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Full Length Research Paper

Prevalence and variability of the common bean rust in Uganda

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Uganda is the second largest producer of dry beans (*Phaseolus vulgaris* L.) in Africa, but common bean rust caused by *Uromyces appendiculatus* (Pers. Unger), is negatively impacting the production of the crop. There is little information on the occurrence and identity of the rust pathotypes present in the country. Consequently, a field survey was carried out during the 2015 second planting season in fifteen districts, representing the areas of high beans production in Uganda. High common bean rust incidence and severity were observed in the low altitudes and the South-Western Highlands of Uganda. Wakiso and Hoima districts had the highest rust disease incidence 72 and 76% respectively and severity rates of 6 and 5.5, respectively. Rust disease incidence was uniformly high on commercial genotypes and landraces. Similarly, high rust disease incidence and severity were observed in the bean-maize–groundnut cropping system. Twenty-three single rust isolates were collected in Uganda and inoculated on 11 bean rust differentials and Ouro Negro *(Ur-14)* genotypes. Six rust pathotypes were identified and these included 2-0, 4-0, 50-0, 5-1, 4-33 and 63-19. Five of the pathotypes were of Andean origin and only pathotype 4-33 was of Mesoamerican origin. The rust pathotype 63-19 showed similar pathogenic characteristics with the Puerto Rico rust race 19-63. This study provides critical baseline information to integrate breeding and crop protection in the efforts to develop an overall strategy for the management of common beans in Uganda.

Key words: *Phaseolus vulgaris*, *Uromyces appendiculatus*, rust differentials, co-evolution, disease severity.

INTRODUCTION

Uganda is the second largest producer of dry beans (*Phaseolus vulgaris* L.) in Africa (Abate et al., 2012). Common beans are grown in all major agro-ecological regions of Uganda (Ugen et al., 2014) but the production rate is higher in the Western region and lower in the Northern region of the country (Abate et al., 2012). Recently, bean rust has been observed to be an important disease that is devastating farmers' bean fields (Odogwu et al., 2014). Common bean rust is a foliar disease that occurs widely in Africa and has been

observed to be the third major production constraint causing yield loss of about 118.7 tonnes per year in Eastern Africa, after angular leaf spot and anthracnose diseases (Assefa, 1994; Kimani et al., 2001). The disease causes premature leaf chlorosis, senescence and in severe cases complete plant defoliation resulting in yield losses ranging from 18-100% (Souza et al., 2014).

The major mode of dissemination of bean rust is by wind, but other agents of dissemination include migratory birds, insects, water and sometimes through contaminated farm implements and infected plant debris (Liebenberg and Pretorius, 2010). The factors that contribute to the distribution and prevalence of the bean rust disease include altitude, ecological zones and human activities (Helfer, 2014; Lin, 2011). Helfer (2014) and Liebenberg and Pretorius (2010) reported that abiotic factors such as temperature, high humidity and leaf surface moisture; and biotic factor such as rust disease host range contribute to the epidemiology of rust disease. According to Liebenberg and Pretorius (2010), temperatures favoring germination and infection of bean rust range from 17 to 21°C and a sharp decrease in number of pustules per leaf at incubation occurs when temperatures are between 21 to 25°C. Harter et al. (1935) observed high levels of infection when exposed to rust at appropriate temperature ranges, high levels of infection were obtained when plants were exposed to a relative humidity (RH) of 96% or higher, provided free moisture was present on the leaves. However, at lower humidity levels infection levels were reduced, and no infection would take place.

According to Babel and Turyatunga (2014), Uganda has an equatorial type of climate with ample sunshine and heavy rainfall in most parts of the country. Mean annual rainfall near Lake Victoria is about 2,100 mm, while the mountainous regions of the west, southwest, and northeast receive average annual rainfall of about 1,500 mm. The lowest mean annual rainfall (-500 mm) occurs in the extreme northeast (Byrnes, 1990). Mean annual temperatures range from about 16°C in the southwestern highlands to 25°C in the northwest, but in the northeast, temperatures exceed 30°C in the dry season. The maximum temperature ranges between 18 and 35°C and the minimum temperature between 8 and 23°C depending on the part of the country (Byrnes, 1990). Also, Uganda is divided into seven broad agro-ecological zones: the banana-coffee system, the banana–millet–cotton system, the montane system, the Teso system, the Northern system, the West Nile system, and the pastoral system (Mwebaze, 2006). An agro-ecological zone (AEZ), as defined by the Food and Agriculture Organization (FAO 2010), is a land resource mapping unit, defined in terms of climate, landform, soils, and land cover, fairly homogeneous across the AEZ, and having a specific range of potentials and constraints for land use (Babel and Turyatunga, 2014).

Cultural practices were once thought to have only a minimum effect on the prevalence of bean rust (Mmbaga et al., 1996). Lin (2011) suggested that cropping systems such as crop diversification can contribute to the spread or suppression of the disease. Liebenberg and Pretorius (2010) reported that cultural practices such as cultivar mixtures, crop rotation, planting time and age of crop, intercropping and choice of bean varieties could affect the level of infection and spread of the rust disease. Mmbaga et al. (1996) suggested that airborne rust spores produced on volunteer, wild or cultivated beans are sources of infection that could reduce the effectiveness of crop rotation. Ronner et al. (2013) stated that common bean are mostly grown as either as sole crops or as intercrops (on 2/3rd of the total plots planted with beans) with maize, cassava, cotton, bananas and groundnuts in Uganda. The effect of these cultural practices on rust prevalence has not been reported in the country.

According to Steadman et al. (2002), the virulence structure of *U. appendiculatus* and its properties related to the host selection effect on the pathogen population, depends on assessing the pathogen based on the reaction of the pathotypes on a standard differential set of 12 common bean cultivars established during the 3rd Bean rust and 2nd Bean common Bacterial Blight International Workshops in 2002. In this method a binary system based on the position of each cultivar within the series was used to define the virulence level of isolates under study (Pastor-Corrales and Liebenberg, 2010). There is no information on the identity and distribution of bean rust pathotypes in Uganda. Therefore, a survey was conducted to assess rust disease distribution and severity as well as its association with the cropping system and agro-ecological zones in Uganda. Also, other factors contributing to the rust disease epidemiology and uniqueness of the rust pathotypes in the selected bean growing areas were considered.

MATERIALS AND METHODS

Study area and fields

In the second planting season of 2015, 15 districts located in six of the major AEZs of Uganda were surveyed. Bean fields were visited in AEZs and districts are indicated in Table 1. The districts were selected based on their bean production intensity. Fields were selected at random at intervals of 5 to 10 km along the main roads.

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Table 1. Details of agroecological zones and districts surveyed for rust disease assessment in the second planting season of 2015.

Agroecological zone	Districts	Number samples collected
Intensive banana coffee lakeshore system in central region (CR)	Wakiso	10
	Butambala	10
Montane system in the eastern region (ER)	Kapchorwa	10
	Bulambuli	10
	Mbale	10
Montane system in the South-Western highlands of the South-Western Highlands (SWH)	Sheema	10
	Mbarara	10
	Kabale	10
	Masaka	10
Western banana-coffee cattle system of the South-Western region (SWR)	Hoima	10
	Masindi	10
Northern system of Northern Central (NC) region	Amuru	10
	Kole	10
	Lira	10
Annual cropping and cattle West Nile system of the Northern Savannah Grassland (NSG)	Arua	10

When necessary, the sample size (the number of observed fields per region) and the number of sample units (the randomly selected single plants) per field were adjusted to suit the field size and crop distribution. All sampled fields belonged to small-holder farmers and each field was visited once.

Sample units

Following the methodology of Assefa (1994), in each sampled field, the size of the field was estimated and the crop age was determined. Sample units were selected by making a specific number of equally spaced paces following an inverted "V" pattern from the edge of the field. Having made the pre-set number of paces based on the field size, the nearest plant to the right foot was taken as the sample unit. In each sample field, 20 sample plants were selected for disease assessment. A sub-sample of 3 trifoliate leaves per plant was selected, yielding a total of 60 leaves per field. The sub-sample was composed of one leaf from each of the upper, middle and bottom canopy layers of the main stem.

Crop and disease assessment

Data on disease incidence and severity were collected mostly from plants at the V3= first trifoliate leaf stage; V4= third trifoliate leaf stage; R5= pre-flowering; R6= flowering; R7= pod formation; R8= pod filling plant developmental stages (Van Schoonhoven and Pastor-Corrales, 1991). Disease incidence was expressed as the percentage of the number of infected plants over the 20 plants within the sampling point. Rust disease severity was rated using the CIAT 1 to 9 scale following Van Schoonhoven and Pastor-Corrales (1991), where 1-3 = resistant (no visible pustules to few pustules covering 2% of foliar area), 4-6=intermediate (small pustules covering 5% foliar area to large pustules often surrounded by chlorotic halos covering 10% foliar area) and 7-9 = susceptible (large to very large pustules covering 25% foliar area). Also the global positioning (GPS) readings of latitude, longitude and elevation were recorded for each location where data were collected using Garmin eTrex 10x GPS.

Data analysis

Rust disease incidence and severity maps were developed using GPS survey data points obtained from each sampling location and incidence and severity means generated from data analysis (Ddamulira et al., 2014). The altitude was calculated from the elevation data using Spatial Data Download | DIVA-GIS. Maps were exported and visualized in Arc View® GIS3.2 software (Rockware Inc). Analysis of variance and correlation between incidence and severity means were done using GenStat 12th edition (Payne et al. 2011). Multiple mean comparisons for rust disease incidence and severity for all districts surveyed were performed using Tukey's studentised range test, where $\alpha = 0.05$ using the GenStat 14th edition. Bar charts for each factor affecting disease severity and incidence were done using Microsoft Excel 2013.

Fungal isolation and inoculum preparation

Two infected common bean leaves from landraces, commercial and introduced genotypes, with two to three rust pustules, were collected from each sampled point and placed inside a well labeled coin envelope which were left opened while the leaves were left to air dry and taken to the laboratory for isolation. For isolation, the single pustule isolation method currently in use at the pathology laboratory, University of Nebraska, Lincoln, USA was used. Pure isolates were obtained and multiplied by inoculating single pustules' spores on the abaxial surface of the 10-day old leaves of NABE 16, a released cultivar known to be susceptible to rust. From viable pustules, twenty-three isolates were obtained from the diseased bean leaves collected during the survey from the districts of Wakiso, Sheema, Hoima, Masindi and Masaka. The pustules from

Table 2. Analysis of variance of environmental and production on the incidence and severity of in Uganda.

Source of variance	Incidence (%)		Severity
	DF[1]	MS[2]	
Altitude	2	648***	20.36***
Agro-ecological zone	5	128***	41.68***
District	14	648***	20.36***
Crop stage	5	336ns	13.53*
Cropping system	2	988**	33.37**
Intercropping	9	352*	09.73**
Fungicide treatment	2	587*	31.47**
Other diseases	19	211ns	5.05ns
Previous crops	24	232*	8.46ns
Variety	34	299***	8.29**
$LSD_{(0.005)}$		0.058	3

[1]DF: degree of freedom; MS: Mean square, [2]Values with *, ** and *** implies significant at P = .05, P < .01 and P < .001 respectively; [2]ns: not significant.

the other 10 regions were likely not viable since they did not sporulate.

Inoculation and pathotype determination

To determine the rust isolate pathotype, a set of differential cultivars with specific resistance genes where inoculated with each bean rust isolate. The differential set included 11 cultivars from the 2002 set of 12 bean rust differentials suggested by Steadman et al. (2002) which were obtained from the Pathology Lab of the University of Nebraska, USA. They include, 1=Early Gallatin; 2=Redlands Pioneer; 3=Montcalm; 4= Golden Gate Wax; 5= PI260418; 6= Great Northern 1140; 7= Aurora; 8= Mexico 309; 9= Mexico 235; 10=CNC; 11= PI181996 and the 12th genotype was Ouro Negro (*Ur-14*) of the Mesoamerican gene pool that was obtained from Dr. E. Arunga, formerly of the Department of Biotechnology, Eldoret University, Kenya. Six seeds of each cultivar were pre-germinated for two days before planting in 2-L disposable cups containing black soil, manure and sand in a ratio of 3:1:1 and allowed to grow for 10 days. The 10-days old bean plants were inoculated with spores of each isolates and kept in a humid chamber at 18-23°C and 95% relative humidity for 16 h. The plants were air-dried before they were transferred into the screen house. The plants were observed daily for pustule sporulation and size until they are 15 days old. The pustules types were measured using the iGAGING ocular lens (www.iGAGING.com). Rust races were named following the suggestion of Pastor-Corrales and Liebenberg (2010). The virulence reactions of the cultivars were recorded as disease scores based on the rust pustules types (size) using the CIAT scale of 1 to 6 (Van Schoonhoven and Pastor-Corrales, 1991) as follows: 1= no visible symptoms; 2= non-sporulating necrotic spots; 3= sporulating pustules smaller than 300 µm in diameter; 4= sporulating pustules 300-500 µm in diameter frequently surrounded by chlorotic halos; 5= sporulating pustules 500-800 µm in diameter frequently surrounded by chlorotic halos; 6= sporulating pustules larger than 800 µm in diameter frequently surrounded by chlorotic halos. Where several infection grades were present, the predominant or most prevalent was chosen. Cultivars were considered resistant when they were predominantly of grade 3 or lower and susceptible with a predominance of grade 4 and higher. Pathotypes were determined by adding binary values of the differential genotypes that were susceptible to a particular with the respective bean rust isolate based on the predominance of virulence on the Andean [large seeded] or Mesoamerican [small seeded] cultivars (Gepts, 1998). According to Pastor-Corrales and Liebenberg (2010), if a new isolate of the rust pathogen is compatible with Andean bean cultivars Montcalm and Golden Gate Wax, and with Middle American cultivars GN 1140 and Aurora, the new race would be named 20-3. The first digit (20) is obtained from the addition of the binary values of the Andean bean cultivars Montcalm (4) and Golden Gate Wax (16). The second digit (3) is obtained from the addition of the binary values of the Middle American bean cultivars GN 1140 (1) and Aurora (2). Inoculation of the differentials with the different isolates was repeated for authentication of the results. Some isolates were sent to the pathology laboratory, University of Nebraska, Lincoln, USA for authentication.

RESULTS AND DISCUSSION

Rust disease incidence and severity

The results of the rust disease survey showed that bean rust was present in all locations and altitudes sampled confirming findings by Wortmann et al. (1998). The incidence of rust ranged from 10-76% while rust severity scores ranged from 3.0 to 7.2. Rust disease incidence and severity were significantly different (P<0.001) across locations surveyed (Table 2). Significant differences (P<0.001) were observed in incidence and severity across the altitudes, AEZ and districts. Incidence and severity was also significantly (P<0.01) influenced by crop developmental stage and cropping history (previous crop planted). Similar findings were reported by Lin (2011) and Helfer (2014). There was no significant contribution by other disease observed in the field to rust incidence and severity, indicating that the presence of other diseases had not effect on the prevalence of rust disease.

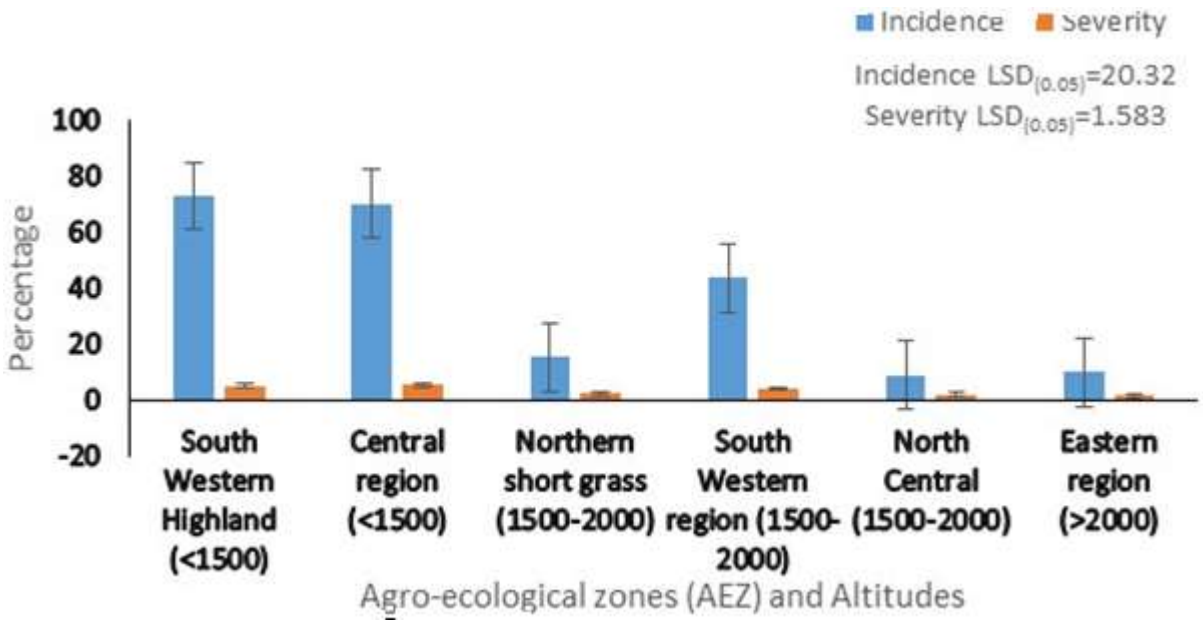

Figure 1. The level of rust incidence and severity based on the AEZ and altitude in Uganda in the 2015 second planting season.

The South-Western Highlands (SWH) had the highest rust incidence of 73% followed by Central region (CR) with 70% and South Western region (SWR) with 44% while the lowest incidence of 9% was observed in North Central (NC) region (Figure 1). On the other hand, CR had the highest rust severity level of 6 followed by SWH (5) and the lowest severity of 2 was observed in the Eastern region (ER). These findings agree with Wortmann et al. (1998) who reported that rust was moderately severe in Western Region (WR), ER, CR and SWH, while it was low in the NC. Both the CR and SWH regions lie at lower altitude (<1500 m) and had the highest rust incidence of 70 and 73%, respectively. While AEZs in altitudes above 2000 m, such as NC and ER had the lowest rust incidence of 9 and 10% respectively, and severity of 2. The recommended temperature threshold of 18°C and relative humidity of 95% are necessary for high rust disease severity to occur (Pastor-Corrales and Liebenberg, 2010). Mwebaze (2006) reported that the SWH had temperatures of 16 to 18°C and the NR had temperatures exceeding 25°C, which may be the reason for the high rust disease prevalence in the SWH and CR AEZs. Similar findings were reported by Wortmann et al. (1998). The highest rust incidence was recorded in Hoima district (76%) followed by Wakiso (72%) and Masindi (71%). Mbale and Kabale recorded the lowest incidence of 10% each (Figure 2). Moderate disease incidence ranging from 67-69% were recorded in Wakiso, Masaka, Butambala and Arua whereas the highest rust severity was recorded in Wakiso district (6) followed by Hoima (5.5). Mbale (2), Kabale (3) and Kapchorwa (3) found in higher altitude recorded the lowest severities.

Paparu et al. (2014) reported moderate rust severity for Mbale and Kabale districts. However, in this study low severity were observed in Mbale, and Kabale. This may be the result of seasonal changes in weather conditions observed in Uganda (Hepworth et al., 2008). The effect of seasonal changes in weather conditions on rust prevalence were reported in Ethiopia by Assefa (1994). In general, rust severity and incidence were found at different levels in all altitudes studied, which suggests that all bean growing areas in Uganda have conditions that favour common bean rust development and spread. It was also observed that the disease severities of Hoima and Wakiso where statistically different with values of 5.55 and 5.75 respectively, while the disease incidence was not statistically different for Masaka, Butambali, Hoima and Wakiso (Table 3).

Effect of cultural systems on rust prevalence

Cropping systems either increased or decreased rust disease prevalence. The effect of cropping system on rust incidence and severity was significant ($P<0.01$) for all the locations surveyed. The mixed cropping system had the highest rust incidence (49%), while sole cropping system was 41%. However, the sole cropping system had the highest rust severity level of 6.2, while mixed cropping system had 3.8. The high severity level of sole cropping system may result from the re-infection of the beans fields with rust pathogens from debris or volunteer crops and weeds. High rust severity in sole cropping system has been reported by Mmbaga et al. (1996). At

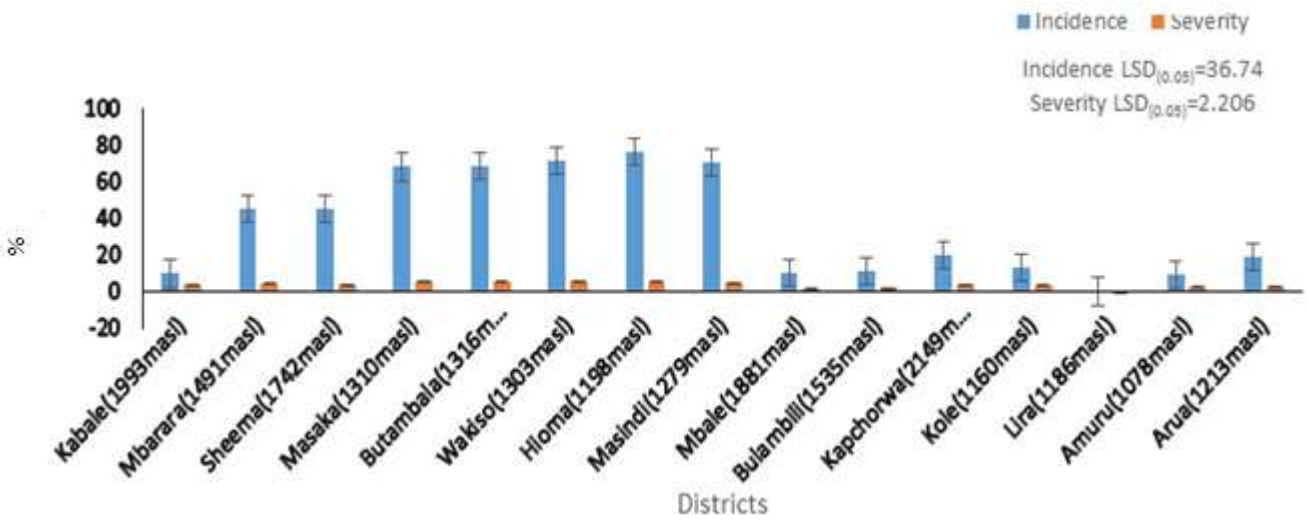

Figure 2. The level of rust incidence and severity on each district in Uganda in the 2015 second planting season.

Table 3. Mean incidence and severity of common beans rust for the districts surveyed in Uganda.

District	Incidence	Severity
Bulambili	0^{a}	0^{a}
Mbale	9^{ab}	2^{ab}
Arua	10^{ab}	2.333^{abc}
Amuru	13^{ab}	2.501^{bc}
Kole	14^{ab}	3.035^{bcd}
Kabale	20^{ab}	3.182^{bcde}
Kapchorwa	27^{abc}	3.429^{bcdef}
Sheema	46^{bcd}	3.515^{bcdef}
Mbarara	50^{bcd}	4.5^{cdef}
Masindi	68^{cd}	4.7^{cdef}
Masaka	69^{d}	5.1^{def}
Butambali	71^{d}	5.167^{def}
Hoima	72^{d}	5.556^{ef}
Wakiso	76^{d}	5.75^{f}

the crop diversity level, the beans-maize-groundnut intercropping system showed the highest disease incidence (100%) while the bean-coffee-banana intercropping system had the lowest score of 2%. However, the beans-coffee and beans-maize-groundnut intercropping system showed the highest disease severity of 6 while the bean-coffee-banana intercropping system had the lowest score of 2. Msuku and Edje (1980) reported that the common bean-maize cropping system had reduced rust severity while Mmbaga et al. (1996) indicated that intercropping beans and maize affected bean rust epidemiology by influencing spore dispersal, spore retention and infection efficiency. However, the high rust severity in the bean-groundnut and maize intercrop might have resulted in the rust disease build-ups in the fields because of the higher relative humidity resulting from the maize-bean-groundnut canopies which favoured uredospore production (Msuku and Edje, 1980).

Rust disease incidence was significantly influenced by cropping history (<0.05), whereas rust severity was not. Fields which were previously grown with bush beans and left to fallow in the 2015A season had high rust incidence levels of 100%, while fields grown with sorghum the previous season had the lowest disease incidence level of 3.33%. The rust disease prevalence in fields previously grown with bush beans and left fallow may be attributed to infected plant debris from previous season (Liebenberg and Pretorius, 2010). Similar findings were reported by Souza et al. (2008).

On the contrary, crop developmental stage had a significant effect on rust disease severity (<0.01) but was not true for rust incidence in all locations surveyed. The plants at the pre-flowering stage (R5) and third trifoliate stage (V4) had more rust disease severity of 4.8 and 4.7 respectively than other stages. While those plants at the pod filling (R8) stage had the lowest rust severity of 2.7. Similar findings have been reported by Assefa (1994). Early planting following the onset of rainfall has been recommended as a strategy in managing rust disease which enables the bean plants to escape the onset of the rust disease which is high and prevalent during the mid-season (Steadman et al., 2002; Ronner, 2013), that is October and November for the second cropping season in Uganda.

Production practices significantly influenced rust incidence and severity in all locations surveyed (Figure 3). Fields without fungicide treatment showed high rust incidence of 53% while those with fungicide application had low disease incidence (45%). The fungicide commonly used by farmers was the Indofil-M45

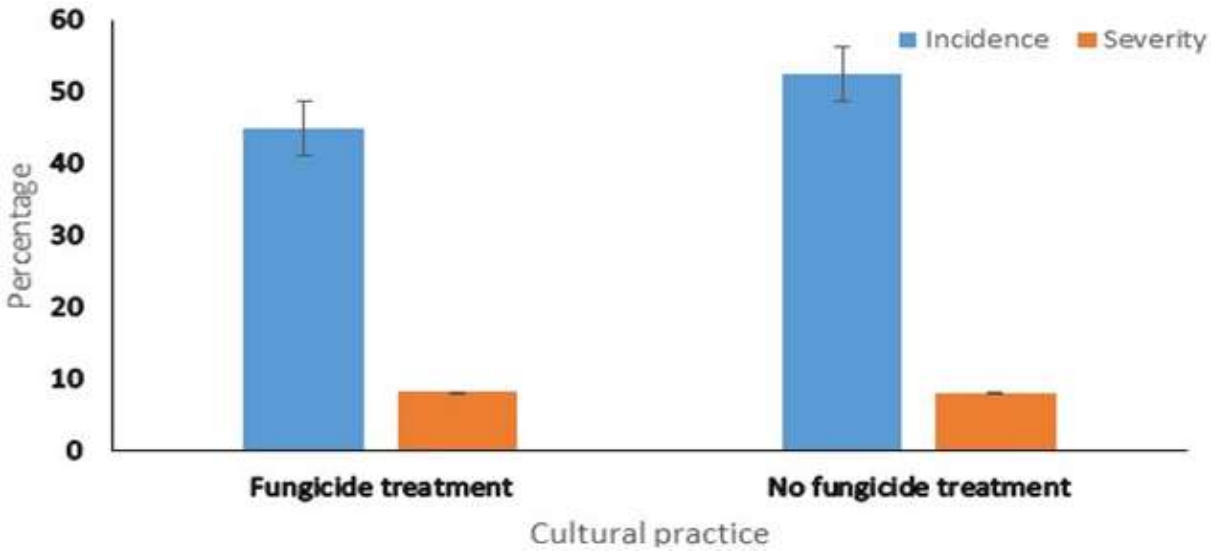

Figure 3. The level of rust incidence and severity based on the cultural practice in Uganda in the 2015 second planting season.

(Mancozeb 80%W. P). Similarly, unsprayed fungicide fields showed high rust severity (6.6) while those sprayed with fungicide treatment had lower rust severity (4.1). These findings confirm the importance of a disease management in small-holder farms. Farmers could also reduce rust disease on their farms by planting resistant varieties (Mmbaga et al., 1996). In this study, rust disease incidence and severity were significantly influenced by the type of bean variety grown (Figure 4). The commercial varieties NABE 1, NABE 5 and NABE 16 had the highest rust disease incidence levels of 100% while fields cultivated with the introduced genotypes, Mac 44 and Nutri-beans, screened by the Ugandan legume programmes had no rust disease. On the other hand, the landraces Kamenyameggo, Kanyebwa and Masindi yellow had the highest rust severity levels of 7, 6.5 and 6.1 respectively. In general, high disease severity was observed in fields cultivated with farmers' preferred landraces and commercial cultivars. These findings provide information that will guide the rust resistance breeding programme in Uganda. Also, the genotypes Mac 44 and Nutri-beans which were rust free needs to be further investigated to confirm and determine the resistance genes they may possess.

Rust pathotypes virulence

The results on the pathogenic reaction of 23 *U. appendiculatus* isolates on 12 bean cultivars with specific resistance genes are presented in Table 4. The reaction of the isolates on the different cultivars revealed the existence of pathogenic variability among rust isolates. Most isolates were pathogenic to both Andean and Mesoamerica differentials but one isolate, Masindi-4, was more pathogenic on Andean than Mesoamerican cultivars. Based on the isolates' pathogenic reactions on the rust resistance cultivars, 22 isolates were classified as Andean group because they were virulent on most of Andean cultivars, while one isolate, Masindi-4, was virulent on most Mesoamerican cultivars and is grouped as Mesoamerican. All the 23 isolates were grouped in six pathotypes 2-0, 4-0, 50-0, 5-1, 4-33, and 63-19. Five of the pathotypes, 2-0, 4-0, 50-0, 5-1, and 63-19, were most virulent on the Andean differentials, indicating the co-evolution of host and pathogen as the large-seeded beans are most preferred in Uganda. Similar findings were reported in South Africa and Kenya by Liebenberg and Pretorius (2011) and Arunga et al. (2012) respectively.

The pathotype 63-19 was identified based on the complete differential set at the University of Nebraska, USA. This pathotype had resistant reactions on the Mesoamerican differentials 'Mexico 309' with the resistant gene *Ur-5*, 'Mexico 235' (*Ur-3*+) and 'PI 181996' (*Ur-11*). Susceptible reactions were observed on the Andean differentials 'Early Gallatin' (*Ur-4*), 'Redlands Pioneer' (*Ur-13*), 'Montcalm' and 'PC-50' (*Ur-9*, *Ur-12*), 'Golden Gate Wax' (*Ur-6*), and 'PI 260418' and Mesoamerican differentials 'GN 1140' (*Ur-7*), 'Aurora' (*Ur-3*) (Figure 4), and 'Compuesto Negro Chimaltenango' (CNC). The Andean differentials were all susceptible to the 63-19 pathotype but half of the Mesoamerican differentials were resistant. Based on the reaction of the differentials with the pathotype 63-19 we can conclude that pathotype 63-19 had similar pathogenicity with the highly virulent race 19-63 identified in Puerto Rico (Vega, et al., 2009).

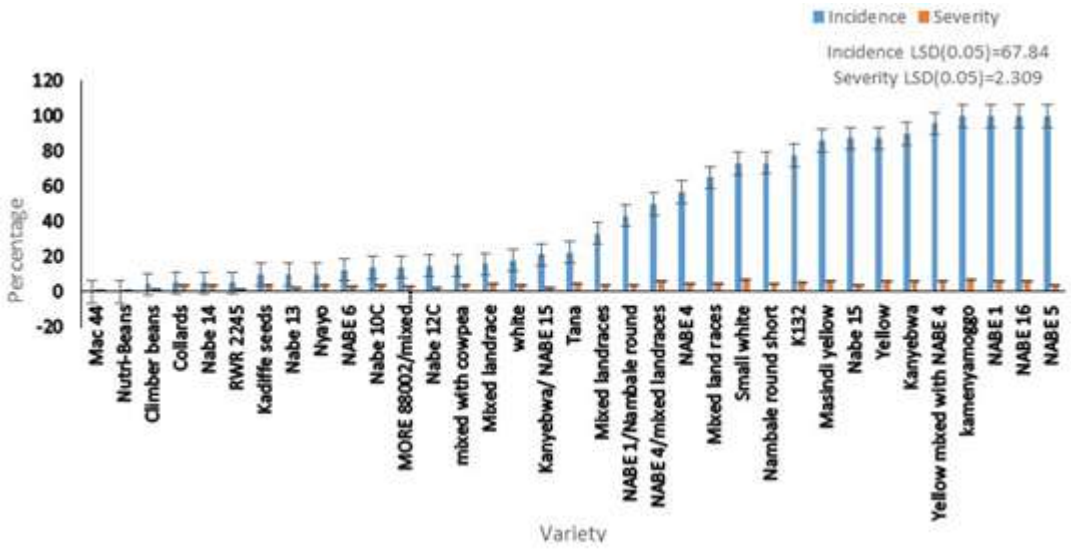

Figure 4. The effect of the variety type on the level of rust incidence and severity in the 2015 second planting season.

Table 4. Pathogenicity of 23 *U. appendiculatus* isolates on 12 common bean rust differential genotypes possessing specific resistance.

Genotypes*[1]	Andean origin					Mesoamerican origin							Rust pathotypes
	1	2	3	4	5	6	7	8	9	10	11	12	
Rust genes (*Ur*)[2]	4	13	UNK	6	UNK	7	3	5	3+	CNC	11	14	
Linkage map(PV)[3]	06	08	UNK	11	UNK	11	11	04	UNK	UNK	11	04	
Binary number	1	2	4	8	32	1	2	4	8	16	32	UNK	
WAKISO-1	1	1	5.6	1	1	1	1	1	1	1	1	1	4-0
WAKISO-2	5.4	5.3	5.3	5.2	4.3	6.2+	5.2+	3.2+	2	4.1	1	0	63-19†
WAKISO-3	1	1	5.6	1	1	1	1	1	1	1	1	1	4-0
SHEEMA-1	1	1	5	1	1	1	1	1	1	1	1	1	4-0
HIOMA-1	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
HIOMA-2	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
HIOMA-3	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
HIOMA-4	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASINDI-1	6	1	6	1	1	6	1	1	1	1	3	1	5-1
MASINDI-2	1	6	1	4	3.4	1	1	1	1	1	1	2.3	50-0
MASINDI-3	1	6	1	4	3.4	1	1	1	1	1	1	2.3	50-0
MASINDI-4	1	1	6	1	1	6	1	1	1	1	4	5.4	4-33
MASINDI-5	1	6	1	4	3.4	1	1	1	1	1	1	2.3	50-0
MASAKA-1	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-2	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-3	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-4	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-5	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-6	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-7	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-8	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-9	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0
MASAKA-10	1	5.6	1	1	3	1	1	1	1	1	1	1	2-0

† Pathotype 63-19 was validated at the Plant Pathology Laboratory at University of Nebraska, Lincoln, USA; [1]1=Early Gallatin; 2=Redlands pioneer; 3=Montcalm; 4= Golden Gate Wax; 5= PI260418; 6= Great Northern 1140; 7= Aurora; 8= Mexico 309; 9= Mexico 235; 10=CNC; 11= PI181996; 12= Ouro Negro; *Ur*= rust resistance genes; Pv= chromosomes. [2]UNK=unknown.

The pathotypes 2-0 and 4-0 were the most predominant. The occurrence of several rust pathotypes in a district was an indication that there was high variability of the rust pathogens within those locations. Masaka district had only one pathotype, 2-0 which indicates low variability of the rust pathogens in that location. The diversity of the isolates collected in Uganda has implications on the release of common bean cultivars, for instance, the three pathotypes 5-1, 50-0 and 4-33 were found in Masindi district whereas two races, 63-19 and 4-0 were found in Wakiso district. These two districts represent the major common bean growing regions (WR and CR) where farmers grow different types of common bean cultivars which are susceptible to diseases including rust as reported by Abate et al. (2012). Deploying cultivars with single resistance genes will not be appropriate in such areas because of the different rust pathotypes, and therefore requires the use of a combinations of resistance genes as suggested by Arunga et al. (2012).

The cultivars with the Mesoamerican background, Mexico 309 (*Ur-5*) and Mexico 235 (*Ur-3*$^{+}$) were resistant to all rust pathotypes, followed by Aurora (*Ur-3*), CNC (*UNK*) which were resistant to all rust pathotypes except pathotypes 63-19 and Ouro Negro (*Ur-14*) which was susceptible to only pathotype 4-33. On the other hand, the genotype Montcalm (UNK) of the Andean background were susceptible to five rust pathotypes 4-0, 63-19, 5-1, 4-33 and 2-0. The pathotype 4-33 was observed to be pathogenic to Mesoamerican cultivars, GN1140 (*Ur-7*) and PI181996 (*Ur-11*) and Ouro Negro (*Ur-14*). The Mesoamerican cultivars Mexico 309, Mexico 235, Aurora, CNC and Ouro Negro could be good sources of resistance to bean rust in Uganda. Similar Mesoamerican sources of resistance have been recommended in South Africa, Kenya and Brazil (Arunga et al., 2012; Liebenberg and Pretorius, 2011; Souza et al., 2011).

Conclusion

High severity of common bean rust was observed in the low altitudes and in the South-Western Highlands of Uganda. In addition, higher rust disease severity was observed for the bean-maize–groundnut cropping systems, and fields cultivated with either commercial genotypes or landraces. Six unique Ugandan rust pathotypes where identified. Most of the pathotypes had Andean background. The rust pathotype 63-19 showed similar pathogenic characteristics with the Puerto Rico rust race 19-63. Also, the similarity in these two races will help in identification of new rust resistance sources to manage bean rust disease in Uganda.

Conflict of Interests

The authors have not declared any conflict of interests.

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Authors' contributions

This work was carried out in collaboration between all authors. Author BAO designed the study, carried out the experiment and wrote the first draft of the manuscript. Authors STN, CM, PP, PR, JK and JS reviewed the experimental design and all drafts of the manuscript. Authors BAO, STN and PR performed the statistical analysis and managed the literature searches. All authors read and approved the final manuscript.

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