

Yield Loss Assessment in Common Bean (*Phaseolus vulgaris* L.) due to Ascochyta Blight (*Phoma exigua* var. *diversispora* (Bubak) Boerema) Disease

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Abstract

Ascochyta blight (*Phoma exigua* var. *diversispora* (Bubak) Boerema) causes a severe, rapidly developing disease on common beans (*Phaseolus vulgaris* L.) that can bring about complete plant defoliation and extensive yield loss. Studies were conducted in Rwanda to quantify the yield loss attributed to bean ascochyta blight on 64 common bean genotypes including bush and climbing. Using a split plot design, trials were conducted at three locations, where ascochyta disease is prevalent. The different genotypes used had variable levels of susceptibility and were compared with resistant genotypes ICTA Hunapu and ASC 87 for bush type and G 35034 G 35306 for climber type. The results obtained showed that market class genotypes recorded higher disease severity and higher yield losses compared to the controls. There was a strong positive correlation between the Relative Area Under Disease Progress Curve (RAUDPC) values and yield losses. It was also established that as a result of the ascochyta, the yield of a susceptible genotype is reduced by about 69%. The pod infection had a direct effect on seed yield for both bush and climbers. However, the bush genotypes showed larger reduction in yield as compared to climbers. The study suggests the use of desirable resistant genotypes as the best way of reducing yield loss caused by ascochyta blight.

Keywords: Ascochyta blight, common bean, diseases severity, *Phaseolus vulgaris* L., yield loss

INTRODUCTION

Ascochyta blight, caused by *Phoma exigua* var. *diversispora* (Bubak) Boerema is a highly destructive disease of common bean in cool and wet bean production regions [1, 2]. It causes a severe, rapidly developing disease that can bring about complete plant defoliation and extensive yield loss if plants become diseased prior to and/or during pod filling [3].

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The disease can easily be identified by its symptoms, which initially appear on the leaves as circular dark gray lesions, and when they enlarge, become like a set of concentric rings 1–3 cm in diameter on both leaves and pods, which can lead to collapsed and black nodes, petioles and stems [4]. The disease is spread in cool and humid bean growing regions and often causes severe damage, which affects yield, seed quality, and marketability of beans. It is one of the most important bean diseases in Rwanda and yield losses are extensive, especially when infected seeds are used [5].

In Rwanda, ascochyta blight is most important in the high altitude, low temperature areas [6] where the disease causes severe losses because of the favourable climatic conditions, which enhance disease development.

Being a seed borne disease, ascochyta blight easily spreads as farmers depend highly on farm saved seed and exchange of seed is common [6]. With the exchange of farm saved seed between farmers, there is an increased chance of disease transmission between farmer fields, and between different agro-ecological zones where beans are grown. Ascochyta blight has been observed to develop and spread rapidly during the rainy seasons and when the temperatures are low [1, 2, 7]. Significant disease development and yield loss occur if these weather conditions are prolonged throughout the pod formation and pod filling stages of the crop [8–10]. Yield loss is due to premature defoliation and plant death, shrunken seed and an increase in the amount of seed that has disease lesions on the seed coat [11, 12]. Such beans have a poor appearance and are not popular with consumers, which results in reduced marketability and income. It has been observed that for many fungal diseases a high lesion density is associated with premature yellowing and defoliation of leaves [13–16] resulting in lower yields. The extent of the yield loss depends on the climatic conditions and the crop growth stage at which disease starts [17, 18]. In areas where the disease is endemic, yield losses have been known to be very high, especially on susceptible genotypes [18]. Study conducted by Schwartz et al. showed that the yield loss due ascochyta can extend to 43%. The knowledge of the economic loss of disease to the different Rwanda market class varieties is not known. However, before developing and/or implementing any research interventions against any pathogen or disease, it is necessary to quantify the extent and nature of damage attributed to that disease. It is for this reason that a study was conducted to quantify yield loss due to ascochyta blight for common beans in Rwanda.

MATERIALS AND METHODS

Study Area

The study was conducted at three research stations namely Rwerere, Musanze and Kitabi (Figure 1). Rwerere is in Burera district, located in North Eastern Rwanda at 2060–2312 m above the sea level (masl) at longitude of 29° 19' East and latitude of 1° 36' South with an annual rainfall and temperature of 1200 mm and 20°C, respectively (Figure 2). Musanze represents the highlands with volcanic soils. It is located at an altitude of 2200 (masl), on longitude of 29° 38' East and latitude 1° 30' South [19]. Annual temperature and rainfall averages at 16°C and 1480 mm, respectively. Kitabi research station is in Nyamagabe district, altitude of 1600–2800 masl on longitude of 29° 33' East and latitude of 1° 33' South with respective annual rainfall and temperature of 1600 mm and 19°C. Climatically, all research stations are in bean growing areas and ascochyta blight epidemics are common because of the moderate temperature and high moisture conditions [20], all of which favour the development of ascochyta blight. Rainfall is bimodally distributed with the short rains from March–May and long heavy rains from September–December.



Figure 1. Plot of beans treated against ascochyta infection at Kitabi site.



Figure 2. Plot of beans inoculated with ascochyta debris at Rwerere site.

The agricultural related activities are the main occupation of the people and it is estimated that over 90% of the population is engaged in agriculture [6]. Most of the crops produced are consumed at the household level and it is only the surplus that is marketed [20]. Of the crops produced, common beans rank among the most important food and cash crops within these regions [21].

Field Experimental Design and Treatments

The study used 64 bean genotypes. The details of the germplasm are described in Table 1.

Two trials were conducted one for bush (Type I, II and III) and another for climbers (Type IV). The experiments were planted in March 2014 at three sites. Each main plot was subjected to either a Benlate fungicide spray at a rate of 2.5 g per l of water or was inoculated with ascochyta infected debris.

The experiment was arranged in a split plot design with three replicates. The main plots were those with either fungicide application or ascochyta debris inoculation, while the subplots were the genotypes. Each subplot was measured 2 × 2 m and consisted of four rows of beans planted at a spacing of 0.5 m between rows and 0.2 m within rows for bush and 0.6 m between row and 0.3 m within row for climbers.

The inoculation was done 15 days after planting by uniformly spreading the infected debris in the bean field. The debris was collected from the same region in the previous season. In the fungicide-protected plots, fungicide application started one week after planting and continued at two weeks intervals until physiological maturity.

Before planting, 0.24 kg of NPK (17% 1:1:1) fertilizer was applied to each plot.

Data were collected from 15 days after planting from the two inner rows. Disease severity, defined as the percentage of the plants showing necrosis of the surface area (leaves and pods) caused by ascochyta, was recorded at two weeks intervals.

Plots were harvested by hand after physiological maturity and total grain weight, moisture percentage and the weight of the two inner rows were recorded. Plot grain yield was converted to kg/ha⁻¹ at 14.5% grain moisture basis. The yield loss was determined using the equation below:

Yield loss (%) is calculated as $\{(1 - (\text{yield of infected plot} / \text{yield of protected plot}) \times 100\}$ [22] (1)

Data were analysed using analysis of variance and the least significance difference ($P \leq 0.05$) statistic using the correct error term in split plot analysis. The least significance difference was used to compare mean grain yield of inoculated versus noninoculated plots of each genotype and ascochyta severity ratings of inoculated plot of each genotype.

Table 1. List of 64 genotypes used in the study.

Genotypes	Origin	Growth habit	Seed size	Genotypes	Origin	Growth habit	Seed size
Agronome	Rwanda	Climber	Large	ALB 102	Rwanda	Bush	Large
CAB 2	Rwanda	Climber	Large	ALB 155	Rwanda	Bush	Medium
Claudine	Rwanda	Climber	Medium	ALB 58	Rwanda	Bush	Large
G 2331	Rwanda	Climber	Large	ASC 87	CIAT Col	Bush	Small
G 2333	Rwanda	Climber	Large	CAL 96	Rwanda	Bush	Medium
G 35034	CIAT Col	Climber	Medium	CMS 17	Rwanda	Bush	Medium
G 35306	CIAT Col	Climber	Medium	ECAB 026	Rwanda	Bush	Large
Garukurare	Rwanda	Climber	Small	ICTA Hunapu	CIAT Col	Bush	Small
Gasilida	Rwanda	Climber	Large	Maharagesoja	Rwanda	Bush	Small
Gitanga	Rwanda	Climber	Medium	NUA 377	Rwanda	Bush	Medium
Ibanga 2	Rwanda	Climber	Medium	NUA 379	Rwanda	Bush	Medium
Kenyerumpure	Rwanda	Climber	Medium	NUA 397	Rwanda	Bush	Medium
Kigondo	Rwanda	Climber	Medium	NUA 566	Rwanda	Bush	Medium
Kivuzo	Rwanda	Climber	Large	RWR 1180	Rwanda	Bush	Large
MAC 44	Rwanda	Climber	Large	RWR 1668	Rwanda	Bush	Large
MAC 49	Rwanda	Climber	Large	RWR 2154	Rwanda	Bush	Large
MBC 12	Rwanda	Climber	Medium	RWR 2245	Rwanda	Bush	Large
Nyamanza	Rwanda	Climber	Small	RWR 229	Rwanda	Bush	Large
Nyaragikoti	Rwanda	Climber	Large	RWR 278	Rwanda	Bush	Large
Nyirabukara	Rwanda	Climber	Small	RWR 281	Rwanda	Bush	Large
Nyiramagorori	Rwanda	Climber	Small	RWR 3033	Rwanda	Bush	Large
Rwibarura 2	Rwanda	Climber	Large	RWR 310	Rwanda	Bush	Large
RWV 1129	Rwanda	Climber	Large	RWR 3194	Rwanda	Bush	Large
RWV 1348	Rwanda	Climber	Large	RWR 3228	Rwanda	Bush	Large
RWV 2070	Rwanda	Climber	Large	RWR 3332	Rwanda	Bush	Large
RWV 2872	Rwanda	Climber	Large	RWR 3338	Rwanda	Bush	Large
RWV 2887	Rwanda	Climber	Large	RWR 390	Rwanda	Bush	Large
RWV 3006	Rwanda	Climber	Large	SER 16	Rwanda	Bush	Medium
RWV 3316	Rwanda	Climber	Large	SER 83	Rwanda	Bush	Medium
RWV 3317	Rwanda	Climber	Large	SER 96	Rwanda	Bush	Large
UCB 82013	Rwanda	Climber	Medium	SMC 18	Rwanda	Bush	Medium
Vuninkingi	Rwanda	Climber	Small	SMC 21	Rwanda	Bush	Medium

The severity was calculated as mean percentage blighted foliar area per plot at each rating. Evaluation continued until susceptible genotypes reached 90–100% of leaf blight assessments. The area under the disease progress curve AUDPC [3] was calculated within a single experiment following this formula:

$$AUDPC = \sum_{i=1}^n [(X_{i+1} + X_i)/2] * [t_{i+1} - t_i] \quad (2)$$

Where X_i is the percentage necrosis at each at i^{th} the evaluation day, $t_{i+1}-t_i$ is Times (in days) between two diseases scores and n is the total number of observations. Means were separated by least significant difference at $P = 0.05$.

The estimate of AUDPC was normalized and Relative Area Under Disease Progress Curve (RAUDPC) (%) was used in the analysis of variance. The RAUDPC was calculated using the following formula:

$$RAUDPC = \frac{\sum(T_{i+1}) * \left(\frac{D_{i+1} + D_i}{2}\right)}{T_{total} * 100} \quad (3)$$

In Eq. (3), T_i is the i^{th} day when an estimation of percentage foliar late blight is made, and D_i is the estimated percentage of area with blighted foliage at T_i . T_{total} is the number of days at which the final assessment was recorded. The correlations between RAUDPC, yield, mean RAUDPC and mean yield for seasons A and B were determined. The RAUDPC was used to evaluate and select genotypes to be used in the breeding experiment.

Linear regression was used to determine the relationship between percentage loss in grain and ascochyta severity.

RESULTS

Ascochyta Severity and RAUDPC on Bean Genotypes

Results of ascochyta severity for pod filling to the end of seed development stage (R6) are presented in Table 2. They indicate significant differences in ascochyta severity between the sites ($P < 0.001$), and bean genotypes ($P < 0.01$) for both bush and climbers.

The significance difference ($P < 0.01$) is also seen for site and genotype for relative area under disease progress curve (RAUDPC) for both climber and bush type (Table 2). The two-way interaction between site and genotype was also significant for climber ($P < 0.05$),

Among local bush varieties, genotypes CMS 17 and CMS 21 had lowest ascochyta severity levels across the three sites while genotypes RWK 10 and RWR 2245 consistently had the highest severity levels. Climbing genotypes G 2333 and Vuninkingi had the lowest ascochyta severity, while MAC 44 and MAC 49 had the highest severity level of all climbing genotypes at all sites (Table 3). In general, bush genotypes had higher severity (24.2%) comparing to climbers (8.9%).

Table 2. Mean square on ascochyta severity and RAUDPC of bean genotypes tested at three locations in Rwanda.

Mean square					
Source	DF	Severity		RAUDPC	
		Bush	Climber	Bush	Climber
Site	2	1816.89**	200.83**	597.89**	100.27**
Rep*Site	4	403.73	12.05	193.35	10.96
Variety	31	1506.15**	82.12**	629.37**	60.63**
Site*Variety	62	160.63	21.79	61.54	15.48*
Residual	92	157.39	12.68	70.45	9.51
Total	191				
CV		19.4	15.1	17.8	13.7

*, ** = significant at 0.05 and 0.01, respectively; CV = Coefficient of variation; DF = Degrees of freedom.

Effect of Ascochyta on Bean Yield

Results presented in Table 4 show the analysis of variance of yields obtained from the protected and inoculated bean genotypes tested. The data obtained showed that there were significant differences between varieties and between sites for both protected and inoculated ($P < 0.01$). The combination between genotype and sites was significantly different for both inoculated and treated ($P < 0.05$) (Figures 3–8).

Table 5 show the yields obtained from the protected and inoculated bush bean genotypes tested at three sites. The protected bean at Rwerere yielded highest (1101.5 kg/ha) (Figure 5) followed by Musanze (867.2 kg/ha) (Figure 7) and Kitabi lower (862.5 kg/ha) (Figure 3). For the inoculated plots bean at Rwerere yielded highest (819.8 kg/ha) followed by Kitabi (371.2 kg/ha) and Musanze (337.7 kg/ha).

Table 3. Mean severity of ascochyta disease on bean genotypes tested at three locations in Rwanda.

Genotypes	Type	Mean Severity	Genotypes	Types	Mean Severity
ALB102	Bush	40.0	Agronome	Climber	8.8
ALB155	Bush	33.3	CAB2	Climber	8.2
ALB58	Bush	14.2	Claudine	Climber	6.2
ASC87	Bush	3.0	G2331	Climber	10.3
CAL96	Bush	25.0	G2333	Climber	5.2
CMS17	Bush	4.3	G35034	Climber	1.7
ECAB026	Bush	31.5	G35306	Climber	1.3
ICTAHuna	Bush	2.2	Garukura	Climber	7.8
Maharage	Bush	32.8	Gasilida	Climber	8.3
NUA377	Bush	19.7	Gitanga	Climber	11.5
NUA379	Bush	16.2	Ibanga2	Climber	17.7
NUA397	Bush	22.5	Kenyerum	Climber	16.4
NUA566	Bush	51.5	Kigondo	Climber	14.3
RWK10	Bush	60.8	Kivuzo	Climber	15.8
RWR1180	Bush	12.3	MAC44	Climber	25.0
RWR1668	Bush	50.0	MAC49	Climber	33.0
RWR2154	Bush	14.3	MBC12	Climber	16.5
RWR2245	Bush	68.4	Nyamanza	Climber	12.8
RWR229	Bush	17.8	Nyaragik	Climber	9.0
RWR278	Bush	55.0	Nyirabuk	Climber	10.4
RWR281	Bush	12.3	Nyiramag	Climber	7.2
RWR3033	Bush	29.5	RWV1129	Climber	13.2
RWR310	Bush	23.2	RWV1348	Climber	9.0
RWR3194	Bush	32.0	RWV2070	Climber	8.2
RWR3228	Bush	23.3	RWV2872	Climber	9.0
RWR3332	Bush	19.5	RWV2887	Climber	8.8
RWR3338	Bush	38.8	RWV3006	Climber	8.7
RWR390	Bush	14.3	RWV3316	Climber	10.3
SER16	Bush	24.0	RWV3317	Climber	9.7
SER83	Bush	40.0	Rwibarur	Climber	15.7
SMC18	Bush	16.3	UCB82013	Climber	15.7
SMC21	Bush	10.0	Vuninkin	Climber	4.3
Grand Mean		24.2	Grand Mean		8.9
LSD = 12.6			LSD = 6.3		

Table 4. Mean square on yield of ascochyta treated and inoculated field of bean genotypes tested at three locations in Rwanda.

Mean square					
Source	DF	Treated		Inoculated	
		Bush	Climber	Bush	Climber
Site	2	5500412.91**	9547307.94**	3275576.98**	6241472.76**
Rep*Site	4	18739.97	157975.26	65417.5	95166.43
Variety	31	107887.26**	260584.26**	141525.09**	182947.54**
Site*Variety	62	68449.65*	258756.20*	97042.39*	133875.16*
Residual	92	46350.91	156933.59	66652.4	121823.12
Total	191				
CV		16.4	10.1	9.4	12.2

*, ** = significant at 0.05 and 0.01, respectively; CV = Coefficient of variation; DF = Degrees of freedom

In the protected plots, genotype RWR 3338 (1350 kg/ha) yielded highest followed by RWR 3033 (1258.3 kg/ha) and SER 83 (1253.2 kg/ha). Genotype SER 16 yielded lowest (585 kg/ha). In the inoculated plots, the checks: ICTA Hunapu (1108.3 kg/ha) and ASC 87 (1225.0 kg/ha) yielded higher compare to other genotypes.

Table 5. Comparison of yield (kg ha⁻¹) of bush bean genotypes grown under ascochyta inoculated and protected condition.

Genotypes	Kitabi site		Rwerere site		Muhanga site		MP	MI
	Protected	Inoculated	Protected	Inoculated	Protected	Inoculated		
ALB 102	760	125	1250	625	625	120	878.3	290.0
ALB 155	760	125	775	500	375	120	636.7	248.3
ALB 58	760	375	625	375	1125	120	836.7	290.0
ASC 87	1020	1025	1450	1500	1000	1150	1156.7	1225.0
CAL 96	760	125	1250	875	875	719	961.7	573.0
CMS 17	630	250	1100	875	525	240	751.7	455.0
ECAB 026	1020	250	750	625	750	120	840.0	331.7
ICTA Hunapu	1280	1240	1000	985	1125	1100	1135.0	1108.3
Maharagesoja	760	375	1250	1000	375	24	795.0	466.3
NUA 377	760	113	1375	1000	375	120	836.7	410.8
NUA 379	630	125	1250	375	625	48	835.0	182.7
NUA 397	604	250	875	875	875	240	784.7	455.0
NUA 566	630	250	750	625	850	719	743.3	531.3
RWK 10	1150	250	1125	375	1125	24	1133.3	216.3
RWR 1180	760	125	1250	1000	750	120	920.0	415.0
RWR 1668	760	375	875	750	1125	839	920.0	654.7
RWR 2154	760	625	1250	750	625	479	878.3	618.0
RWR 2245	1150	750	875	750	1375	479	1133.3	659.7
RWR 229	630	125	1250	875	875	240	918.3	413.3
RWR 278	890	125	975	750	750	719	871.7	531.3
RWR 281	1260	875	1250	1125	500	359	1003.3	786.3
RWR 3033	1150	250	1750	1375	875	359	1258.3	661.3
RWR 310	604	375	875	750	1125	240	868.0	455.0
RWR 3194	630	375	925	875	1375	599	976.7	616.3
RWR 3228	760	125	1250	625	1000	359	1003.3	369.7
RWR 3332	1280	375	1125	1000	875	240	1093.3	538.3
RWR 3338	1150	875	1400	1250	1500	240	1350.0	788.3
RWR 390	1020	500	1000	875	1250	120	1090.0	498.3
SER 16	630	375	750	625	375	240	585.0	413.3
SER 83	1150	500	1375	1000	1250	168	1258.3	556.0
SMC 18	890	125	1375	500	875	24	1046.7	216.3
SMC 21	604	125	875	750	625	120	701.3	331.7
Mean	862.6	371.2	1101.6	819.8	867.2	337.8	943.8	509.6
lsd (0.05)a	242.1							
lsd (0.05)b	562.7							
lsd (0.05)c	864.0							

^a Treatment; ^b Genotype; ^c Treatment x Genotype; MP= Mean protected genotype; MI= Mean of inoculated genotype

Table 6 shows the yields obtained from the treated and inoculated climbing bean genotypes tested at three sites. It is observed from the table that yields at Musanze were highest (1978.8 kg/ha) (Figure 6) followed by Rwerere site (1826.6 kg/ha) (Figure 8) whereas Kitabi sites yielded lowest (1144.5

kg/ha) (Figure 4). Yield of the inoculated plots at Rwerere were highest (1021.9 kg/ha) followed by Musanze (912.2 kg/ha) and Kitabi (665.1 kg/ha).

Table 6. Comparison of yield (kg ha⁻¹) of climbing bean genotypes grown under ascochyta inoculated and protected conditions.

Genotypes	Kitabi site		Rwerere site		Musanze site		MP	MI
	Protected	Inoculated	Protected	Inoculated	Protected	Inoculated		
Agronome	587	363	1775	1025	1900	1063	1420.7	817.0
CAB 2	838	250	1775	975	1588	375	1400.3	533.3
Claudine	1025	813	2150	1125	2212	750	1795.7	896.0
G2331	1525	1562	2462	1125	1650	938	1879.0	1208.3
G2333	1462	995	2150	1400	1462	1000	1691.3	1131.7
Garukurare	1025	650	2088	1350	1900	1375	1671.0	1125.0
Gasilida	1150	570	2462	1175	1650	613	1754.0	786.0
Gitanga	1588	938	1338	1025	2025	938	1650.3	967.0
Ibanga 2	1612	950	2087	1250	2212	1188	1970.3	1129.3
Kenyerumpure	1213	438	2212	925	1525	938	1650.0	767.0
Kigondo	1525	1000	2025	875	1712	563	1754.0	812.7
Kivuzo	1275	525	1650	1200	1462	388	1462.3	704.3
MAC 49	837	438	1462	900	1588	1063	1295.7	800.3
MAC44	1087	375	1900	950	1462	1188	1483.0	837.7
MBC 12	1400	313	1088	600	1588	750	1358.7	554.3
G 35306	1062	1005	1775	1725	1712	1735	1516.3	1488.3
Nyamanza	1088	500	1463	825	1400	750	1317.0	691.7
Nyaragikoti	1212	250	1775	1450	1275	813	1420.7	837.7
Nyirabukara	1362	1188	1900	1150	1275	635	1512.3	991.0
Nyiramagorori	1900	938	2212	1400	1962	875	2024.7	1071.0
Rwibarura 2	637	875	1525	725	1462	500	1208.0	700.0
RWV 1129	400	375	1775	800	1962	1125	1379.0	766.7
RWV 1348	900	363	1963	1550	2400	875	1754.3	929.3
RWV 2070	1588	375	1838	1375	1275	750	1567.0	833.3
G 35034	1900	1870	2338	2250	1963	2000	2067.0	2040.0
RWV 2887	1025	688	1650	1250	2138	1125	1604.3	1021.0
RWV 3006	1150	438	1338	1000	1462	813	1316.7	750.3
RWV 3316	712	363	1588	975	1275	313	1191.7	550.3
RWV 3317	838	375	1525	700	1775	688	1379.3	587.7
RWV2872	588	500	2150	1050	1525	1188	1421.0	912.7
UCB 82013	962	688	1462	950	1738	1000	1254.0	879.3
Vuninkingi	1150	313	1550	825	1588	875	1429.3	671.0
Mean	1144.5	665.1	1826.6	1021.9	1978.8	912.2	1550.0	899.7
lsd (0.05)a	120.9							
lsd (0.05)b	421.1							
lsd (0.05)c	774							

^a Treatment; ^b Genotype; ^c Treatment x Genotype; MP = Mean protected genotype; MI = Mean of inoculated genotype

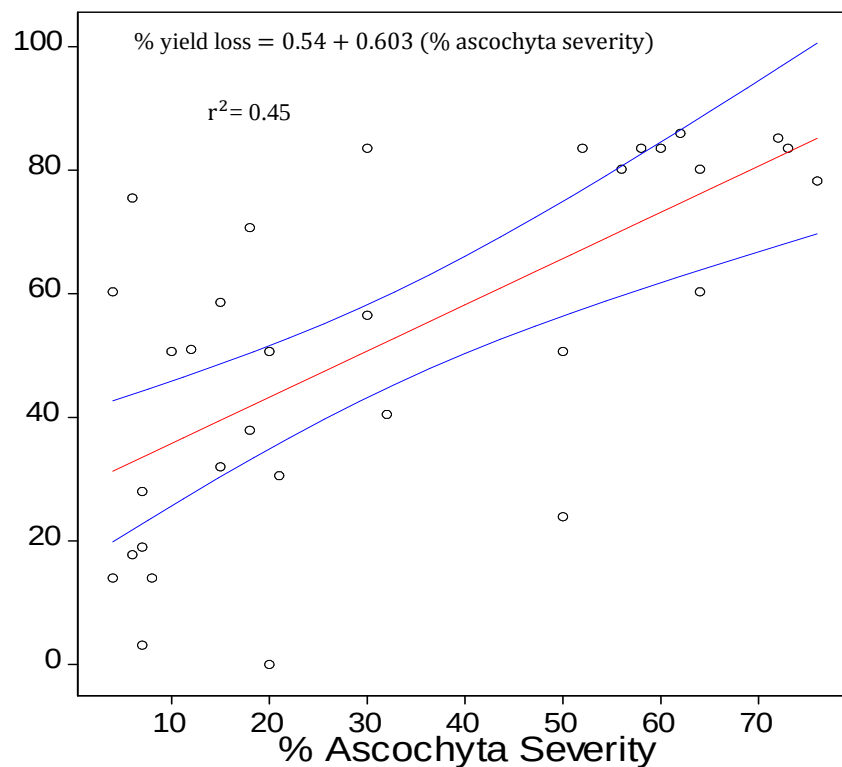


Figure 3. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for bush. Data point are the means of three replications at Kitabi research station.

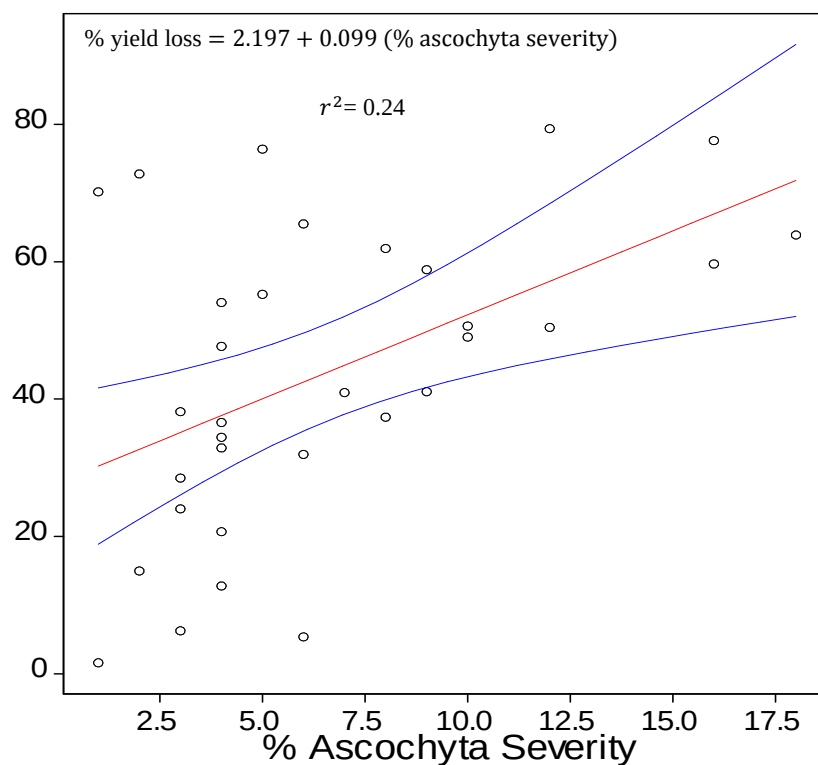


Figure 4. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for climber. Data point are the means of three replications at Kitabi research station.

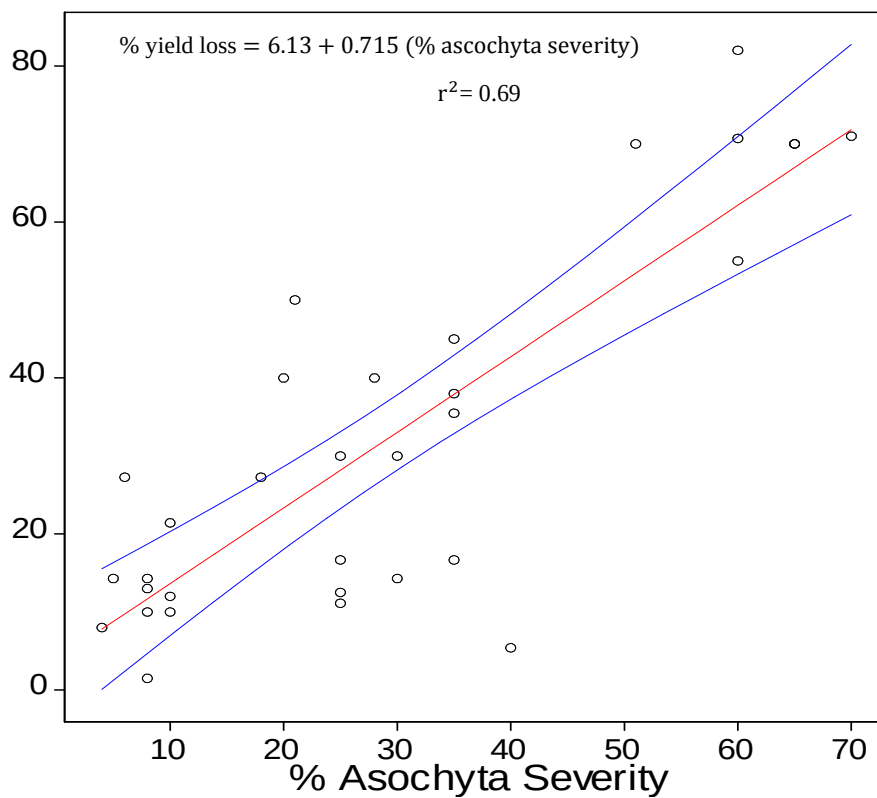


Figure 5. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for bush. Data point are the means of three replications at Musanze research station.

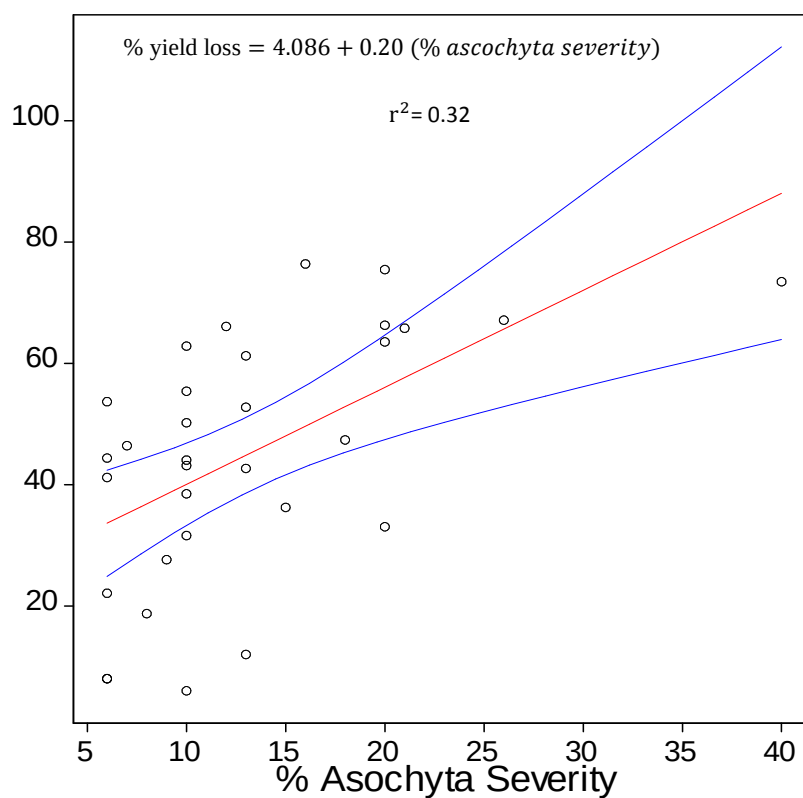


Figure 6. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for climber. Data point are the means of three replications at Musanze research station.

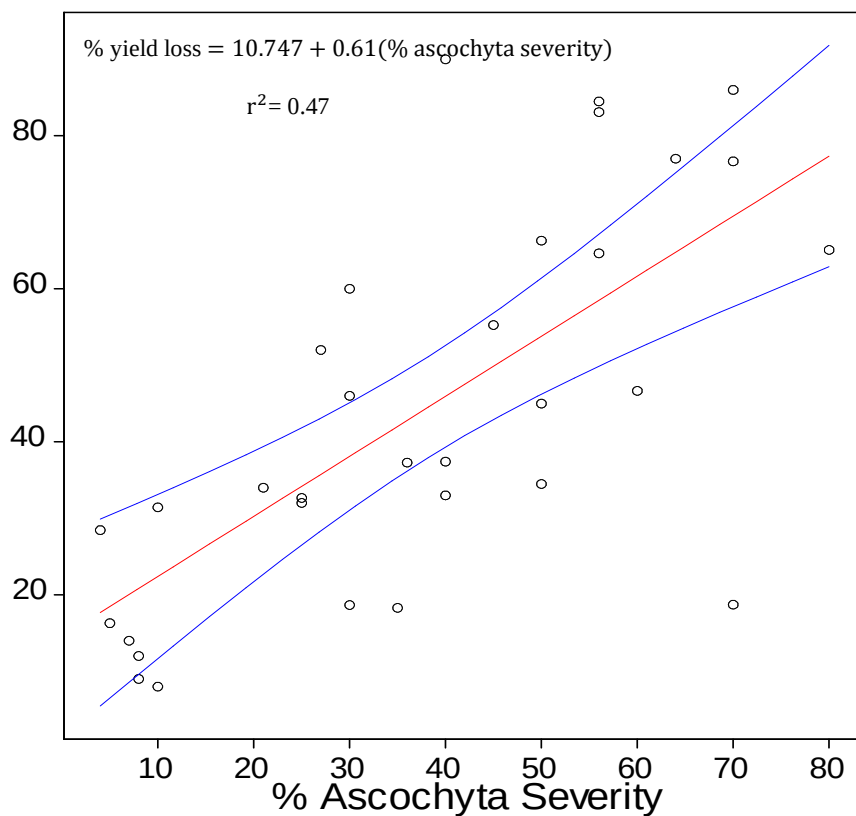


Figure 7. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for bush. Data point are the means of three replications at Rwerere research station.

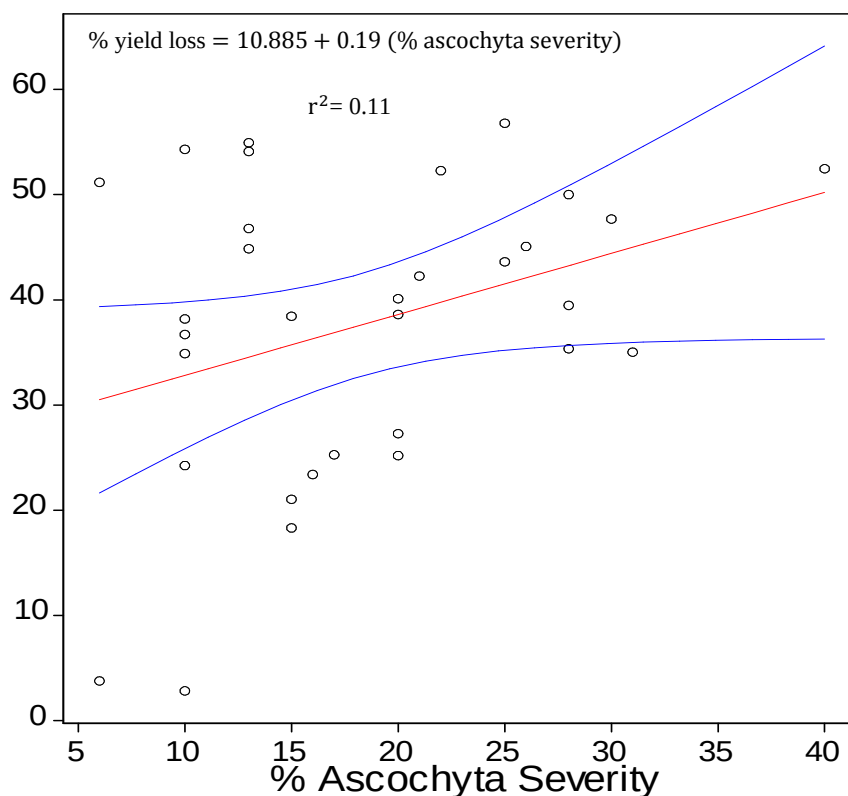


Figure 8. Relationship between severity of bean ascochyta blight (%) and percentage yield loss for climbers. Data point are the means of three replications at Rwerere research station.

In the treated plots, genotype G35034 (2067.0 kg/ha) had the highest yield followed by Nyiramagorori (2024.7 kg/ha) and Ibanga2 (1970.3 kg/ha) compared to other genotypes including checks. Genotype RWV 3316 gave the lowest yield (1191.7 kg/ha). For inoculated plots checks: G 35034 (2040 kg/ha) and G35306 (1488.3 kg/ha) yielded highest compared to all other genotypes. The results further show that for all genotypes, protected plots yielded significantly higher than inoculated plots Table 5 and 6.

Yield Loss

The analysis of variance showed significant difference ($P < 0.01$) in yields decrease between both sites and varieties for both climber and bush (Table 7). The two-way interaction between site x genotype was also significant at ($P < 0.05$).

Table 8 show that Musanze showed highest yield decrease (45.5%) due to ascochyta blight followed by Kitabi (43.8%) whereas Rwerere showed lowest yield decrease.

Genotype RWR 1668 had the greatest yield loss (63.9%) among bush genotype while checks ICTA Hunapu and ASC 87 had the lowest yield loss of 9.6% and 4.8%, respectively.

When all sites are considered, Musanze site had the highest RAUDPC and Rwerere had the lowest. Genotype RWV 3338 (83.89) had the highest RAUDPC followed by RWR 281 (80.67). Checks (ICTA Hunapu, ASC 87) had lowest RAUDPC.

Table 9 shows the yield loss per climber genotype and disease progress for all sites (Figure 5). The data shows that the yield decrease due to ascochyta blight was highest at Kitabi (58.9%) followed by Rwerere (33.4%) and Musanze had (24.8%). Musanze had the highest RAUDPC (10.1) and Rwerere had the lowest (6.3).

Climbing genotype Agronome had the greatest yield loss (75.7%), followed by Claudine (73.9%) while checks G35034 and G35306 had the lowest yield loss 2.1% and 0.9%, respectively. This trend was the same for the RAUDPC values. Additionally, there was a strong positive correlation ($r = 0.68$ and 0.72) between the RAUDPC values and yield loss for bush and climbers, respectively.

Table 7. Analysis of variance on % yield decrease caused by ascochyta on bean genotypes tested at three locations in Rwanda.

Source	DF	Mean square	
		Bush	Climber
Site	2	2191.59**	2228.58**
Rep*Site	4	422.92	368.33
Genotype	31	1910.75**	1802.76**
Site*Genotype	62	557.99*	592.89*
Residual	93	393.72	185.52
Total	191		
CV		7.8	16.1

*, ** = significant at 0.05 and 0.01, respectively; CV = Coefficient of variation; DF = Degrees of freedom.

Relationship between Yield Loss and Ascochyta Severity

Disease severity varied greatly in and between experimental sites and generally was highest at 9th to 10th week after germination. Disease inoculations successfully initiated infection; abundant rainfall

and low to moderate temperatures persisted throughout the growing season and were conducive to infection by the ascochyta. Benomyl application effectively controlled ascochyta blight in treated plots.

Table 8. Yield loss obtained per bush genotype and the disease assessment.

Genotype	Kitabi		Rwerere		Muhanga		MYL	M RAUDPC
	Yield loss (%)	RAUDPC	Yield loss (%)	RAUDPC	Yield loss (%)	RAUDPC		
ALB 102	50.6	107.8	36.7	5.8	55.4	4.5	47.6	39.4
ALB 155	54.0	16.2	43.6	9.2	46.4	109.7	48.0	45.0
ALB 58	6.3	4.0	54.9	9.2	42.7	141.7	34.6	51.6
ASC 87	72.8	2.2	46.8	2.7	44.9	2.3	54.8	2.4
CAL 96	36.6	4.0	35.3	55.7	27.6	87.5	33.2	49.1
CMS 17	76.4	14.2	25.2	6.3	41.2	5.5	47.6	8.7
ECAB 026	55.3	1.5	54.1	8.3	61.2	7.8	56.9	5.9
ICTA Hunapu	28.5	0.7	35.0	2.3	25.3	2.0	29.6	1.7
Maharagesoja	65.5	17.7	50.0	6.2	18.7	88.3	44.7	37.4
NUA 377	20.7	36.3	47.7	8.3	66.1	6.3	44.8	17.0
NUA 379	37.4	5.8	52.5	9.8	65.8	8.7	51.9	8.1
NUA 397	47.7	14.8	38.4	46.8	33.1	11.7	39.7	24.4
NUA 566	24.0	108.0	54.3	90.3	43.2	5.8	40.5	68.1
RWK 10	15.0	1.5	51.2	9.2	22.1	7.8	29.4	6.2
RWR 1180	50.4	4.0	52.3	60.8	62.8	7.5	55.2	24.1
RWR 1668	70.2	35.7	45.1	6.8	76.4	6.5	63.9	16.3
RWR 2154	5.4	105.7	2.8	9.2	0.0	8.0	2.7	40.9
RWR 2245	77.6	31.7	44.9	10.5	52.8	8.0	58.4	16.7
RWR 229	79.4	5.8	18.3	30.8	36.2	11.0	44.6	15.9
RWR 278	31.9	21.5	34.9	57.5	31.6	7.0	32.8	28.7
RWR 281	38.2	36.5	42.3	78.3	44.1	127.2	41.5	80.7
RWR 3033	34.4	21.3	56.8	15.2	67.1	12.7	52.8	16.4
RWR 310	49.0	2.7	38.6	13.2	75.5	10.5	54.4	8.8
RWR 3194	41.1	4.5	40.1	16.2	46.3	15.0	42.5	11.9
RWR 3228	1.6	5.0	3.8	90.3	0.0	6.3	1.8	33.9
RWR 3332	12.8	17.3	39.5	7.3	50.2	6.2	34.1	10.3
RWR 3338	61.9	105.2	25.3	90.7	44.4	55.8	43.9	83.9
RWR 390	58.8	118.3	27.3	14.3	73.5	14.3	53.2	49.0
SER 16	40.9	74.3	23.4	8.7	53.7	24.3	39.3	35.8
SER 83	63.9	7.0	58.2	7.5	38.5	6.0	53.5	6.8
SMC 18	59.7	5.7	21.0	11.5	63.5	9.8	48.1	9.0
SMC 21	32.9	5.0	24.2	11.2	47.4	126.7	34.8	47.6
Average	43.8	29.4	38.3	25.3	45.5	29.8	42.5	28.2
Isd (0.05)1	32.6							
R (P<0.05)	0.68							

MYL = Genotype mean yield loss; MAUDPC = Genotype mean relative area under disease progress curve

Table 9. Yield loss obtained per climber genotype and the disease assessment.

	Kitabi		Rwerere		Muhanga			
<i>Genotype</i>	<i>Yield loss (%)</i>	<i>RAUDPC</i>	<i>Yield loss (%)</i>	<i>RAUDPC</i>	<i>Yield loss (%)</i>	<i>RAUDPC</i>	<i>MYL</i>	<i>M RAUDPC</i>
Agronome	80.2	10.3	77.0	20.9	70.0	15.4	75.7	15.5
CAB 2	50.7	2.8	28.0	4.6	20.0	15.6	32.9	7.7
Claudine	78.3	17.6	76.7	7.8	66.7	16.3	73.9	13.9
G 2331	56.5	9.1	25.3	6.0	27.3	14.4	36.4	9.8
G 2333	50.7	6.4	16.3	8.3	14.3	4.2	27.1	6.3
G 35034	3.1	0.4	1.5	0.2	1.5	0.4	2.0	0.3
G 35306	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.2
Garukurare	86.0	11.2	25.1	7.0	23.1	0.7	44.7	6.3
Gasilida	30.6	3.6	11.0	1.4	10.0	4.7	17.2	3.2
Gitanga	40.5	2.7	12.7	3.5	16.7	6.0	23.3	4.1
Ibanga 2	75.5	10.8	18.7	8.0	16.7	14.0	36.9	10.9
Kenyerumpure	23.9	6.6	18.7	3.0	10.7	14.0	17.8	7.9
Kigondo	83.6	9.8	52.0	2.9	50.0	10.7	61.9	7.8
Kivuzo	85.2	9.6	37.3	1.4	27.3	11.3	49.9	7.4
MAC 44	78.3	22.2	31.4	8.0	21.4	9.8	43.7	13.3
MAC 49	37.9	5.1	18.3	23.5	14.3	13.1	23.5	13.9
MBC 12	51.0	4.3	84.5	2.7	12.5	15.1	49.3	7.3
Nyamanza	80.2	9.7	32.0	24.0	30.0	12.1	47.4	15.2
Nyaragikoti	86.0	13.2	64.6	0.7	63.6	16.2	71.4	10.1
Nyirabukara	83.6	9.7	33.0	10.6	30.0	3.0	48.9	7.8
Nyiramagorori	60.3	6.6	26.7	5.4	16.7	2.6	34.6	4.9
Rwibarura 2	40.5	3.1	7.4	3.5	5.4	9.4	17.8	5.3
RWV 1129	58.6	4.9	10.0	18.7	0.0	12.1	22.9	11.9
RWV 1348	83.6	10.8	34.5	5.9	35.5	11.3	51.2	9.4
RWV 2070	83.6	8.8	56.0	3.9	50.0	13.5	63.2	8.7
RWV 2872	83.6	10.9	21.0	10.2	20.0	14.0	41.5	11.7
RWV 2887	50.7	4.2	60.0	2.0	40.0	14.9	50.2	7.0
RWV 3006	17.8	1.2	46.0	1.8	40.0	3.9	34.6	2.3
RWV 3316	70.7	19.8	73.1	3.4	11.1	12.1	51.6	11.8
RWV 3317	79.3	6.5	16.3	0.5	14.3	13.5	36.6	6.8
UCB 82013	34.8	3.9	24.3	2.2	14.3	10.9	24.5	5.7
Vuninkingi	60.3	3.5	28.5	0.4	20.5	9.0	36.4	4.3
Average	58.9	7.8	33.4	6.3	24.8	10.1	39.0	11.1
Isd (0.05)1	47.3							
R (P<0.05)	0.72							

MYL = Genotype mean yield loss; MAUDPC = Genotype mean relative area under disease progress curve

DISCUSSION AND CONCLUSION

Ascochyta blight has been reported on beans in Rwanda since the late 1980s [5], but the yield loss due to the disease had not been quantified. This study was conducted to establish the effect of ascochyta blight on the yield of 32 bush common bean and 32 climbing common bean across three sites.

As an aggressive foliar disease, ascochyta destroys plant photosynthetic tissue [7] causing premature defoliation and early maturation thus lowering yields [8, 15]. Although susceptible bean

genotypes can be infected at all growth stages, yield loss will depend on the crop stage when infection occurs [9]. The most important crop stages determining yield loss are between early flower stage (R1) through pod fill to the end of seed development stage (R6) [11]. The significant differences in ascochyta severity between genotypes in this study could be indicative of differences in susceptibility levels. Significantly, different RAUDPC between genotypes was found, indicating that ascochyta progressed differently among genotypes. The study showed that *Phoma exigua* grows faster on the more susceptible genotypes. These findings are in agreement with earlier studies that showed that susceptible common bean genotypes succumbed to fungal earlier than the resistant varieties [23, 24]. Visual estimation of leaf, foliar or pods damage was generally reliable and consistent for the disease.

The analysis of variance showed significant difference ($P < 0.01$) in yields decrease between both sites and varieties for both climber and bush.

Musanze showed highest yield decrease (45.5%) due to ascochyta blight followed by Kitabi (43.8%) whereas Rwerere showed lowest yield decrease. Genotype RWR 1668 had the greatest yield loss (63.9%) among bush genotype while checks ICTA Hunapu and ASC 87 had the lowest yield loss of 9.6% and 4.8%, respectively. For climber, decrease due to ascochyta blight was highest at Kitabi (58.9%) followed by Rwerere (33.4%) and Musanze had (24.8%). Climbing genotype Agronome had the greatest yield loss (75.7%), followed by Claudine (73.9%) while checks G35034 and G35306 had the lowest yield loss 2.1% and 0.9%, respectively. This trend was the same for the RAUDPC values for both bean types. The data obtained show a high positive correlation ($r = 0.68$ and 0.72) between the RAUDPC and the genotype yield losses. In comparison with the resistant genotypes, severe yield losses were observed in all susceptible genotypes for three locations. In general, bush genotype was more susceptible than climbers. The relatively low loss is consistent with that expected from delay in development of ascochyta until podding filling growth stage.

When percentage yield loss of bush genotype and climbers from different locations were regressed against ascochyta severities, differences in variation were observed. For bush genotypes, grain yield loss was reduced 0.60, 0.71 and 0.61% for each percentage ascochyta severity at the pod filling growth stage for Kitabi, Musanze and Rwerere, respectively. Climbers grain yield were reduced at an average of 0.09, 0.2 and 0.19% for each percentage ascochyta severity at the pod filling stage for Kitabi, Musanze and Rwerere, respectively. This study demonstrates that the most susceptible genotypes, which were artificially inoculated and grown under conditions favourable for disease, sustain a significant grain yield loss to ascochyta.

It has been reported that total yield loss of 45% may occur when ascochyta contaminated seed is used and the climatic conditions are conducive for disease development [10, 16, 25]. This loss in marketable yield can be a very big hindrance to the farmers in terms of household income, considering that over 85% of the common bean producers in Rwanda have very limited resources [26]. The significant low percentage yield losses observed for the resistant genotypes highlight the importance of using plant resistance to manage ascochyta. Unfortunately, the resistant genotypes used in this study have poor marketability in Rwanda [19] and as such, cannot easily replace the marketable susceptible genotypes. The use of suitable ascochyta resistant or tolerant genotypes would be the best option in the management of this disease. Therefore, it is recommended that a breeding programme should be established to facilitate the introgression of ascochyta resistance genes into the susceptible market class genotypes.

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