Distribution and Relative Importance of Common Bean Angular Leaf Spot in Subsistence Farming Systems in Southern Ethiopia

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Abstract

Angular leaf spot (ALS), incited by *Phaeoisariopsis griseola*, is one of the most destructive diseases of common bean in Ethiopia. Field surveys were conducted in southern Ethiopia during 2016 and 2016 cropping season to determine distribution, relative importance and association of bean ALS severity with cultural practices and environmental factors. A total of 190 common bean fields were inspected in five major bean-growing districts in both years. The association of ALS severity with independent variables was analyzed using logistic regression model. Angular leaf spot was widely distributed with variable importance among the surveyed districts. Common bean ALS severities of 61.38, 40.98, 28.63 and 13.94% were recorded in Burjdi, Konso, Demba Gofa and Mihirab Arbaya districts, respectively, compared to Arbamich areas. The year 2016 attained 11.35% disease severity that was higher than the severity in 2017 cropping season. District, cropping season, altitude, seed source, cropping system, planting date, fertilizer application, growth stage and weed infestation were very highly and significantly ($P<0.0001$) associated with ALS severity in a multiple variable model. High (>50%) disease severity was highly associated with Arbaminch, Mihirab Arbaya and Demba Gofa districts, <2000 altitude ranges, poorly prepared farms, farm saved and local market seed sources, intercropping systems, pre-flowering to pod forming growth stages in 2016 cropping season. Also, early planting, none to less level of fertilizer application and high weed infestation contributed to high disease severity in the model. Conversely, low disease severity had strong association with the remaining variables in 2017. Survey results demonstrated that ALS was a major bean production constraint in the study areas and, thus, comprehensive and effective management options should be targeted to sustain bean productivity in the study areas and other locations having similar agro-ecologies.

Keywords: Angular leaf spot, common bean, cultural practices, environmental factors, *Phaeoisariopsis griseola,* severity.

Introduction

Amongst the legume crops grown in Ethiopia, common bean (*Phaseolus vulgaris* L.) is ranked as one of the most well-known crops both in production and household consumption. Apart from serving as a staple food (a good source of protein, carbohydrates, vitamins, minerals, such as iron and zinc, and low glycemic index), it is also providing cash to farmers and traders. In addition, it has a good foreign exchange potential and earn foreign currency from export markets (Buruchara et al. 2011; Romero-Arenas et al. 2013; Suárez-Martínez et al. 2015). The global total production of common bean was 22.8 million metric tons of dry beans in 2014 (FAOSTAT 2014). Also, bean production constituted about 32.25% land and 26.65% share of production from pulse cultivation in Ethiopia, of which 8.45 million tons of annual production is reported from 673,847.61 hectares of land in the country in 2016. Similarly, common bean covered 186,347.27 hectares of land with a total production of 0.16 million tons in southern Ethiopia, implying for the potential of common bean production in the region (CSA 2017).

However, productivity in the region (0.88 t ha^{-1}) is far lower than the national average (3.291 t ha^{-1}) bean yield (CSA 2017). Diseases, insect pests, weeds, poor soil fertility and farm management systems and insufficient supply of improved seeds are the most important factors that constrained bean production in Africa (Allen et al. 1989). Such production challenges are known to cause significant yield reductions in its production (Christensen et al. 2007; Miklas et al. 2007; Mwangombe et al. 2007; Suriyagoda et al. 2010). Of diseases, bean angular leaf spot (ALS), caused by *Phaeoisareopsis griseola*, is widely distributed in the tropics and subtropics of major bean-producing counties, including Australia, Brazil, Burundi, Democratic Republic of Congo, Ethiopia, Kenya, Mexico, Rwanda, Tanzania, Uganda and USA (Ferreira et al. 2000; Mahuku et al. 2002; Lemessa et al. 2011).

A yield loss that reached up to 80% had been reported on susceptible common bean genotypes under severe conditions of infection (Stenglein et al. 2003; Mwangombe et al. 2007; Singh and Schwartz 2010). Yield losses of up to 61% have been reported in southern Tanzania (Mongi 2016). Recently, it has become a major production-limiting problem in southern Ethiopia. Recent reports also confirmed the existing challenges of the disease to both subsistence farmers and commercial producers in the country. Thus, it is important to have the whole picture of ALS with regard to factors that influence disease and the relative importance of ALS in the production systems of southern Ethiopia. Occurrence, epidemic development and severity of a disease is influenced by cropping systems and production practices, topographical features, crop genotypes, altitudinal ranges and cropping season and field management practices under a given environment (Zhu et al. 2000).

Assessing of different factors associated with disease development is important to obtain relevant data for gaining insight into the occurrence, distribution and relative importance of different crop diseases (Rusuka et al. 1997). Moreover, disease management requires a thorough understanding of all such factors which contribute to disease epidemics (Fininsa and Yuen 2001; Mwang'ombe et al. 2007; Ddamulira et al. 2014; Kijana et al. 2017). However, detail information on the distribution, relative importance and how the different cropping practices and environmental factors affect ALS epidemics is lacking in the study areas. Yet, reliable information on ALS epidemics is a prerequisite for the development of feasible interventions and to develop effective integrated management options. Generating knowledge about the associations between the disease and different biological and environmental factors through comprehensive survey is considerable significant. Therefore, the objectives of this study were to: 1) determine the distribution and relative importance of bean ALS; and 2) determine the association between ALS severity and cropping systems and environmental factors in subsistence common bean production systems of southern Ethiopia.

Materials and Methods

Description of the surveyed areas

Angular leaf spot surveys were conducted in five major common bean-growing districts of southern Ethiopia in 2016 and 2017 main cropping seasons. The districts assessed for ALS severity and other field management practices and environmental factors were Arbaminch, Mihirab Arbaya, Demba Gofa, Konso and Burjdi. The districts were purposively selected for their potential for bean production, altitudinal and weather (monthly average temperature and total rainfall) variation (Figure 1). The areas are characterized by a bimodal rainfall distribution. The short rainy season is starting from mid-March to early May and the long rainy season is from mid-June to late November. The altitude in the inspected areas ranged from 801-2600 meter above sea level (m.a.s.l.). Surveyed areas and their respective geographic locations are shown hereunder (Figure 2). A total of 190 common bean fields were assessed over the two years.

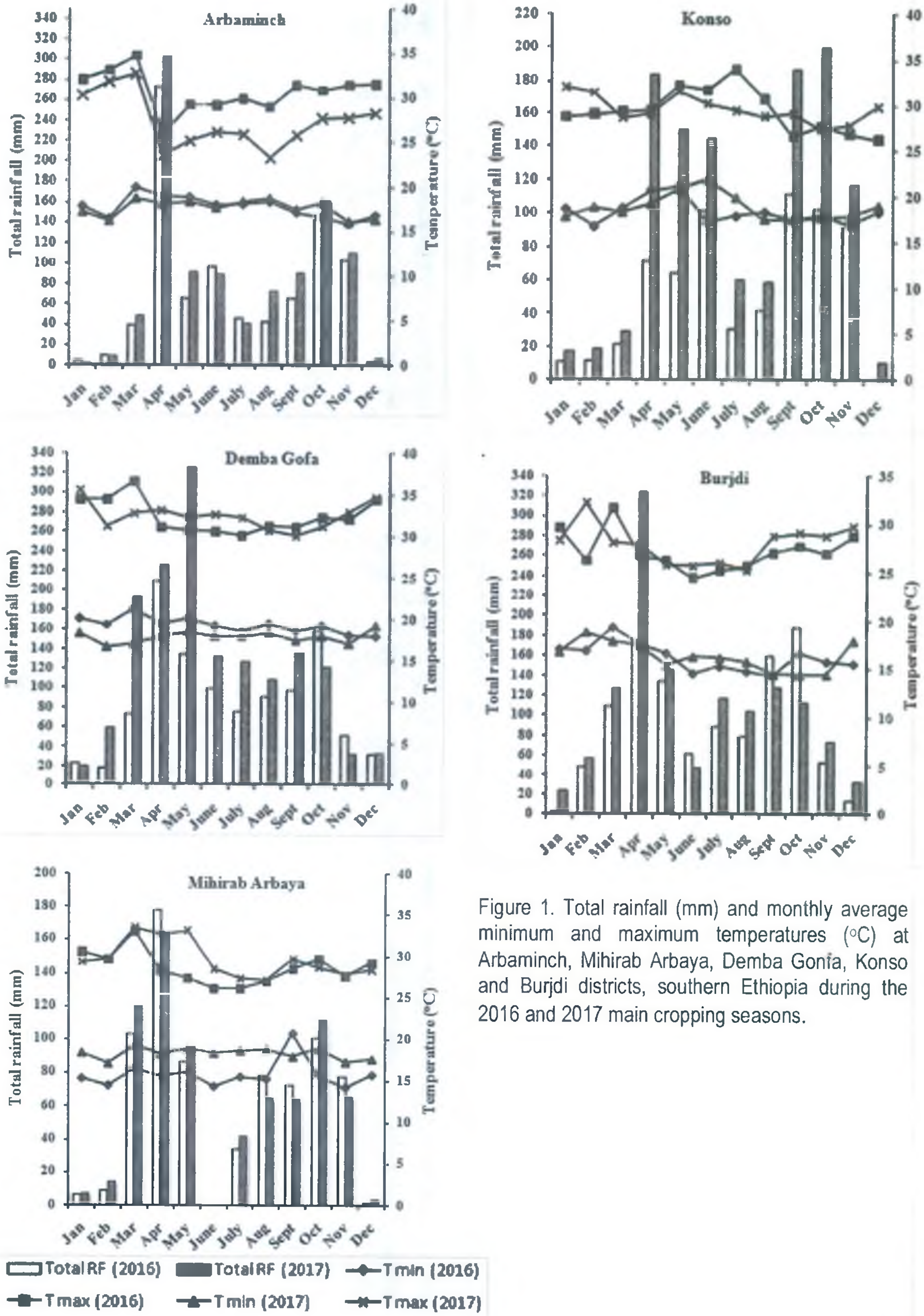

Figure 1. Total rainfall (mm) and monthly average minimum and maximum temperatures (°C) at Arbaminch, Mihirab Arbaya, Demba Gonfa, Konso and Burjdi districts, southern Ethiopia during the 2016 and 2017 main cropping seasons.

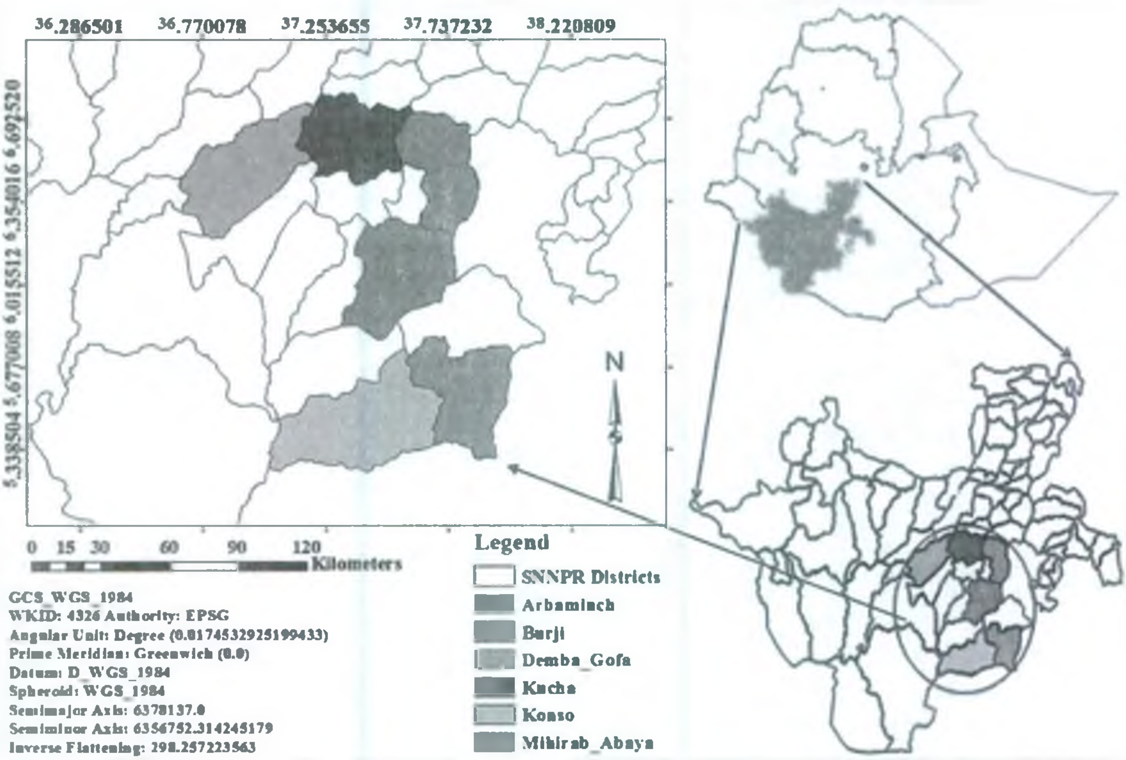

Figure 2. Map showing districts surveyed for angular leaf spot (*Phaeoisariopsis griseola*) of common bean in southern Ethiopia.

Survey Methodology

The survey was conducted by on-spot inspection of bean farms and by interviewing growers involved in bean production in the selected districts. The assessment was made with regard to the distribution and relative importance of ALS in each district. Common bean fields were randomly taken at an interval of 5 km along the main and accessible feeder roads. Within selected fields, four quadrats (2 m x 2 m) 10 to 15 m apart were sampled by making diagonal moves. All plants in each quadrat were served as sampling units. When it was necessary, the sample size (the number of observed fields per district) and sample units (the number of quadrats per field) were adjusted to suit the crop distribution and field size, respectively. The severity of ALS was recorded from each quadrat using proper assess methods.

Disease assessment

Common bean farms were inspected for ALS prevalence, relative importance among districts and severity. The prevalence of ALS was computed based on the presence and absence of the disease within the farms per district. Disease severity was recorded by estimating the percentage of leaf area damaged and it was assessed by visually examining trifoliate leaves of sampled plants within quadrats. In each quadrat, 12 plants were sampled and evaluated using a 1-9 scoring scale (van Schoonhoven and Pastor-Corrales 1987); where, 1 = no visible disease symptom and 9 = plants with 90% leaf area having lesions, associated with early leaf fall and death. The severity scores recorded were transformed into percentage severity index (PSI) using formula employed by Wheeler (1969).

$$PSI = \frac{\text{Sum of numerical ratings}}{\text{No. of plants scored x maximum score on scale}} x\ 100$$

In addition to disease data, altitude ranges, crop growth stages, cropping systems (sole cropping and intercropping), weeding practices and infestation levels, land preparation practices, bean genotypes grown, sources of seed, previous crops grown and fertilizer application were recorded for each field. Relative field location (latitude and longitude) and altitude (elevation) were recorded using a geographical positioning system (GPS). Similarly, crop growth stage was recorded as pre-flowering, flowering, pod forming and pod filling using CIAT (1987) phenology scale. Weed management practice was recorded as good weeding (any weed is removed or weed-free); intermediate weeding (few weeds are present) and poor weeding (no weeding practiced and/or high weed infestation occurred) by visual observations. Meteorological data, for the cropping years, of the districts were obtained from the nearest meteorological stations.

Data analysis

Descriptive analysis was done to describe the spatial and temporal distribution and relative importance of ALS severity across districts. Disease severity was classified into distinct groups of binomial qualitative data as described by Fininsa and Yuen (2001) and Sahile et al. (2008). Contingency tables of the disease severity and independent variables were built to represent the bivariate distribution of the fields according to data classifications (Tables 1 and 2). Class boundaries) were selected so that groups contained approximately equal totals; thus, the binary variable classes $\leq$ 50 and >50% were set for disease severity. Angular leaf spot severity was analyzed using the SAS software system (SAS 2009). The associations of mean disease severity with cultural practices and environmental factors were analyzed using a logistic regression model (Yuen 2006) through SAS procedure of GENMOD (SAS 2009). The importance of the independent variables was evaluated twice in relation to their effects on disease severity. First, the association of all the independent variables with ALS severity was tested in a single-variable model. Second, the association of an independent variable with ALS severity was tested when entered first and last with all the other variables in the model. Lastly, those selected independent variables that have significant association with disease severity were sequentially added to a reduced multiple-variable model (Yuen 2006).The parameter estimates and their standard errors were analyzed using the GENMOD procedure both for the single and multiple models. Deviance reduction and odds ratios were computed for each independent variable as it was added to the reduced multiple-variable model. The deviance, the logarithm of the ratio of two likelihoods, was used to compare the single- and multiple variable models. The difference between the likelihood ratio tests (LRTs) was used to examine the importance of the variable and was tested against the chi-square (χ^2) value (McCullagh and Nelder 1989).

Table 1. Categorization of variables used in analysis of distribution of bean angular leaf spot (*Phaeoisariopsis griseola*) epidemics in five districts (n = 190) of southern Ethiopia during 2016 and 2017 main cropping seasons

Variable	Variable class	Number of fields	Variable	Variable class	Number of fields
District	Arbaminch	35	Cropping system [c]	Sole cropping	75
	Mihirab Abaya	30		Intercropping	115
	Demba Gofa	40	Source of seed	Farm saved	102
	Konso	40		Local market	48
	Burjdi	45		Bureau of Agri.	40
Year	2016	78	Planting date	June	55
	2017	112		July	93
Altitude (m) [a]	≤ 1500	121		August	28
	1500 to 2000	48		September	14
	> 2000	21	Crop growth stage [d]	Pre-flowering	25
Land preparation [b]	Two times	42		Flowering	43
	Three times	114		Pod formation	54
	Four times	34		Pod filling	68
Bean genotype	Hawasa Dume	31	Weed infestation [e]	Low level	37
	Nasir	64		Medium level	66
	Awash 1	25		High level	87
	Local	24	Fertilizer application ($Kg\ ha^{-1}$)	No Fertilizer	57
	Buraburjdi	46		1 to 50	106
				51 to 100	27

[a]Areas with ≤ 1500, (1500, 2000] and >2000 m.a.s.l are classified as lowland, midland and highland, respectively, in Ethiopia. [b] Land preparation indicates frequencies of ploughing of land during bed preparation before seed sowing. [c] Intercropping refers to farms with bean plus maize and/or sorghum and/or banana and/or mango and/or papaya and/or trees. [d] Pre-flowering (R5) refers to appearance of the first flower bud; flowering is when the first flower opens; pod formation refers to appearance of the first pod and pod filling stage refers to the fist pod begins to fill, seed growth (CIAT 1987). [e] Weed infestation was recorded as low, medium and high level indicating weed free, few weeds and no weeding, respectively.

Table 2. Independent variable x disease contingency table for logistic regression analysis of bean angular leaf spot (*Phaeoisariopsisgriseola*) severity (%) in Southern Ethiopia, during 2016 and 2017 main cropping seasons

Variable	Variable class	Number of field	Disease severity (%)		Variable	Variable class	Number of field	Disease severity (%)	
			≤50	>50				≤50	>50
District	Arbaminch	35	12	23	Croppingsystem [c]	Sole cropping	75	51	24
	Mihirab Abaya	30	8	22		Intercropping	115	64	51
	Demba Gofa	40	23	17	Source of seed	Farm saved	102	40	62
	Konso	40	32	8		Local market	48	15	33
	Burjdi	45	40	5		Bureau of Agri.	40	20	20
Year	2016	78	36	42	Fertilizer application	No fertilizer	57	37	20
	2017	112	79	33	(Kg ha^{-1})	1 to 50	106	56	50
Altitude (m)[a]	≤ 1500	121	57	64		51 to 100	27	22	5
	1500 to 2000	48	40	8	Planting date	June	55	35	20
	> 2000	21	18	3		July	93	65	28
Land preparation [b]	Two times	42	20	22		August	28	11	17
	Three times	114	67	47		September	14	4	10
	Four times	34	28	6	Crop growth stage[d]	Pre-flowering	25	6	19
Common bean genotype	HawasaDume	31	15	16		Flowering	43	30	13
	Nasir	64	37	27		Pod formation	54	40	14
	Awash 1	25	11	14		Pod filling	68	39	29
	Local	24	11	13	Weed infestation[e]	Low level	37	25	12
	Buraburjdi	46	41	5		Medium level	66	37	29
						High level	87	53	34

[a]Areas with ≤ 1500, (1500, 2000] and >2000 m.a.s.l. are classified as lowland, midland and highland, respectively, in Ethiopia. [b] Land preparation indicates frequencies of plowing of land during bed preparation before seed sowing. [c] Intercropping refers to farms with bean plus maize and/or sorghum and/or banana and/or mango and/or papaya and/or trees.[d] Pre-flowering (R5) refers to appearance of the first flower bud; flowering is when the first flower opens; pod formation refers to appearance of the first pod and pod filling stage refers to the fist pod begins to fill, seed growth (CIAT 1987). [e] Weed infestation was recorded as low, medium and high level indicating weed free, few weeds and no weeding, respectively.

Results

General feature of surveyed fields

Different agro-ecologies, cropping systems, field management practices (nutrient management), land uses, gentle slope to rugged mountainous and amazing water-shade management systems were major characteristics of surveyed areas. Districts differed in altitude ranges in which 55.26, 33.16 and 11.58% of the assessed farms were located at <1500, 1500-2000 and >2000 m.a.s.l., respectively. Field sizes ranged from 2400 m^2 (Burjdi district) to 4100 m^2 (Demba Gofa district). The highest plant populations within 4 m^2 area were observed from farms in Demba Gofa and Burjdi districts.

Common bean genotypes grown in the areas were Nasir, Hawasa Dume, Awash 01, Buraburjdi and local cultivars (which are improved genotypes introduced to the farming systems in 20 to 30 years back). Farmers obtained the first four bean genotypes from Bureau of Agriculture (20.96%), local market (24.76%) and/or farm saved (recycled from previous cropping season). Farm saved seeds constituted about 54.28% of seed sources recorded. Farmers observed to practice sole cropping (39.05%) and intercropping (60.95%) systems. Maize, sorghum, banana, mango, papaya and some beneficial agro-forestry trees were associated with bean intercropping systems. But maize-bean intercropping was the most common system across districts. Farmers followed variable planting dates starting from June to September in response to the onset of precipitation. During the survey, pre-flowering, flowering, pod forming and pod filling growth stages were noted.

The majority of the farmers used to plough their farms twice or three or four times before planting. Though farmers used to rotate fields with cereals and legumes, the common cropping pattern observed was bean to bean at least for the last two to three years. Only 11.91% of farmers were using nitrogen-phosphorous-sulfur-boron (NPSB) blended fertilizer at a recommended rate (51-100 kg ha^{-1}), while 55.71 and 32.38% of farmers applied <50 kg ha^{-1} and none at all, respectively, in bean fields. Weeding was not as such very common. As a result, many weed species were registered, including *Amaranthus graecizans, Amaranthus spinosus, Amaranthus hybridus, Tagetes minuta, Ageratum conyzoides, Commelina latifolia, Xanthium sinuatum, Xanthium spinosus, Xanthium strumarum, Cyperus rotundus, Galinsoga parviflora* and others in different densities. In majority of inspected fields, ALS and common bacterial blight were prevalent in both cropping years. About 75.24% of bean farms were infected with ALS. But none of the farmers applied pest management practices.

Angular leaf spot distribution and relative importance

Different levels of angular leaf spot severity were recorded on five types of bean genotypes encountered among districts in 2016 and 2017 cropping years (Table 3). Mean angular leaf spot severity of 59.06, 50.83, 42.15, 34.86 and 22.81% were observed at Arbaminch, Mihirab Abaya, Demba Gofa, Konso and Burjdi districts, respectively, in the two years. A maximum range of mean disease severity was recorded from Mihirab Abaya (35-66%), followed by Arbaminch (54.14-63%) areas, while the lowest (8.33-37.28%) range of mean disease severity was obtained from Burjdi district in both cropping seasons.

In all fields surveyed in each district, common bean plants were infected with angular leaf spot except a few fields mainly in Burjdi, followed by Konso district. In this regard, bean cultivation at Burjdi, Konso, Demba Gofa and Mihirab Arbaya districts reduced angular leaf spot mean severity by 61.38, 40.98, 28.63 and 13.94%, respectively, as compared to bean farming at Arbaminch district. Likewise, disease severity in three of the districts was higher in 2016 than in 2017, except Konso and Burjdi districts where the reverse was marked. But, the overall observations demonstrated that growing conditions in 2017 reduced angular leaf spot severity by 11.35% in comparison to cropping conditions in 2016. Many bean farms assessed would fall at altitudinal ranges of ≤1500 and 1500-2000 m.a.s.l., where maximum mean disease severity values were recorded from.

Table 3. Distribution of angular leaf spot (*Phaeoisariopsis griseola*) in five major bean growing districts of southern Ethiopia, during 2016 and 2017 main cropping seasons

District	Year	Total number of fields assessed	Angular leaf spot severity (%) ± SE[a]	Probability value
Arbaminch	2016	18	63.97 ± 6.27	<0.0001
	2017	17	54.14 ± 8.52	<0.0001
	Mean		59.06 ± 7.40	
Mihirab Arbaya	2016	17	66.32 ± 6.25	0.0001
	2017	13	35.34 ± 8.81	0.0017
	Mean		50.83 ± 7.53	
Demba Gofa	2016	20	51.72 ± 2.42	<0.0001
	2017	20	32.57 ± 6.84	0.0001
	Mean		42.15 ± 4.63	
Konso	2016	15	31.98 ± 6.41	0.0002
	2017	25	37.75 ± 5.51	<0.0001
	Mean		34.87 ± 5.96	
Burjdi	2016	8	8.33 ± 8.33	0.3506
	2017	37	37.28 ± 3.95	<0.0001
	Mean		22.81 ± 6.14	

[a] SE = standard error of mean angular leaf spot severity.

Association of bean angular leaf spot with cultural practices and environmental factors

The association of all independent variables with bean angular leaf spot is presented (Table 4). The independent variables, such as cropping year, district, altitude range, seed source, cropping system, fertilizer application, planting date, growth stage and weed infestation levels were very highly and significantly ($P<0.0001$) associated with ALS mean severity when entered into the logistic model as single variable. Also, land preparation showed highly significant ($P<0.0003$) relationship with ALS mean severity when entered first into the model. However, bean genotypes grown showed non-significant relationship with disease severity in the model. On the other hand, when all variable entered last into the regression model, all independent variables found very highly ($P\leq0.0001$) significant in their association with bean ALS mean severity, except land preparation, which showed only highly significant ($P<0.0065$) association. Among the independent variables district (χ^2= 803.53, 4df), altitude (χ^2= 686.46, 2df), weed infestation (χ^2= 250.80, 2df) and planting date (χ^2= 139.50, 3df) were the most important variables in their association with mean disease severity when entered first and last into the model.

Table 4. Logistic regression model for bean angular leaf spot (*Phaeoisariopsis griseola*) severity (%) and likelihood ratio test on independent variables in Southern Ethiopia, during 2016 and 2017 main cropping seasons

Independent variable	df	Angular leaf spot severity, LRT [a] Type 1 analysis (VEF)		Type 3 analysis (VEL)	
		DR	$Pr>\chi^2$	DR	$Pr>\chi^2$
District	4	803.53	<0.0001	169.52	<0.0001
Year	1	68.17	<0.0001	19.73	<0.0001
Altitude (m)	2	686.46	<0.0001	522.19	<0.0001
Land preparation	2	16.26	0.0003	10.08	0.0065
Seed source	2	58.00	<0.0001	22.88	<0.0001
Common bean genotype	4	6.86	0.1436	32.24	<0.0001
Fertilizer app. (Kg ha^{-1})	2	34.67	<0.0001	52.81	<0.0001
Planting date	3	139.50	<0.0001	109.88	<0.0001
Crop growth stage	3	58.24	<0.0001	44.75	<0.0001
Cropping system	1	56.49	<0.0001	53.51	<0.0001
Weed infestation	2	250.80	<0.0001	250.80	<0.0001

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

However, all independent variables were tested in a reduced multiple-variable regression model and the results for analysis of deviation for variables and variable classes are presented (Table 5). The output from this reduced model indicated the importance of all the variables and variable classes considered. The parameter estimates, standard error and odds ratio are presented (Table 5). The probability of high (>50%) mean disease severity was highly associated with Arbaminch, Mihirab Arbaya and Demba Gofa districts, low to mid altitudinal ranges, poorly prepared farm lands or seed beds, seeds sourced from farm savings and local markets, pre-flowering to pod forming growth stages and the 2016 cropping season.

Bean cultivation at Arbaminch and Mihirab Arbaya districts, and on pre-flowering growth stage had twice high probability of association with mean disease severity as compared to planting at Burjdi and on pod filling stages, respectively. With regard to altitude ranges, farms relatively at low (<1500) and mid (1500-2000) altitudes showed a 4 and 6 times higher probability of association with angular leaf spot mean severity than farms at high altitudes, respectively. Though inconsistent, bean genotypes, intercropping, fertilizer application practices, weed infestation levels and planting dates had significant association with angular leaf spot severity. And local bean genotype planted early in June without any fertilizer application with high weed infestation demonstrated strong association with high angular leaf spot severity.

On the contrary, late Buraburjdi genotype (obtained from Bureau of Agriculture) planting on well and frequently ploughed farms at high altitudes in sole cropping systems at Burjdi and Konso districts complied with low (<50%) angular leaf spot mean severity in the 2017 cropping season. Moreover, farm weeding practices and fertilization with a recommended rate (51-100 kg ha^{-1}) of blended inorganic fertilizer, peak reproductive growth stage had high probability of association with low disease mean severity in the same cropping season.

Discussion

Angular leaf spot is a major constraint of common bean production in bean-growing areas (Sartorato and Alzate-Marin 2004; Damasceno-Silva et al. 2008), including eastern Africa (Mwang'ombe et al. 1994; Wortmann et al. 1998). In the surveyed areas, the disease was widely distributed on 75.24% of assessed farms. However, spatial distribution and relative importance of ALS varied across districts. Arbaminch (59.06%) and Mihirab Arbaya (50.83%) areas scored the maximum mean disease severity of 59.06 and 50.83%, respectively, compared to Demba Gofa (42.15%), Konso (34.86) and Burjdi (22.81%) districts. Also, 11.35% disease severity was recorded in 2016 which is higher disease severity than 2017. Such variation could partly be attributed to differences in ecological locations and weather variables (Figure 1). Similarly, variable disease parameters were recorded across surveyed fields in Kenya (Mwang'ombe et al. 2007; Leitich et al. 2016), Uganda (Ddamulira et al. 2014) and Congo (Kijana et al. 2017).

Table 5. Analysis of deviance, natural logarithms of odds ratio and standard error of bean angular leaf spot (*Phaeoisariopsis griseola*) severity (%) and likelihood ratio test on independent variables in reduced regression model in southern Ethiopia during 2016 and 2017 main cropping seasons

Added variable	Residual deviance [a]	df	Angular leaf spot, LRT [b]		Variable class	Estimate Log_e (odds ratio) [c]	SE	Odds ratio
			DR	Pr>χ^2				
Intercept	8623.87	0	17.84			-0.5967	0.1413	0.551
District	7820.34	4	26.00	<0.0001	Arbaminch	0.7485	0.1468	2.114
			34.71	<0.0001	Mihirab Arbaya	0.8498	0.1442	2.339
			7.85	0.0051	Demba Gofa	0.3893	0.1389	1.476
			21.02	<0.0001	Konso	-0.4422	0.0965	0.643
			-	-	Burjdi	0*	.	.
Year	7752.17	1	38.97	<0.0001	2016	0.2493	0.0399	1.283
			-	-	2017	0*	.	.
Altitude (m)	7065.71	2	118.30	<0.0001	<1500	1.3726	0.1262	3.946
			483.49	<0.0001	1500-2000	1.8548	0.0844	6.390
			-	-	>2000	0*	.	.
Land preparation	7046.01	2	1.78	0.1823	Two times	0.1039	0.0779	1.109
			3.43	0.0639	Three times	0.1011	0.0546	1.106
			-	-	Four times	0*	.	.
Fertilizer app. (Kg ha^{-1})	6947.64	2	13.20	0.0003	None	-0.2523	0.0694	0.777
			46.24	<0.0001	1 to 50	-0.4097	0.0603	0.664
			-		51 to 100	0*	.	.
Common bean genotype	6752.30		9.54	0.0020	Hawasa Dume	-0.2805	0.0908	0.755
			9.61	0.0019	Nasir	-0.2382	0.0768	0.788
			11.88	0.0006	Awash 1	-0.2793	0.0810	0.756
			0.55	0.4567	Local	-0.0614	0.0825	0.940
			-	-	Bura burjdi	0*	.	.
Seed source	6984.60	2	3.42	<0.0001	Farm saved	0.2164	0.0566	1.242
			17.22	0.0012	Local market	0.1046	0.0497	1.110
			-	-	Bureau of Agr.	0*	.	.
Planting date	6811.86	3	53.31	<0.0001	June	-0.6855	0.0939	0.504
			99.37	<0.0001	July	-0.8765	0.0879	0.416
			98.28	<0.0001	August	-0.8243	0.0831	0.439
			-	-	September	0*	.	.
Growth stage	6752.30	3	45.03	<0.0001	Pre-flowering	0.4558	0.0679	1.577
			36.30	<0.0001	Flowering	0.3168	0.0526	1.373
			0.51	0.4766	Pod formation	0.0330	0.0463	1.034
			-	-	Pod filling	0*	.	.
Cropping system	6703.07	1	62.53	<0.0001	Sole cropping	-0.3930	0.0497	0.675
			-	-	Intercropped	0*	.	.
Weed infestation	6460.51	2	197.10	<0.0001	Low level	-0.8226	0.0586	0.439
			3.96	0.0465	Medium level	-0.0928	0.0466	0.911
			-	-	High level	0*	.	.

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

District-wise ALS severity variation could also be due to altitudinal ranges. About 88.42% of the farms assessed were found below 2000 m.a.s.l. and showed high probability of association with high ALS severity. Low altitudes are characterized by warm temperatures and high relative humidity, which could enhance the onset and development of ALS in the study areas. This could also explain absence of severe ALS at Burjdi, which is located at high altitude. Results of surveys conducted in Uganda (Ddamulira et al. 2014) and Kenya (Mwang'ombe et al. 2007) confirmed the presence of high ALS incidence and severity at altitudes <2000 m.a.s.l. and vice versa. Otherwise, cold temperatures delay the development of ALS epidemics (Correa-Victoria et al. 1989). Thus, intermittent wet and dry conditions during the growing period could further aggravate sporulation and infection of *P. griseola* and subsequent ALS development. Similar studies by Stenglein et al. (2003) and Adikshita (2012) might assure our findings where ALS is favored by moderate to warm temperatures (Pria et al. 2003; Gupta et al. 2005; Jackson 2017).

Land preparation alone is not an independent factor to influence ALS establishment. But four times tillage during land preparation before planting reduced ALS severity by 54.94% compared to twice prepared bean fields. However, only 18.95% of bean farmers prepared their farms four times before planting. In addition, farmers were observed practicing bean to bean cropping patterns and depended heavily on uncertified seeds of local varieties obtained from own farm savings (54.28%). Continuous bean planting on same field and adopting farm saved seeds from previous cropping season registered the highest ALS prevalence and intensity in Kenya (Mwaniki 2002; Wachenje 2002). Tillage disturbs bean residue on the field and could also increase plant health by stimulating root growth and decreasing inoculum of pathogen populations in the soil (Hall and Nasser 1996). That is, absence of tillage might result in high incidence and severity of bean diseases (Krupinsky 2002).

Low ploughing frequency, dependency on local seed sources and continuous sole cropping year after year might boost the buildup of primary inoculum from bean debris and infected seeds, which are responsible for primary infection and development of ALS. In this regard, *P. griseola* is noted to survive on infected crop debris over two winters and the stroma that form in lesions allow the pathogen to remain dormant until environmental conditions are favorable for sporulation (Monda et al. 2001; Celletti et al. 2006). Own seed sources and supplementary germplasm obtained from informal markets result in inoculum accumulation, which significantly contributes to ALS development in field conditions (Mwaniki 2002; Wachenje, 2002). Thus, different scientists recommended the importance of tillage (Krupinsky et al. 2002; Karavina et al. 2011), debris elimination and crop rotation (Sartorato 2002; Stenglein et al. 2003), and use of certified seeds and field sanitation (Sartorato 2002; Wagara et al. 2003) to minimize risks of ALS severity.

Although agro-ecology, weather variables, land preparation (field hygiene) and seed sources greatly influenced ALS severity, continuous cropping with less or without inorganic fertilizer or any organic input results in a poor crop establishment, which predisposes the crop to severe disease damage (Mwang'ombe et al. 2007). However, only 11.91% of bean growers in the study areas applied NPS blended fertilizers. The rest farmers applied insufficient amount of inorganic fertilizer or fertilized their fields with crop residues. As a result, high level of ALS recorded across many of the farms assessed. That is, fertilization affects nutritional status and vigorosity of plants and indirectly affects the development of plant disease under field conditions (Oborn et al. 2003). And adequate fertility reduces plant stress, improves physiological resistance, and decreases diseases risks in different pathosystems (Dordas 2008; Veresoglou et al. 2013). On the other hand, field sanitation through residual management reduces pathogen inoculum and minimizes bean diseases risks (Gilbertson et al. 1990; Fourie 2002).

The study showed that planting date and associated crop developmental stages influenced ALS epidemics. Several studies also confirmed that planting date and crop phenology had correlation with epidemic development of various diseases (Bhardwaj et al. 1994; Fininsa and Yuen 2002; Fourie 2002). Bean planting starting from late June to August and subsequent growth stages, such as pre-flowering, flowering and pod formation, had high association with higher ALS severity than late planting and pod filling growth stages. Similarly, Gupta and Shyam (1988) reported that the disease often assumes epiphytotic proportions during the months of July and August and reduces potential yields. This implies that planting in June to August could bring the crop to pre-flowering to pod formation stages and characterized by warm and moist weather conditions. Such conditions enhance spore germination, initiate infection, reproduction and disease development; and subsequently, premature defoliation and severe yield loss (Correa-Victoria et al. 1989; Saettler 1991; Mwang'ombe et al. 1994; Adikshita 2012).

The prevalence and severity of bean diseases vary with cropping practices. About 60.95% of bean farms were intercropped. However, intercropping systems did not show significant variation as compared to sole cropping in ALS severity. But inconsistent results with regard to effect of cropping systems on ALS incidence and severity have been reported (Van Rheenen et al. 1981; Boudreau 1993; Vieira et al. 1999; Fininsa 2003; Altieri et al. 2005). For instance, Boudreau (1993, 2013) observed that bean-maize intercropping lead to reduce disease parameters of ALS by declining foraging sites and impeding free transfer of spores due to the presence of maize. Intercrops could also reduce plant population and modify microclimate and consequently hampered rust and common bacterial blight in bean-maize intercrops (Fininsa 1996), common bacterial blight in bean-sorghum intercrops (Hailu et al. 2015) and rust and chocolate in faba bean-maize intercrops (Terefe et al. 2015).

On the contrary, mean disease severity values were relatively severe in intercrops (46.88%) compared to sole crops (40.04%) in the two years. Similar findings were reported by several authors (Vieira 1999; Vieira et al. 2009; Kijana et al. 2017). This could be due to the fact that the mechanism of intercropping might not be effective once the disease infects the crop. On the other hand, associated crops such as maize, sorghum, banana, mango, papaya and some trees in bean intercrops could modify microclimates under the canopy towards a temperature and moisture level that would favor infection and development of bean ALS. In line with this, Kijana et al. (2017) noted severe ALS severity in bean intercrops. The component crops might have created conducive microclimate, including intermittent warm, wet and dry conditions under the canopies, which favor ALS infection and establishment (Pria et al. 2003; Celetti et al. 2006; Mugisha 2008; Ddamulira et al. 2014).

Angular leaf spot was also found severe in moderately to highly weed infested bean farms assessed in both cropping years. However, only 21.58% of assessed farms were apparently weed-free, implying that most of the inspected farms were weedy and farmers did not practice weeding. As a result, highly weed infested fields increased ALS severity, on average, by 20.52% compared to weed free fields. Many of the weed species recorded were aggressive competitors for available soil nutrients, space, light and moisture that would later reduce crop vigor and make the crop prone to infection (Sahile et al. 2008; Belet et al. 2013; Yimer et al. 2018). Dense weed population could also enhance relative humidity and warmness of the microclimate under the crop canopy, which would favor onset, infection and development of ALS (Stenglein et al. 2003; Gupta et al. 2005; Adikshita 2012; Ddamulira et al. 2014).

The logistic regression model used in the analysis of the survey data demonstrated that district, cropping year, altitude ranges, land preparation practices, seed sources, bean genotypes, crop growth stages, common bean genotypes, weed infestation levels, fertilizer application and cropping systems were associated with ALS and were important. These variables had significant contributions to the development of epidemics with varying levels alone or in combination. The model quantified the relative importance of independent variables (also variable classes), implying that ALS epidemics was the function of these variables. Some of the variables were more important to reduce or enhance ALS development than others (Tables 4 and 5).

Conclusions

Results of this study revealed that ALS is one of the most important yield constraining diseases of common bean in southeast Ethiopia. The study identified that ALS severity and relative importance varied among districts, between cropping years, altitudinal ranges and other biophysical factors. The study suggested the importance of repeated land preparation and inorganic fertilizer application at a recommended rate in relation to crop residue management to reduce inoculum buildup and increase crop vigor. Proper weeding practice along with other crop management tactics would reduce disease risks and sustain bean productivity. Late planting date was also identified as an alternative option to escape coincidence of susceptible growth stages with warm and moist weather variables that favor ALS development. Seed recycling was observed as one of the most probable reasons for high ALS severity in most of the studied districts. Thus, strong and certified or clean seed supply system would reduce dependence on local sources and local varieties, supported with other disease management practices, should be considered to minimize ALS risks and maintain bean production and productivity in the study areas and elsewhere with similar agro-ecologies.

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