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To cite this article: Fekede Girma, Chemedha Fininsa, Habtamu Terefe & Berhanu Amsalu (2022) Distribution of common bacterial blight and anthracnose diseases and factors influencing epidemic development in major common bean growing areas in Ethiopia, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 72:1, 685-699, DOI: [10.1080/09064710.2022.2063168](https://doi.org/10.1080/09064710.2022.2063168)

To link to this article: <https://doi.org/10.1080/09064710.2022.2063168>



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Published online: 20 Apr 2022.



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# Distribution of common bacterial blight and anthracnose diseases and factors influencing epidemic development in major common bean growing areas in Ethiopia

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## ABSTRACT

Common bean is an important legume consumed as a source of food and used as a cash crop worldwide. However, its production and productivity are mainly constrained by bacterial and fungal diseases. A field survey was conducted to determine the prevalence, incidence, severity and association of factors influencing common bacterial blight (CBB) and anthracnose epidemics in major bean growing areas of Ethiopia, during 2019. In three regions within six zones from 12 districts, a total of 180 common bean fields were assessed for CBB and anthracnose. The results revealed that CBB and anthracnose were 100% prevalent though CBB was more severe than anthracnose. The logistic regression model showed CBB and anthracnose components were significantly associated with biophysical factors. High CBB incidence (>70%) at Ambo, Arsi-Negele and Shashemene-zuriya and high severity (>30%) at Ambo, Boricha and Shashemene-zuriya were strongly associated with sole cropping, July sowing, poor weeding practices, maturity stage and own saved seeds. Anthracnose incidence of >50% and severity of >30% had high probabilities of associations with zones, sole cropping, own saved seeds, variety, poor weeding practices and maturity stages. The study indicated that CBB and anthracnose are severe and 100% prevalent in Ethiopia, and efforts should be done towards the usage of clean seeds, weeding practices, following appropriate sowing dates and other appropriate agronomic practices to manage the diseases.

## ARTICLE HISTORY

Received 1 February 2022  
Accepted 1 April 2022

## KEYWORDS

Anthracnose; common bacterial blight; biophysical factors; common bean diseases; logistic regression analysis; *Phaseolus vulgaris*

## Introduction

Common bean (*Phaseolus vulgaris* L.) is a highly adapted, warm-season legume that grows under tropical, subtropical and temperate agro-ecologies in the world. It is a major food legume consumed as cooked and snacked beans in different forms of dishes all over the world (FAOSTAT 2020). Under Ethiopian conditions, it is grown well and in wider agro-ecological zones in the eastern, central, southern, southwestern and western parts of the country at an altitude range of 1200–2500 metres above sea level (Assefa et al. 1996; Fininsa 2003). In Ethiopia, the common bean is one of the most important crops for smallholder farmers for household consumption. On the other hand, Ethiopia is supplying white beans to the export canning industry to European Union and other eastern European markets (Ferris and Kaganzi 2008). The contribution of the crop to the national export earnings was 95.3 million USD in 2012, and white and red common bean types contribute about 15%

of the total export of agricultural commodities with more than 100 million USD per annum (Amsalu et al. 2016).

In 2018/2019, about 48 million hectares of fields were covered with common bean crop with 33 million tons of production worldwide (FAOSTAT 2020). In the 2019/2020 main cropping season, pulses covered 12.16% of the total grain crop areas of Ethiopia, of which 2.19% were allotted for common bean types (CSA 2020). About 110,597.54 hectares (0.206 million ton) was from Oromia and 90,849.56 hectares (0.14-million-ton yield) was from SNNPR regions. In Africa, the highest production is from Uganda and Kenya (FAOSTAT 2020). However, the average yield produced by Ethiopia is lower even though it has suitability for common bean production. This is mainly due to various constraints.

Diseases and insect pests are major constraints of common bean production and productivity in the world besides environmental factors. Common bean yield loss

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due to diseases in East Africa is higher when compared to environmental constraints like drought and soil infertility (Pretty et al. 2011). Infections caused by multiple pathogens are a major factor in reducing common bean yields in Ethiopia (Assefa 1987; Fininsa and Yuen 2001). Most common bean diseases caused by fungi, bacteria, viruses and nematodes occurred in Ethiopia. The major diseases that are threatening common bean production in Ethiopia include common bacterial blight, CBB (*Xanthomonas axonopodis* pv. *phaseoli*), anthracnose (*Colletotrichum lindemuthianum*), rust (*Uromyces appendiculatus*) and bean common mosaic virus (Assefa et al. 1996; Fininsa and Yuen 2001).

Among the diseases, CBB and anthracnose are frequently occurring and the most important diseases in bean producing areas of Ethiopia (Fininsa and Yuen 2001; Negera and Dejene 2018). These diseases could cause complete crop loss when fields are left unmanaged and growers use susceptible cultivars (Sharma et al. 2008). Bean yield loss due to CBB is estimated to be 22.4% in the intercropping system and more in the sole cropping system (Fininsa 2003) and 68–80% losses occurred due to anthracnose when used susceptible cultivars (Beshir and Pretorius 2005; Mohammed et al. 2013). The primary sources of inoculum of CBB and anthracnose diseases are infected seed, infested soil and debris and primarily spread by rain splash. Independent survey studies were done by different scholars in different parts of Ethiopia for CBB for various reasons (Fininsa and Yuen 2001; Gudero and Terefe 2018), but up-to-date work has been lacking for anthracnose in the country.

Cropping systems and environmental factors in different agro-ecologies affect disease onset, epidemic development and yield loss. Monitoring the effects of diversified environmental factors and cropping practices on crop diseases and productions is an important strategic approach to determine the status and dynamics of diseases (Rusuka et al. 1997; Fininsa and Yuen 2001). Prevalence, intensity and importance of common bean major diseases may vary across geographical areas, cropping practices and overcropping seasons. Common bacterial blight and anthracnose are more important and widely distributed diseases, while rust, angular leaf spot (*Phaeoisariopsis griseola*) and halo blight (*Pseudomonas syringae* pv. *phaseolicola*) were much more restricted in specific growing areas (Gudero and Terefe 2018; Negera and Dejene 2018).

Diseases monitoring at intervals of years would help in identifying the most important factors and for designing and development of effective, eco-friendly and sustainable management strategies and tactics. Endeavours were made to determine the occurrence, distribution and significance of diseases of common beans in major

growing areas of Ethiopia in the past (Assefa 1987; Assefa et al. 1996; Fininsa and Yuen 2001). However, under a changing climate scenario and productions systems, pathogen genetic variability is supposed to be getting increased and new common bean varieties were developed, released and disease and crop management options were apparently changed. Thus, disease distribution across geographical locations, intensity and relative importance may vary with changing climate and production systems. Therefore, it is important to monitor common bean diseases at intervals of years and cropping seasons to determine their occurrence, distribution and status changes. Therefore, this study was conducted with the objectives to assess the current status of common bean common bacterial blight and anthracnose diseases prevalence and intensity, and to determine factors influencing the epidemic development of the diseases in major bean growing areas in Ethiopia.

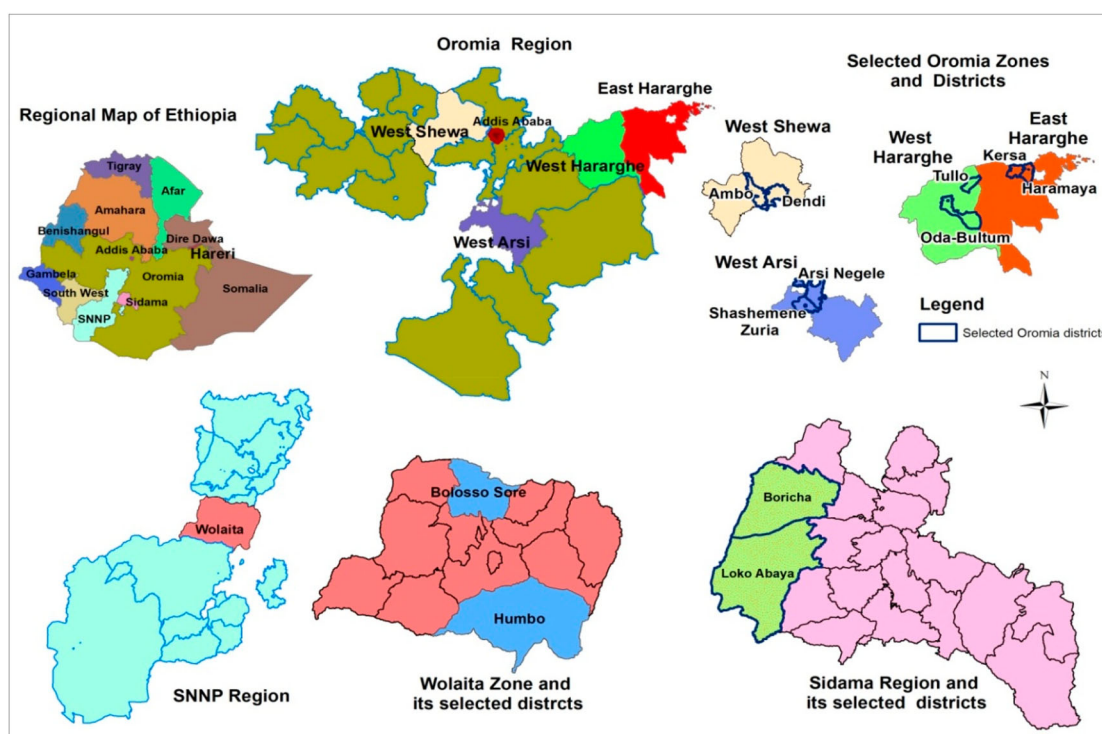
## Materials and methods

### Description of survey areas

Field surveys of common bean diseases were conducted in three regions [Oromia, Sidama and Southern Nations Nationalities Peoples' Region (SNNPR)] of Ethiopia. Six major common bean growing zones were considered in the three regions. The six zones were East Hararghe, Sidama (now a region), West Arsi, West Hararghe, West Shewa and Wolaita. Among the zones, 12 districts (Ambo, Arsi-Negele, Dendi, Haramaya, Kersa, Oda-Bultum, Shashemene-zuriya and Tullo from the Oromia region; Boricha and Loko-Ababaya from Sidama region and Bolossosore and Humbo from SNNP region) were purposively selected based on production potentials during the 2019 main cropping season (Figure 1). Most of the districts obtain rainfall during the main rainy season though there is a bimodal rainfall distribution pattern in districts of the two Hararghe zones. That is, the short rainy season (*Belg*) extends from March to May and the main rainy season starts from late June and to the end of August. However, the assessment was done during the main rainy season from August to October in all districts of the surveyed areas. The districts mainly differ in their agro-ecological features, such as mountainous landscape, altitude ranges, sowing dates, cropping systems and typical weather conditions. Selected surveyed regions, zones and districts are displayed in Figure 1.

### Sampling procedures and sampling units

Common bean field surveys were conducted from flowering to maturity growth stages of the crop from



**Figure 1.** Map showing surveyed zones and districts for common bacterial blight and anthracnose diseases of common bean in Ethiopia during the 2019 main cropping season.

August to late October in the sampled regions/zones/districts. Based on the availability of common bean fields, three farmer associations (FAs) (*kebeles* = the smallest administrative unit in the country) from each district were selected purposively in response to production potential and consent from the agricultural offices of each district. From each FA, five farmers' common bean fields were selected systematically based on the size of common bean fields and varieties used, and inspected for the target diseases (i.e. a total of 15 farmers' fields per district were assessed). Thus, a total of 180 common bean fields were assessed during the survey periods. The fields were randomly sampled at intervals of 5–10 km along the main and feeder roads to *kebeles* using a motorbike odometer. In each farmers' field, 5–10 m apart were moved diagonally across each field with an 'X' pattern and five quadrats were dropped and formed a 2 m × 2 m (4 m<sup>2</sup>) and plants were assessed for diseases, scored and values were recorded.

### Disease assessment

During the survey, common bean fields were assessed and inspected for disease prevalence, disease incidence and disease severity of CBB and anthracnose. Disease prevalence is referring to the proportion of common

bean fields infested with the target disease per total number of fields inspected in each district, zone or region (in this case common bacterial blight and anthracnose diseases). Prevalence is commonly expressed in percentage as follows:

Disease prevalence (%)

$$= \frac{\text{Number of fields with disease per district}}{\text{Total number of fields assessed per district}} \times 100$$

On the other hand, disease incidence is referring to the proportion of the number of plants showing disease symptoms per the total number of plants considered within a sampling quadrat (five quadrats in this case) during the assessment and expressed in percentage as follows:

Disease incidence(%)

$$= \frac{\text{Number of plants showing disease symptoms per quadrat}}{\text{Total number of plants assessed per quadrat}} \times 100$$

Moreover, disease severity is referring to the proportion of plant area (leaves and pods) affected with diseases from the total part of the tissue. It measures the amount of damage on the plant tissue and is assessed based on symptomatic lesions. In this case, symptoms initially appeared as small water-soaked spots, necrotic

and bordered by a chlorotic zone on leaves and circular and brownish-red spots on pods were recorded for CBB. Similarly, symptoms of black to red spots on leaves and pods were considered for anthracnose upon scoring. Twelve plants in every five quadrats were assessed for CBB and anthracnose diseases simultaneously. The assessments were made using a 1–9 standard scoring scale for both diseases as suggested by CIAT (1987); where, 1 = 1%, 2 = 2–5%, 3 = 6–10%, 4 = 11–15%, 5 = 16–30%, 6 = 31–50%, 7 = 51–75%, 8 = 75–85% and 9 = >85% lesion area on the infected leaves/pods. The severity scoring has been made on 10 randomly taken plants in each quadrat per field. Disease severity values were converted into percentage severity index (PSI) for the analysis as suggested by Wheeler (1969).

PSI

$$= \frac{\text{Sum of numerical ratings}}{\text{Number of plants rated} \times \text{maximum score on the scale}} \times 100$$

### Biophysical factors assessment

Biophysical factors are referring to both biotic and abiotic factors that influence the epidemic development of the diseases. Such factors were carefully collected and processed to determine their associations (positive or negative) with disease parameters, such as incidence and severity. In this regard, an automatic global positioning system (GPS) instrument was used to determine the geographical coordinates (latitude and longitude) and altitude of each inspected field. Field data recording sheet was used for noting crop growth stage (flowering, podding or maturity) and cropping practices, such as sowing date, fertiliser application (fertilised or unfertilised), crop density (number of plants  $\text{m}^{-2}$ ), a preceding crop grown, cropping system (sole cropping or intercropping), weed management practices (poor, intermediate or good), crop variety and seed sources (own seeds or other sources). Data were collected through growers' interview and on-spot observation of bean fields during the survey periods.

### Data analyses

Descriptive statistics were used for summarising the data obtained from fields using SPSS version 20. The descriptive statistics were meant for studying the distribution and the magnitude of CBB and anthracnose diseases across districts and zones. Disease incidence and severity were classified into distinct groups of binomial qualitative data as described by Yuen (2006). Based on the

approximate similarity of the variables to the total assessed fields, class boundaries were estimated and cut points were determined. As a result,  $\leq 70$  and  $> 70\%$  boundaries were selected for disease incidence and class boundaries of  $\leq 30$  and  $> 30\%$  for CBB severity. Similarly, class boundaries of  $\leq 50$  and  $> 50\%$  and  $\leq 30$  and  $> 30\%$  were used for anthracnose incidence and severity, respectively. A contingency table of dependent and independent variables was constructed to represent the bivariate distribution of the fields (Table 1). The logistic regression model (Yuen 2006) was used to determine the association of CBB and anthracnose disease parameters with biophysical factors using the SAS procedure of GENMOD (SAS 2014).

The model was run twice to determine the association of independent variables with CBB and anthracnose disease parameters. The reduced multiple variable models were run to test variables resulting in a significant association with incidence and severity, and the analysis of deviance for these variables was added to the reduced model to show the importance of each variable class. First, the association of all the independent variables was tested on CBB and anthracnose incidence and severity in a single variable model. Second, the association of an independent variable with the incidence and severity of the diseases was tested, when entered first and last with all the other variables in the model. The parameter estimates and their standard errors were analysed for single and multiple variable models. The odds ratio was obtained by exponentiation of the parameter estimates to compare the effect based on a reference point, which is interpreted as the relative risks of a specific factor for a specific disease (Yuen et al. 1996; Yuen 2006). The differences between the likelihood ratio tests (LRTs) were used to check the importance of the variables and tested against the Chi-square ( $\chi^2$ ) value (McCullagh and Nelder 1989).

## Results

### General characteristic features of common bean fields

More than 60% of surveyed areas ranged from 1500 to 2000 metres above sea level. Major common bean varieties grown in the surveyed areas were Awash-1, Awash-2, Hawassa-dume, Ibado, Mexican-142, Nasir, Red-Wolaita and a mixture of varieties, which were obtained from own saved, other farmers' store, agricultural offices, research centres and local markets. Farmer saved seed sources covered 57.2% of common bean seeds with different varieties (Table 1). More than 54%



**Table 1.** Categorisation of variables used in logistic regression analysis for common bacterial blight (CBB) and anthracnose epidemics in 12 districts of six zones ( $n = 180$ ) during the 2019 main cropping season in Ethiopia.

Variables	Variable class	Number of fields	CBB intensity				Anthracnose intensity			
			Incidence (%)		Severity (%)		Incidence (%)		Severity (%)	
			≤ 70	>70	≤ 30	>30	≤ 50	> 50	≤ 30	> 30
Zone	East Hararghe	30	22	8	21	9	8	22	9	21
	Sidama	30	9	21	7	23	19	11	10	20
	West Arsi	30	9	21	11	19	22	8	17	13
	West Hararghe	30	18	12	13	17	14	16	10	20
	West Shewa	30	11	19	16	14	11	19	11	19
	Wolaita	30	22	8	21	9	26	4	15	15
District	Ambo	15	10	5	11	4	10	5	7	8
	Arsi-Negele	15	7	8	9	6	3	12	6	9
	Bolossosore	15	8	7	8	7	13	2	7	8
	Boricha	15	5	10	3	12	6	9	3	12
	Dendi	15	1	14	2	13	3	12	4	11
	Haramaya	15	12	3	9	6	11	4	4	11
	Humbo	15	13	2	13	2	13	2	13	2
	Kersa	15	10	5	11	4	11	4	13	2
	Loko-Abaya	15	4	11	4	11	10	5	7	8
	Oda-Bultum	15	11	4	10	5	8	7	9	6
	Shash-zuriya	15	2	13	2	13	4	11	3	12
	Tullo	15	7	8	3	12	3	12	2	13
	Altitude (m a.s.l.) <sup>a</sup>	1500–2000	60	55	73	42	72	43	65	50
	>2000	65	30	35	25	40	23	42	27	38
	Sowing date	June	14	32	31	15	20	26	16	30
Weed management <sup>b</sup>	July	98	47	51	44	53	42	56	40	58
	August	36	29	7	28	8	33	3	26	10
	Poor	113	31	82	30	83	39	74	32	81
Crop density <sup>c</sup>	Intermediate	33	28	5	26	7	25	8	22	11
	Good	34	31	3	29	5	31	3	28	6
	>10	98	23	75	24	74	34	64	28	70
Cropping systems <sup>d</sup>	≤ 10	82	67	15	61	21	60	22	54	28
	Sole cropping	91	22	69	23	68	33	58	30	61
	Inter cropping	89	68	21	62	27	67	22	52	37
Variety	Red-Wolaita	17	15	2	14	3	14	3	15	2
	Mexican-142	5	2	3	3	2	1	4	1	4
	Awash-2	23	11	12	8	15	9	14	8	15
	Awash-1	25	1	24	3	22	3	22	5	20
	Nasir	27	20	7	22	5	25	2	23	4
	Hawassa dume	32	8	24	10	22	17	15	10	22
	Ibado	14	7	7	4	10	8	6	4	10
	Mixtures	37	26	11	23	14	20	17	17	20
	Fertiliser application	97	21	76	23	74	39	58	28	69
	Unfertilised	83	69	14	64	19	61	22	54	31
Growth stage <sup>e</sup>	Flowering	11	10	1	11	0	10	1	11	0
	Pod Filling	54	45	9	44	1	44	10	42	12
	Maturity	115	35	80	30	85	46	69	29	86
Seed source <sup>f</sup>	Own seeds	103	38	65	37	66	48	55	35	68
	Other sources	77	52	25	48	29	50	27	47	30
Previous crop <sup>g</sup>	Sorghum	70	41	29	37	33	48	22	37	33
	Maize	39	18	21	16	23	19	20	13	26
	Chick pea	33	16	17	14	19	13	20	14	19
	Teff	22	12	10	13	9	10	12	14	8
	Others	16	3	13	1	15	5	11	4	12

<sup>a</sup>Altitude ranged from 1500 to 2000 and >2000m a.s.l. are considered as mid- and highland areas, respectively, according to agro-ecological classification of Ethiopia for crop production.

<sup>b</sup>Weed management practice was recorded as poor (presence of high weed infestation), intermediate (few weeds present) and good (fields free of any weed infestation).

<sup>c</sup>Crop density was determined in 4 m<sup>2</sup> quadrat as highly dense (>10 bean plants m<sup>-2</sup>) and sparsely populated (≤10 bean plants m<sup>-2</sup>).

<sup>d</sup>Cropping system refers to planting only common bean as sole cropping and sowing common bean simultaneously with other crops (sorghum, maize, khat, coffee and cabbage) as intercropping.

<sup>e</sup>Growth stage referred as flowering when half of the plants in the quadrat are showing flowers, pod filling when plants in the quadrat start to pod formation and maturity when the crop reaches their physiological maturity.

<sup>f</sup>Other seed source refers to seeds obtained from open market, agricultural offices and research centres.

<sup>g</sup>Previous crop refers to crop that grew before common bean in the same field.

of the growers' fields were fertilised with blended NPS fertiliser. Sowing dates varied among districts usually starting from June and August depending on the start and end of rainfall. In this regard, in most assessed zones,

54.4% of fields were sown in early July, whereas 25.6% of fields were sown in June and 20% in August (Table 1).

Regarding cropping systems, 50.56% of growers practised sole cropping and 49.4% practiced intercropping.

The most companion crops in the intercropping system were sorghum (47.9%), maize (31.7%) and chickpea, Khat, coffee and cabbages which together constituted only 20.4%. Concerning weed management, only 18.9% of common bean fields were free from any weed infestation. Fields that were infested with weeds were found to display different levels of infestation and diversity of weed species (Table 1). It was observed that farmers did not practice and apply any disease management options, such as chemicals. Common weed species observed during the survey periods include black-jack (*Bidens pilosa*), scutch grass (*Cynodon dactylon*), adey abeba (*Bidens macroptera*), parthenium (*Parthenium hysterophorus*), yeberechew (*Convolvulus oxalis*), Mexican prickly poppy (*Argemone mexicana*), *Erucastrum abyssinicum* and some others.

### Common bacterial blight prevalence, incidence and severity

Common bacterial blight (CBB) was prevalent across common bean fields surveyed. Variable CBB incidence and severity were recorded among the districts. The highest (82.9%) mean disease incidence of CBB was recorded in the Ambo district, followed by Shashemene-zuriya (82.2%), Boricha (73.8%), Loko-Abaya (70.9%), Tullo (71.2%), Arsi-Negele (69.9%) and Dendi (64.7%). Conversely, the lowest incidence was observed in Haramaya (53.6%) and Humbo (57.8%) districts. The highest mean severity of CBB was recorded in Tullo (40.3%), followed by Shashemene-zuriya (39.9%), Loko-Abaya (39.5%) and Ambo (39.3%) districts. But the lowest severity was recorded in Kersa (21.9%) and Humbo (21.9%) districts (Table 2).

The highest CBB mean disease incidence of 75.5% and severity of 37.9% were recorded from fields sown in July, while the lowest incidence (53.8%) and severity (22.6%) were noted from August planting. Fields found at an altitude of 1500–2000m had the highest mean incidence (68.7%) and severity (34.9%) when compared to fields found at above 2000 metres above sea level. Disease incidence and PSI in weed-infested fields were highest with mean values of 69.9% and 43.8%, respectively, and fields with good weed management practices had the lowest mean CBB incidence and severity. The lowest (58.9%) mean incidence was recorded from the intercropped fields, whereas the highest mean incidence (77.6%) was recorded from sole cropped fields. Regarding the crop growth stage, the highest mean disease incidence (74.5%) and severity (37.2%) were recorded at the maturity growth stage. While, at the flowering growth stage, comparably lower incidence (54.34%)

and severity (20.2%) were recorded than in other growth stages.

With regard to varieties encountered, the highest mean incidence was recorded when farmers sown their field with variety Awash-2 (83.4%) and the lowest (56.4%) value was obtained from Red Wolaita variety covered fields. The highest (41.1%) mean severity was recorded on variety Mexican-142, whereas the lowest (23.1%) value was recorded from Red-Wolaita variety. Densely bean populated fields were found to have a higher incidence of 77.8% than sparsely populated common bean fields, which recorded only 57.1%. The majority of bean fields were sown with farmers' own saved seeds, which had a CBB incidence of 72.9% and severity of 34.9% compared with fields cultivated with seeds obtained from other sources, with the incidence of 62.2% and severity of 28.5% (Table 2). At the zonal level, the highest CBB severity was recorded in Sidama, followed by West Arsi with respective mean values of 38.9% and 34.8% in that order. West Shewa zone had a moderate level of disease severity of 33.1%, which was closer to the severity observed in Western Hararghe. However, East Hararghe and Wolaita zones showed relatively low CBB disease severity (Table 2 and Figure 2).

### Anthraxnose prevalence, incidence and severity

Common bean anthracnose was 100% prevalent with varied incidence and severity in different agro-ecological zones, districts and agronomic practices. Mean incidence of bean anthracnose ranged from lowest 37.2% (Humbo) to highest 61.1% (Haramaya) and mean severity ranged from lowest 21.8% (Humbo) to highest 39.4% (Tullo) districts. The disease incidence and severity were less in intercropping systems such as CBB. On average, anthracnose incidence was reduced by 11.5% in intercropping systems compared to sole cropping systems. Similarly, severity was increased by 6.72% when the common bean was sown as a sole crop than intercropped (Table 2). The mean incidence of bean anthracnose was increased by 5.78% of fields found at the mid-altitude range (1500–2000 m) than in fields found at an altitude of >2000 m. The highest mean incidence of anthracnose was recorded in fields having more weed species (52.8%) than properly weeded (35.9%) fields. Maximum mean anthracnose severity (52.5%) was recorded at the maturity stage of the crop. The highest bean anthracnose incidence of 50.8% and severity of 33.3% were recorded from fields sown during July, while the lowest incidence and severity were recorded from fields sown in other months (Table 2).

Different varieties grown in the surveyed districts showed varied reactions to anthracnose. The highest

**Table 2.** Disease incidence and severity (mean  $\pm$  SE) of common bean common bacterial blight (CBB) and anthracnose for different independent variables in 12 districts of Ethiopia during the 2019 main cropping season.

Variables	Variable class	CBB disease parameters		Anthracnose disease parameters	
		Incidence (%) $\pm$ SE	Severity (%) $\pm$ SE	Incidence (%) $\pm$ SE	Severity (%) $\pm$ SE
District	Ambo	82.9 $\pm$ 2.33	39.3 $\pm$ 1.92	55.9 $\pm$ 2.69	36.3 $\pm$ 2.52
	Arsi-Negele	69.9 $\pm$ 3.55	29.7 $\pm$ 2.10	42.1 $\pm$ 4.14	37.2 $\pm$ 2.82
	Bolossosore	64.3 $\pm$ 3.66	30.1 $\pm$ 2.89	37.9 $\pm$ 3.04	32.7 $\pm$ 2.39
	Boricha	73.8 $\pm$ 2.48	38.4 $\pm$ 2.53	50.1 $\pm$ 1.88	33.8 $\pm$ 1.39
	Dendi	64.7 $\pm$ 4.48	27.0 $\pm$ 3.22	43.2 $\pm$ 3.86	29.3 $\pm$ 2.54
	Haramaya	53.6 $\pm$ 4.33	32.3 $\pm$ 3.76	61.1 $\pm$ 2.96	35.0 $\pm$ 1.91
	Humbo	57.8 $\pm$ 3.05	21.9 $\pm$ 1.95	37.2 $\pm$ 2.71	21.8 $\pm$ 1.89
	Kersa	58.8 $\pm$ 3.41	21.9 $\pm$ 2.33	53.8 $\pm$ 1.73	37.5 $\pm$ 1.72
	Loko-Abaya	70.9 $\pm$ 2.31	39.5 $\pm$ 2.64	45.2 $\pm$ 3.07	28.5 $\pm$ 1.84
	Oda-Bultum	61.3 $\pm$ 3.11	25.5 $\pm$ 2.45	44.6 $\pm$ 3.42	28.1 $\pm$ 2.56
	Shashemene-zuriya	82.2 $\pm$ 2.73	39.9 $\pm$ 2.16	38.7 $\pm$ 3.42	22.7 $\pm$ 1.49
	Tullo	71.2 $\pm$ 2.32	40.3 $\pm$ 2.72	58.0 $\pm$ 1.83	39.4 $\pm$ 1.39
Altitude (m a.s.l)	$\leq 1500$ –2000	68.7 $\pm$ 1.41	34.9 $\pm$ 1.11	51.0 $\pm$ 1.22	30.5 $\pm$ 0.88
	>2000	68.2 $\pm$ 2.02	30.2 $\pm$ 1.48	45.2 $\pm$ 1.74	34.2 $\pm$ 1.28
Sowing date	June	55.9 $\pm$ 1.11	31.4 $\pm$ 0.98	49.9 $\pm$ 1.98	32.8 $\pm$ 1.42
	July	75.5 $\pm$ 1.89	37.9 $\pm$ 1.34	50.8 $\pm$ 1.23	33.3 $\pm$ 0.98
Weed management	August	53.8 $\pm$ 3.21	22.6 $\pm$ 1.53	34.6 $\pm$ 1.68	26.6 $\pm$ 1.55
	Poor	69.9 $\pm$ 1.11	41.4 $\pm$ 1.98	52.8 $\pm$ 1.11	35.2 $\pm$ 0.88
	Intermediate	57.5 $\pm$ 1.89	23.9 $\pm$ 1.34	40.2 $\pm$ 1.95	27.3 $\pm$ 1.21
	Good	43.8 $\pm$ 2.31	19.6 $\pm$ 1.01	35.9 $\pm$ 1.94	25.0 $\pm$ 1.59
Crop density	>10	77.8 $\pm$ 1.11	37.8 $\pm$ 1.04	52.5 $\pm$ 1.21	35.3 $\pm$ 0.95
	$\leq 10$	57.1 $\pm$ 1.36	25.4 $\pm$ 1.11	41.1 $\pm$ 1.44	27.6 $\pm$ 0.98
Cropping system	Sole cropping	77.6 $\pm$ 1.12	37.6 $\pm$ 1.05	53.0 $\pm$ 1.26	35.2 $\pm$ 0.98
	Intercropping	58.9 $\pm$ 1.47	26.6 $\pm$ 1.19	41.5 $\pm$ 1.36	28.4 $\pm$ 0.98
Variety	Red-Wolaita	56.4 $\pm$ 2.40	23.1 $\pm$ 1.99	39.1 $\pm$ 2.81	25.2 $\pm$ 1.53
	Mexican-142	64.5 $\pm$ 8.99	41.1 $\pm$ 7.92	51.7 $\pm$ 1.59	44.3 $\pm$ 6.46
	Awash-1	71.3 $\pm$ 2.94	36.3 $\pm$ 2.29	50.3 $\pm$ 2.71	35.1 $\pm$ 2.10
	Awash-2	83.4 $\pm$ 1.44	39.8 $\pm$ 1.36	60.6 $\pm$ 1.70	38.4 $\pm$ 1.43
	Nasir	59.9 $\pm$ 2.47	24.2 $\pm$ 1.82	37.3 $\pm$ 1.81	23.4 $\pm$ 1.26
	Hawassa dume	75.5 $\pm$ 2.31	36.1 $\pm$ 1.87	49.4 $\pm$ 1.91	33.9 $\pm$ 1.48
	lbado	73.7 $\pm$ 3.26	37.1 $\pm$ 3.47	47.9 $\pm$ 3.52	35.0 $\pm$ 2.83
	Mixtures	60.4 $\pm$ 2.45	27.9 $\pm$ 1.87	44.9 $\pm$ 2.22	29.8 $\pm$ 1.46
	Fertilised	78.2 $\pm$ 1.06	38.0 $\pm$ 1.02	52.8 $\pm$ 1.18	35.3 $\pm$ 0.93
	Unfertilised	56.9 $\pm$ 1.34	25.3 $\pm$ 1.12	40.9 $\pm$ 1.44	27.8 $\pm$ 1.03
Growth stage	Flowering	54.3 $\pm$ 3.42	20.2 $\pm$ 1.94	32.3 $\pm$ 3.19	18.9 $\pm$ 1.24
	Pod filling	58.1 $\pm$ 1.71	23.9 $\pm$ 1.34	39.4 $\pm$ 1.59	25.8 $\pm$ 1.09
Seed sources	Maturity	74.5 $\pm$ 1.26	37.2 $\pm$ 0.95	52.5 $\pm$ 1.11	35.9 $\pm$ 0.80
	Own seeds	72.9 $\pm$ 1.31	34.9 $\pm$ 0.99	50.8 $\pm$ 1.31	33.8 $\pm$ 0.92
Previous crop	Other sources	62.2 $\pm$ 1.83	28.5 $\pm$ 1.51	42.7 $\pm$ 1.47	29.2 $\pm$ 1.15
	Sorghum	64.9 $\pm$ 1.80	31.1 $\pm$ 1.43	43.5 $\pm$ 1.49	30.1 $\pm$ 1.24
	Maize	69.2 $\pm$ 2.37	33.3 $\pm$ 1.98	46.1 $\pm$ 2.41	33.5 $\pm$ 1.54
	Chick pea	71.3 $\pm$ 2.70	33.4 $\pm$ 2.26	51.8 $\pm$ 2.21	33.6 $\pm$ 1.71
	Teff	65.9 $\pm$ 3.71	29.1 $\pm$ 2.41	48.9 $\pm$ 3.23	28.5 $\pm$ 1.98
	Others	78.8 $\pm$ 2.93	35.8 $\pm$ 2.21	47.3 $\pm$ 1.02	31.8 $\pm$ 0.74

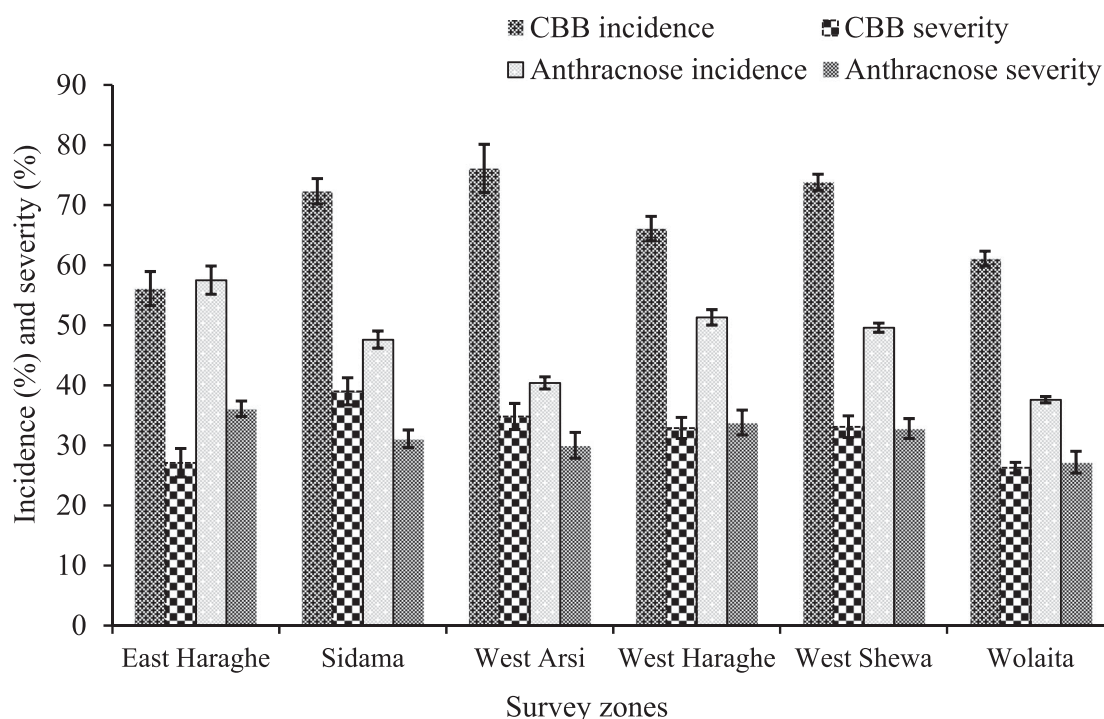
anthracnose mean incidence (60.6%) was recorded in fields sown with variety Awash-2, whereas the lowest anthracnose mean incidence (37.3%) was in fields sown with variety Nasir. The highest severity (44.3%) on variety Mexican-142 and the lowest (23.4%) on variety Nasir severity were recorded. More than 50% mean anthracnose incidence was recorded when the common bean population was high and below 45% mean anthracnose incidence was recorded when the common bean found was less populated. Fields sown with farmers' own seeds increase anthracnose incidence by 8.12% compared to fields sown with other seed sources and 33.8% and 29.2% were recorded as the highest and lowest mean severity for fields sown with farmers' own seeds and other seed sources, respectively. At the zonal level, higher mean anthracnose incidences of 57.5%, 51.3% and 49.6% were recorded from East

Hararghe, West Hararghe and West Shewa, respectively. Similarly, the highest mean anthracnose severity (36.1%) was recorded in East Hararghe followed by West Hararghe (33.8%) and (32.8%) in West Shewa (Figure 2).

### Associations of CBB incidence and severity with biophysical factors

Associations of biophysical factors were proved to be useful in predicting CBB epidemics in the surveyed districts and zones. The associations of all independent variables with CBB intensity are shown in Table 3. Variables such as zone, altitude, sowing date, weed management, cropping system, crop density, variety and crop growth stage were strongly ( $P < 0.0001$ ) associated with CBB incidence, and fertiliser application ( $P < 0.0002$ ) and seed source ( $P < 0.0037$ ) were also significant when





**Figure 2.** Mean ( $\pm$ SE) incidence (%) and severity (%) of common bacterial blight and anthracnose in six zones of Ethiopia, during the 2019 main cropping season.

entered into the logistic regression model as a single variable. However, when all variables entered last into the model, zone, sowing date, cropping system, fertiliser application, weed management, growth stage, variety and seed source maintained their significant relationship with CBB incidence, while altitude and crop density lost their importance. Among variables, zone ( $\chi^2 = 507$  and 98.5, 5df), weed management ( $\chi^2 = 64.4$  and 20.5, 2df), variety ( $\chi^2 = 47.6$  and 40.7, 7df) and growth stage ( $\chi^2 = 32.9$  and 26.8, 2df) were most important and highly associated with CBB incidence. On the contrary, previous crops grown did not have any detectable influence on

epidemic development when entered first and last into the model. The parameter estimates resulting from the reduced regression model and their standard errors are presented in Table 4. High (>70%) CBB incidence had a high probability of association with East Hararghe, Sidama, West Hararghe, West Arsi and West Shewa zones when compared to the Wolaita zone. The flowering growth stage showed more than five times lower CBB incidence (<70%) than at the maturity growth stage. Similarly, fields sown with variety Awash-2 and own saved seed source as a planting material would exceed CBB incidence (>70%) by 1.45

**Table 3.** Logistic regression model for common bean common bacterial blight (CBB) incidence (%) and severity (%) and likelihood ratio test on independent variables in six zones of Ethiopia during the 2019 main cropping season.

Independent variable	df	CBB incidence LRT <sup>a</sup>				CBB severity LRT <sup>a</sup>			
		Type 1 analysis (VEF)		Type 3 analysis (VEL)		Type 1 analysis (VEF)		Type 3 analysis (VEL)	
		DR	Pr > $\chi^2$	DR	Pr > $\chi^2$	DR	Pr > $\chi^2$	DR	Pr > $\chi^2$
Zone	5	507.3	<.0001	98.5	<.0001	157.8	<.0001	64.9	<.0001
Altitude	1	149.3	<.0001	2.26	0.1419	117.0	<.0001	7.02	0.0081
Sowing date	2	32.3	<.0001	12.1	0.0024	14.9	0.0006	0.43	0.8085
Weed management	2	164.4	<.0001	20.5	<.0001	115.6	<.0001	21.5	<.0001
Crop density	1	19.4	<.0001	0.10	0.7567	1.40	0.2368	0.08	0.7816
Cropping system	1	514.1	<.0001	11.4	0.0008	184.3	<.0001	6.90	0.0086
Variety	7	47.6	<.0001	40.7	<.0001	69.6	<.0001	58.7	<.0001
Fertiliser application	1	13.9	0.0002	11.3	0.0008	0.59	0.4429	0.61	0.4348
Growth stage	2	32.2	<.0001	26.8	<.0001	41.3	<.0001	39.1	<.0001
Seed sources	1	15.5	0.0037	10.3	0.0046	53.4	<.0001	21.6	<.0001
Previous crop	4	2.1	0.1499	1.8	0.1672	2.79	0.6143	1.52	0.7833

<sup>a</sup>LRT = likelihood ratio test; VEF = Variable entered first; VEL = Variable entered last; DR = deviance reduction; Pr = probability of an  $\chi^2$  value exceeding the deviance reduction;  $\chi^2$  = Chi-square; and df = degrees of freedom.

**Table 4.** Analysis of deviance, natural logarithms of odds ratio and standard error of bean common bacterial blight (CBB) incidence (%) and likelihood ratio test on independent variables in reduced regression model in six zones during 2019 main cropping season in Ethiopia.

Added variable	Residual deviance <sup>a</sup>	df	CBB incidence LRT <sup>b</sup>		Variable class	Est. log <sup>c</sup>	SE <sup>d</sup>	Odds ratio
			DR	Pr> $\chi^2$				
Intercept	2063.23		—	—		1.27	0.14	3.56
Zone	1555.95	5	8.30	0.0040	East Hararghe	0.42	0.21	1.51
			37.32	<.0001	Sidama	0.51	0.08	1.66
			19.47	<.0001	West Arsi	0.75	0.09	2.12
			6.81	0.0091	West Hararghe	0.26	0.11	1.31
			7.44	0.0051	West Shewa	0.67	0.15	1.95
					Wolaita	0*		.
Sowing date	1374.30	2	0.09	0.76	June	0.02	0.08	1.02
			17.29	<.0001	July	1.17	0.06	3.23
					August	0*		.
Weed management	695.84	2	23.49	<.0001	Poor	1.41	0.07	4.09
			2.33	0.12	Intermediate	-0.09	0.05	0.91
					Good	0*		.
Cropping system	860.18	1	11.42	0.0007	Sole cropping	0.22	0.06	1.24
					Intercropping	0*		.
Variety	648.29	7	0.34	0.5595	Red-Wolaita	-0.05	0.09	0.95
			10.66	0.0011	Mexican-142	0.35	0.12	1.42
			0.02	0.8932	Awash-1	0.01	0.01	1
			16.99	<.0001	Awash-2	0.39	0.09	1.45
			0.36	0.5492	Nasir	0.05	0.07	1.04
			2.62	0.1057	Hawassa dume	0.12	0.08	1.13
			2.27	0.1315	Ibado	0.14	0.09	1.15
					Mixtures	0*		.
Fertiliser application	614.95	1	11.29	0.0008	Fertilised	0.33	0.10	1.39
					Unfertilised	0*		.
Growth stage	582.76	3	19.13	<.0001	Flowering	0.36	0.08	5.52
			14.16	0.0002	Pod filling	-0.17	0.04	0.84
					Maturity	0*		.
Seed source	567.21	2	9.89	0.0017	Own seeds	0.28	0.09	1.32
					Other sources	0*		.

<sup>a</sup>Unexplained variation after fitting the model. <sup>b</sup>LRT = likelihood ratio test; DR = deviance reduction and Pr = probability of an  $\chi^2$  value exceeding the deviance reduction; and  $\chi^2$  = Chi-square. <sup>c</sup>Est. = estimates of the logarithm of the odds ratio and \*Reference group. <sup>d</sup>SE = standard error. df = degrees of freedom.

and 1.32 more times than sowing other varieties and seeds obtained from other sources, respectively.

Regarding CBB severity associations with the independent variables, zone, altitude, sowing date, weed management, cropping system, crop growth stage, variety and seed sources were found to be the important variables when entered first into the model (Table 5). However, independent variables: zone ( $\chi^2 = 158$  and 64.9, 5df), weed management ( $\chi^2 = 116$  and 21.5, 2df), variety ( $\chi^2 = 69.6$  and 58.7, 7df), growth stage ( $\chi^2 = 41.3$  and 39.1, 2df) and seed sources ( $\chi^2 = 53.4$  and 21.6, 1df) are the most important variables in their association with severity when entered first and last into the logistic regression model, respectively. Common bean fields found in Sidama had more than six times greater probability of CBB severity (>30%) occurrence than West Arsi, West Shewa and other provinces. A high probability ( $P < 0.0001$ ) of CBB severity (>30%) was indicated when growers used their own saved seed as a planting material (four times than seeds from other sources), and when growers' fields were sown with variety Mexican-142 (Table 5). Lower CBB severity ( $\leq 30\%$ ) has

shown a high probability of association with the intercropping system, good weed management, flowering stage and unfertilised common bean fields. For fields sown with variety Nasir, CBB severity is 0.95 times lower than fields sown with other types of varieties (Table 5).

### Associations of anthracnose incidence and severity with biophysical factors

The associations of independent variables with bean anthracnose incidence and severity differed among variables and are presented in Table 6. Parameter estimates resulted from the reduced regression model and their standard errors are presented in Tables 7 and 8 for anthracnose incidence and severity, respectively. Zone, altitude, sowing date, weed management, cropping system, variety and growth stage ( $P < 0.0001$ ) and seed source ( $P < 0.0004$ ) were significantly associated with bean anthracnose incidence when entered first and zone, altitude, sowing date, cropping system and variety ( $P < 0.0001$ ), weed management ( $P < 0.0002$ )

**Table 5.** Analysis of deviance, natural logarithms of odds ratio and standard error of bean common bacterial blight (CBB) severity and likelihood ratio test on independent variables in reduced regression model in six zones of Ethiopia during the 2019 main cropping season.

Added variable	Residual deviance <sup>a</sup>	df	CBB severity LRT <sup>b</sup>		Variable class	Est. log <sup>c</sup>	SE <sup>d</sup>	Odds ratio
			DR	Pr> $\chi^2$				
Intercept	1186.08		–	–		1.02	0.14	2.77
Zone	1028.31	5	15.2	0.0002	East Hararghe	1.22	0.12	3.38
			25.55	<.0001	Sidama	1.57	0.08	6.96
			22.01	<.0001	West Arsi	1.94	0.09	4.81
			10.06	0.0080	West Hararghe	1.94	0.09	4.81
			20.11	<.0001	West Shewa	1.47	0.10	4.34
					Wolaita	0*		.
Weed management	596.52	2	13.71	0.0002	Poor	0.27	0.07	1.3
			0.39	0.5311	Intermediate	–0.04	0.06	0.96
					Good	0*		.
Altitude (m a.s.l.)	911.28	1	6.96	0.0083	1500–2000	–0.17		0.84
					>2000	0*		.
Cropping system	712.07	1	6.90	0.0086	Sole cropping	0.15	0.06	1.16
					Intercropping	0*		.
Variety	526.95	7	1.50	0.0478	Red-Wolaita	0.07	0.09	1.07
			44.72	<.0001	Mexican-142	0.71	0.11	2.03
			11.90	0.0006	Awash-1	0.24	0.07	1.27
			8.52	0.0035	Awash-2	0.25	0.08	1.28
			3.91	0.0066	Nasir	–0.05	0.08	0.95
			4.39	0.0053	Hawassa dume	0.05	0.09	1.05
			1.17	0.027	Ibado	0.11	0.10	1.12
					Mixtures	0*		.
Growth stage	483.61	2	21.84	<.0001	Flowering	–0.42	0.10	0.65
			23.97	<.0001	Pod filling	–0.24	0.05	0.79
					Maturity	0*		.
Seed source	501.45	1	19.37	<.0001	Own seeds	1.53	0.04	4.6
					Other sources	0*		.

<sup>a</sup>Unexplained variation after fitting the model. <sup>b</sup>LRT = likelihood ratio test; DR = deviance reduction and Pr = probability of an  $\chi^2$  value exceeding the deviance reduction; and  $\chi^2$  = Chi-square. <sup>c</sup>Est. = estimates of the logarithm of the odds ratio and \*Reference group. <sup>d</sup>SE = standard error. df = degrees of freedom.

and seed source ( $P < 0.0007$ ) were significantly associated with bean anthracnose incidence when entered last into a logistic regression model. However, crop density, previous crop and fertiliser application did not show any importance for anthracnose epidemic development (Table 6).

East Hararghe had a 3.86 times higher probability of anthracnose occurrence than other Zones. The probability of occurrence of high (>50%) anthracnose

incidence in poorly weeded bean fields was significantly ( $P < 0.0003$ ) 1.28 times higher than in well-managed fields. Similarly, in own saved seed source as planting material, there was about 3 times greater probability of association with mean anthracnose incidence exceeding 50% than other seed sources. Moreover, a high anthracnose incidence was strongly associated with common bean fields sown in July (2.73 times than other months), maturity growth stage, altitude of

**Table 6.** Logistic regression model for common bean anthracnose incidence (%) and severity (%) and likelihood ratio test on independent variables in six zones during the 2019 main cropping season in Ethiopia.

Independent variable	df	Anthracnose incidence LRT <sup>a</sup>				Anthracnose severity LRT <sup>a</sup>			
		Type 1 analysis (VEF)		Type 3 analysis (VEL)		Type 1 analysis (VEF)		Type 3 analysis (VEL)	
		DR	Pr> $\chi^2$	DR	Pr> $\chi^2$	DR	Pr> $\chi^2$	DR	Pr> $\chi^2$
Zone	5	323.1	<.0001	68.7	<.0001	66.6	<.0001	29.4	<.0001
Altitude	1	158.0	<.0001	16.3	<.0001	91.2	<.0001	7.58	0.0059
Sowing date	2	52.9	<.0001	44.1	<.0001	15.6	0.0059	4.57	0.1019
Weed management	2	75.9	<.0001	17.0	0.0002	44.9	<.0001	2.33	0.3114
Crop density	1	1.34	0.2467	2.16	0.1416	1.40	0.2369	1.70	0.1921
Cropping system	1	152.3	<.0001	15.5	<.0001	70.8	<.0001	11.9	0.0016
Variety	7	60.6	<.0001	49.6	<.0001	113.9	<.0001	80.7	<.0001
Fertiliser application	1	0.57	0.4490	0.22	0.6372	0.67	0.4138	1.87	0.1716
Growth stage	2	31.7	<.0001	31.2	<.0001	61.2	<.0001	58.5	<.0001
Seed sources	1	13.6	0.0004	7.91	0.0007	23.7	<.0001	9.88	0.0034
Previous crop	4	2.75	0.6013	2.86	0.5815	4.52	0.3397	4.44	0.3496

<sup>a</sup>LRT = likelihood ratio test; VEF = Variable entered first; VEL = Variable entered last; DR = deviance reduction; Pr = probability of an  $\chi^2$  value exceeding the deviance reduction;  $\chi^2$  = Chi-square; and df = degrees of freedom.

**Table 7.** Logistic regression model for common bean anthracnose incidence (%) and likelihood ratio test on independent variables in six Zones during the 2019 main cropping season in Ethiopia.

Added variable	Residual deviance <sup>a</sup>	df	Anthracnose incidence LRT <sup>b</sup>		Variable class	Est. log <sup>c</sup>	SE <sup>d</sup>	Odds ratio
			DR	Pr> $\chi^2$				
Intercept	1397.74		—	—		−0.43	0.13	0.65
Zone	1074.62	5	16.09	<.0001	East Hararghe	1.35	0.08	3.86
			9.76	0.0003	Sidama	−0.09	0.10	0.91
			14.74	<.0001	West Arsi	−0.36	0.09	0.69
			10.39	0.0002	West Hararghe	0.049	0.07	1.05
			6.33	0.0005	West Shewa	−0.05	0.09	0.95
					Wolaita	0*		.
Sowing date	863.69	2	4.66	0.0309	June	0.15	0.07	1.16
			33.78	<.0001	July	1.36	0.06	3.89
					August	0*		.
					Poor	0.25	0.08	1.28
Weed management	635.56	2	13.08	0.0003	Intermediate	−0.002	0.05	0.99
			0.00	0.9684	Good	0*		.
					1500–2000	−0.24	0.06	0.78
Altitude (m a.s.l.)	916.61	1	16.25	<.0001	>2000	0*		.
Cropping system	711.42	1	15.44	<.0001	Sole cropping	0.22	0.06	1.24
					Intercropping	0*		.
Variety	575.02	7	1.39	0.2384	Red-Wolaita	−0.10	0.09	0.90
			17.47	<.0001	Mexican-142	1.26	0.10	3.52
			0.13	0.7170	Awash-1	−0.02	0.06	0.98
			9.87	0.0017	Awash-2	1.12	0.08	3.06
			1.72	0.1899	Nasir	−0.10	0.07	0.90
			0.23	0.63	Hawassa dume	0.04	0.07	1.04
			2.48	0.1155	Ibado	0.14	0.09	1.15
					Mixtures	0*		.
Growth stage	541.37	2	20.64	<.0001	Flowering	−0.37	0.08	0.69
			16.89	<.0001	Pod filling	−0.18	0.04	0.83
					Maturity	0*		.
Seed sources	538.06	1	11.07	0.0006	Own seeds	1.09	0.97	2.97
					Other sources	0*		.

<sup>a</sup>Unexplained variation after fitting the model. <sup>b</sup>LRT = likelihood ratio test; DR = deviance reduction and Pr = probability of an  $\chi^2$  value exceeding the deviance reduction; and  $\chi^2$  = Chi-square. <sup>c</sup>Est. = estimates of the logarithm of the odds ratio and \*Reference group. <sup>d</sup>SE = standard error. df = degrees of freedom.

1500–2000 m, Mexican-142 and Awash-2 bean variety and sole cropping system (Table 7).

Zone, altitude, weed management practices, cropping system, variety, growth stage and seed source ( $P < 0.0001$ ) and sowing date ( $P < 0.0059$ ) were highly associated with bean anthracnose severity when entered first, and on the other hand, bean anthracnose severity showed a high probability of ( $P < 0.0001$ ) association with zones, growth stages and variety, and altitude ( $P < 0.0059$ ), cropping system ( $P < 0.0016$ ) and seed source ( $P < 0.0034$ ) were significantly associated with bean anthracnose severity when entered last into a multiple reduced logistic regression model (Table 7). Fields sown in early July along with poor weed management practices resulted in high significant relationship (>30%) to anthracnose severity. An altitude of 1500–2000 m showed 3.22 times the high probability of association with high anthracnose severity (>30%) compared to an altitude of > 2000 m (Table 8). Similarly, when growers' field was sown with variety Mexican-142 (1.92 times), Awsh-2 (1.39 times) and Awash-1 (1.25 times) showed a greater probability of association with high bean anthracnose severity. Lower bean

anthracnose severity (<30%) was associated with the flowering growth stage (0.93 times) than other growth stages.

## Discussion

Yield and yield components of the common bean are affected by a number of diseases (Gudero and Terefe 2018). Detailed information on the spatial distribution of common bean diseases are important to determine, characterise, know the diseases, develop diseases management practices and technologies under current global climate change scenarios. As shown in Table 1, CBB and anthracnose were found to be widely distributed and 100% prevalent in all the surveyed districts and zones regardless of the biophysical factors. Diseases intensity varied with biophysical factors, and CBB was more severe than anthracnose as indicated in Table 2.

The current survey-determined zone had a variable CBB and anthracnose diseases distribution. Of course, previous studies also indicated that common bean diseases occurred widely and erratically. However, the magnitude of CBB incidence and severity in three districts of

**Table 8.** Analysis of deviance, natural logarithms of odds ratio and standard error of anthracnose severity and likelihood ratio test on independent variables in reduced regression model in six Zones during the 2019 main cropping season in Ethiopia.

Added variable	Residual deviance <sup>a</sup>	df	Anthracnose severity		Variable class	Est. log <sup>c</sup>	SE <sup>d</sup>	Odds ratio
			LRT <sup>b</sup>					
			DR	Pr> $\chi^2$				
Intercept	835.40		–	–		–0.66	0.14	0.52
Zone	768.79	5	0.04	0.8498	East Hararghe	–0.017	0.09	1.01
			0.03	0.8640	Sidama	0.014	0.08	0.98
			10.78	0.0010	West Arsi	–0.31	0.10	0.73
			3.94	0.0472	West Hararghe	–0.21	0.11	0.81
			12.21	0.0005	West Shewa	–0.35	0.10	0.70
				Wolaita	0*		.	
Altitude (m a.s.l.)	677.55	1	7.51	0.0061	1500–2000	1.17	0.06	3.22
					>2000	0*		.
Cropping system	601.16	1	11.89	0.0016	Sole cropping	0.0819	0.05	1.08
					Intercropping	0*		.
Variety	442.37	7	1.1	0.0912	Red-Wolaita	0.01	0.09	1.01
			39.66	<.0001	Mexican-142	0.66	0.10	1.92
			11.69	0.0006	Awash-1	0.24	0.07	1.25
			15.46	<.0001	Awash-2	0.34	0.08	1.39
			5.87	0.0154	Nasir	–0.21	0.08	0.82
			0.47	0.4923	Hawassa dume	0.05	0.07	1.05
			2.88	0.0898	Ibado	0.16	0.09	1.17
				Mixtures	0*		.	
Growth stage	379.08	2	45.16	<.0001	Flowering	–0.62	0.10	0.93
			20.72	<.0001	Pod filling	–0.21	0.04	0.81
				Maturity	0*		.	
Seed sources	373.68	1	22.88	<.0001	Own seeds	1.37	0.04	3.93
					Other sources	0*		.

<sup>a</sup>Unexplained variation after fitting the model. <sup>b</sup>LRT = likelihood ratio test; DR = deviance reduction and Pr = probability of an  $\chi^2$  value exceeding the deviance reduction; and  $\chi^2$  = Chi-square. <sup>c</sup>Est. = estimates of the logarithm of the odds ratio and \*Reference group. <sup>d</sup>SE = standard error. df = degrees of freedom.

West Hararghe (Habro, Chercher and Wobera) was reduced by more than half studied for two consecutive cropping years (Fininsa and Yuen 2001) when compared to the current studied districts as shown in Table 2 (Oda-Bultum and Tullo) and only 36% CBB incidence was recorded in some rift valley parts (Assefa et al. 1996) and few fields for CBB occurrence in southern Ethiopia. But, in this study, West Arsi and West Shewa zones were closely associated with high levels of CBB and intermediate levels of anthracnose diseases as shown in Figure 2. Sidama was closely associated with a low level of anthracnose and CBB occurrence. Despite enormous efforts and public investment in developing disease-resistant common bean varieties, this survey indicated that CBB and anthracnose diseases are in increasing trend in eastern, central and southern Ethiopia and remain an unresolved major challenge for common bean production in Ethiopia.

Tables 4 and 6 clearly indicated that independent variables such as cropping system, variety grown, date of sowing, crop growth stage, weed management and seed source were important factors influencing CBB and anthracnose epidemics differently. In this study, common bean intercropped with various crops played an important role in disease suppression with CBB incidence reduced by 18.7% and severity by 10.9% than the sole cropping system. Despite being unpredictable,

intercropping with non-host plants has been shown to reduce insect pest and disease damage. Diversity in production systems, where more than one crop cultivar or species are grown simultaneously, has benefits that include increased production and reduced epidemics development. Boudreau (2013) reported that intercropping effects mimics heterogeneity of plant communities which affect disease dynamics altering the host density, wind speed, vector spread and microclimate (temperature, relative humidity and leaf wetness). When a common bean is grown with maize or sorghum in intercropping, the incidence of CBB was reduced because the maize appears to provide a physical barrier to the movement of the pathogen between bean plants. This finding confirmed earlier reports of Fininsa (1996) and Fininsa and Yuen (2001, 2002) who reported that intercropping bean with maize delays CBB epidemic onset, lowers disease incidence, severity and disease progression rate in Ethiopia, which clearly agreed with our study as indicated by Table 2. Similarly, Hailu (2019) indicated that anthracnose disease incidence and severity were reduced when common bean is intercropped and applied compost compared with sole cropping.

Different diseases have specific environmental requirements for occurrence and epidemic development. CBB disease epidemic is favoured by warm temperatures (>25°C) and high rainfall and temperatures of



13–26°C, and free moisture favours the germination of spores and initial infection. Due to altitude differences among the geographic areas, both CBB and anthracnose incidence and severity were wide-ranging (Figure 2). Akhavan et al. (2013) reported that under high rainfall and warm temperature conditions (25–30°C), CBB could be very severe. Studies indicated that CBB incidence and severity have been progressive at low-to-mid altitude (1200–2000 m.a.s.l) under the warm condition with high humidity and rainfall (Vauterin et al. 2000) in which it was agreed with our findings as shown in Table 2. The presence of low disease intensity at high agro-ecologies (>2000m) indicates that higher altitude areas are less conducive for CBB Epidemic development.

The present study states that poorly weeded fields had increased CBB incidence by 15% and severity by 7%, and anthracnose incidence by 12% and severity by 5%. This showed that weeds in crop fields may aggravate disease occurrence and severity (Table 2). Yimer et al. (2018) indicated that reduced crop vigour has resulted due to intensive competition of weeds for available resources, leading host plants to both foliar and soil-borne disease predisposition. Palumbo (2013) noted that weed species found in and around crop fields served as alternate hosts to many diseases and insect pests that can later infect and infest nearby crops. Races of *Xanthomonas axonopodis* pv. *phaseoli* have been reported on *Phaseolus acutifolius*, *P. calcaratus* (Vigna umbellate) and *P. aureus* (Vignaradiata) (Bradbury 1986). Opio et al. (1996) found eight races of *X. axonopodis* pv. *phaseoli* using *P. acutifolius*, but differences in aggressiveness were found to *Phaseolus vulgaris*. The findings (Tables 3–8) of the present study are in consistency with Bruggen and Finckh (2016) suggestion, and weeds surrounding cropping areas and volunteer crops within the crop field may harbour plant pathogens and insect pests or create a disease-conducive microclimate. Studies showed weeds in infected fields, harbour CBB-causing pathogen for more years (Zhang et al. (2021)). Reports of Karavina et al. (2011) indicated that CBB effects and make an infection on other leguminous and non-leguminous plants. However, the host specificity of *Xanthomonas* is poorly researched and requires further investigation.

Planting date was found as another factor affecting CBB and anthracnose incidence and severity in this survey (Table 2). High mean disease incidence of CBB and anthracnose was recorded from fields sown in early July. This period was characterised by high rainfall in East Hararghe, Sidama, West Arsi, West Hararghe, West Shewa and Wolaita and warm temperature favouring leaf wetness, for infection on leaves and pods in the

growing season. Growers in the study areas usually used old varieties of common bean. The logistic analysis output in Tables 5 and 7 indicated that regarding uses of older varieties for production, there was a probability of high resistance breakdown through time. This would lead to a high risk of common bean diseases and epidemic development. Ketema and Thangavel's (2016) result indicated that the probability of high anthracnose severity was seen when growers have sown their fields with Awash-1 and Mexican-142 varieties. On the other hand, Fininsa and Tefera's (2006) study suggested that the use of varieties resistant to multiple diseases of common bean is one of the best ways of avoiding heavy yield losses.

Sources of seed had a great association with the disease development in the bean production system. Uses of infected seeds are responsible for the survival and transmission mechanism of CBB and anthracnose diseases. Common bacterial blight is extensively a seed-borne disease on *Phaseolus* spp. In the study, growers' own-saved seeds increased CBB incidence by 10.7% and severity by 6.60%. Similarly, anthracnose incidence and severity were increased by 8.12% and 4.67%, respectively, in fields using growers' saved seeds compared with seed collected from other sources as a planting material (Table 2). Infection of flower buds and young pods can result in the transmission of *X. axonopodis* pv. *phaseoli* through the vascular system to the seed, leading to seedling damage (Torres et al. 2009). Koike et al. (2001) stated that poor management practices like the use of uncertified seeds and lack of field sanitation have effects on disease epidemic development. Similarly, anthracnose is primarily a seed-borne disease and causes yield losses as high as up to 100% (Schwartz et al. 2005), which is in agreement with our findings as reported in Tables 3–8 where the diseases had high associations with seed sources. The fungus, *C. lindemuthianum* over seasons has been found in infected plant residues and diseased seeds as spores (Yusuf and Sangchote 2005). There is a common practice of using common bean cultivar mixture under Ethiopian small-scale farmers (Assefa et al. 1996). This was mainly growers' own preferences to obtain varied yield, but most of the cultivars were susceptible to anthracnose.

Common bacterial blight and anthracnose diseases were 100% prevalent and widely distributed in major growing areas of eastern, central and southern areas of Ethiopia. Biophysical factors showed strong associations with CBB and anthracnose disease intensity and significantly influenced disease epidemics in the surveyed areas. The logistic regression model analysis identified that the independent variables namely, zone, altitude,

sowing date, weed management practices, cropping system, variety, crop growth stage, fertiliser application and seed sources were significantly influenced by CBB intensity. Likewise, anthracnose intensity was strongly influenced alone or in combination by zone, altitude, sowing date, weed management practices, cropping system, variety, crop growth stage and seed sources. Identifying the biophysical factors that affect epidemic development would lead to develop effective, environmentally friendly and economically reasonable diseases management strategies and tactics. Therefore, continuous efforts and commitments should be made to curb productivity challenges (diseases) through the use of resistant varieties, healthy seeds, proper weeding practices, appropriate and climate change resilient agronomic practices.

## Acknowledgements

The authors would like to thank all the agriculture and rural development offices of the surveyed districts for their kind information supports. Also, we would like to appreciate farmers who voluntarily involved in the interview sessions to obtain the required information.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

The authors acknowledge the Ministry of Education of Ethiopia for financing the study.

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