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PREVALENCE OF ANGULAR LEAF SPOT DISEASE AND SOURCES OF RESISTANCE IN COMMON BEAN IN EASTERN DEMOCRATIC REPUBLIC OF CONGO

R. KIJANA, M. ABANG¹, R. EDEMA², C. MUKANKUSI¹ and R. BURUCHARA³

National Institute for Study and Agronomic Research (INERA), Mulungu, D/S Bukavu, South Kivu, Democratic Republic of Congo

¹International Centre for Tropical Agriculture (CIAT), P. O. Box 6247, Kampala, Uganda

²College of Agricultural and Environmental Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda

³International Centre for Tropical Agriculture (CIAT), P. O. Box 823, Nairobi, Kenya

Corresponding author: c.mukankusi@cgiar.org

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ABSTRACT

Angular leaf spot (*Pseudocercospora griseola* Crous U, Brown) is one of the most important diseases hindering common bean (*Phaseolus vulgaris* L.) production in the Great Lakes Region of Africa, including the Democratic Republic of Congo. The disease causes extreme yield losses, estimated at 384.2 tonnes per year, in Sub-Saharan Africa. Little is known about the distribution, severity and incidence of the disease and the effect of agronomic practices and environmental factors on the disease prevalence in the country to facilitate interventions. A field survey was conducted during two crop seasons, February to June and September to January, in two main beans growing zones of eastern DRC namely; sub-humid highland and sub-humid mid altitude at low latitudes, in South and North Kivu, respectively. Severity and incidence of angular leaf-spot and other occurring diseases were assessed on common bean plants in farmers' fields. Angular leaf spot in these fields had an average severity index (PSI) of 49.9%. PSI was significantly different ($P < 0.05$) between districts and seasons. Using multiple regression analysis, independent variables: growth stage, cropping system, districts and altitude were shown to have significant influence on the observed PSI ($P < 0.05$) with $R^2 = 96.2\%$. The highest severity (PSI=59.7%) was observed in Kabare district, and the lowest in Uvira district (PSI=39.5%). Screening of a set of 37 released common bean varieties in DRC using virulent Andean and Mesoamerican isolates identified four resistant bean varieties; ARA 4, COD MLV 059, MLV 224/94B, LSA 144 and Mexico 54. Some of these varieties possess useful traits, in addition to acceptable seed market class, and are hence recommended as suitable parents for ALS resistant variety development and promotion in ALS prone environments.

Key Words: *Phaseolus vulgaris*, *Pseudocercospora griseola*, severity

RÉSUMÉ

La tache angulaire (*Pseudocercospora griseola* Crous U, Brown) est l'une des maladies les plus importantes qui entravent la production de haricot commun (*Phaseolus vulgaris* L.) dans la région des Grands Lacs d'Afrique, y compris la République Démocratique du Congo. La maladie provoque des pertes de rendement extrêmes, estimées à 384.2 tonnes par an en Afrique Sub-Saharienne. Il y a encore peu de connaissance sur la distribution, la gravité et l'incidence de la maladie et l'effet des pratiques agronomiques et des facteurs environnementaux sur la prévalence de la maladie dans le pays pour faciliter les interventions. Une enquête sur le terrain a été menée pendant deux saisons de récolte, de Février à Juin et de Septembre à janvier, dans deux zones principales de culture

de haricots de l'est de la RDC, à savoir: Sous-humides de haute altitude et sous-humides à basse altitude, au Sud et au Nord-Kivu. La gravité et l'incidence de la tache angulaire des feuilles et d'autres maladies ont été évaluées sur les plants de haricots dans les champs des agriculteurs. Ces champs étaient infestés par la maladie, avec un indice de gravité moyen (IPS) de 49.9%. PSI était significativement différent ($P < 0.05$) entre districts et saisons. En utilisant l'analyse de régression multiple, les variables indépendantes: stade de croissance, système de culture, districts et altitude ont montré une influence significative sur le PSI observé ($P < 0.05$) avec $R^2 = 96.2\%$. La sévérité plus élevée (PSI = 59.7%) a été observée dans le district de Kabare et la plus faible dans le district d'Uvira (PSI = 39,5%). La sélection d'un lot de 37 variétés de haricot distribuées en RDC utilisant des isolats virulents Andins et Mésoaméricains a permis d'identifier quatre variétés de haricots résistants; ARA 4, COD MLV 059, MLV 224 / 94B, LSA 144 et Mexique 54. Certaines de ces variétés présentent des traits utiles en plus de son acceptabilité sur le marché des semences, et sont donc recommandés comme des parents appropriés pour le développement et la promotion des variétés résistantes ALS.

Mots Clés: Phaseolus vulgaris, Pseudocercospora griseola, sévérité

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is grown in diverse environmental conditions in the sub-Saharan Africa. The Democratic Republic of Congo is among the main producers and consumers of the crop in the region (Wortmann *et al.*, 1998; Katungi *et al.*, 2009), with bean production estimated at 248,957 metric tonnes annually (FAO, 2010). The Eastern part of the country provides more than half of the country's bean production (USAID 2010; FAO, 2014).

However, common bean yields remain low at farmer level, averaging 0.3 t ha^{-1} (CIALCA, 2009) to 0.542 t ha^{-1} (FAO STATS, 2012), though potential yield in the country ranges between $1000\text{-}2500 \text{ kg ha}^{-1}$ for bush beans and $1500\text{-}4000 \text{ kg ha}^{-1}$ for climbing beans (Mbikayi, 2002).

Production is hampered by many diseases including angular leaf spot (ALS) caused by *Pseudocercospora griseola* Crous U, Brown (Crous *et al.*, 2006). Angular leaf spot is a major limiting factor for bean production, in eastern and central Africa, where losses of 374,800 tonnes annually have been reported (Wortmann *et al.*, 1998). Pyndji (1992) reported yield losses of up to 80% attributed to ALS in DRC.

Various production practices and variation in climatic conditions are thought to influence disease occurrence, epidemics development

and damage to the crops, under field conditions (Stenglein *et al.*, 2003; Allarent and Savary, 2005; Mwangombe *et al.*, 2007).

Several management practices such as growing varietal mixture and intercropping have been used to control the disease (Wortmann *et al.*, 1998; Busogoro *et al.*, 1999; Mahuku *et al.*, 2002), and the effect of management practices, especially, intercropping/cropping system on the diseases incidence or prevalence has been documented (Boudreau, 1993; Fininsa and Yuen, 2002; Fernandez *et al.*, 2011). However, losses associated with high ALS disease epidemics still prevail (Yesuf and Sangchote, 2005) and have been shown to vary in different cropping systems (Schoeny *et al.*, 2010).

Resistant varieties have been suggested as a cost effective strategy to manage the disease at small scale farmer level (Pastor Corrales *et al.*, 1998; Busogoro *et al.*, 1999; Mahuku *et al.*, 2009). However, deployment of resistant varieties for the control of ALS requires understanding of others production factors, especially environmental, cultural and epidemiological, upon which the disease management can be anchored (Singh, 2007).

This study aimed at investigating the extent of ALS distribution, incidence, severity and the relationship of the disease parameters with management practices and agro ecological factors in eastern Democratic Republic of Congo (DRC).

MATERIALS AND METHODS

The study area. The study was conducted in two main beans agro-ecological zones in eastern Democratic Republic of Congo (DRC), in the Kivu Province. The two zones included i) the African Bean Production Environment II (AFBE2) 2, in the sub-humid highland areas of Walungu, Kabare and Uvira districts, and ii) AFBE7 in sub-humid mid-altitude at low latitudes in three districts, Rutshuru, Masisi and Lubero (Wortman *et al.*, 1998). They were selected based on their suitability and high potential for bean production; the sub-humid highlands (HL) at more than 1500 metre above sea level (masl) in AFBE 2 and the sub-humid mid-altitudes (MA) ranging between 1000-1500 m.a.s.l in AFBE 7 (Wortmann *et al.*, 1998).

In general, the Kivu highlands and North Kivu landscape are characterised by volcanic soils (Musila 2009; USAID, 2010; Walangululu *et al.*, 2011); while South Kivu is characterised by red clay like soils (Ross *et al.*, 2009). The rainfall in the Kivu region is bimodal; the main season extends from mid-September up to mid-January; and the short rain season starting mid-February up to mid-June. The mean rainfall ranges between 1500-1800 mm per annum (Walangululu *et al.*, 2011) and mean temperature in the Kivu province (eastern part) is 18 °C (Musila, 2009).

Prevalence of angular leaf spot. A field survey was conducted in June 2011 (short rainy season) and November 2012 (long rainy season) in South and North Kivu in eastern DRC. In each of the six districts, fourteen farmers' fields separated by about 5 Km, were randomly selected along the road or path within the village. These fields were assessed for ALS bean disease occurrence and severity; while walking, following "W" path within the field (Delp *et al.*, 1986; Crabb *et al.*, 1994).

Boundaries of one squared meter were delimited in each corner of the "W" and where the lines intersected in the middle. Five sampling points were selected, one in the

middle of the field and one at each of the corner in each field, following the "W" pattern. The incidence and severity of the major bean diseases was recorded in the delimited area, in addition to plant density, cropping system, grain type and weed status.

A total of 168 fields were assessed (2 agro-ecologies x 3 districts x 14 fields x 2 seasons). GIS data were recorded for each field.

Disease incidence was evaluated based on percentage of infected plants in a field (Schoonhoven and Pastor-Corrales, 1987), while severity was assessed using a 1 to 9 CIAT scale (Schoonhoven and Pastor-Corrales, 1998). Severity data were summarised, transformed into percentage severity index (PSI), which was calculated using the formula below (Sahile *et al.*, 2008).

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

ALS incidence and severity (PSI) were classified into distinct variable classes of binominal qualitative data, with class boundaries of <50% and > 50% for PSI, and <75% and > 75% for incidence. A contingency table of incidence and severity of the independent variables was generated to represent the distribution of fields according to data classification. Data were then subjected to analysis of variance, using GenStat software Version 13.0 and multiple linear regression analysis was performed using Microsoft Excel. Furthermore, diseased leaf samples showing ALS symptoms were collected on small and medium seeded (Mesoamerican) and on large seeded (Andean) plants for laboratory test and varieties screening.

Sources of resistance to ALS. Thirty seven common bean breeding lines (Table 1) sourced from the National Institute of Study and Agronomic Research (INERA), Mulungu in eastern DRC, were evaluated in a screen house at the International Centre for Tropical Agriculture (CIAT) station situated at the

TABLE 1. List and characteristics of common bean varieties sourced from INERA and screened for angular leaf spot resistance in eastern Democratic Republic of Congo

Varieties	Grain colour	100 seed weight (gms)	Size
MEXICO 54	Pink	-	Large
ARA 4	Red mottled	42	Large
CODMLV 059	Red mottled	45	Large
LSA 144	Red	19	Small
MLV 224/94B	Red	33	Medium
BRB 194	Red	35	Medium
CAL 143	Red mottled	-	Large
CNF 5520	Red mottled	49	Large
CODMLB 001	Purple mottled	29	Medium
MORE 88002	Yellow	28	Medium
AND 620	Red mottled	33	Medium
CODMLB 078	Cream	32	Medium
AFR 708	Red mottled	34	Medium
CODMLB 033	Red mottled	39	Medium
CODMLB005	Red mottled	35	Medium
G5686	Brown mottled	36	Large
HM-21-7	Red mottled	36	Large
NUA 99	Red mottled	35	Medium
NUA 100	Red mottled	36	Large
NUA 86	Red mottled	36	Large
NUA 92	Red mottled	38	Large
RWR 10	Red kidney	33	Medium
CODMLV 056	Purple mottled	38	Large
NUA 8	Red mottled	38	Large
M'SOLE	Brown	18	Small
NGUAKU-NGUAKU	Yellow	36	Large
NUA 91	Red mottled	37	Large
ACC 714	Black	14	Small
CAL 96	Red mottled	-	Large
CODMLV 052	Purple mottled	-	
K 131	Carioca	13	Small
KIANGARA	Yellow	29	Medium
MLB 49-89A	Black	22	Small
NAMULENGA	Black tattle	34	Medium
NUA 64	Red mottled	38	Large
NUA 93	Red mottled	35	Medium
RWR 2245	Red mottled	36	Large
RWR 362	Red	21	Small
VNB81010	Black	29	Medium
ZKA 93-10M/95	Yellow	26	Medium
ZKA 98-6M/95	Purple	15	Small

Large >36 gm 100 seeds⁻¹; medium >26 gm 100 seeds⁻¹; small < 25 gms 100 seeds⁻¹

National Agricultural Research Laboratories Institute, (NARL) - Kawanda, in Uganda.

The experiment was laid out as a randomised complete block design (RCBD) with three replications. In each replication, five seeds of each of the 37 breeding lines and three resistant checks; Mexico 54, G5686 and CAL 143 and one susceptible check; CAL 96 were planted in 5 litre plastic pots containing pre-sterilised soil.

Seventeen days after planting, two virulent isolates; SK 146, pathotype 57-39 and SK 126, pathotype 61-39 were used to challenge the 37 INERA common bean accessions and the four checks (Table 1). The isolates had been collected and isolated from diseased plants in South Kivu during the field survey, and given a unique identifier code (SK = South Kivu) and isolate number (SK 126). The pathotype numbers, 57-39 and 61-39 separated by dashes represent the degree of virulence based on binary analysis. In the case of SK 126 pathotype 61-39, the first number, 61 was obtained by adding the binary values of the susceptible Andean (large seeded) differential cultivars, each of which was given a letter: acdef: $1+4+8+16+32=61$. The second number, 39, was obtained by adding the binary values of

the susceptible Middle American cultivar (Pastor-Corrales *et al.*, 1998).

Inoculation and evaluation were conducted according to a protocol described by Pastor-Corrales *et al.* (1998). Disease evaluation on individual plants was done at 10, 13, 17, 19 and 21 days after inoculation, using a 1-9 CIAT standard rating scale (Schoonhoven and Pastor-Corrales, 1987), where 1= immunity (no visible symptoms) and 9 = very infected.

Data were subjected to ANOVA using GentStat Version 13.0 and the varieties were then classified according to their reactions to the disease with those scoring less than 3 being classified as resistant, 4-6 intermediate and 7-9 susceptible (Schoonhoven and Pastor-Corrales, 1987).

RESULTS

Disease incidence and severity. Angular leaf spot (ALS) was the most prevalent bean disease in over 95% of the fields. ALS incidence varied from 75 to 100% among the sampled fields, with over 98% of the farms having ALS incidence of more than 75% (Fig. 1). Rust, common bacterial blight (CBB), anthracnose (Anth), ascochyta (Asco) and Halo blight (HB)

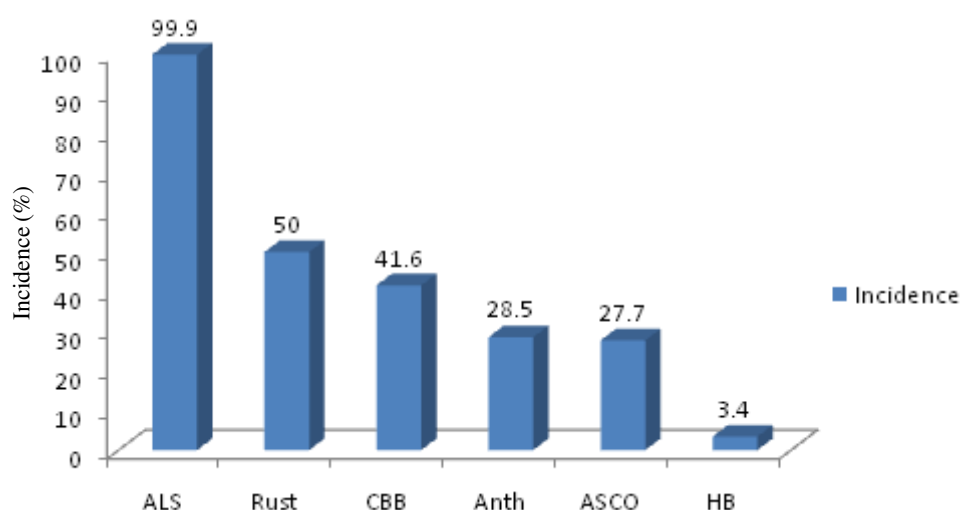


Figure 1. Incidence of six foliar bean diseases in two agro ecological zones of eastern Democratic Republic of Congo (2011 B).

were also observed with the high incidences in the order of 50, 41, 28.5, 27.7 and 3.4%, respectively (Fig. 1).

Angular leaf spot severity index (PSI) was generally high (mean = 49.7%) and varied significantly among districts ($P=0.04$) and, across growing seasons ($P=0.009$). There was a significant interaction between season and districts (Table 2). The maximum severity index (PSI) value of ALS disease was 79.8%; while the minimum was 24.5%. Mean severity

index (PSI) was high in Kabare district located in moderately high altitude (PSI=59.7%), while Uvira district located in low altitude had the lowest mean (PSI =39.5%). Across the two seasons, PSI was conversely low at very high altitudes. Similarly, across the two seasons, PSI was highest at high altitudes (Table 2 and Fig. 2).

A multiple regression model indicated that independent variables: season, district, altitude, growth stage and crop system significantly

TABLE 2. Percentage severity index (PSI) of Angular leaf spot in six districts of eastern Democratic Republic of Congo

No.	Districts	Agroecology	Mean PSI 2011 B	Mean PSI 2012 A	Combined mean PSI 2011/2012 ¹
1	Uvira	lowland	36.0	43.1	39.5 a
2	Rusthuru	lowland	42.1	52.4	47.2 b
3	Lubero	highland	46.1	51.4	48.7 bc
4	Walungu	highland	48.0	52.6	50.3 bc
5	Masisi	highland	56.7	49.6	53.2 c
6	Kabare	highland	57.8	61.6	59.7 d

¹ Number followed by the same letter in the same column are not significantly different ($P<0.05$)

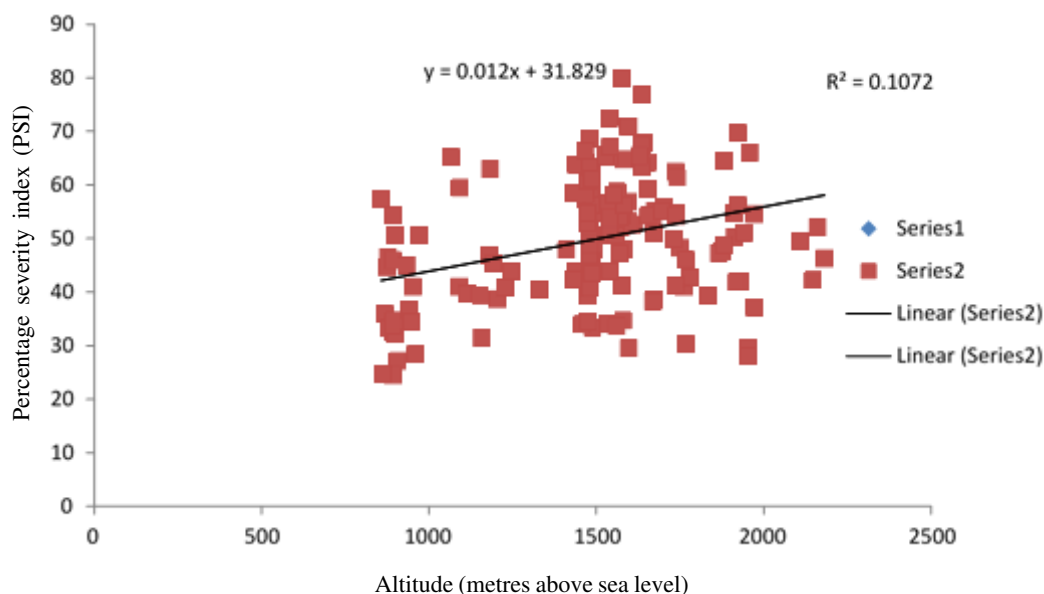


Figure 2. Effect of altitude on percentage severity index (PSI) of angular leaf spot in two agro ecological zones of eastern Democratic Republic of Congo.

contributed to ALS PSI, with $R^2 = 96.2\%$. The variables: growth stage, altitude, and districts were highly significant (Tables 2 and 3). A positive but, weak relationship was observed between precipitation and PSI ($r^2 = 10.7\%$), with areas receiving more than 1200 mm annual rainfall having higher PSI than those receiving less rainfall (Fig. 2). Angular leaf spot disease severity was slightly reduced in mono-cropping compared to intercropping systems (Tables 3 and 4)

Sources of resistance to ALS. Significant differences ($P < 0.001$) were observed among the test varieties for reaction to ALS disease (Tables 5 and 6). Among the 37 accessions tested, four (representing 10.81%) showed resistance, 13 (35.14%) intermediate and 23 (62.16%) susceptible reactions to the *P.*

griseola isolate SK 126, (pathotype 61-39) (Table 7). In the case of isolate SK 146 (pathotype 57-39), eight varieties (21.62%) were resistant, 19 varieties (51.35%) intermediate and 13 varieties (35.14%) susceptible (Table 8). Two bush bean lines, LSA 144 and ARA 4 and two climbing beans, MLV 224/94B and CODMLV 059 varieties showed resistance to the both *P. griseola* isolates (Tables 7 and 8). The ALS resistant check, Mexico 54 maintained resistance to the two isolates; while other varieties reported to be resistant in the region and elsewhere, e.g. variety CAL 143 (Aggarawal *et al.*, 2004) and G 5686 (Mahuku *et al.*, 2009) showed intermediate resistance with disease scores of 4 and 5 on a 1-9 scale. The susceptible check, CAL 96 proved highly susceptible to all isolates with a score 9 (Tables 7 and 8).

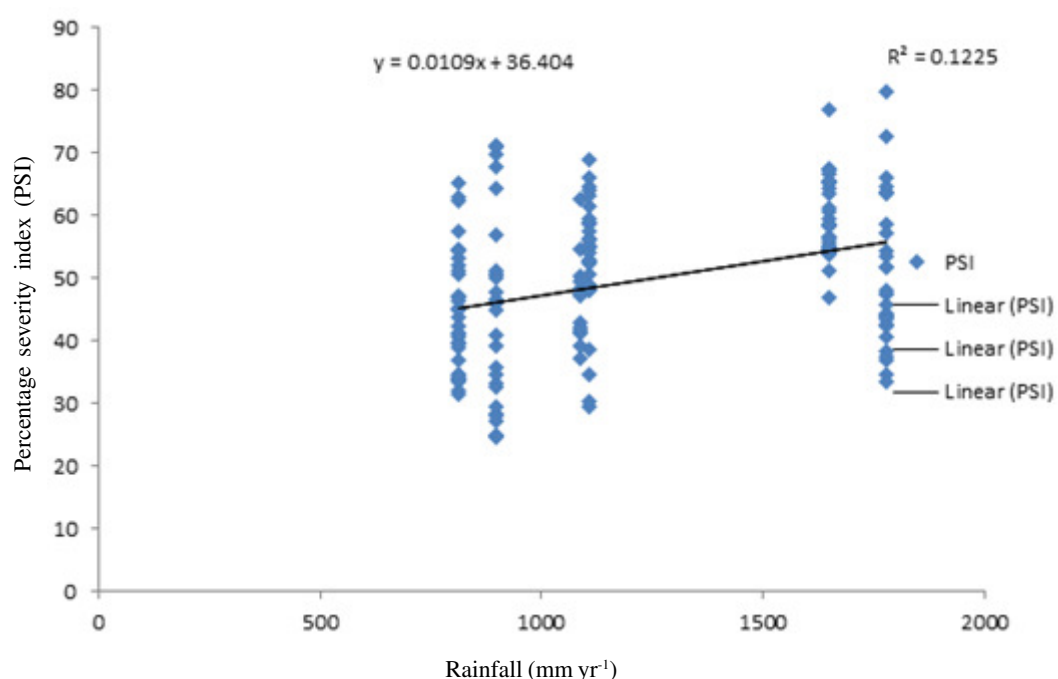


Figure 3. Effect of precipitation on percentage severity index (PSI) of angular leaf spot in two agro ecological zones of eastern Democratic Republic of Congo.

TABLE 3. Independent variable by disease contingency table of ALS for crop season 2011 and 2012 in eastern Democratic Republic of Congo

Variables	Variable class	*Number of fields with ALS			
		Incidence		Severity	
		<75%	>75%	<50%	>50%
Districts	Masisi	0	28	7	21
	Rusthuru	0	28	14	14
	Lubero	0	20	6	14
	Uvira	0	28	18	10
	Walungu	2	26	10	18
	Kabare	0	28	2	26
Altitude	<1200 masl	0	32	29	4
	>1200 masl	2	126	56	71
Plant density	<20 plants/m ²	0	83	45	38
	>20 plants/m ²	2	75	39	38
Crop system	Monocrop	1	40	26	14
	Intercrop	1	118	58	62
Weeds density	<70 weeds/m ²	1	46	26	23
	>70 weeds/m ²	1	112	60	53
Plant type	Climber	2	69	38	35
	Bush	0	89	48	41
Growth stage	Flowering	0	7	2	5
	Pre-podding	1	57	36	22
	Pod filling	1	94	36	21
Year/season	July 2011	2	84	51	33
	November 2012	0	76	33	43

*Total number of fields =160

TABLE 4. Regression coefficients, standard error and P value effects of different independent variables on PSI of 160 fields in eastern Democratic Republic of Congo

No.	Variables	Coefficients	Standard Error	TStat	P-value
1	Growth stage	4.94	1.35	3.66	0.00***
2	Altitude	9.84	3.29	2.98	0.00**
3	Districts	2.74	1.05	2.62	0.00**
4	Crop system	4.54	1.79	2.52	0.01*
5	Season	3.51	1.69	2.08	0.04*

R-Square = 96.2%

*significantly different at P=0.05

TABLE 5. Analysis of variance of severity (mode) values of Democratic Republic of Congo bean germplasm to isolate SK 146 in eastern Democratic Republic of Congo

Source of variation	DF	SS	MS	Fcal	F pr
Replication	2	0.15	0.07	0.27	
Varieties	40	697.17	17.43	61.15	<.001
Residual	79	22.51	0.28		
Total	121	709.38			

TABLE 6. Analysis of variance of severity (mode values) bean germplasm to isolate SK 126 in eastern Democratic Republic of Congo

Source of variation	DF	SS	MS	F pr
Replication	2	0.04878	0.02439	
Varieties	40	788.29268	19.70732**	<.001
Residual	80	5.95122	0.07439	
Total	122	794.29268		

TABLE 7. Mean score of resistant bean germplasm to ALS when challenged by isolate SK 126 in eastern Democratic Republic of Congo

Varieties	Mean of the modal scores per plot	Reaction	Grain colour	100 seedweight	Size
MEXICO 54	1.3	R ¹	Pink	-	-
ARA 4	2.0	R	Red mottled	42	Large
CODMLV 059	2.0	R	Red mottled	45	Large
LSA 144	2.0	R	Red	19	Small
MLV 224/94B	2.0	R	Red	33	Medium
CAL 96 (Susceptible check)	9	S	Red mottled	44	Large

R = Resistant

TABLE 8. Mean score of resistant bean germplasm to ALS when challenged by isolate SK 146 in eastern Democratic Republic of Congo

Varieties	Mean disease score (1-9)	Variety rank	Seed colour	100 seed weight	Size
CODMLV 059	1.9	R	Red mottled	45	Large
LSA 144	2.0	R	Red	19	Small
MEXICO 54	2.0	R	Pink	-	Medium
MLV 224/94B	2.0	R	Red	33	Medium
RWR 362	2.0	R	Red	21	Small
ZKA 98-6M/95	2.0	R	Purple	15	Small
ARA 4	3.3	R	Red mottled	42	Large
RWR 2245	3.3	R	Red mottled	36	Large
CAL 96 (Susceptible check)	9	S	Red mottled	44	Large

R = Resistant, S = Susceptible

DISCUSSION

Angular leaf spot evidently exists in the eastern Democratic Republic of Congo region. The study revealed that the disease is widespread across the different agro-ecological study zones. The high ALS prevalence, incidence (mean=99.6%) and severity (mean PSI=49.6), may be due to the farming practices adopted by smallholder farmers in the area; for instance use of poor quality farmer-saved seed (Njingulula, 2014), lack of crop rotation due to land scarcity, and poor management practices exacerbated by conducive environment conditions for disease development.

Cropping system. Regarding the influence of cropping systems on the prevalence of angular leaf spot, it is clear that the disease was slightly more severe under intercropping systems than the mono-cropping system. Crops such as maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz) and banana (*Musa* spp.) which were grown in association with common beans, may have created conducive microclimates, namely intermittent cool and warm, wet and dry conditions, respectively (Inglis and Hegedom, 1986; Saettler, 1991; Celetti *et al.*, 2006) under their canopies for ALS infection and disease development (Potts,

1990). Contradictory results were reported by Boudreau (1993), who found significant reduction of ALS in a bean-maize intercrop in Kenya during the short rainy season, and no significant difference in the long rainy season. Similarly, Schoeny *et al.* (2010) reported reduced severity aschochyta blight on pods and stems in a pea-cereal intercropping system compared to mono-cropping in western France.

The study showed that ALS severity was highest in the higher altitudes compared to the lower altitude areas (Table 2). In a similar study done in Kenya, it was observed that ALS disease severity was high at altitudes ranging between 1601 and 2000 m.a.s.l. (Mwangombe *et al.*, 2007). This finding may be attributed to the high rainfall and relative humidity common in the high altitudes that are more favourable to ALS infection and disease development. It has been reported that altitude affects temperature and rate of evaporation, and in so doing also influences the incidence and severity of certain diseases (Wortmann *et al.*, 1998). Steinglein *et al.* (2003) reported that moderate temperatures and high relative humidity were the most favourable conditions for the fungal disease epidemic development. Whereas, Sahile *et al.* (2008) observed that altitude alone had no effect on the development of chocolate spot, the interaction of altitude

and season had an effect on the diseases development.

This points to the need to undertake multi-year/multi-season studies of ALS across different altitudinal ranges in eastern DRC. This study showed that ALS severity varies between locations and seasons. Fluctuating weather conditions, especially relative humidity, temperature, and rainfall have been reported to favour diseases development under fields conditions (Correa-Victoria *et al.*, 1989; Anderson *et al.*, 2004). Scheuermann *et al.* (2012) suggested that disease occurrence and severity may vary by year, location and even within field depending on environmental conditions and crop management practices. In contrast, Belete *et al.* (2013) did not find any association between elevation and Fusarium root rot disease of Fabae beans in Northern Ethiopia.

Angular leaf spot resistance. Four common bean varieties from INERA, Mulungu showed resistance to virulent ALS isolates from eastern DRC (Table 7). Varieties: LSA 144, a red small seeded, ARA 4 a red mottled large seeded, COD MLV 059, a red mottled large seeded and MLV 224/94B, a red medium, were resistant to ALS disease when inoculated with two virulent *P. griseola* isolates (Tables 7 and 8). The same trend was true for variety Mexico 54, a known source of ALS resistance (Sartotato *et al.*, 2000). This shows that varieties from DRC may also carry useful ALS resistance genes and could be important sources for ALS resistance. Similarly, variety Mexico 54 is a potential source of resistance to manage ALS disease in DRC.

A single dominant resistance gene, “*Ph-2*” that governs resistance in Mexico 54 was reported by Sartorato *et al.* (2000). Later, it was suggested that ALS resistance in Mexico 54 is governed by two genes, “*Ph-2*” and “*Ph-5*” (Caxieta *et al.*, 2005). However, physical linkage information was not provided and this genetic hypotheses still needs to be validated (Souza *et al.*, 2015).

Variety G5686, also a documented source of resistance (Mahuku *et al.*, 2009) showed intermediate reaction to the two isolates, representing Andean and Mesoamerican group, SK 126:pathotype 61-39 and SK 146:pathotype 57-39. G5686 has been reported to possess three dominant and complementary genes conditioning resistance to pathotype 31-0 (Mahuku *et al.*, 2009).

Another documented source of resistance that exhibits high to intermediate levels of resistance to ALS in several countries of eastern and southern Africa, CAL 143 (Aggrawal *et al.*, 2004), exhibited intermediate disease reaction to the two *P. griseola* isolates. However, in previous studies, CAL 143 showed intermediate reaction to pathotype 7-55 in DRC, and was found to be susceptible in Uganda (Aggrawal *et al.*, 2004). Most recently the major QTL ALS4.1^{GS,UD} on Pv04, present in G5686, and the ALS10.1^{DG,UC} on Pv10, identified in both G5686 (Keller *et al.*, 2015) and CAL143 (Oblessuc *et al.* (2012, 2013) were officially named as *Phg-4* and *Phg-5* (Souza *et al.*, 2015;).

Although small seeded common bean genotypes have been previously reported to be more resistant to ALS compared to the large seeded ones (Pyndji and Trutmann, 1992), this study identified two large seeded bean varieties (ARA 4 and MLV 059) with good levels of resistance to ALS (Tables 7 and 8). These varieties are potential sources of resistance to ALS in eastern DRC in the Andean background. Besides, being a potential source of resistance to angular leaf spot, ARA 4 has market-desired characters and is tolerant to multiple stresses, specifically poor soil fertility (Lunze *et al.*, 2002). Varieties MLV059 and COD MLV224/94B are breeding lines developed at INERA Mulungu; while varieties LSA 144 and ARA 4 were derived from the CIAT nursery, BILFA (Beans for low soil Fertility in Africa) selected for tolerance to acidic soils (Lunze *et al.*, 2012). These varieties could be promoted in areas where ALS is a constraint. Similarly, the identified ALS resistant varieties may be used

as parents in breeding programmes for ALS resistance; host resistance being one of the most effective, economically and friendly strategies for managing ALS disease (Pastor Corrales and Singh, 1999) and also promoted in ALS prone areas for food production. However, the nature of the resistance needs to be explored so as to be appropriately exploited.

CONCLUSION

ALS is a major bean disease in the two main bean agro-ecological zones of eastern Democratic Republic of Congo (DRC) in Kivu Province. Poor farming practices such as the use of poor quality farmer-saved seed, lack of crop rotation due to land scarcity, and poor management practices that are common among the smallholder bean farmers, may have contributed to the high ALS prevalence. ALS severity is influenced by locations and varied from one season/year to another, with the highest severity being observed in Kabareat moderately high altitude, and the lowest in Uvira, located in low altitude in both long and short rainy season. The need to undertake multi-year studies of ALS across different altitudinal ranges in eastern DRC is highlighted. These locations with high ALS severity are suitable as high disease spot areas for ALS screening, while the ones with lowest score are appropriate for seed multiplication. Using representative virulent isolates from DRC, to screen for ALS resistance, allowed us to identify four resistant varieties among DRC bean germplasm. Host resistance is recognised as an effective strategy to manage ALS disease, and as such, these varieties may be used as parents in the breeding programme for ALS resistance or promoted as varieties in ALS infected areas in Eastern DRC. However, their utility to benefit other bean growing regions requires further testing in more sites. In addition, the nature of the resistance in these lines needs to be explored so as to be appropriately exploited.

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