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Yield loss of common bean caused by rust disease in Uganda

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Abstract

One of the major common bean diseases devastating farmers' fields unabated in Uganda is the common bean rust disease caused by *Uromyces appendiculatus* Pers. (Pers) Unger. To decipher the economic importance of this disease, a study was conducted to quantify the yield loss caused by rust disease. Using a completely randomized block experimental design of Mancozeb fungicide treated and non-treated experimental plots, six common bean genotypes comprising of two rust resistant genotypes Redlands pioneer and Mexico 235, and four susceptible genotypes NABE 15, NABE 16, K132 and Masindi yellow were evaluated under field conditions in 2015B and 2016A planting seasons on-station at NaCRRI-Namulonge. These genotypes responses were further validated on-station at BUZARDI-Hoima, and Mbarara-ZARDI during the 2016A season. The resistant genotypes recorded low rust disease severity and yield losses (5-33%) in both treated and non-treated plots whereas the susceptible genotypes had high disease severity and yield losses of up to 67% in non-treated plots. Rust severity and yield losses were highest in Mbarara-ZARDI, and lowest in the NaCRRI-Namulonge. These findings will be valuable in the development of rust resistance in the farmer preferred bean genotypes and enhance the deployment of the integrated disease management strategy of rust disease in Uganda.

Keywords: *Phaseolus vulgaris*, *Uromyces appendiculatus*, Mancozeb, fungicide, rust resistance, Disease management

Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the important crop in Uganda, ranked fifth behind banana, cassava, indigenous cattle meat, and cattle milk in terms of value of output (Sibiko *et al.*, 2013). It is a food security crop to Ugandan farmers and traders because of its high demand, being a source of income and food for many. Due to the increasing demand for the crop both in the domestic and export markets in other sub-Sahara African countries such as Kenya (Sibiko *et al*., 2013), it has been reported to accounted for 6.1% of the total agricultural GDP of Uganda (FAO, 2009). The estimated economic value of total bean output when valued at the 2009 market prices was higher than total earnings from coffee, which is Uganda's chief export commodity (FAO, 2009). This implies that harnessing the common bean yield potential could lead to significant improvements in the health and well-being of Ugandans and subsequently sub-Saharan Africa (Potts and Nagujja, 2012).

On common dry beans (*Phaseolus vulgaris* L.), the disease rust caused by the obligate fungus *Uromyces appendiculatus* (Pers. Unger) is one of the major foliar disease in Uganda. This destructive disease occurs worldwide especially in areas with humid to moderate humid conditions and cool temperatures ranging from 17 to 23°C (Pastor-Corrales and Liebenberg, 2010). Severe infection of the rust disease causes the crop leaves to curl up, dry up, turn brown, and then drop prematurely resulting in reduced pod set, pod fill, and seed size. A severely rusted bean field often appears scorched (Harveson, 2013).This leads to extensive yield losses ranging from 18-100% with an estimated grain yield loss of about 191,400 metric tons (MT) per annum (Lindgren *et al*., 1995; Wortmann *et al.*, 1998). In Africa, rust has been reported to occur in common bean growing regions in Kenya, South Africa, Tanzania and Uganda (Kimani *et al.*, 2001; Liebenberg and Pretorius, 2004; Wasonga and Porch, 2010; Paparu *et al*., 2014a,b).

Negussie and Pretorius (2008) reported that quantitative data on the relationship between disease and yield losses are useful in understanding disease epidemics, crop loss assessment and management. Quantifying disease-yield loss relationships requires disease assessment throughout the season as well as monitoring the growth of healthy and diseased plant populations (Negussie and Pretorius, 2008). This approach has been effectively used in establishing relationships between disease, crop growth, yield and yield components in the bean rust pathosystem (Habtu *et al*., 1997; Negussie and Pretorius, 2008). Available information on bean yield loss due to diseases is inadequate to determine the economic importance of any disease of beans in Africa. For instance, an estimated 9.1 kg/ha and 19 kg/ha yield 1osses for a 1% increase in anthracnose and bean rust may perhaps be the most useful estimate for both diseases (Lindgren *et al*., 1995; Nkalubo *et al*., 2007), however, this may be high as some of the effect was probably due to other factors. Another instance is when yield loss is estimated for multiple diseases, the effect of a specific disease is shrouded. For instance, the yield loss estimate obtained for rust and angular leaf spot in Uganda (Paparu *et al.*, 2014b) is useful for setting a minimum level, but then the effects of rust disease alone could not be separated from those of angular leaf spot. Therefore, there is a need to estimate the yield loss caused exclusively by bean rust.

The current methods used in managing Bean rust disease is fungicides and resistant varieties (Liebenberg and Pretorius, 2010). The use of fungicides such as Tebuconazole, Mancozeb, Benomyl and Triazole have routinely been used to control rust in dry beans in Eastern and Southern Africa, which successfully increased grain yields under high disease pressure (Liebenberg and Pretorius, 2010). According to Paparu *et al*. (2014a) the use of fungicide in Uganda is limited to snap beans, because they are mostly grown by commercial farmers. The fungicide observed to be commonly used by farmers in Uganda is the Indofil-M45 [Mancozeb 80%W. P] (Odogwu *et. al*., 2016). However, the use of fungicide on dry common bean production is rare because most dry bean farmers are small-holders that have limited resources and knowledge in the use of this strategy (Kelly et al., 2013). The use of resistant varieties is currently the trend in managing plant diseases. Genetic host resistance is the most economical and effective strategy to manage plant diseases. The common bean genotypes, Redlands pioneer and Mexico 235 have been reported to be resistant to bean rust pathotypes from Kenya (Arunga *et al*.,2012). Nevertheless, it would be pertinent to provide information about the impact and the best disease management strategies for bean rust disease in Uganda. Therefore, the aims of this study were to (i.) determine the severity and yield losses caused by bean rust in Uganda on some selected bean genotypes; and (ii.) identify and suggest the best management strategy for the disease.

Materials and Methods

Plant Materials

Six cultivars used in this study comprised of two rust resistant genotypes, Redland pioneer (*Ur-13*) and Mexico 235 (*Ur-5*) from the Andean and Mesoamerican background respectively (Liebenberg and Pretorius, 2010); four susceptible genotypes comprising of one landrace Masindi yellow and the three commercial varieties K132, NABE 15 and NABE 16 which are commonly grown and preferred by farmers in all regions in Uganda (Ugen *et al*., 2014).

Experimental sites and design

The experiment was conducted in the months of October to December 2015 second planting season (2015B) and April to June 2016 first planting season(2016A) on-station at the National Crop Resources Research Institute (NaCRRI), Namulonge [latitude: 00°31 '30.4"N; longitude: 032°36'54" E; altitude: 1,160 m above sea level]. This location has been used in previous yield loss studies on bean rust (Paparu *et al*., 2014b). For confirmation purpose and to validate the observed genotypes reactions on-station at multi-locations, evaluation was done viz-a-viz the regions with high to moderate rust disease severity (Odogwu *et al*., 2016). Therefore, the six genotypes were assessed in 2016A planting season in three on-station locations namely NaCRRI (Namulonge) in the central region; BULINDI Zonal Agricultural Research and Development Institute (BUZARDI, Hoima) [latitude: 01°30 '07.7"; longitude: 031°29'37.3" E; elevation 1133m above sea level] in the South Western region and Mbarara Zonal Agricultural Research and Development Institute (Mbarara-ZARDI) [latitude: 00°36 '33.4"; longitude: 030°36'52.7" E; elevation 1243m above sea level] in the South-Western highlands region.

In each season and location, the experimental units consisted of 3 x 3 m plots, with both inter- and intra-row spacing of 30 cm and 10 cm respectively (Paparu *et al*., 2014). There was 2 m spacing between plots to avoid inter-plot interference. Each genotype was planted in a plot sown with 33 seeds in 3 rows. Also, for each genotype, half of these plots (6 plots, corresponding to replications 1, 2 and 3) were treated with the fungicide indofil®M-45 (Mancozeb 80%W.P.) at a rate of 50g per 15Litres of spray water and the other half plots were untreated with the fungicides and acted as controls. The fungicide was applied on a weekly basis starting from when the disease symptoms first appeared and then repeated at 7-day intervals till 14 days before harvest (CIAT, 1989; Pastor-Corrales and Liebenberg, 2010). All treatments were laid out in a randomized complete block design with three replicates and the susceptible genotype, NABE 16 was planted after every three rows at relatively high plant density to ensure uniformity of natural inoculum and increased disease pressure (Odogwu *et al*., 2017). The data for temperature, rainfall and relative humidity values were collected from the Uganda National Meteorological Authority (UNMA, 2016).

Disease and yield evaluation

For disease evaluation, three visual assessments and scoring of rust severity (RS) and incidence were carried out when 50% of the genotypes were at the first trifoliate leaf (V3), pre-flowering (R5) and pod formation (R7) developmental stages (Paparu *et al*., 2014b). Ten plants of the central rows were randomly selected and tagged for disease assessment. On each assessment date, RS was measured as the affected leaf area which was scored at the upper, middle, and lower leaf canopy layers separately on each of the 10 tagged plants. It was rated using the CIAT 1 to 9 scale by van Schoonhoven and Pastor-Corrales (1991), where scores 1-2 = resistant (i.e. no visible pustules to few pustules covering 2% of foliar area), 3-6=intermediate (i.e. small pustules covering 5% foliar area to large pustules often surrounded by chlorotic halos covering 10% foliar area) and 7-9 = susceptible (i.e. large to very large pustules covering 25% foliar area). On the other hand, disease incidence was expressed as the percentage of infected plants over the 20 plants within the sampling point. (Getachew et al., 2014).

Marketable yields of each genotype were measured as weight of clean dry seed per plot (Paparu *et al*., 2014b). Yield loss was determined using the formula:

$$\%\text{Yield loss} = \frac{\text{Yield of treated plot (YTP)} - \text{Yield of untreated plot(YUP)}}{\text{Yield of treated plot (YTP)}} * 100$$

Data analysis

The disease incidence, severity and yield data were subjected to a normality test prior to statistical analysis. Data was transformed using log (base 10) function with the equation log10(x+c), where x to represent the data variate, and *c* represents additional scalar constants. Analysis of variance and post-hoc tests were conducted in GenStat 12th edition using the following general linear model: $Y_{ijk} = \mu + \boldsymbol{\beta}_{i} + +\boldsymbol{\tau}_j + \boldsymbol{\tau\beta}_{ij} + \boldsymbol{\varepsilon}_{ijk.}$, where Y_{ijk} is the observation; μ is the grand mean; $\boldsymbol{\beta}_j$ is the *i*th block effect; $\boldsymbol{\tau}_j$ is the *j*th treatment effect; $\boldsymbol{\tau\beta}_{ij}$ is the interaction of the treatment and block, and$\boldsymbol{\varepsilon}_{ijk}$ is the experimental error. Treatment mean were separated by Tukey's student range test, where $\alpha = 0.05$ using the SAS version 9.4 for windows and the severity data was graphically represented as a Biplot using the additive main effects and multiplicative interaction (AMMI) model of SAS version 9.4 for windows (SAS Institute Inc., 2020).

Results and Discussion

The foliar disease, rust has been reported on common bean in Uganda since the early 1970s (Atkins, 1973). However, the quantification of the yield caused specifically by rust has not been given attention since then until in recent times. Several reports had quantified yield loss caused by rust in combination with other foliar diseases such as anthracnose or angular leaf spot (Bassanezi *et al.*, 2001; Paparu *et al*., 2014). This study was conducted to establish the difference in rust severity (or the damage levels) between six common bean genotypes and the relationship of this damage to yield losses and possibly recommend the best rust disease management strategy.

Rust disease incidence and severities due to season

Common bean rust disease was observed in 2015B and 2016A planting seasons for all experiments carried out on–station in Namulonge. The results of the analysis of variance for rust disease incidence and severity evaluated in both planting seasons are presented in Table 1. The results indicated that the differences among the genotypes and seasons were highly significant ($P < 0.001$) for both incidence and severity in both years. Also, the interaction of the genotype and season was significant for incidence ($P < 0.05$), and highly significant ($P < 0.001$) for severity in both years. However, there was no difference observed for the fungicide treatment, and the interaction between genotype and fungicide in both seasons. The high significant differences in the rust severity and incidence of rust disease among the six common bean genotypes in both 2015A and 2016A planting seasons indicated there was variability in the disease intensity between the two seasons studied. This variability could be attributed to change in the climatic conditions. Similar findings had been reported by Atkins (1973) in which the different climatic conditions were identified as a factor that contributed to the differences in rust disease intensity in the first and second planting season in Uganda.

Table 1: Analysis of variance of the mean of rust disease incidence and severity of six bean genotypes infected with bean rust in 2015B and 2016A planting seasons on-station, Namulonge, Uganda.

Source of variation	DF	Mean Square	
		Incidence	Severity
Genotype	5	0.5039***	0.61259***
Fungicide	1	1.1029ns	0.8243ns
Genotype. Fungicide	5	0.4864ns	0.4199ns
Season	1	0.9506***	1.44594***
Genotype. Season	5	0.1276**	0.17117***
CV%		13.4	10

DF: degree of freedom, values with * and *** implies significant at P = .05, and P < .001 respectively; ns: not significant; CV= coefficient of variation.

The means for rust disease incidence and severity evaluated in 2015B and 2016A planting seasons on-station at NaCCRI- Namulonge are presented in Table 2. In season 2015B, the resistant genotype Redlands Pioneer had the least rust disease incidence of 1.1% while NABE 16 had the highest rust disease incidence of 53%. Also, in the season 2016A, the resistant genotype Redlands Pioneer still had the least rust disease incidence of 1.8% while Masindi yellow had the highest rust disease incidence of 45%. Although, the result indicated that the levels of rust disease severity were low in both seasons, yet there were statistical differences between the resistant and/among susceptible genotypes. For instance, the resistant genotypes, Mexico 235 and Redlands pioneer had very low rust disease incidence (1% and 1.1% respectively), while the susceptible genotypes, NABE 16, Masindi yellow, K132 and NABE 15 had rust disease severity of 1.4 to 2.8 respectively.

The resistant genotypes, Redlands pioneer and Mexico 235 had low rust incidence and severity in both seasons. This indicated that they are highly resistant to rust (Arunga *et al*.,2012) and can be used as sources of resistance to rust in a common bean breeding program. The genotypes NABE 15, NABE 16, K132 and Masindi yellow have been reported to be susceptible to rust (Odogwu et al., 2016). The high rust incidence of these plants not treated with Mancozeb fungicide further confirmed this. It was observed that the rust severity was low for all genotypes in both seasons at the NaCCRI- Namulonge. This was attributed to the dry spell with its resultant high temperatures reported during the two planting seasons in Uganda (UNMA, 2016). Notwithstanding, the genotypes, Masindi yellow, K132, NABE 15 and NABE 16 which are among the farmer preferred common bean genotypes (Kilimo Trust, 2012) were susceptible to rust. Therefore, there is a need to deploy rust resistant genes into these genotypes as a cost-effective measure to reduce yield losses caused by rust disease.

Rust disease incidence and severities due to location

The bean rust disease was observed in all locations of experimentation on–stations at Namulonge, Hoima and Mbarara in 2016A season. The results of the analysis of variance for rust disease incidence and severity evaluated are presented in Table 3. The results of the analysis of variance for rust disease incidence and severity in all locations indicated high significant differences ($P < 0.001$) among the genotypes, fungicide treatment, interactions between location and genotype, and interactions between location and fungicide. Although there was significant difference ($P < 0.05$) for the interaction between genotype and fungicide for incidence, highly significant difference ($P < 0.001$) for severity was observed. The interaction of the locations, fungicide treatment and genotype were highly significant, indicating that the variability of these factors contributed to the levels of disease incidence and severity in this study.

Table 2: Statistical means for rust disease incidence and severity evaluated in 2015B and 2016A planting seasons on-station, NaCCRI, Namulonge, Uganda.

Mean scores (mean ± standard error)			
	Incidence_T (%)		
Genotype	Season 1	Genotype	Season 2
NABE16	53.0 ± 0.7^{a}	Masindi yellow	45.0 ± 0.2^{a}
NABE15	49.2 ± 0.60^{ab}	NABE16	28.1 ± 0.2^{b}
Masindi yellow	45.2 ± 0.65^{ab}	K132	22.1 ± 0.0^{b}
K132	34.4 ± 0.17^{b}	NABE15	18.4 ± 0.2^{c}
Mexico235	9.0 ± 0.00^{c}	Mexico235	11.50 ± 0.0^{d}
Redlands Pioneer	1.1 ± 0.66^{d}	Redlands Pioneer	1.80 ± 0.3^{d}
	Severity		
NABE16	3.0 ± 0.32^{a}	NABE16	2.1 ± 0.13^{a}
Masindi yellow	3.0 ± 0.31^{a}	Masindi yellow	2.0 ± 0.13^{a}
NABE15	2.2 ± 0.26^{b}	NABE15	2.0 ± 0.11^{b}
K132	2.0 ± 0.07^{b}	K132	1.4 ± 0.30^{c}
Mexico235	0.4 ± 0.00^{c}	Mexico235	1.1 ± 0.00^{c}

Redlands Pioneer	0.0 ± 0.30^{c}	Redlands Pioneer	1.0 ± 0.12^{c}

Table 3: Analysis of variance (ANOVA) of the mean of rust disease incidence and severity of six bean genotypes infected with bean rust in three locations- NaCRRI-Namulonge, Hoima and Mbarara in 2016A planting seasons in Uganda

Source of variation	DF	Mean Square	
		Incidence	Severity
Location	2	53673.42***	42.48***
Genotype	5	25702.64***	17.74***
Fungicide	1	9625.64***	10.31***
Location* Genotype	10	5235.65***	4.30***
Location*Fungicide	2	2608.15***	4.60***
Genotype *Fungicide	5	824.66*	1.90***
Location* Genotype *Fungicide	10	5235.65***	4.30***
CV%		47.03	27.5

DF: degree of freedom, values with *, ** and *** implies significant at p = .05, < .01 and < .001 respectively; ns: not significant; CV= coefficient of variation.

The means of the disease incidence and severity on the six bean genotypes infected with bean rust on-station in the three locations namely, Hoima and Mbarara and Namulonge during the 2016A planting seasons in Uganda are presented Table 4. Generally, it was observed that rust disease incidence and severity in fungicide treated plots were lower than the plots not treated with fungicide. Also, the rust disease incidence and severity were higher in Mbarara and Hoima than in Namulonge. In terms of the response of the genotypes to the treatments across the three locations, it was observed that the resistant genotype, Redlands Pioneer had the least rust disease incidence and severity in both fungicide and non-fungicide treated plots in all locations studied. For instance, in Hoima, it was observed that the resistant genotype, Redlands Pioneer had the least rust disease incidence of 0.75 and 0.71% in both fungicide non-treated and treated plots while NABE 15 and Masindi yellow in non-fungicide treated plots had 90.34% and 82.14% respectively.

In Mbarara, it was observed that the genotype Redlands Pioneer had the least rust disease incidence of 2.00% and 5.56% in fungicide and non-fungicide treated plots respectively. On the other hand, NABE 16 and NABE 15 had the highest rust disease incidence of 92.93% and 88.99% in non-fungicide treated plots. Also, in Namulonge, Redlands Pioneer had the least rust disease incidence of 1.59% and 2.00% in both fungicide and non-fungicide treated plots while in non-fungicide treated plot of Masindi yellow, rust disease incidence was 67.04%. In Hoima, the rust disease severity of the genotype Redlands Pioneer was observed to have the least severity of 0.17 and 1.72 in both fungicide and non-fungicide treated plots respectively while for the non-fungicide treated plots of NABE 15 and Masindi yellow, severity was 3.48 and 3.36 respectively. Similarly, in Mbarara, Redlands Pioneer had the least severity of 1.01 and 1.17 in both fungicide and non-fungicide treated plots respectively while NABE 15 and Masindi yellow had higher rust disease severity of 3.48 and 3.32 respectively. In Namulonge, rust disease severity was generally low, however Redlands Pioneer had the least rust disease severity of 0.72 in the fungicide treated plot. The differences in statistical means for Redlands Pioneer was not different in all locations for rust disease incidence but was different for severity in Hoima and Namulonge. Also, it was observed that there were statistical differences between the two resistant genotypes, Redlands Pioneer and Mexico 235 in all locations for rust disease incidence and severity, however there was no statistical differences for Mexico 235, NABE 16, K132, Masindi yellow and NABE 15 for rust disease severity in Namulonge.

Table 4: Statistical means for rust disease incidence and severity evaluated in 2016A planting seasons on-station atBUZARDI-Hoima, Mbarara-ZARDI and NaCRRI-Namulonge, Uganda

Location	Genotype	Treatment	Means score (means± standard error)	
			incidence	Severity
Hoima+I5:M2I5:M32	NABE15	Non-fungicide	90.34±0.95[a]	3.38±0.13[a]
Hoima	NABE15	Fungicide	66.43±2.00[b]	2.49±0.48[b]
Hoima	Masindi yellow	Non-fungicide	82.14±1.71[a]	3.36±0.12[a]
Hoima	Masindi yellow	Fungicide	57.38±3.45[b]	3.30±0.06[b]
Hoima	NABE16	Non-fungicide	69.28±1.57[b]	2.82±0.37[b]
Hoima	NABE16	Fungicide	56.06±0.93[b]	2.34±0.42[b]
Hoima	K132	Non-fungicide	44.29±1.60[c]	3.11±0.17[a]
Hoima	K132	Fungicide	43.84±1.15[c]	1.97±0.65[c]
Hoima	Mexico 235	Non-fungicide	20.80±2.00[d]	1.00±0.17[c]
Hoima	Mexico 235	Fungicide	15.22±1.62[d]	1.17±0.15[c]
Hoima	Redlands Pioneer	Non-fungicide	0.72±0.25[e]	1.72±0.74[c]
Hoima	Redlands Pioneer	Fungicide	0.71±0.55[e]	0.17±0.15[d]
Mbarara	NABE16	Non-fungicide	92.93±0.18[a]	3.21±0.19[a]
Mbarara	NABE16	Fungicide	63.56±2.10[b]	2.17±0.67[b]
Mbarara	NABE15	Non-fungicide	88.99±0.51[a]	3.48±0.07[a]
Mbarara	NABE15	Fungicide	47.71±3.42[c]	2.15±0.71[b]
Mbarara	Masindi yellow	Non-fungicide	67.05±0.44[b]	3.32±0.06[a]
Mbarara	Masindi yellow	Fungicide	58.92±5.10[b]	2.41±0.53[b]
Mbarara	K132	Non-fungicide	64.38±1.67[b]	3.01±0.28[a]
Mbarara	K132	Fungicide	31.63±4.04[c]	1.81±0.30[c]
Mbarara	Mexico 235	Non-fungicide	20.48±2.59[d]	1.91±0.82[c]
Mbarara	Mexico 235	Fungicide	17.98±3.67[d]	1.33±0.28[c]
Mbarara	Redlands Pioneer	Non-fungicide	5.56±4.08[e]	1.17±0.15[c]
Mbarara	Redlands Pioneer	Fungicide	2.00±2.02[e]	1.01±0.15[c]
Namulonge	Masindi yellow	Non-fungicide	67.04±2.44[a]	1.04±0.16[c]
Namulonge	Masindi yellow	Fungicide	22.87±2.02[b]	1.17±0.15[c]
Namulonge	NABE16	Non-fungicide	29.92±6.19[b]	1.72±0.39[c]
Namulonge	NABE16	Fungicide	26.25±4.33[b]	1.17±0.15[c]
Namulonge	K132	Non-fungicide	25.15±2.47[b]	1.02±0.15[c]
Namulonge	K132	Fungicide	19.05±7.56[b]	1.26±0.28[c]
Namulonge	NABE15	Non-fungicide	22.84±1.46[b]	1.02±0.18[c]
Namulonge	NABE15	Fungicide	13.92±3.23[b]	1.17±0.15[c]
Namulonge	Mexico 235	Non-fungicide	13.09±3.00[b]	1.00±0.17[c]
Namulonge	Mexico 235	Fungicide	10.00±0.17[c]	1.17±0.15[c]

Means sharing the same letters down the column not significantly different by Tukey's Student (HSD) range test

Generally, the high significant differences in the rust severity and incidence of rust disease among the six common bean genotypes in the three locations namely, Namulonge, Hoima and Mbarara showed that the agroecological zones greatly influenced these disease parameters. Similar finding has been reported by Mwang'ombe *et al.* (2007), in which the foliar fungus angular leaf spot (ALS) severity in Kenya was reported to be significantly influenced by agroecology. It was observed that rust disease severity and incidence were low in

Namulonge than the other two locations. This location has been used in previous studies (Paparu *et al*., 2014a). The low rust disease severity may be because of the dry spell reported by the UNMA (2017). The high temperatures of 25°C to 29°C and the low relative humidity below 95% was not suitable for the proliferation of the rust pathogen in the field. Although this climatic condition reduced rust disease severity in the field, the lack of moisture affected the grain yields of the crop since the field was rain-fed and not irrigated.

Marketable grain yield and yield losses caused by bean rust

In general, marketable grain yields for non-treated beans plots were lower than the treated plots with yield loss estimates higher among the susceptible genotypes (Figure 1). In 2015B planting season, it was observed that the resistant genotype, Redlands pioneer had the highest marketable grain yields of 110 g and 120 g for both non-fungicide and fungicide treated plots. However, the genotypes NABE 16 (16g) and Masindi yellow (21g) respectively in the non-fungicide treated plots had the least marketable grain yields. The genotype NABE 16 had the highest yield loss of 57% while Redlands pioneer had the least yield loss of about 8.3%. In 2016A planting season, the genotypes, K132 and NABE 16 respectively, had the highest marketable yields of 98g and 93g for the fungicide treated plots. However, it was observed that the marketable yields for the resistant genotypes, Redlands pioneer and Mexico 235 were relatively low for both non-fungicide and fungicide treatments. From the result, yield losses for all genotypes were 8.3% to 49% in 2015B with genotype, NABE 16 having the highest yield loss of 49% while Redlands pioneer had the lowest yield loss of 8.3. In 2016A planting season, yield loss was 13% to 55% with Masindi yellow having the highest yield loss of 55% and Mexico 235 having the least yield loss of 13%.

This finding were similar to the report by Paparu *et al.* (2014a), in which beans plots treated with the fungicide Mancozeb significantly increased grain yields. However, it was observed that the marketable grain yields for each resistant genotype i.e. Redlands pioneer and Mexico 235, for both the fungicide treated and non-fungicide treated plants was not different. For instance, the genotype, Redlands pioneer in the 2015A planting season was 110g and 120g for the non-treated and treated plots with yield losses of 8.3% and 9.4% respectively. This indicated that the fungicide treatment did not influence the yield of the plants but their innate resistant genes.

For the three locations, marketable beans yield for all genotypes for non-treated plots were lower than the treated plots with yield loss estimates higher among the susceptible genotypes (Figure 2). The genotype, Masindi yellow was observed to have the highest marketable yield (107g) in the fungicide treated plot in Hoima while it had the least marketable yield for NABE 15 in the non-fungicide treated plot in Mbarara. The marketable yields of the resistant genotype Redlands pioneer were relatively high of about 84g and 86g respectively for non-fungicide and fungicide treated plots. There were no yield data obtained for the genotype Mexico 235 in Hoima. It was also observed that Masindi yellow had the highest yield loss of 55% in Namulonge while the least yield loss was recorded for Redlands pioneer (2%) in Mbarara.

The fungicide treatment significantly increased the marketable yields of susceptible genotypes, NABE 15, NABE 16, K132 and Masindi yellow between seasons (Figure 1) and locations (Figure 2). These findings were similar to the report by Paparu *et al.* (2014a), in which beans plots treated with the fungicide Mancozeb significantly increased grain yields. However, it was observed that the marketable grain yields for each resistant genotype i.e. Redlands pioneer and Mexico 235, for both the fungicide treated and non-fungicide treated plants was not different. For instance, the genotype, Redlands pioneer in the 2015A planting season was 110g and 120g for the non-treated and treated plots with yield losses of 8.3% and 9.4% respectively. This indicated that the fungicide treatment did not influence the yield of the plants but their innate resistant genes. However, it was observed that the yields of Redlands pioneer and Mexico 235 were generally low in all locations with no yield data for Mexico 235 in Hoima. This is because, these two genotypes are not indigenous to Uganda and are not adapted to the environment. Holbrook *et al*. (2000) observed that resistance sources are adapted to environments in which they were developed; and this limits their use in other environments where they are not acclimatized to.

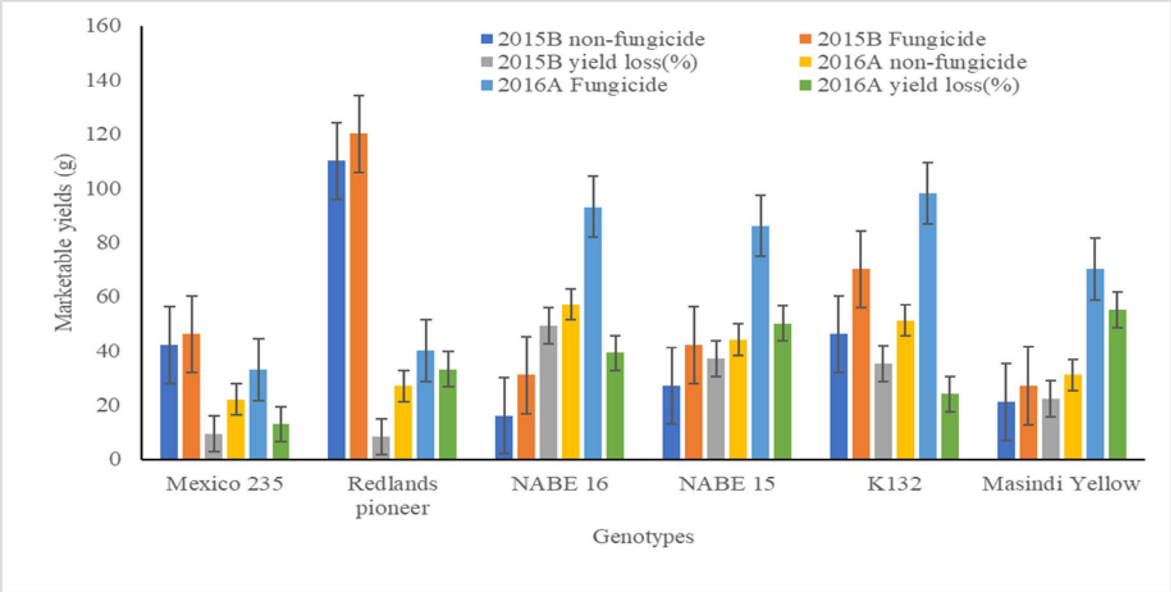

Fig. 1: The marketable grain yields (g), yield loss and rust tolerance index of six beans genotypes namely NABE 15, NABE16, K132, Masindi yellow, Mexico 235 and Redlands pioneer, infected with bean rust during the 2015B and 2016A planting seasons at Namulonge, Uganda. Error bars represent standard error of the mean.

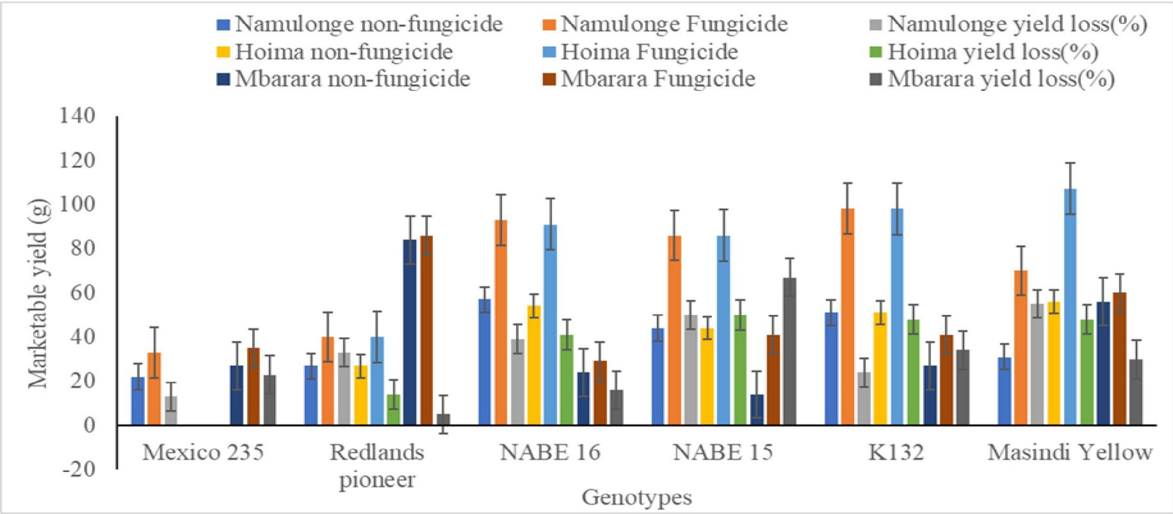

Fig. 2: The marketable yields (g) and yield loss (%) of six beans genotypes namely NABE 15, NABE16, K132, Masindi yellow, Mexico 235 and Redlands pioneer, infected with bean rust during the 2016A planting seasons at Namulonge, Hoima and Mbarara, Uganda. Error bars represent standard error of the mean.

This was further reiterated by Ddamulira *et al*. (2014), who discouraged the use of exotic sources of resistance in a disease resistance breeding program because of their limitations such as low adaptability and undesirable traits. Therefore, there is a need to develop resistance to rust in the indigenous farmer preferred genotypes and deploy these developed rust resistant genotypes to augment the integrated disease management strategy of beans rust disease in Uganda.

Conclusion

In this study, the levels of bean rust, an important disease in Uganda, severity and incidence with their resultant yield losses on six common bean genotypes were investigated. It was observed that the disease caused an estimated yield loss of 5% to 67% in the six genotypes namely Masindi yellow, K132, NABE 15, NABE 16, Mexico 235 and Redlands pioneer. The rust resistant genotype, Redlands Pioneer had low rust yield losses in all location studied while the farmer preferred genotypes Masindi yellow, K132, NABE 15, and NABE 16 were susceptible to the rust disease and had high yield losses of up to 67% on plots not treated with Mancozeb fungicide. Therefore, there is a need to explore the rust resistant genes from Mexico 235 and Redlands pioneer genotypes and introgress the putative genes into these farmer preferred genotypes to augment the integrated disease management strategy of beans rust disease in Uganda.

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Conflict of Interests

There is no conflict of interest.

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