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Rice Blast Prevalence in Smallholder Rice Farmlands in Uganda

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Abstract

Rice blast disease remains the most important contributor to low and stagnated rice yields in Uganda. However, the role of the smallholder farming system in shaping the prevalence of the disease in the country is not known. In 2015B and 2016A, we surveyed smallholder rice farmlands in 27 districts of Uganda and recorded blast incidence, severity, and symptoms expression. Infected rice samples taken from the infected plants were sub-cultured on PDA media to confirm the pathogen and obtain isolates for the establishment of a core collection for breeding work. Rice blast prevalence in the districts varied from 50-100% and the national average stood at 72.61%, higher than that recorded five years ago. Mean incidence and severity varied significantly (< 0.001) with the highest incidence (96.8%) recorded in Luwero district and the least (21.3%) was recorded in the Amuru district. However, the eastern region recorded the highest average incidence (74.5%) followed by the central, the northern, and Mid-western regions. In the rice ecologies, the highest blast incidence was recorded in the rain-fed lowland rice (72.18%) followed by irrigated lowland (59.53%) and rain-fed upland rice (47.27%). This is the first report on the prevalence of blast in smallholder rice farmlands in Uganda and showed a higher prevalence of the disease.

Keywords: incidence, rice blast, rice farmlands, severity, symptom expression

1. Introduction

Rice is increasingly becoming an important staple food in most parts of the world with hundreds of millions of people worldwide depending on it (International Rice Research Institute [IRRI], 2013; TeBeest, Guerber, & Ditmore, 2007, 2016; Oerke & Dehne, 2004) for food and household income. The crop is cultivated by both large-scale and small-scale farmers in developed, developing, and under-developed countries in every continent except in Antarctica (Muthayya, Sugimoto, Montgomery, & Maberly, 2014). In Uganda, the *O. sativa* was the most cultivated rice type until the introduction of upland rice cultivars (NERICA series) slightly over 10 years ago. In general, the production of the crop among smallholder farmers has increased steadily over the years (Food and Agriculture Organization Statistics [FAOSTAT], 2014) as more swamps and arable lands are opened-up for cultivation. Despite the increase in production often attributed to an increase in acreage rather than increased yields of the crop, the production vis-à-vis consumption is still in deficit (Ministry of Agriculture, Animal Industries and Fisheries [MAAIF], 2009). On-farm yields have remained low averaging 2 Tons/ha compared to the potential average yield of about 4.9 Ton/Ha (Lamo et al., 2010; Miyamoto et al., 2012). The low and stagnated yield of the crop despite efforts made by rice breeders to develop high-yielding varieties is due to the increasing challenges of abiotic and biotic stresses (Onaga & Asea, 2016). These include a high prevalence of pests and diseases as major constrains as well as increasing cases of drought, soil infertility, and increased urbanization (Skamnioti & Gurr, 2009). According to Séré et al. (2013), rice in Sub Saharan Africa, Uganda inclusive, succumb to three major diseases, namely: Bacterial Leaf Blight caused by *Xanthomonas oryzae* pv. *oryzae*, Rice Yellow Mottle Virus Disease caused by *Rice yellow mottle sobemovirus* and Rice Blast caused by

Magnaporthe oryzae. The other potentially important disease is brown-spot caused by *Bipolaris oryzae*, observed in various rice fields in the Eastern part of Uganda. Diseases like leaf scald caused by *Gerlachia oryzae*; sheath blight caused by *Rhizoctonia solani*; the sheath rot caused by *Sarocladium oryzae*; narrow brown spot caused by *Cercospora jansenea*; and bakanae disease caused *Fusarium moniliforme* are not considered important but could be mistaken for rice blast by an ordinary farmer. During this study, the last category of diseases was observed in farmers' fields, but in isolated areas. Of all the diseases affecting rice, the rice blast disease whose devastating effect is experienced Worldwide (Li, Wu, Jiang, Wang, & He, 2007; Kwon & Lee, 2002) remains the most important disease of the crop. The disease affects both low- and upland rice cultivars in about 85 countries where it is cultivated causing up to 100% yield loss (DeVries, 2008; Mousanejad, Alizadeh, & Safaie, 2010; National Crop Resources Research Institute [NaCRRI], 2010). It also affects all above-ground plant organs causing leaf blast, neck blast, panicle blast, collar rot and node blast (Skamnioti & Gurr, 2009) and recently, a study report has shown that the fungus can infect the root system (Sesma & Osbourn, 2004) though it is not soil-borne. Worst still, *Magnaporthe oryzae* is also known to be seed-borne (Guerber & TeBeest, 2006; Chadha & Gopalakrisshna, 2006; Mew & Gonzales, 2002; Long, Correl, Lee, & TeBeest, 2001) and capacity to infect germinating seedling was investigated (Faivre-Rampant, Genies, Piffanelli, & Tharreau, 2013). However, the spores/conidia are efficiently moved from crop-to-crop and field-to-field by wind, and rain-water as well as the movement and accumulation of infected crop residues (Raveloson, Ratsimiala Romanta, Tharreau, & Sester, 2018). Though infection occurs at all stages of growth, infection at an early vegetative stage for foliar blast and at booting for neck blast is critical on the crop yield (Puri, Shrestha, Joshi, & Chhetri, 2006; Ramappa, Ravishankar, & Prakash, 2002). Early and severe infection causes stunting, development of small panicles, and a white-head often mistaken for insect pest damage (Mousanejad et al., 2010; Bonman, 1992). Despite its importance, in Uganda, limited information is available on the occurrence of the rice blast in smallholder rice farmlands where most rice is produced in the country. Recently published research study on the occurrence of the disease in the country (Onaga & Asea, 2016) focused majorly on a few large-scale rice farms in 17 districts known for rice growing, and some experimental fields in selected districts. It should be noted that most of the large-scale farms are owned by well-to-do farmers who are either knowledgeable about the disease or tend to manage their fields very well. Also, field extension workers who provide resourceful information on proper crop management to farmers often visit the large-scale, unlike the small-scale rice farmers. The aforementioned differences among rice farmers coupled with low capacity to access disease-free seeds from reliable sources expose small-scale rice farmlands to high risks of blast disease attack leading to high disease prevalence and perpetually low yields. Therefore, there is a need to re-establish the prevalence of rice blast disease in the country with a focus on small-scale rice farmlands as well as assess how the incidence and severity vary with the different rice ecologies, cropping systems and growth stages. We used the concept of a large sample size from a well-structured location (meta-population) and targeted small production areas with diverse crop varieties as a sampling strategy as described by Park, Milgroom, Han, Kang, and Lee (2008). It is presumed that highly diverse crop variety in smallholder gardens limit the incidence and severity of diseases (Falvo, 2000b). In brief, the main objective of this study was to re-establish the prevalence of rice blast disease in Uganda. Specifically, the study was conducted to; determine the incidence, severity and symptom expression of blast disease in smallholder rice fields, and ascertain whether the incidence and severity of the rice blast disease vary across different rice ecologies, cropping systems, and growth stages as well as in the agro-ecologies and elevation. We also sought to establish a core collection of pathogen isolates by collecting and isolating pathogens from the diseased samples.

2. Method

2.1 Rice Blast Disease Survey and Sample Collection

Small-scale rice fields (< 1.5 acres) were surveyed in 27 major rice-growing districts in eastern, northern, mid-western, and central regions of Uganda in the seasons of 2015B and 2016A. During the survey, rice plant samples (leaves and panicles) showing blast-like symptoms were collected for further analysis in the laboratory. Since the planting of rice crops varied across the districts due to erratic rains experienced in the two seasons, some surveys and sampling were done at different times in the different districts per season. The sampling points lied at altitudes between 850 and 1350 meters above sea level (ASL). The average minimum and maximum relative humidity, temperature, and rainfall ranged between 56.94 and 96.76%, 22.8 and 29.18 °C, and 59.75 and 1132.66 mm, respectively. The districts surveyed were selected based on the record of the previous occurrence of the rice blast disease (Onaga & Asea, 2016) and prevailing rice farming activities.

Table 1. Scoring scale for Rice Blast Disease severity adopted from IRRI 1996

Scoring Scale		Description
1-5	1-9	
1	1	No or small brown specks of pin-point size or larger brown specks without sporulating center
2	2	Small roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter, with a distinct brown margin (lesions are mostly found on the lower leaves)
3	3	Lesion types are the same as in scale 2, but a significant number of lesions are on upper leaves
	4	Typical susceptible blast lesions 3 mm or longer, infecting less than 4% of the leaf area
	5	Typical susceptible blast lesions infecting 4-10% of the leaf area
4	6	Typical susceptible blast lesions infecting 11-25% of the leaf area
	7	Typical susceptible blast lesions infecting 26-50% of the leaf area
5	8	Typical susceptible blast lesions infecting 51-75% of the leaf area
	9	More than 75% of the leaf area affected

Note. 1: Very Resistant (VR); ≤ 3.0 Resistant (R); 3.1 < Moderate Resistant ≤ 4.0 (MR); 4.1 ≤ Moderate susceptible ≤ 5.0 (MS); Suceptible ≥ 5.1 (S). Standard Evaluation System for leaf blast (IRRI, 1996).

Districts known to grow rice and yet not surveyed in the previous study were also included in this study. The survey excluded large-scale rice fields including national rice schemes since the previous study focused on them. In each district, on average three sampling sites were identified at a distance of approximately 10 km apart. At least two (2) rice fields were sampled per sampling site. Symptomatically, the presence of the blast-like disease was detected as described (Hodgson et al., 2011) and with the help of field guide (Webster, 2000). Three and five sampling spots randomly selected per field depending on the size of the fields were scored for blast incidence and severity. Final field incidence and severity scores were obtained as averages of the sampling spots. At each sampling spot, a sampling frame measuring one square meter was used to score for rice blast disease incidence. Blast severity (scored on three plants per sampling spot) was scored as described (IRRI, 1996) at a scoring scale of 1-5 (Table 1). Incidence and severity of blast-like symptoms were also scored in neighbouring finger millet fields (where present). Diseased rice plant tissues (leaves, panicles, and sheath/neck) were picked from five (5) to 10 blast symptomized rice plants per field using a zig-zag pattern. The mean relative humidity (RH%), mean temperature (°C), and mean rainfall (mm) during the seasons of the survey were also obtained. GPS data of fields sampled were taken from approximately the center of the fields using Garmin GPS 72H. The GPS data were later used to generate rice blast disease incidence and severity distribution maps. Rice cropping pattern, as well as different rice ecologies as described in Wortman and Eledu (1999), was also recorded.

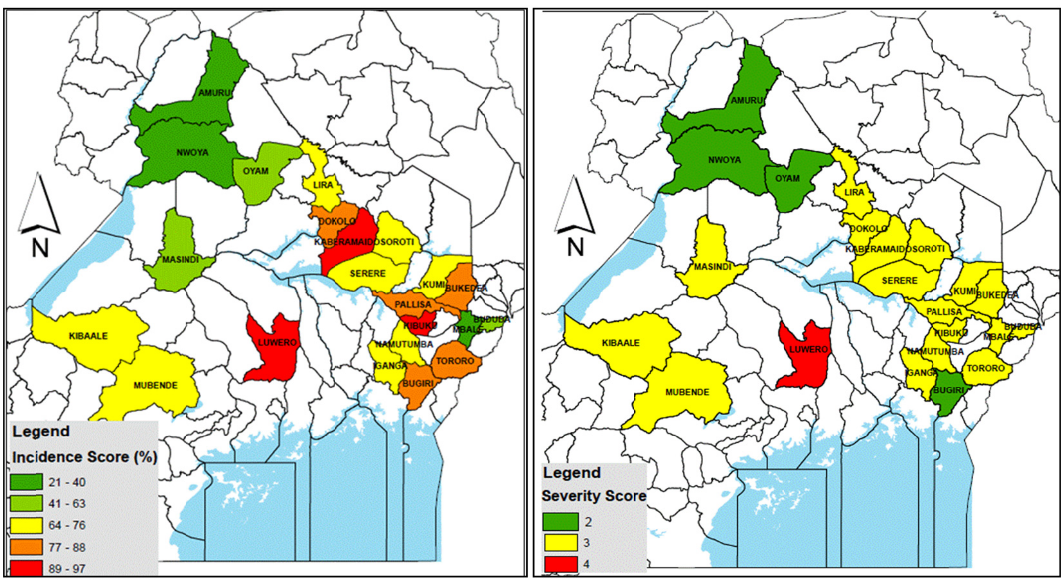

Figure 1. Rice blast distribution maps-incidence map scored at a scale of 0 to 100% (left), and severity map scored at a scale of 0 to 5 (right)

2.2 Isolation, Identification, and Preservation of Pathogen Isolates

From the samples collected, symptomatic portions were cut into small pieces of 2 to 3 cm length, rinsed once in distilled water, and surface sterilized by dipping in 0.1% HgCl for 1 min and again rinsed three times with sterile distilled water. The sterilized plant tissues were blotted on sterile Watman filter paper and transferred onto the surface of full strength streptomycin amended potato dextrose agar (PDA), thus 1.5 g/L of Streptomycin Sulphate in 39 g/L PDA. After four to five days of incubation, a dilute spore suspension was prepared in sterilized distilled water and plated onto 0.8% water agar in the petri dish. After 12 hours of incubation at 26±1 °C, single germinating conidia were observed under a microscope, excised and sub-cultured to streptomycin amended potato agar (PDA). The plated media were incubated at 25 °C for 7 to 10 days under 12 hours of light and 12 hours of darkness. The pathogen isolates were identified based on the morphological and cultural characteristics and confirmed by observing the conidia under a microscope. The identified isolates were maintained following the method described by Valent, Crawford, Weaver, and Chumley (1986) and Jia (2009), where a small piece (0.5 cm in diameter) of PDA containing the fungal structures were excised from actively growing fungal cultures and inoculated onto sterilized filter paper spread on freshly prepared PDA plates. The plates were incubated at room temperature (24-25 °C) for 1-2 weeks under 12 hours of an alternating light-dark period until the fungus significantly colonized the surfaces of the filter papers. After colonization, the filter papers were removed and dried at room temperature (27-30 °C) under sterile conditions (laminar flow hood). The dried filter papers with fungal structures (mycelia and spores) were then cut aseptically into pieces of 0.5-1.0 cm diameter, transferred to sterile vials, and stored at -20 °C in a freezer.

2.3 Data Analysis

All analyses of variance (ANOVA) including mean separations at 95% confidence interval and test of significance were done using R statistics version 3.3.2. The distribution maps were generated from GPS data and corresponding mean severity and incidence of blast using QGIS 2.12.2 software for windows.

3. Results

3.1 Sampling and Identification of Pathogen Causing Rice Blast

In this study, we assessed 257 small-scale rice farmlands in the 27 districts and collected 1219 samples with blast-like symptoms for further analysis in the laboratory. Twelve (12) of the districts surveyed were from the eastern region that also constituted the largest number of small-scale rice farmlands (165) followed by the northern, central, and mid-western regions in descending order. The districts of Amuru, Nwoya, and Oyam in the northern region had blast-affected fields with isolated plants or groups of plants that displayed blast-like symptoms, unlike the districts in the eastern region where most parts of the rice farmlands were symptomized. Though some of the samples that showed blast-like symptoms did not have the pathogen when isolated, 96.7% of the symptoms were due to *Magnaporthe oryzae* infection following microscopic assessment of colony morphology and conidia characteristics.

3.2 The Prevalence and Symptom Expression of Rice Blast

The rice blast disease prevalence in the districts ranged from 50 to 100% with the national average standing at 72.61% (Table 2). The eastern region recorded the highest rice blast prevalence, followed by the central region, the northern, and lastly mid-western. Typical rice blast symptoms were observed in the fields, but the expression of these symptoms varied between the different rice ecologies, type of rice grown, and the growth stage of the rice plant. Blast-like brown lesions were also observed on weed species and the identified species included *Cyperus* spp (sedge grass), *Echinochloa colonum*, *Paspalum conjugatum* (Hilo grass), *Paspalum dilatatum* (knotgrass), *Panicum repens*, *Panicum rigidulum*, and *Pennisetum purpureum*.

Table 2. Percentage prevalence, mean-field incidence, and severity of rice blast disease per district per region

Region	District	Total No. fields		Prevalence of blast (%)	No. of rice blast infected samples	Mean-field Incidence (%ge)	Mean Severity (1-5)
		Surveyed	Blast affected				
Eastern	Budaka	9	6	66.67	30	53.00**	2.83*
	Bugiri	9	9	100.00	45	**85.72*****	2.46
	Bukedea	15	15	100.00	75	78.80***	2.57
	Iganga	15	15	100.00	75	75.44***	2.97**
	Kibuku	12	9	75.00	45	**94.16*****	**3.17****
	Kumi	15	14	93.33	70	66.36***	2.88**
	Mbale	15	12	80.00	60	33.61	2.83*
	Namutumba	15	15	100.00	75	75.55***	**3.17*****
	Pallisa	15	15	100.00	75	81.20***	2.88**
	Serere	15	15	100.00	75	**88.52*****	**3.00****
	Soroti	15	13	86.67	65	73.88***	2.77*
	Tororo	15	15	100.00	75	**88.48*****	**3.46*****
Subtotal 1		165	153	92.73	795	74.56	2.92
Northern	Amuru	9	6	66.67	30	21.33*	2.00***
	Dokolo	15	9	60.00	45	79.89***	**3.22*****
	Gulu	12	6	50.00	22	43.76	2.33
	Kaberamaido	9	6	66.67	10	76.91***	**3.00****
	Lira	15	14	93.33	70	72.71***	2.71*
	Nwoya	9	6	66.67	30	39.83	2.33
	Oyam	9	6	66.67	25	61.16**	2.50
Subtotal 2		78	53	67.95	232	56.51	2.58
Mid-Western	Hoima	9	6	66.67	23	48.96*	2.07
	Kibaale	12	6	50.00	27	63.38***	2.83*
	Masindi	9	6	66.67	20	53.63**	2.33
	Kyenjojo	6	3	50.00	15	55.63*	2.67
Subtotal 3		36	21	58.33	85	55.40	2.47
Central	Luwero	9	6	66.67	30	**96.83*****	**3.67*****
	Mubende	9	6	66.67	22	63.40***	2.67
	Wakiso	15	12	80.00	55	57.72***	**3.00****
	Nakaseke	9	6	66.67	30	25.63	2.00
Subtotal 4		42	30	71.43	137	60.89	2.84
Total		321	257	72.61	1219		
	Grand mean					68.7	2.84
	%CV					30.5	22.8
	LSD (5%)					26.09	0.81
	SED					11.21	0.41
	P-value					< 0.001	< 0.001

Note. ***, **, and * represent P-value = < 0.001, 0.01 & 0.05, respectively.

3.3 Incidences and Severity of Rice Blast in the Rice Farmlands

Generally, mean rice blast incidence and severity varied significantly (< .001) in the districts. The highest mean incidence (96.8%) was recorded in Luwero district in the central region and the least (21.3%) was recorded in Amuru located in the northern region. However, incidences ranging from 0 to 100% were recorded in individual rice farmlands across the country. The eastern region had the highest average blast incidence (74.5%) followed by the central region, the northern and Mid-western in descending order (Table 2). The variation of blast severity was also significant (< 0.001) with a mean severity score ranging from 2.0 to 3.67. In some fields mean severity score as high as 5.0 was also recorded.

With the rice ecology, the highest mean blast incidence was recorded in the rain-fed lowland rice (72.18%) followed by irrigated lowland (59.53%) and rain-fed upland rice (47.27%), while the highest mean severity score (3.67) was recorded in irrigated lowland rice followed by rain-fed lowland and least in rain-fed upland rice (Table 3). Besides rice-maize “intercrop”, rice fields intercropped or mix-cropped with other cereals recorded higher blast incidences than sole rice planted in rows (Table 3). The highest mean severity (4.19) was recorded in rice fields that have a mixture of rice, maize, and finger millet which also recorded the highest mean incidence (99.2%). In terms of the rice growth stage, the highest mean blast incidence (70.51%) was recorded in rice fields at grain filling or milk stage and least in fields at the maturity stage (42.38%). However, highly significant ($P < 0.001$) variation in both mean blast incidence and severity was observed in rice fields at the booting stage (Table 3). In terms of agroecology, the Lake Victoria Crescent and Mbale farmlands (70.65%, 3.06), and Southern and eastern L. Kyoga basin (80.13%, 2.85) had higher mean blast incidence and severity than the other agro-ecologies (Table 4). About elevation, the highest mean blast incidence averaging at 75.24% was recorded at altitudes between 1000 and 1100 m above sea level, while lower mean incidences were recorded at altitudes < 1000 and > 1100 m above sea level (Table 4).

Table 3. Variation in Rice Blast Incidence and severity with rice ecology, rice cropping system, and rice growth stage

Source of variation	Mean incidence	SE	P-value	Mean Severity	SE	P-value
Rice ecology						
Irrigated lowland	59.53	14.89	<0.001	**3.67**	0.397	<0.001
Rain fed lowland	**72.18**	14.99	0.400	2.89	0.400	0.051
Rain fed upland	47.27	15.51	0.430	2.45	0.414	0.004
Cropping system						
Rice/Maize intercrop	57.53	4.51	< 0.001	2.67	0.120	<0.001
Rice/Maize/Sorghum intercrop	**97.20**	26.71	0.138	2.60	0.712	0.914
Rice/Finger Millet intercrop	**87.80**	26.71	0.258	2.30	0.712	0.597
Rice/Maize/Finger millet intercrop	**99.20**	19.15	0.027	**4.19**	0.510	0.003
Rice/Sorghum intercrop	**92.45**	13.91	0.013	2.87	0.371	0.593
Sole Rice planted randomly	**70.44**	4.87	0.008	2.84	0.130	0.184
Sole Rice Planted in Rows	48.40	9.87	0.260	2.77	0.263	0.700
Growth stage						
Vegetative	69.14	6.42	0.290	2.82	0.169	0.527
Booting	62.33	6.03	<0.001	2.93	0.158	<0.001
Grain filling	**70.51**	6.74	0.225	2.86	0.177	0.675
Maturity	42.38	14.77	0.178	2.50	0.388	0.275

Note. SE = Standard error.

Table 4. Mean rice blast incidence and severity in the surveyed agro-ecologies, farming systems and range of altitudes

	Mean incidence	SE	P-value	Mean Severity	SE	P-value
Agro-ecologies						
Central wooden savannah	39.41	7.33	<0.0001	2.17	0.19	<0.0001
L. Victoria crescent & Mbale farmlands	**70.65**	7.80	<0.0008	**3.06**	0.21	<0.0003
Northeast Central Bush fallow	43.77	12.69	0.732	2.87	0.34	0.623
Northern moist farmland	64.88	8.03	0.002	2.70	0.21	0.012
Southern & eastern L. Kyoga basin	**80.13**	7.96	<0.0006	2.85	0.21	0.002
Western Mid-altitude farmlands	58.16	9.18	0.04	2.72	0.25	0.026
Range of altitudes (m)/ASL						
851-900	21.33	11.44	<0.0004	2.00	0.32	0.001
901-950	54.50	18.40	0.265	2.50	0.51	0.303
951-1000	28.68	12.32	0.0002	2.20	0.34	0.02
1001-1050	**75.07**	5.21	<0.0002	**3.03**	0.14	<0.0002
1051-1100	**75.40**	5.69	0.954	2.87	0.16	0.326
1101-1150	68.75	6.02	0.295	2.94	0.17	0.563
1151-1200	54.46	7.36	0.006	2.63	0.20	0.05
1201-1250	56.75	18.40	0.320	**3.00**	0.51	0.959
1251-1300	56.76	11.44	0.111	2.67	0.32	0.258
1301-1350	65.37	13.52	0.474	2.50	0.37	0.162

Note. ASL = above sea level, SE = Standard error.

4. Discussion

This study provides a comprehensive surveillance study on the occurrence of rice blast disease in Uganda targeting mainly small-scale rice farmlands as compared to the most recent documented study that focused on relatively large-scale farmers and experimental fields (Onaga & Asea, 2016). Except in some isolated fields especially in the northern and mid-western parts of the country that were free of the disease, most of the 257 rice fields assessed were moderately or severely infected with blast disease. This skewed occurrence of the disease in the country is attributed to the differences in the history of rice cultivation in the country as stated by Onaga and Asea (2016). The eastern region, in particular, that has a long history of rice growing and constitutes the traditional rice-growing districts of Uganda had the highest number of blast-infected rice fields. Therefore, it remains a hub for rice production as well as an inoculum source for the perpetuation of rice blast disease in the country. The sampling strategy of targeting a large sample size in a more structured location followed the assertion that pathogen variability is well represented when large sample sizes are used (Park et al., 2008). Both upland and lowland rice fields were assessed since it was reported that rice blast disease occurs in both low- and upland rice cultivars (Kato, 2001). However, no clear differences were observed in the occurrence of the disease in upland or lowland rice ecologies though symptoms were clear on upland rice types. Of the districts surveyed, 12 were previously surveyed in the 2009/2010 study (Onaga & Asea, 2016), and the remaining 15 were surveyed for the first time. This is important because it provides information on the spread of the disease into new rice-growing areas as well as assesses the persistence nature of the disease in the country. We identified the blast-infected rice plants in the sampling frame of the fields through observation of typical blast-like symptoms as described by Kato (2001). A field guide (Webster, 2000) that contained symptoms of major rice diseases quickened the process of blast identification and its differentiation from similar symptoms caused by other diseases. Though some of the samples that showed blast-like symptoms did not have the pathogen when isolated, 96.7% of the symptoms were due to *Magnaporthe oryzae* following microscopic assessment of colony morphology and conidia characteristics. Higher blast prevalence was recorded in this study than what was recorded five years ago (Onaga & Asea, 2016). In their study conducted in 2009/2010 seasons, the team reported a 54% prevalence of rice blast in Uganda which represents 156 ha out of 290 ha of the area under rice being affected by rice blast. This means that the prevalence of rice blast in Uganda has gone up by over 18% in five years. This increasing trend in blast prevalence could result in an epidemic if immediate mitigation measures are not deployed. The variation in the rice blast prevalence, incidence, and severity concurs with what was observed in the previous study (Onaga & Asea, 2016). Comparing the two national prevalence, rice blast disease is increasingly spreading across the country even into new rice-growing areas though higher prevalence was recorded in the traditional rice-growing areas. The same trend was observed for field incidences and severities. The presence of the disease in the new areas is an indication that the disease is spreading with expansion in rice-growing areas. It is however possible that this spread is facilitated by farmers who plant blast-infected seeds obtained from other farmers. This is because the movement of infected seeds has been highlighted as one of the most convenient and reliable means of long-distance spread of diseases from infected to new and disease-free areas (Guerber & TeBeest, 2006; Chadha & Gopalakrisshna, 2006; Mew & Gonzales, 2002; Long et al., 2001). The disease affects seeds and affected rice seeds have a relatively small brown diamond-shaped spot (Hajano, Pathan, Rajput, & Lodhi, 2011). Several studies have also reported isolating the pathogen from rice seeds (Hajano et al., 2011; Naeem, Anwar, Haque, Riaz, & Khan, 2001; Khan, Gill, Nasir, & Bukhari, 1999; Mew & Gonzales, 2002). Some reports have shown that *Magnaporthe oryzae* is indeed seed-borne and transmission from infected seeds to seedlings has been documented (Long et al., 2001). However, the high prevalence rate reported in this study could also be explained by the farmer category targeted (small-scale farmers) who can hardly access nor afford to purchase clean seeds, they practice rudimentary methods for management of rice fields and crop residues and lack sufficient information and skills on disease identification and management. Part of the results of this study showed that the majority of the small-scale rice farmers do not know rice blast disease regardless of the years of experience in rice production. Hashim, Mamiro, Mabagala, and Tefera (2018) have reported similar findings in their study to investigate farmers' knowledge and management of rice blast disease in Tanzania. This ineptness does not only fuel proliferation, but aides the spread and continuation of the disease in the fields resulting in yield losses and low returns (Rehman, Mehboob, Islam, & Khan, 2013) as well as environmental pollution due to inappropriate use of pesticides (Islam & Ahmad, 2016). There is, therefore, an urgent need to build the capacity of small-scale rice farmers to identify and manage the disease. Also, build an efficient seed system that allows small-scale farmers to access disease-free seeds or resistant cultivars as suggested in a review by Islam (2017).

Symptoms expression varied between the different rice ecologies, type of rice grown, and the growth stage of the rice plant. The majority of the infected rice plants found in the upland rice fields showed clear and typical foliar blast symptoms compared to those in the lowland rice fields. This observation is in agreement with that of Grahame (2014) that blast leaf infection is less severe in lowland tropical areas than in upland areas. This is due to temperature differences during the day and in the night that favour the disease development. The switch from warm temperatures during the day to cooler temperatures during the night has been reported to result in the formation of dew on the leaves of the rice plants that create overall cool and wet conditions that support spore germination and growth (Grahame, 2014; Bevitori & Ghini, 2014; Wilson & Talbot, 2009). According to Onaga, Wydra, Koopmann, Sere, and von Tiedemann (2016), changes in the prevailing temperature potentially alter the incidence and severity of rice blast disease in rice crops and affect the development of the disease in the rice plant. Typical brown diamond-shaped lesions were commonly observed in upland rice fields mostly at the vegetative stage in humid and wet conditions. Broad and elongated lesions with grey-center were commonly observed on rice plants with broad dark-green and relatively soft leaf blades in both upland and lowland rice fields. Small brown to dark brown and slightly elongated lesions were common among lowland rice plants with tough and stiff-leaf blades. Among the rice plants with tough and stiff-leaf blades, most of the lesions did not coalesce to form bigger lesions, thus displaying resistance tendency for resistant rice cultivars. Brown to dark brown or black discoloration was also observed at the collar region and nodes which often was associated with broken panicles and empty grains. Blast-like brown lesions were also observed on weed species were common in and around lowland rice fields, and could be a likely harbour for the pathogen to survive between seasons. Genetic relationship between pathogen isolates from rice and those from other rice associated grass hosts have been studied (Couch, & Kohn, 2002), which showed a single ancient invasion of rice followed by shifts to other grass-hosts that grew in association with rice.

About the rice ecology, the lowland rainfed rice fields that recorded the highest incidence and severity were from the eastern region, a traditional rice-growing area in Uganda (Onaga & Asea, 2016). It should be noted that the upland rice system is relatively new and is concentrated in the new rice-growing areas of the northern region. Therefore, with time when the disease pressure has been built in the upland rice system, the severity and incidence levels of the blast are expected to shift to the higher side. This is because it has been reported that upland cultivation systems favour rice blast epidemics (Roboin et al., 2012). Though based on mechanisms of dilution, barrier effect and induced resistance, cultivar mixture and/or species mixture have been reported to lower pests and diseases damage in a crop (Roboin et al., 2012; Wolfe, 2000, 1985; Zhu et al., 2000, 2005; Garrett & Mundt, 1999), in this study, growing a mixture of different cereals in the same field with rice appear to exacerbate incidences and severity of the blast. Wubneh and Bayu (2016) in an experiment conducted in Ethiopia and that conducted by Shahijahandar, Huassain, Nabi, and Masood (2010) in Kashmir valley have reported that blast prevalence, incidence, and severity increased from vegetative through booting to dough stage. Similarly in this study significantly high mean blast incidence and severity were observed in rice fields at the booting and grain filling stage than at the vegetative and pre-anthesis stage. This was congruent with observation in other similar studies elsewhere (Puri et al., 2006; Ramappa et al., 2002). Comparable to a study reported by Asfaha, Selvaraj, and Woldeab (2015), at higher altitude blast incidence and severity were lower probably due to low relative humidity that hinders the development of the disease, while at a lower altitude, the temperatures were high and therefore not favorable for spore germination. Reports have also shown that the incidence of rice blast is positively correlated with rainfall and relative humidity, but negatively correlated with temperature (Shahriar, Imtiaz, Hossain, Husna, & Eaty, 2020; Shafaullah, M. A. Khan, N. A. Khan, & Ysir, 2011).

5. Conclusion

This study has shown that the prevalence of rice blast disease in Uganda is still high and increasing. Compare with the previous study, the incidences in smallholder farmlands were higher. The incidence and severity of the disease are still low in new rice-growing areas especially in the northern part of the country as compared to traditional rice-growing areas. The incidence and severity of the disease varied with the cropping system, elevation, and rice ecologies. We established a core collection of 166 isolates that could be used for developing rice blast-resistant rice varieties. We recommend a study to be conducted on pathogen diversity and the identification of pathogenic races.

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