fertilization	100 Kg ha^{-1}	48	48	12	25	23	33.85 ± 2.00	49.50 ± 3.48
	0 Kg ha^{-1}	37	37	29	6	31	55.07 ± 2.90	76.80 ± 3.58
Seed source	Farmer saved	32	32	21	7	25	50.18 ± 3.60	69.40 ± 5.33
	Local market	28	28	17	10	18	46.65 ± 3.73	62.90 ± 5.09
	Improved	25	25	5	14	11	31.59 ± 1.88	45.50 ± 3.88
Previous crop	Maize with bean	25	25	17	4	21	49.78 ± 3.48	69.70 ± 4.23
	Maize	7	7	2	2	5	33.30 ± 6.57	47.00 ± 3.10
	Onion + Maize	9	9	1	6	3	26.44 ± 2.80	38.50 ± 6.07
	Bean + Maize	28	28	20	7	21	51.74 ± 3.40	71.60 ± 4.62
	Groundnut + Maize	8	8	0	8	0	24.13 ± 3.04	31.70 ± 7.06
	Sorghum with bean	8	8	3	2	6	43.16 ± 5.90	67.62 ± 8.90

[a] *Areas with <1200, [1200-1500] and >1500 m.a.s.l. are classified as low, tepid humid and midland, respectively in Ethiopia.* [b] *Land preparation refers to tillage frequency during land tillage before bean planting.* [c] *Cropping system refers to bean farms with pulse + maize/bean + sorghum, sunflower + bean as intercrops or sole bean.* [d] *Plant population refers to number of bean productive plants per m^2.* [e] *Weed management was recorded as poor, intermediate and good, indicating high density, medium density and little/no weed.*

Weed status influenced common bacterial blight intensity (Table 4). Well-managed fields reduced mean disease incidence by 49.00% and mean disease severity by 45.80% as compared to highly weed-infested fields. In all the surveyed fields, highly weed infested fields increased disease incidence by 49.63% and severity by 45.82% compared with well-managed bean fields. This could imply that weed infestation favors development of common bacterial blight by increasing the humidity within the crop canopy, which is more favorable for disease progression.

In this regard, Sahile *et al.* (2008) reported that the presence of a high weed population in a field increases the humidity and modifies the microclimate under the canopy, which is more favorable for the development of chocolate spot disease epidemics. On other hand, weeds might harbor causal pathogen to host plants. For instances, fields infested with *Xanthium stranium* weed in the surveyed areas showed severe infection of common bacterial blight. It is a well-established fact in the literature that *Xanthomonas axonopodis* pv. *phaseoli* survives on weeds (Cafati and Saettler, 1980; Angeles-Ramos *et al.*, 1991; Opio *et al.*, 1996), and some species may harbor the pathogen for up to 6 months (Opio *et al.*, 1996). Moreover, highly weed infested fields might have increased intense competition for available resources reduced crop vigor that could promote the development of the disease as reported by Sahile *et al.* (2008) and Gudero and Terefe (2018).

Fields that received recommended rate (100 Kg ha^{-1}) of blended NPS fertilizer reduced mean disease severity (38.53%) compared with non-fertilized bean fields. Different researchers indicated that nutrient management an option to manage common bacterial blight of common bean under field conditions (Krupinsky *et al.*, 2002; Dordas, 2007; Veresoglou *et al.*, 2013; Parthasarathy, 2015). Likewise, this study obtained that application of NPS blended fertilizer at a rate of 100 kg ha^{-1} reduced disease intensity by 36-39% as compared to absence of field fertilization. It could be attributed to an increase in soil fertility status and crop vigor and improved physiological resistance (Oborn *et al.*, 2003). Krupinsky *et al.* (2002) and Parthasarathy (2015) also reported that nutrients can reduce disease to an acceptable level or at least to a level at which further control are more successful and less expensive.

Fields cropped for the last two seasons with common bean, followed by maize (Bean + Maize) showed the highest mean disease incidence (71.60 %) and severity (51.74 %) over other fields previously covered by different crops. On the other hand, lower disease incidence (31.70%) and severity (24.13%) were attended from bean fields previously covered by groundnut, followed by maize sown fields (Table 4). The situation could be related to poor hygiene and accumulation of crop debris that would have enhanced accumulation of pathogen propagules and subsequent development of CBB. Previous studies also noted that residues left on the soil favor survival of bacterial pathogens (Gilbertson *et al.*, 1990; Fininsa and Tefera, 2001). Thus, primary inocula on crop residues are likely to have a more consistent and predictable impact on disease risk under conducive conditions (Krupinsky *et al.*, 2002; Fininsa and Tefera, 2001). Growers of the study areas also used to continuously cultivate bean that would load the reservoir source of inocula of the target pathogen. Accordingly, studies confirmed that *Xanthomonas axonopodis* pv. *phaseoli* survives and over-seasons in infested soils and plant debris of unploughed plots (Gilbertson *et al.*, 1990; Fininsa and Tefera, 2001; Fourie, 2002; Gudero and Terefe, 2018).

Association of CBB epidemics with agro-ecological factors

Different variables like district, altitude, land preparation, variety, NPS fertilization, sowing time, previous crops, cropping system, weed management and plant population had shown very highly significant ($p<0.0001$) associations with disease incidence in logistic model as single variable (Table 3). Katungi *et al.* (2010) and Belete and Bastas (2017) reported that different agro-ecological factors have significant influence on disease intensity. Similarly, Mwangombe *et al.* (2007) reported different practices and climatic factors influence disease epidemics. Among the tested variables, district, NPS fertilization, previous crop and weed management were the most important variables to influence disease severity (Table 3). Poorly weeded farms showed strong association with high incidence (>50%) and severity (≥40%) of common bacterial blight Sahile *et al.* (2008).

Those variables that showed significant relationship with disease incidence and severity were tested in a reduced multiple-variable model; and analysis of deviance for the variables added to the reduced model showed the importance of each variable. The parameter estimates resulting from the reduced regression model and their standard errors are presented in Tables 4 and 5. Higher mean disease incidence (>50%) and severity (≥40%) revealed high probability of association with district (Arba Minch Zuria, Bena-Tsemay and Debub Ari), absence of blended NPS fertilization, pod filling to early maturity crop growth stage, poor weed management practice, dense plant population (≥20 m^{-2}) and preceding crops (mainly of maize with bean or vice versa and maize) (Tables 4 and 5). Altitudinal ranges of 1200-1500 m.a.s.l. and sole cropping system also had high probability of association with high (≤40%) disease severity (Table 5). On the other hand, broadcast planting and only twice land preparation obtained probability of relationship with high (>50%) disease incidence in the study periods (Table 4).

Table 3. The result of logistic regression model for common bacterial blight incidence and severity, and likelihood ratio test on independent variables in Southwestern, Ethiopia, during the 2018-19 main cropping season.

Variable	df	CBB incidence LRT [a]				CBB incidence LRT [a]			
		Type 1 analysis		Type 3 analysis		Type 1 analysis		Type 3 analysis	
		DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
District	3	805.40	<0.0001	118.40	<0.0001	273.80	<0.0001	21.80	<0.0001
Altitude	2	29.50	<0.0001	4.34	0.1141	36.32	<0.0001	6.95	0.0309
Land preparation	1	270.40	<0.0001	20.20	<0.0001	154.90	<0.0001	3.66	0.0559
Variety	2	453.90	<0.0001	13.80	0.0010	187.06	<0.0001	5.00	0.0822
Seed source	2	10.40	0.0053	0.90	0.6227	6.13	0.0468	6.61	0.0368
NPS Fertilization	1	102.60	<0.0001	77.20	<0.0001	52.47	<0.0001	30.75	<0.0001
Sowing time	1	94.30	<0.0001	1.20	0.2676	34.95	<0.0001	2.06	0.1514
Crop growth stage	2	9.520	0.0085	20.30	<0.0001	13.13	0.0014	22.46	<0.0001
Cropping system	1	118.60	<0.0001	0.96	0.3283	104.57	<0.0001	2.69	0.00090
Previous crop grown	5	202.80	<0.0001	117.40	<0.0001	80.37	<0.0001	49.27	<0.0001
Weed management	2	110.70	<0.0001	99.90	<0.0001	32.86	<0.0001	30.54	<0.0001
Cropping pattern	1	6.140	0.0132	4.11	0.0426	0.66	0.4164	0.14	0.7100
Plant population	1	23.80	<0.0001	23.80	<0.0001	18.22	<0.0001	18.22	<0.0001

[a]LRT = likelihood ratio test; DR = deviance reduction; Pr = probability of χ^2 value exceeding the deviance reduction; χ^2 = chi-square and CBB = common bacterial blight. df = degrees of freedom.

Table 4. Analysis of deviance, natural logarithms of odds ratio and standard error of CBB incidence (%) and likelihood ratio test on independent variable in reduced regression model in Southwestern, Ethiopia, during the 2018-19 main cropping season.

Added variable	Residual deviance [a]	df	CBB LRT [b]		Variable class	Estimate $\log_e$ (odds ratio) [c]	SE	Odds ratio
			DR	Pr > χ^2				
Intercept	3101.68		-	-	-	-0.52	0.27	0.58
District	2296.20	3	11.41	0.0007	Arba Minch Zuria	-0.50	0.15	0.60
			20.01	<0.0001	Bena-Tsemay	0.55	0.12	1.74
			27.24	<0.0001	Debub Ari	0.69	0.13	2.00
					Male	0*	-	-
Land preparation	1996.25	1	20.27	<0.0001	Twice	0.33	0.07	1.40
					More than twice	0*	-	-
Variety	1542.30	2	2.97	0.085	Hawassa dume	0.56	0.32	1.76
			2.31	0.1282	Local	-0.24	0.16	0.78
					Nasir	0*	-	-
NPS fertilization	1429.14	1	76.97	<0.0001	0 Kg ha^{-1}	0.69	0.07	1.99
					100 Kg ha^{-1}	0*	-	-
Crop growth stage	1325.29	2	18.25	<0.0001	Flowering	-0.48	0.11	0.61
			13.54	0.0002	Pod filling	-0.35	0.09	0.70
					Early maturity	0*	-	-
Previous crop	1003.81	5	10.96	0.0009	Maize with bean	0.45	0.13	1.57
			15.27	<0.0001	Maize	0.61	0.15	1.84
			6.37	0.0116	Onion + Maize	0.40	0.16	1.50
			20.22	<0.0001	Bean + Maize	0.60	0.13	1.83
			13.07	0.0003	Groundnut+ Maize	-0.64	0.18	0.52
					Sorghum with bean	0*	-	-
Weed management	893.06	2	36.71	<0.0001	Poor	0.69	0.11	2.00
			1.51	0.2196	Intermediate	-0.11	0.09	0.88
					Good	0*	-	-
Cropping pattern	886.93	1	4.11	0.0426	Broadcasting	0.24	0.12	1.27
					Row planting	0*	-	-
Plant population	863.10	1	24.09	<0.0001	<20 plants m^{-2}	-0.37	0.07	0.69
					≥20 plants m^{-2}	0*	-	-

[a] Residual deviance = unexplained variation after fitting model; [b] LRT = likelihood ratio test; DR = deviance reduction; Pr = probability of χ^2 value exceeding the deviance reduction; χ^2 = chi-square and CBB = common bacterial blight; [c] reference group. SE = standard error. df = degrees of freedom.*

Table 5. Analysis of deviance, natural logarithms of odds ratio and standard error of CBB Severity (%) and likelihood ratio test on independent variable in reduced regression model in Southwestern, Ethiopia, during the 2018-19 main cropping season.

Added variable	Residual deviance [a]	df	CBB LRT [b]		Variable class	Estimate $\log_e$ (odds ratio)[c]	SE	Odds ratio
			DR	Pr > χ^2				
Intercept	1236.30					-0.10	0.23	0.36
District	962.55	3	13.37	0.0003	Arba Minch Zuria	0.05	0.14	1.06
			8.95	0.0028	Bena-Tsemay	0.04	0.12	1.06
			0.36	0.5494	Debub Ari	0.36	0.12	1.44
					Male	0*		.
Altitude	926.52	2	2.32	0.1277	<1200	-0.08	0.14	0.92
			0.11	0.7457	1200-1500	0.14	0.09	1.15
					>1500	0*		.
Seed source	490.66	2	0.90	0.3435	Farm saved	-0.08	0.25	0.92
			30.86	<0.0001	Local market	-0.25	0.26	0.78
					Extension office	0*		.
NPS fertilization	525.60	1	21.04	<0.0001	0 Kg ha^{-1}	0.38	0.06	1.4
					100 Kg ha^{-1}	0*		.
Growth stage	477.53	2	12.56	0.0004	Flowering	-0.45	0.09	0.64
			2.69	0.1008	Pod filling	-0.29	0.08	0.75
					Early maturity	0*		.
Cropping system	259.08	1	6.32	0.0120	Sole cropping	0.04	0.12	1.03
					Intercropping	0*		.
Previous crop	292.59	5	1.38	0.2402	Maize with bean	0.35	0.14	1.42
			0.04	0.8456	Maize	0.17	0.15	1.20
			3.51	0.0611	Onion +maize	-0.03	0.16	0.97
			5.58	0.0181	Bean + maize	0.25	0.13	1.28
			16.02	<0.0001	Groundnut +maize	-0.41	0.17	0.66
					Sorghum with bean	0*		.
Weed management	250.70	2	0.13	<0.0001	Poor	0.44	0.11	1.56
			18.29	0.7229	Intermediate	0.03	0.09	1.03
					Good	0*		.
Plant population	240.86	1	18.29	<0.0001	<20 plants m^{-2}	-0.28	0.06	0.75
					≥20 plants m^{-2}			.

[a] Residual deviance = unexplained variation after fitting model; [b] LRT = likelihood ratio test; DR = deviance reduction; Pr = probability of χ^2 value exceeding the deviance reduction; χ^2 = chi-square and CBB = common bacterial blight. [c] = reference group. SE = standard error. df = degrees of freedom.*

In this regard, at Debub Ari, Bena-Tsemay and Arba Minch Zuria, it was found nearly 1.44, 1.06 and 1.06 times high probability of association with mean disease severity compared with disease severity at Male district. Similarly, Debub Ari (2 times) revealed higher probability of association with mean disease incidence of >50% than mean incidence reported from Male and Arba Minch Zuria districts. Highly weed infested fields (1.56 times) showed high probability of association with mean disease severity compared with well weed managed fields Sahile *et al.* (2008) and Gudero and Terefe (2018) reported high weed infestation had strong association with disease epidemics. In addition, Habtu *et al.* (1996) stated that different crop cultural practices showed influences on disease epidemics. Conversely, recommended rate (100 kg ha^{-1}) of NPS fertilization had twice greater probability that disease incidence would not exceed 40% as compared to bean planting without NPS fertilizer application. Veresoglou *et al.* (2013) noted the effects of NPS fertilization on disease intensity.

The logistic model quantified the relative importance of independent variables. Common bacterial blight epidemics was the function of these variables either to increase or decrease disease epidemics. Such analyses were carried out from diverse environments, crop growth stages, land preparation schemes, cropping systems, weed management practices, plant populations, NPS fertilization of the soil, planting patterns and field histories to generate both quantitative and qualitative data identifying epidemic risk factor.

Conclusions

Common bacterial blight is widely distributed and is a major production constraint in common bean growing areas of the surveyed districts. CBB intensity and importance varied among districts, altitudinal ranges, weeding practices and crop cultural practices. The study identified the importance of good weed management practices, repeated land preparation, NPS fertilizer application at recommended rate, sparse plant population and bean intercropping with other crops. However, the relationship of *Xanthium stranium* weed to CBB needs further investigation. The influence of different variables on CBB intensity assured the need of designing appropriate integrated management strategies. Therefore, proper weeding practices, appropriate agronomic practices, crop rotation with non-legume and other related cultural practices should be used to reduce the effect of common bacterial blight on bean production in study areas and other similar agro-ecologies until sustainable integrated management strategies are developed for all common bean-growing environments including surveyed districts.

Conflict of Interest

Authors declare that there is no conflict of interest with regarding the publication of this article

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