Distribution and Association of Common Bean Angular Leaf Spot (*Phaeoisariopsis griseola*) with Biophysical Factors in Southern and Southwestern Ethiopia

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Abstract: In Ethiopia, the average yield of common bean is low due to a wide range of factors. Angular leaf spot (ALS), caused by *Phaeoisariopsis griseola*, is one of the most destructive diseases in major bean growing areas of the country. Therefore, a field survey was conducted in four districts and two agricultural research centers to determine the distribution and importance of ALS intensity and its association with different biophysical factors in southern and southwestern parts of Ethiopia. In the survey, ALS was found prevalent in all common bean growing fields. However, mean incidence and severity varied among independent variables and variable classes. Mean incidence varied from 66.35% in Awassa Zuria district to 88.06% in Jimma Agricultural Research Center (JARC), whereas mean severity ranged from 81.14% in Bako Tibe district to 90.58% in Hawassa Agricultural Research Center (HARC). Higher mean incidence of 81.57% was obtained at altitude of >1718m.a.s.l than lower altitude class. The highest (86.56%) disease severity was obtained at pod filling stage compared to other growth stages. The independent variables showed a variable association response to ALS disease intensity in logistic regression model. Variables like districts, cropping system, growth stage, sowing date and weed density were significantly ($p \leq 0.05$) associated with disease incidence. Low mean disease incidence had high probability of association to Bako Tibe district, lower weed density and intercropping system. Similarly, low mean disease severity had high probability of association to Bolloso Sore district and lower altitudinal range. Findings of this study showed that ALS is a major constraint of common bean production, implying the need for proper intervention to improve available common bean varieties through careful weeding, intercropping practices and use of clean seed in the study areas and other agro-ecologies.

Keywords: Angular leaf spot; Biophysical factors; Common bean; Incidence; Severity

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is widely cultivated in tropical and subtropical countries. It is an important source of proteins, carbohydrates, fiber, vitamins and minerals (Voysest, 2000). Its high nutritional value and high rate of consumption make common bean an important food for many people in developing countries in Africa, Asia, and Latin America (Beebe, 2014). Worldwide, about 22.8 million metric tons (MT) of dry beans were produced and India is the highest producer with an annual production of more than 4 million MT (FAO, 2012; FAOSTAT, 2014). Common bean is grown widely and is becoming an important commodity in the cropping systems of smallholder producers both for food security and income in Ethiopia. The crop is widely grown in areas between 1400-2000 m. According to CSA (2017), about 290, 202.43 ha of land was allocated for common bean production and a total of 483,922.66 ton was obtained with an average productivity of 1.60 t ha^{-1} for white and 1.69 t ha^{-1} for red common beans in the 2016/17 main cropping seasons in Ethiopia.

However, productivity of common bean is constrained by several factors including a wide range of biotic, abiotic and socio-economic issues that limit the genetic potential of the crop (Singh and Schwartz, 2010). Among biotic factors, diseases and pests are affecting the production and productivity of common bean in Ethiopia (Kutangi*et al.,* 2010). Different diseases are reported as major constraints that threaten the productivity of common bean in the country. Of which, anthracnose (*Colletotrichum lindemuthianum*), rust (*Uromysis appendiculatus*), angular leaf spot (*Phaeoisariopsis griseola*) and common bacterial blight (*Xanthomonas campestris* pv. *phaseoli*) are the dominant ones (Yesuf, 2005).

Among the major fungal diseases, angular leaf spot (ALS) is one of the most destructive diseases of common bean in tropical and subtropical regions of the world (Allorent and Savary, 2005). The disease is favored by intermittent dry-wet and warm-cool weather (Correa-Victoria *et al.,* 1989). Under favorable temperature conditions of 18 to 24 ^{o}C, high humidity (>70%) and in the presence of a susceptible host, the pathogen has the ability to colonize different parts of bean plants including leaves, pods and seeds (Stenglein *et al.,* 2003). About 47% yield reduction of common bean due to ALS is reported so far in Ethiopia (Fikre *et al.,* 2011). Different production practices and variation in climatic conditions are thought to influence disease occurrence, epidemics development and damage to the crops under

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field conditions (Allerent and Savary, 2005; Mwangombe *et al.*, 2007). The effects of the disease also vary from season to season, between production situations, agro-ecological areas and other biophysical factors.

The effects of various management practices like cropping system on disease prevalence and intensity was reported (Fernandez *et al.*, 2011). And also resistant varieties have been suggested as a cost effective strategy to manage the disease at small scale farms (Mahuku *et al.*, 2009). However, deployment of resistant varieties for the control of ALS requires understanding of environmental, cultural and epidemiological factors (Singh, 2007). Understanding the association of disease intensity with cropping systems, crop combinations and management practices would help to identify the most important variables and to develop an integrated and sustainable management options (Rusuka *et al.*, 1997; Zewde *et al.,* 2007). In spite of this, information on disease occurrence, importance and effects of different agronomic practices, environmental variables and other biophysical factors on ALS of common bean are limited in Ethiopia. Thus survey studies are found useful to gain insights into the distribution and relative importance of plant diseases. Therefore, the objectives of this study were to determine (1) the prevalence, intensity and relative importance of angular leaf spot of common bean in southern and southwestern Ethiopia and (2) the association between disease intensity with different biophysical factors in the study areas.

2. Materials and Methods

2.1. The Survey Areas

Survey of angular leaf spot of common bean was conducted in four major common bean growing districts (Bako Tibe, Kerisa, Bollosso Sore and Awassa Zuria) and two agricultural research centers, namely Hawassa Agricultural Research center (HARC) and Jimma Agricultural Research Center (JARC) of southern and southwestern Ethiopia during the 2017 main cropping season. Bollosso Sore is located in Wolaita zone of Southern Nations, Nationalities and Peoples Region (SNNPR), while Awassa Zuria and HARC are placed in Sidama zone of SNNPR. Bako Tibe is located in West Shoa zone of Oromia National Regional State (ONRS), of Ethiopia, whereas Kerisa and JARC are found in Jimma zone of ONRS (Figure 1). The surveyed districts are different in agro-ecological characteristics and weather conditions (Table 1).The districts were selected purposively as the disease is frequently reported in those areas and with due consideration in potential of bean production, spatial and ecological location which representing the diverse conditions under which beans are cultivated.

Table 1. Characteristic features of surveyed common bean districts and research centers in Southern and Southwestern Ethiopia, during the 2017 cropping season.

District and research centre	Altitude (m.a.s.l)	Latitude	Longitude	Relative humidity (%)	Mean temperature range (°C)
JARC	1774-1814	7°40.11"-7°40.13"	36°40.50"-36°47.53"	48.05-50.6	28-28.7
Kersa	1746-1785	7°42.41"-7°42.799"	37°00.00"-37°00.62"	50.45-64.4	22.05-28.65
Bako Tibe	1602-1681	9°01.30"-9°06.23"	36°59.70"-37°02.52"	31.5-49.25	26.45-32.1
Bolloso Sore	1760-1801	7°03.040"-7°05.123"	37°41.142'-37°41.924"	50.3-72.45	24.4-30.45
HARC	1696-1702	7°03.616"-7°03.640"	38°30.517"-38°30.565"	45-46.3	25.8-27.65
Awassa Zuria	1686-1750	7°00.803"-7°01.380"	38°22.154"-38°23.911"	36.85-57.15	27.05-32.1

2.2. Sampling and Sample Units

Group discussions were held with development agents and agricultural district officials who are working with farmers to have broader understanding of the production potentials of common bean and route in the survey *kebeles* (small population unit in the district = peasant association) and fields. Formal survey questionnaires were prepared to gather the information from the farmers via personal interviews. The maximum of three peasant associations (PAs) were selected from Bolloso Sore district and about 17 fields were assessed from them. Similarly, two PAs each were selected from Awassa Zuria and Bako Tibe districts, and 12 and 10 fields were assessed, respectively. On the other hand, only one PA and seven fields were assessed from Kerisa district. The rest nine fields were assessed from research centers (four from JARC and five from HARC) and a total of 55 fields were surveyed from all districts and research centers. Peasant associations per district were selected purposively based on intensity of bean production, while fields were randomly selected at intervals of about 5 km along the main and accessible rural roads. Within selected fields, four quadrats (1m^2) diagonally spaced about 5 to 8 m apart were sampled. Then, plant samples exhibiting symptoms of angular leaf spot disease were assessed systematically for each field.

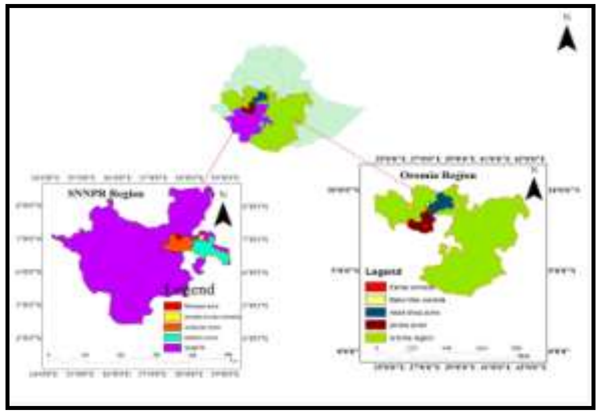

Figure 1. Map showing districts and zones (where each respective research center is found) surveyed for angular leaf spot (*Phaeoisariopsis griseola*) of common bean in Southern and Southwestern Ethiopia.

2.3. Geographical and Agronomic Data

Global Positioning System (GPS) instrument was used to determine the coordinates (latitude and longitude) and altitude of each field visited. GPS based survey sheet was prepared to collect information on disease status from each area. Additionally, data on agronomic parameters like field size, cropping systems (sole or intercropping), planting date, weed density, planting pattern (row or broadcast), growth stage and plant density were collected to determine the relationship with disease intensity. Information like planting date was obtained from growers through interview. The plant population and weed density were assessed using 1m^2 area placed diagonally three times within a field. The mean plant and weed population density were obtained by taking the average number of population in four quadrants. The average value of relative humidity and temperature of surveyed fields were also measured using thermos-hygrometer.

2.4. Disease Assessment

Angular leaf spot incidence was determined from priory laid four quadrats of 1m^2 in each inspected field across districts and research centers, while disease severity was scored from randomly taken 20 plants per field using standard scoring scales.

2.4.1. Disease Incidence

Angular leaf spot incidence was assessed by counting the number of plants showing typical ALS symptoms in the four quadrats (1m^2) and incidence per farm was computed using the following formula:

$$\text{Incidence (\%)} = \frac{\text{Total No. of plants infected}}{\text{Total No. of plants counted}} \text{X100}$$

2.4.2. Disease Severity

Angular leaf spot severity was rated from 20 randomly selected plants per field by scoring five representative plants for each spaced quadrat using standard scales of 1 to 9 (Pastor-Corrales and Jara, 1995). The description of the scales is given in Table 2.

Table 2. Scales, parts affected and descriptions of scales used to score angular leaf spot severity.

Scale	Plant parts affected by angular leaf spot
1	No visible disease symptoms;
2	The presence of up to 3% leaf lesions;
3	the presence of up to 5% leaf lesions, without sporulation of the pathogen;
4	The presence of sporulating lesions covering 10% of the leaf area
5	The presence of various sporulating lesions from 2 to 3 mm in size, covering 10-15% of the leaf area;
6	Presence of numerous sporulating lesions greater than 3 mm in size, covering 15-20% of the leaf area
7	The presence of numerous sporulating lesions greater than 3 mm in size, covering 20-25% of the leaf area;
8	Presence of numerous sporulating lesions greater than 3 mm in size, covering 25-30% of the leaf area
9	>30% of the leaf or pod surface area is covered by large sporulating and often coalescing lesions. Leaf tissues are generally chlorotic resulting in severe and premature defoliation. Infected pods are often deformed and shriveled and contain a low number of seeds. Abundant sporulating lesions are present on stem and branches.

The severity grades obtained were converted into percentage severity index (PSI) using the formula suggested by Whleer (1969).

$$\text{PSI} = \frac{\text{Sum of numarical ratings}}{\text{Total number of plants scored x Maximum score on scale}} X100$$

2.5. Data Analysis

Simple descriptive statistics were used to summarize data obtained from field surveys after using Stata computer program version 12 for Windows. Summary of incidence and severity of angular leaf spot was presented for each independent variable and variable classes. Disease incidence and severity data were classified into distinct classes of bivariate qualitative data. Class boundaries were chosen so that classes contained approximately equal numbers. Contingency table of independent variables by disease intensity was built to represent the bivariate distribution of fields according to two classifications (e.g. weed density by ALS incidence) (Table 3). An entry in a cell of a contingency table represents the frequency of fields falling into that cell. T-tests were used to compare the frequencies of diseased fields between sowing date, cropping pattern, cropping system and plant population based on the proportion of fields in each district that were assigned to a given disease incidence class (Samuel *et al.,* 2008a).

The associations of ALS intensities with independent variables were analyzed using logistic regression as described by Yuen *et al.* (1996) and Hosmer and Lemeshow (1989) with the SAS Procedure GENMOD (SAS, 2007). The logistic regression model allows evaluation of the importance of multiple independent variables that affect the response variable. Logistic regression calculates the probability of a given binary outcome as a function of the independent variables (McCullagh and Nelder, 1989). If the predicted probability of the outcome is denoted as (P), the logistic regression model assumes the logarithm of the odds of P (P/(1-P)), which equals logit (P), and is a linear function of the independent variables (Yuen *et al.,* 1996).

The GENMOD Procedure gives parameter estimates and standard error of the parameter estimates. Exponentiation the parameter estimate yields the odds ratio, which is interpreted here as the relative risk (Yuen *et al.,* 1996). The importance of each independent variable was evaluated in two ways. First, the association of an independent variable alone with disease incidence or severity was tested in a single variable model. This consisted of testing the deviance reduction attributed to a variable when it first enters into the model. Second, the association of an independent variable with disease incidence or severity was tested when enter last in to the model with all other independent variables. The deviance was used to compare different models. The difference between two models, a likelihood ratio test (LRT) was used to examine the importance of variables and was tested against a χ^2 value (McCullagh and Nelder, 1989).

Table 3. Categorization of variables used in analysis for distribution of angular leaf spot epidemics of common bean in four different districts and two research centers (*n* = 55) of Southern and Southwestern Ethiopia, during the 2017 cropping season.

Variable	Variable class	Number of fields	Angular leaf spot intensity			
			Incidence		Severity	
			≤80%	>80%	≤85%	>85%
District	Bolloso Sore	17	6	11	11	6
	HARC [a]	5	1	4	1	4
	Awassa Zuria	12	11	1	4	8
	Bako Tibe	10	3	7	5	5
	JARC [b]	4	0	4	1	3
	Kerisa	7	2	5	3	4
Altitude (m.a.s.l)	≤1718	26	14	12	10	16
	>1718	29	9	20	15	14
Field size (m^2)	≤1000	30	10	20	13	17
	>1000	25	13	12	12	13
Sowing date	Late June-June 30	23	5	18	9	14
	>August 01	32	18	14	16	16
Cropping pattern	Row planting	46	16	30	22	24
	Broadcasting	9	7	2	3	6
Cropping system [c]	Sole cropping	42	13	29	19	23
	Intercropping	13	10	3	6	7
Growth stage	Flowering	15	12	3	7	8
	Pod filling	29	9	20	13	16
	Maturity	11	2	9	5	6
Plant density [d]	≤34	19	11	8	11	8
	>34	36	12	24	14	22
Weed density [e]	≤50	36	15	21	14	22
	>50	19	8	11	11	8
Incidence	≤80%	23	…	…	..	..
	>80%	32	..	..	..	..
Severity	≤85%	25	..	..	..	..
	>85%	30	..	..	..	..

Note: [a] HARC = Hawassa Agricultural Research Center and [b] JARC = Jimma Agricultural Research Center; [c] Cropping system in which intercropping refers to common bean fields planted with maize, *enset*, coffee and/or sweet potato; [d] Plant density was determined as number of plants per 1 m^2 quadrat; [e] Weed density was determined as number of weeds less than or equal to 50 or greater than 50 per 1m^2 quadrat. Field size was measured in m^2.

3. Results

3.1. Overview of Surveyed Fields

Out of 55 common bean farms inspected, the most (30.9%) and least (7.27%) number of farms were assessed in Bolloso Sore district and JARC, respectively. Similarly, both of the smallest (100 m^2) and the largest (3,333.33 m^2) field sizes were visited in Bolloso Sore and over 54% of observed fields were below 1000 m^2. About 58% of common bean farms were sown in August, while the remaining farms were sown from late June to the end of July. Most (83.64%) of surveyed fields were row planted and the rest farms were broadcasted. With regard to cropping system, 76.36% of inspected farms were sole cropped and the remaining 23.64% was intercropped with maize, *enset*, coffee and/or sweet potato. Common bean fields were found at three growth stages during the time of survey in which 27.27%, 52.73% and 20% were at flowering, pod filling and maturity growth stages, respectively.

None of the common bean growers were used chemical spray as angular leaf spot management option, but over 40% of growers were found to apply cultural practices like rouging and cutting of diseased plants and plant parts as disease management schemes to reduce rapid pathogen dispersal among plant canopies. High weed infestation was observed in Kerisa and some part of Bolloso Sore districts. In addition, some other common bean diseases and pests were also observed in association with ALS. All districts, excluding Awassa

Zuria, showed floury leaf spot (*Mycovellosiella phaseoli*). On the other hand, about 35% of Awassa Zuria farms were infected by rust (*Uromyces appendiculatus*). Moreover, bean stem maggot (*Ophiomyia phaseoli*) was encountered as key insect pest in Kerisa as 71.43% of observed fields were showed maggot (larvae) on stem of plants.

3.2. Distribution and Disease Intensity of Angular Leaf Spot

Angular leaf spot was prevalent and widely distributed in all common bean fields studied. However, there was variation in mean disease incidence and severity of ALS among independent variables and variable classes (Table 4 and Figure 2). Different level of ALS incidence and severity were recorded among districts and research centers. Higher mean disease incidence (88.06%) was obtained in JARC compared to the other districts and research centers. Contrary, mean disease incidence in Awassa Zuria district was lowered by 24.65%, 19.93%, 17.44%, 16.71% and 15.63% compared to JARC, Bako Tibe, HARC, Bolloso Sore and Kerisa, respectively. On the other hand, minimum mean disease severity of ALS was recorded in Bako Tibe (81.14%) and the maximum was obtained in HARC (90.58%). Mean disease severity in HARC was 2.78%, 4.87%, 6.03%, 6.54% and 10.42% higher than JARC, Awassa Zuria, Kerisa, Bolloso Sore and Bako Tibe, respectively. Higher mean disease incidence of 81.57% was obtained in altitude of >1718m.a.s.l than lower altitude class. Similarly, mean disease severity was one and half percent higher in semi-highland areas (altitude >1718m.a.s.l) than semi-lowland areas (altitude ≤1718m.a.s.l).

There were no much mean incidence and severity variation between variable classes of field size and sowing date. Conversely, intercropped fields reduced disease incidence by 13.47% than sole cropping. On the other hand, mean disease severity was 1.21% higher in intercropped fields than sole cropped fields. Regarding cropping pattern, mean disease incidence in row planted fields was 10.84% higher than broadcasted fields, while mean severity was 1.94% higher in broadcasted fields than row planted fields. With regard to growth stage, mean disease incidence at maturity growth stage was 19.98% and 4.11% higher than flowering and pod filling growth stages, respectively. Mean disease severity at pod filling stage was 5.39% and 2.16% higher than maturity and flowering growth stages. This indicates that growth stage might have an influence to the disease epidemics. There was a variation in mean disease incidence with regard to crop and weed density even though the variation in mean disease severity was minimum. The mean disease incidence was higher in highly weed infested farms than farms with low to free weed infestations. Likewise, mean disease incidence reduced by 8.38% in sparsely populated farms to densely populated beans. Unfortunately, we failed to report varietal differences in incidence and severity of angular leaf spot due to lack of sufficient information upon the survey period.

Comparison of common bean fields of low and high plant population, cropping system (sole cropping and intercropping), early (late June to July 30) and late (>August 01) planting as well as cropping pattern (row planting and broadcasting) with disease incidence showed significant ($p \leq 0.05$) variation in t-test (Table 5). Cropping system showed high association to disease incidence (*t-value* = 3.1, $p \leq 0.0031$), followed by sowing date (*t-value* = 2.67, $p \leq 0.0099$). However, none of the variables showed significant association with disease severity (data not shown).

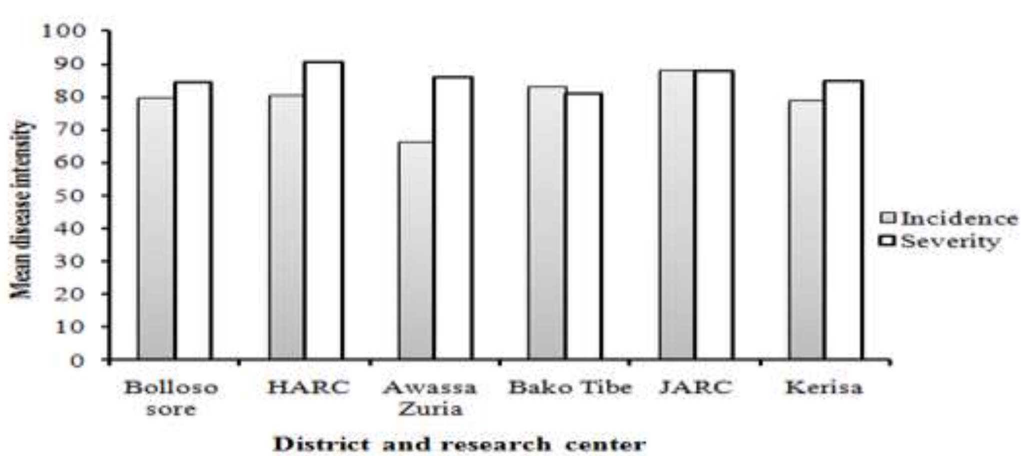

Figure 2. Mean disease incidence and severity of angular leaf spot across different districts and research centers in Southern and Southwestern Ethiopia, during the 2017 cropping season.

Table 4. Mean disease intensity of angular leaf spot of common bean for different independent variables in Southern and Southwestern Ethiopia, during the 2017 cropping season.

Variable	Variable class	Angular leaf spot intensity							
		Incidence (%)				Severity (%)			
		Min.	Max.	Mean	SD [a]	Min.	Max.	Mean	SD [a]
District	Bolloso Sore	52.93	93.94	79.66	12.42	77.14	94.67	84.66	5.03
	HARC [b]	72.4	84.27	80.37	4.69	82.22	96	90.58	5.49
	Awassa Zuria	50.07	84.99	66.35	9.53	73.33	93.33	86.17	6.41
	Bako Tibe	66.67	93.33	82.87	9.15	60	90	81.14	10.69
	JARC [c]	86.14	92.01	88.06	2.73	83.33	91.42	88.06	3.79
	Kerisa	50.07	95.56	78.64	11.97	60	96	85.12	7.11
Altitude(m.a.s.l)	≤1718	50.07	93.33	75.36	11.73	60	96	84.84	8.64
	>1718	52.93	95.56	81.57	11.61	72	94.67	85.37	5.53
Field size (m^2)	≤1000	50.07	93.94	79.71	12.06	62.86	96	85.32	6.57
	>1000	59.64	95.56	77.33	11.99	60	94.67	84.87	7.84
Sowing date	Late June-July 30	66.34	93.94	83.46	7.76	60	96	85.14	8.5
	>August 01	50.07	95.56	83.46	7.76	60	96	85.14	8.5
Cropping pattern	Row planting	50.07	95.56	80.06	12.06	60	96	84.84	7.44
	Broadcasting	61.77	87.95	71.38	8.89	77.78	94.67	86.52	5.18
Cropping system [d]	Sole cropping	52.93	95.56	81.22	11.15	60	96	84.87	7.49
	Intercropping	50.07	88.98	70.28	11.01	76	94.67	85.91	5.89
Growth stage	Flowering	50.07	92.06	68.11	11.35	72	94.67	84.69	5.84
	Pod filling	52.93	95.56	81.62	10.49	73.33	96	86.56	5.9
	Maturity	68.64	93.33	85.12	6.87	60	90.83	81.89	10.48
Plant density [e]	≤34	50.07	93.33	74.19	13.63	73.33	94.67	85	6
	>34	54.32	95.56	80.98	10.45	60	96	85.18	7.71
Weed density [f]	≤50	52.93	93.94	78.38	11.83	60	96	85.6	7.62
	>50	50.07	95.56	79.12	12.56	72	93.33	84.2	6.1

Note: [a] SD = Standard deviation; [b] HARC = Hawassa Agricultural Research Center; [c] JARC = Jimma Agricultural Research Center; [d] Cropping system in that intercropping refers to planting common bean fields with maize, *enset*, coffee and/or sweet potato; [e] Plant density was determined as number of plants per 1 m^2 quadrat; [f] Weed density was determined as number of weeds less than or equal to 50 or greater than 50 per 1m^2 quadrat.

Table 5. Contingency t-test analysis of mean disease incidence difference of angular leaf spot of common bean, Southern and Southwestern Ethiopia, during the 2017 cropping season.

Independent variable	Variable class	Angular leaf spot incidence		
		SE	*t-value*	p-value
Plant density [a]	≤34	1.74	2.06**	0.0445
	>34	3.13		
Cropping system [b]	Sole cropped	1.72	3.10***	0.0031
	Intercropped	3.05		
Sowing date	Late June -July 30	1.62	2.67***	0.0099
	>August 01	2.35		
Cropping pattern	Row planting	1.78	2.05**	0.0457
	Broadcasting	2.96		

Note: *** and ** indicates that there is significant difference in the frequency of diseased fields based on disease incidence at $p<0.001$ and $p \leq 0.05$, respectively; [a] Plant density was determined as number of plants per 1 m^2 quadrat; [b] Cropping system in that intercropping refers to planting common bean fields with maize, *enset*, coffee and/or sweet potato.

3.3. Association of Angular Leaf Spot Intensity with Biophysical Factors

The independent variables showed a variable association response to angular leaf spot incidence and severity (Table 6). Variables including district (χ^2 = 149.48, 5df), cropping system (χ^2 = 5.95, 1df), growth stage (χ^2 = 67.91, 2df), field size (χ^2 = 4.1, 1df), sowing date (χ^2 = 7.3, 1df) and weed density (χ^2 = 3.82, 1df) were significantly ($p \leq 0.05$) associated with ALS incidence in logistic regression model. However, field size lost its significance when entered last into the model. On the other hand, district (χ^2 = 21.61, 5df), cropping system (χ^2 = 4.06, 1df), growth stage (χ^2 = 47.68, 2df), sowing date (χ^2 = 8.9, 1df) and weed density (χ^2 = 3.82, 1df) maintained their association with ALS incidence when entered into the reduced variable model. Variables such as altitude (χ^2 = 0.06, 1df), cropping pattern (χ^2 = 0.92, 1df) and plant density (χ^2 = 0.18, 1df) were not significantly ($p \leq 0.05$) associated with ALS incidence when entered first and last into the model.

The influencing magnitude of sowing date on disease incidence slowly increased, while the contribution of district, cropping system and growth stage to incidence decreased in the reduced model (Table 6). Growth stage was the most significantly associated variable with angular leaf spot incidence when entered first and last into the model (χ^2 = 67.91 and 47.68, $p < .0001$, 2df). All significantly associated variables, excluding field sizes, were tested in reduced multiple variable model and their analysis of deviance showed the importance of each variable and variable class to mean disease incidence (Table 7). The parameter estimate and standard error resulted from reduced regression model are shown in Table 7. The probability of ALS incidence >80% was highly associated to Kerisa, JARC and Bolloso Sore districts, in sole cultures, at pod filling to maturity growth stage, in early planting and in farms with high weed infestation. On the other hand, low incidence had high association to Bako Tibe and HARC districts, intercropping system, flowering growth stage, late planting and farms with low weed infestation. The probability of occurrence of high incidence in JARC was twice higher than disease incidence in Bako Tibe and HARC. Similarly, the probability of occurrence of high incidence in sole culture was about 1.2 times higher than incidence in intercropping system. Regarding growth stages, the probability of occurrence of high incidence at flowering stage was about twice and 2.5 times lesser than pod filling and maturity growth stages, respectively. There were 1.37 and 1.2 times higher probability of high disease incidence could occur in early planting and high weed density (>50) than disease epidemics in late planting and low weed density, respectively.

Table 6. Independent variables used in logistic regression model for angular leaf spot intensity and their likelihood ratio test in Southern and Southwestern Ethiopia, during the 2017 cropping season.

Variable	df	Angular leaf spot Incidence LRT [a]				Angular leaf spot Severity LRT [a]			
		VEF		VEL		VEF		VEL	
		DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
District	5	149.48	<.0001	21.61	0.0006	29.37	<.0001	24.49	0.0002
Altitude	1	0.06	0.81	0.36	0.55	4.07	0.043	6.11	0.013
Field size	1	4.1	0.04	1.45	0.23	3.85	0.049	2.63	0.104
Cropping system	1	5.95	0.015	4.06	0.044	0.25	0.62	0.58	0.45
Growth stage	2	67.91	<.0001	47.68	<.0001	1.62	0.44	3.13	0.21
Cropping pattern	1	0.92	0.34	2.56	0.11	2.88	0.089	2.95	0.086
Sowing date	1	7.3	0.0069	8.9	0.0028	2.26	0.13	2.12	0.12
Plant density	1	0.18	0.67	0.27	0.6	0.41	0.52	1.04	0.31
Weed density	1	3.82	0.05	3.82	0.05	0.9	0.34	0.9	0.34

Note: [a] LRT= likelihood ratio test; VEF = variable entered first; VEL = variable entered last; df = degrees of freedom; DR = deviance reduction; Pr = probability of a value χ^2 exceeding the deviance reduction; χ^2 = chi square.

Table 7. Analysis of deviance, natural logarithms of odd ratio and standard error of ALS incidence and likelihood ratio test on independent variables in Southern and Southwestern Ethiopia, during the 2017 cropping season.

Added variable	Residual deviance [a]	df	ALS incidence LRT [b]		Variable class	Estimate Log_e (odds ratio)[c]	SE[d]	Odds ratio
			DR	Pr > χ^2				
Intercept	460.74	0				2.3151	0.23	10.13
District	311.26	5	14.86	0.0001	Bolloso Sore	-0.6011	0.16	0.55
			8.88	0.0029	HARC	-1.0241	0.34	0.36
			11.38	0.0007	Awassa Zuria	-0.9724	0.29	0.38
			9.42	0.0022	Bako Tibe	-1.1113	0.36	0.33
			2.09	0.148	JARC	-0.3279	0.23	0.72
					Kerisa	0*		.
Cropping system	301.15	1	4.06	0.044	Sole cropping	0.2339	0.12	1.26
					Intercropping	0*		.
Growth stage	233.24	2	20.93	<.0001	Flowering	-0.9742	0.21	0.38
			2.44	0.12	Pod filling	-0.2786	0.18	0.76
					Maturity	0*		.
Sowing date	225.02	1	8.75	0.0031	Late June to July30	0.3149	0.11	1.37
					>August 01	0	0	.
Weed density	221.02	1	3.84	0.05	≤50	-0.2013	0.10	0.82
					>50	0*		.

Note: [a] Unexplained variations after fitting the model; [b] LRT = likelihood ratio test; [c]* reference group; [d] SE = Standard error; Dr = deviance reduction; df = degrees of freedom; Pr = probability of a value χ^2 exceeding the deviance reduction; χ^2 = chi square.

Table 8. Analysis of deviance, natural logarithms of odd ratio and standard error of angular leaf spot severity and likelihood ratio test on independent variables in Southern and Southwestern Ethiopia, during the 2017 cropping season.

Added variable	Residual deviance [a]	df	ALS severity LRT [b]		Variable class	Estimate Log_e (odds ratio)[c]	SE [d]	Odds ratio
			DR	Pr > χ^2				
Intercept	201.9159	0				1.6212	0.2735	5.06
			2.29	0.13	Bolloso Sore	-0.251	0.1658	0.78
			7.45	0.0063	HARC	1.3412	0.4913	3.82
			3.54	0.06	Awassa Zuria	0.8185	0.4353	2.27
District	172.5443	5	1.87	0.1719	Bako Tibe	0.6791	0.4972	1.97
			0.61	0.4366	JARC	0.1882	0.2419	1.21
					Kerisa	0*		.
Altitude	168.4765	1	5.26	0.0219	≤1718	-0.9854	0.4298	0.37
					>1718	0*		.

Note: [a] Unexplained variations after fitting the model; [b] LRT= likelihood ratio test; [c] * reference group; [d] SE = Standard error; Dr = deviance reduction; df = degrees of freedom; Pr = probability of a value χ^2 exceeding the deviance reduction; χ^2 = chi square; ALS = angular leaf spot.

Some independent variables, namely district (χ^2 = 29.37, 5df), altitude (χ^2 = 4.07, 1df) and field size (χ^2 = 3.85, 1df) were significantly ($p \leq 0.05$) associated with disease severity when first entered to the model (Table 6). However, field size lost its importance when entered last in to the model. District was the most significantly associated variable with severity when entered first and last into the model (χ^2 = 29.37 and 24.49, 5df). Variables including cropping system (χ^2 = 0.25, 1df), growth stage (χ^2= 1.62, 2df), cropping pattern (χ^2 = 2.88, 1df), sowing date (χ^2 = 2.26, 1df), plant density (χ^2 = 0.41, 1df) and weed density (χ^2 = 0.9, 1df) were not significantly ($p \leq 0.05$) associated with severity when entered first and last in to the model. This implies that the effects of sowing date, cropping system, cropping pattern, growth stage, weed and crop density on disease severity may vary with agro-ecology, pathosystem and weather factors. On the other hand, district (χ^2 = 24.49, 5df) and altitude (χ^2 = 6.11, 1df) maintained their association with severity when entered into reduced variable model. The influencing magnitude of altitude on severity highly increased, while the contribution of district to severity decreased in the reduced variable model (Table 6). Classes of district and altitude were tested in reduced multiple variable model and their parameter and standard error resulted from reduced regression analysis are shown in Table 8. The probability of ALS severity >85% was highly associated to at higher altitude range (>1718m.a.s.l), HARC and Awassa Zuria districts. Low severity had high association to lower altitude ranges, Bolloso Sore and Kerisa districts. There were one and half, two, three and four times higher probabilities of association for the occurrence of high severity in HARC than Awassa Zuria, Bako Tibe, JARC and Kerisa, respectively. On the other hand, the probability of occurrence of high severity in semi-low land areas (altitude ≤1718m.a.s.l) was two and half times lower than semi-high land areas (altitude >1718m.as.l).

4. Discussion

Angular leaf spot was prevalent and widely distributed in all common bean growing fields studied regardless of agro-ecology, altitude, field size, sowing date, cropping system, growth stage as well as weed and crop density. The distribution of this destructive disease in all surveyed areas might be either due to the environmental conditions which favor development of the disease and/or due to presence of diversified causative pathogens across different common bean growing areas. Comparatively, higher mean disease incidence and severity were observed in JARC and HARC that might be partly due to fluctuating high temperatures and relative humidity, which favor the disease development under field condition together with other epidemic factors. Angular leaf spot was reported to be the important disease in bean growing areas characterized by a humid climate, high temperature and high rainfall in Ethiopia (Habtu *et al.,* 1996). Variation in disease prevalence and intensity across locations would be attributed to prevailing environmental conditions and crop management practices, which is similarly reported by Sceuemann *et al.* (2012).

Furthermore, the high mean disease intensity observed in all agro-ecologies might be associated to the poor cultural practices adopted by smallholder farmers in the area including use of poor quality farmer-saved seed sources, lack of crop rotation and poor management practices exacerbated by conducive environment conditions for disease development (Njingulula, 2014; Kijana *et al*., 2017). Dependency on own seed sources, as observed in the studied areas, could result in the build-up of inoculum and significantly contribute to the development disease epidemics (Wachenje, 2002; Mwangombe *et al.,* 2007). The amount of inoculum present in each farm, level of field sanitation and type of cropping system employed might also had an influence on overall disease distribution and epidemics (Stenglein *et al*., 2003, Mwangombe *et al.,* 2007).

The findings of the study revealed that mean disease intensity was more pronounced in semi-high land areas (altitude >1718m.a.s.l). This might be partly due to the high rainfall and relative humidity common in the areas, which could favor ALS infection and epidemic development. Mwangombe *et al.* (2007) also obtained high disease incidence in altitude ranges of 1601-2000 m.a.s.l, which was lower in areas above 2000 m.a.s.l. due to the cool temperature in high altitude areas that may inhibit ALS developments. In contrast, Kijana *et al.* (2017) reported that ALS severity was high in the higher altitudes than lower altitude areas. Similarly, Ddamulira *et al.* (2014) found slightly high disease incidence and low severity observed in high altitude areas of Uganda, which are characterized by cold conditions. This indicated that cold temperatures alone might not be the only factor contributing to ALS epidemics, but bean cultivar type grown may also influence disease incidence.

Cropping system showed unavoidable effects on ALS disease epidemics as mean disease incidence reduced by 13.47% in intercropped fields. The effects of intercropping on disease incidence might be due to an increase in spatial distance between host plants, which might inhibit free dispersal of pathogen and suppress weeds responsible for the build-up of high humidity under the canopy. There are also several studies with regard to the inhibition potential of intercrops against different pathogens in various pathosystems (Chemeda, 2003; Altieri *et al.,* 2005; Samuel *et al.,* 2008b; Habtamu *et al.,* 2015). However, intercropping did not show reduction effects on disease severity, which might imply that intercropping could not be effective to reduce disease epidemics once the disease has established on host plants. Chemeda and Jonathan (2001) also observed higher maize rust epidemics in maize-sorghum intercropped fields than in sole cropped fields. The effects of intercropping on disease epidemics also depend on the temperature and relative humidity requirements of pathogens (Boudreau and Mundt, 1992; Chemeda, 1996).

Cropping pattern also showed strong association with ALS disease epidemics. Mean disease incidence was 10.84% higher in row planted fields than broadcasted. This could be due to bean association with component crops in intercropping systems as majority of broadcasted fields were observed intercropped with other crops. On the other hand, the effects of cropping pattern on disease epidemiology may vary with pathosystem, other cropping practice, geographic area and weather factors too. There was a variation with regard to the influence of crop growth stage on the disease epidemics. Mean disease incidence at maturity stage was 19.98% and 4.11% greater than flowering and pod filling growth stages, respectively. On the other hand, mean disease severity at pod filling stages was higher than flowering and maturity growth stages even though there was a minimum variation among them. This might be due to defoliation of early infected leaves before reaching maturity growth stage. If the conditions are conducive for ALS development, it may result in premature defoliation (Saettler, 1991). The reduction effects of disease incidence at flowering stage might partly associated with cropping system as majority of intercropping fields were at flowering growth stages. The effects of growth stage on disease severity might explain the fact that as far as the environmental condition is conducive and once the disease infects the plant, it might damage the whole growth stages during the growing season. In addition, a change in agronomic practices and climate might have contributed to development of new aggressive strain which may lead to devastation of the crop. Moreover, the influence of growth stage on disease epidemics might vary with seasonal effects, sowing date, cultivar used and many other epidemic factors. Reports of CIAT (2010) showed that ALS is more prominent during late flowering and pod formation stages. A study by Kijana *et al.* (2017) also found significant association between disease intensity and common bean growth stages in which angular leaf spot disease was higher in pod filling stage than flowering and pre-podding stages. In contrast, Samuel *et al.* (2008b) found higher disease intensity of faba bean chocolate spot at flowering stage than pod filling stage and associated to defoliation or aging of already infected leaves of the plant at pod filling crop growth stage.

Crop and weed density had strong association to disease incidence. The mean disease incidence was higher in highly weedy farms as well as in densely populated beans than weed free and sparsely populated beans. High weed infestation could reduce crop vigor and promote disease development through competition for available resources that render crops susceptible to both foliar and soil-borne pathogens. In addition to competition for resources, weed modifies the microclimate and increase canopy humidity that would assist epidemic development (Samuel *et al*., 2008b; Eshetu *et al*., 2013). Dense population could also increase relative humidity and competition for similar resources, which in turn could make host plants weak and susceptible for the pathogen to enhance the development of high disease incidence. Low plant population is also supposed to decrease canopy enclosure and may increase free circulation of air under the crop canopy. Free circulation of air might reduce damp sites responsible for high humidity build-up. Similarly, Habtu *et al.* (1996) reported that high plant densities are associated with high disease development and high population density favor easy spread of bacterial blight and anthracnose propagules between crops. A study by Samuel *et al.* (2008b) also found that a higher number of faba bean was infected with chocolate spot in densely populated fields than in sparsely populated faba beans.

The logistic regression model revealed that district, cropping system, growth stages, sowing date and weed density were significantly associated with ALS incidence individually or in combination. Variables like altitude and cropping pattern were not significantly associated with incidence. The insignificant association of altitude and disease incidence might be partly due to the suitable environmental conditions favouring ALS development and/or there might be variable pathogen races in the surveyed areas, which enable the pathogen to widely infect the host regardless of elevation differences. In addition, the survey was made during typical bean growing period with wet and dry weather conditions which is conducive for ALS development. If environmental conditions are known to favor disease development, there might be high disease incidence and severity even in low altitude areas ranging from 1000 to 1200 m.a.s.l (Correa-Victoria *et al*., 1989; Ddamulira *et al.,* 2014). Angular leaf spot development is stimulated under temperature conditions of 18-22 °C and relative humidity of 70-100%. Such conditions are experienced in low altitude bean growing areas (Stenglein *et al*., 2003; Mugisha, 2008). Higher temperatures, with an optimum for disease development between 24 and 28 °C, favored the infection and colonization by *P. griseola as* well as ALS development (Bassanezi *et al.,* 1998).

The probability of occurrence of high disease incidence was triple times in early planting than late planting. Early sowing might be associated with high infestation of weed that may modify the micro-environment to humid in planting fields, which could favor the germination of spores, growth and developments of disease. In addition, early sown common bean genotypes were at pod filling to physiological maturity stages in which ALS disease expected to be high. According to Habtu *et al.* (1996), sowing date had a clear effect on disease epidemics. A study by Essubalew *et al.* (2015) also revealed that early bean sowing increased ALS incidence in which early planting expose plants for long period of rainfall, leaf wetness, pathogen and high humidity. Similarly, ALS spreads and develops rapidly if production conditions of moderate temperature, prolonged periods of wet weather or high humidity alternates with warm weather (Celetti *et al*., 2006). In addition, most of the surveyed common bean fields were at pod filling stage at which the crop is expected to be susceptible to the pathogen and the development of ALS is supposed to be high keeping the effects of the other epidemic factors constant. With regard to weed population, high probability of disease incidence was highly associated with high weed density. Weed population could modify micro-environment under the crop canopy, which might favor disease development. Low weed density was highly associated with low bacterial blight, whereas medium and high weed population were strongly associated with high bacterial blight (Habtu *et al*., 1996). Several studies also indicated that weedy farms positively associated with high disease parameters in different host-pathogen pathosystems (Zewdie *et al.,* 2007; Samuel *et al.,* 2008; Eshetu *et al.,* 2013). The logistic model quantified the relative importance of independent variables implying that ALS epidemics was the function of these variables either to increase or decrease disease epidemics.

5. Conclusions

Results of the study identified that angular leaf spot was widely distributed and high mean disease incidence and severity was observed in all agro-ecologies surveyed. ALS intensity varied among districts and research centers, altitude, field size, sowing date, cropping system, crop growth stages as well as weed and crop density. These independent variables were confirmed as important to the developments of common bean ALS. Results from regression analysis also indicated that the independent variables have strong association with disease epidemics and implying appropriate interventions are needed to perform through creating awareness for growers about disease causative agent characteristics, survival, dispersal as well as possible management options to reduce effects below economic injury level. In addition, proper cultural practices such as using of quality seed, practicing crop rotation and intercropping should be adopted by growers to minimize the associated inoculum load and ALS epidemics. Likewise, maintaining optimum crop density and managing weeds below economic damaging level also should be included in disease management strategies. Improving locally and commercially available common bean varieties is highly desirable to reduce sensitivity of the crop to the pathogen.

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