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Major pearl millet diseases and their effects on-farm grain yield in Uganda

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Pearl millet (*Pennisetum glaucum*) is an important food and cash crop for many people living in the semi arid areas of Uganda. But information about the common diseases and their effect on yield is lacking yet it is important in designing a realistic and focused pearl millet breeding programme aimed at increasing yield. A disease survey was done in 2012 in the farmers' fields in the predominantly pearl millet growing districts of Kumi and Katakwi in eastern and Kitgum and Lamwo in northern Uganda to identify the major diseases of pearl millet and establish their incidence, severity correlation and effect on grain yield. The aim of the study therefore was to identify the major pearl millet diseases that affect production in Uganda. In terms of incidence, rust (*Puccinia substriata*) (73.58%) was the most frequent disease followed by ergot (*Claviceps fusiformis*) (62.98%), then leaf blast (*Pyricularia grisea*) (61.25%) and smut (*Moesziomyces penicillariae*) (26.76%). However, in terms of severity, leaf blast (62.20%) was the most severe followed by rust (43.33%), ergot (29.46%) and smut (14.18%). Using SPSSv20, backward model reduction regression of disease parameters against grain yield, results show disease severities of rust, ergot, leaf blast and incidences of smut and rust were the most important in affecting grain yield. The correlation of disease severity with grain yield further indicated that ergot and rust severities were causes of the significant effect on yield.

Key words: Pearl millet, diseases, severity, incidence, Uganda.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], also known as bulrush millet, is a staple food for many people living in the semi arid agro-ecological zones of eastern (in teso region), northern (mainly in greater Kitgum district), northeastern and to some extent in northwestern (west nile districts) Uganda. It is a food and source of income and to a lesser extent forage crop and yeast for local brewing. As food, the grain is ground and used to make thin porridge known as ugi and thick porridge commonly known as atapa in teso region or kwon in northern region. In Teso region the flour is normally mixed with cassava flour to enhance the hardness of the atapa and tamerine or tangerine to improve the taste but in the north and northeastern regions nothing is mixed with the flour prior to making a pearl millet food product. It is an excellent source of yeast but there is decline in the use of pearl

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millet as yeast source because those who take such alcoholic drink claim to have severe headache thereafter. The stover is an important source of fodder in many countries where the crop is grown but in Uganda not much emphasis is put on the crop for this purpose.

It is cultivated as a subsistence rain-fed crop by people living in the semi arid agro-ecological zones in Uganda. In African countries, the national average grain yield of pearl millet is generally in the low range of 400-600 Kg ha^{-1} (FAO, 2002) and for Uganda yields between 0-900Kg ha^{-1} have been reported by farmers in this survey. However, in India the National Rainfed Area Authority (NRAA) (2012) reported a grain yield range of 1720 to 3870 Kg ha^{-1} and a productivity potential of over 5000 Kg ha^{-1} from farmers' fields. This shows a great increase in productivity since the potential productivity of 3000 Kg ha^{-1} was recorded from research centres over ten years age (Rai et al., 1999). The variation in yield at farmers' and research centres has been mainly attributed to biotic constraints faced in the production areas (Baltensperger, 2002; Crampton et al, 2009) and farmers growing inherently low yielding local landraces. Extensive studies have been done about pearl millet biotic constraints such as diseases and the inherent low yielding ability of the crop in the USA, India, West and Southern Africa but no studies have been conducted about the pearl millet disease and their association with yield in Uganda. For example in the USA, rust and blast have been reported to severely affect pearl millet and extensive research has been done on the two diseases to ascertain their effect on grain and fodder yield and quality (Wilson et al., 1996). In India and Western and Southern Africa, much research has been done and reported about downy mildew [*Sclerospora graminicola* (Sacc.) Schroet.] (Hash et al., 1999; Singh, 1995) as being the most important pearl millet disease in Asia and Africa (Williams, 1984); ergot which severely affects hybrids in India and OPVs in Africa (Arya and Kumar, 1982); rust, blast and smut diseases but no such studies and reports have been done to even identify the common diseases that affect pearl millet in Uganda. The objective of this study was therefore to identify the common pearl millet diseases and their association with yield.

MATERIALS AND METHODS

Study area

The study was conducted in two agro-ecological zones namely the Teso and the Northern farming systems which are characterized by dry months towards the end and beginning of the year. In the two agro-ecological zones annual crops such as sweet potatoes, cassava, and legumes are grown in addition to livestock and poultry rearing (Mwebaze, 2001). In the Teso zone the survey was conducted in Kumi and Katakwi districts while in the Northern zone Kitgum and Lamwo districts were covered (Figure 1). Data collection was done in January 2012 where one hundred and forty households were surveyed. Pearl millet is generally grown late in the second season starting October to January of the following year, thus this time was appropriate for conducting the survey as most of the farmers had not yet harvested so it was easy to conduct disease incidence and severity score on-farm.

The study

Pearl millet is mostly grown once every year and the study was done in January 2012 at the time when the crop in most fields was at physiological maturity. The crop is not grown by many farmers so purposive selection of pearl millet farmers who had grown pearl millet for at least two years was done. Prior to field data collection, demographic data about the household head (age and uses/importance of pearl millet) were collected using a semi-structured questionnaire. In Kumi (Kumi sub county) and Katakwi (Katakwi and Usuku sub counties) districts forty fields were selected for disease survey while thirty fields were selected from Kitgum (Kitgum town council, Mucwini, and Kitgim Matidi sub counties) and Lamwo (Agoro sub county) districts. Thus, a total of one hundred and forty pearl millet fields, also considered as replicates (Kutama et al., 2010), were covered in the study. In each, field five quadrants (2 x 4 m) were made (four at the corners and one in the middle of the field) and incidence score and disease severity was calculated by assessing fifty plants in each quadrant making a total of 250 plants per field (Thakur et al., 2003). Within the quadrant, the fifty plants were randomly selected and identification of diseases was done using the sorghum and pearl millet disease identification hand book developed for ICRISAT by William et al. (1978). Severity score for rust and leaf blast was noted on the third and fourth leaves from the top as these are reported to have a direct contribution to grain yield (Joshi et al., 2003). Infected leaf samples were collected for diseases which could not be identified using the field book and incubated in the laboratory for microscopic identification. In the laboratory, leaf samples were cut into small pieces and put on moist filter paper and incubated under UV light for three days for pathogen growth. Pathogen observation was done under the stereo while conidia were observed using compound light microscope. The percentage disease incidence was calculated using the formular;

%incidence = (total number of diseased plants/250 total plants selected) ×100

For leaf blast, leaf samples showing disease symptoms were collected and observed in the laboratory to confirm the presence of the pathogen *Pyricularia grisea* but for ergot, rust and smut this was not necessary as the pathogens are visible with unaided eyes. Ergot was identified basing on the condia commonly known as honey dew (Frederickson and Mantle, 1996) and severity score was recorded using the scale developed by Thakur and Williams (1980). Rust disease was identified based on the small reddish-brown to reddish orange, round to elliptical uredinia developing mainly on foliage (Ramakrishnan and Narasimhalu, 1941) and severity score was calculated using the Cobbs scale modified by Niks (2011). The leaf blast disease severity was scored using the 1–9 progressive scale developed at International Rice Research Institute (IRRI) for rice blast (IRRI, 1996) whereas the smut severity was scored using the 1 to 90% scale developed by Thakur and King (1988a).

Data analysis

Data were analysed using IBM SPSS statistics20. The yield data were transformed to base ten. The analysis of variance (ANOVA) at 5% probability was done to establish whether there was significant variation in disease incidence and severities across locations. A regression analysis was also done to assess the contribution of the major diseases to the farmers' grain yield. The Pearson's correlation analysis was also performed to establish the relationship

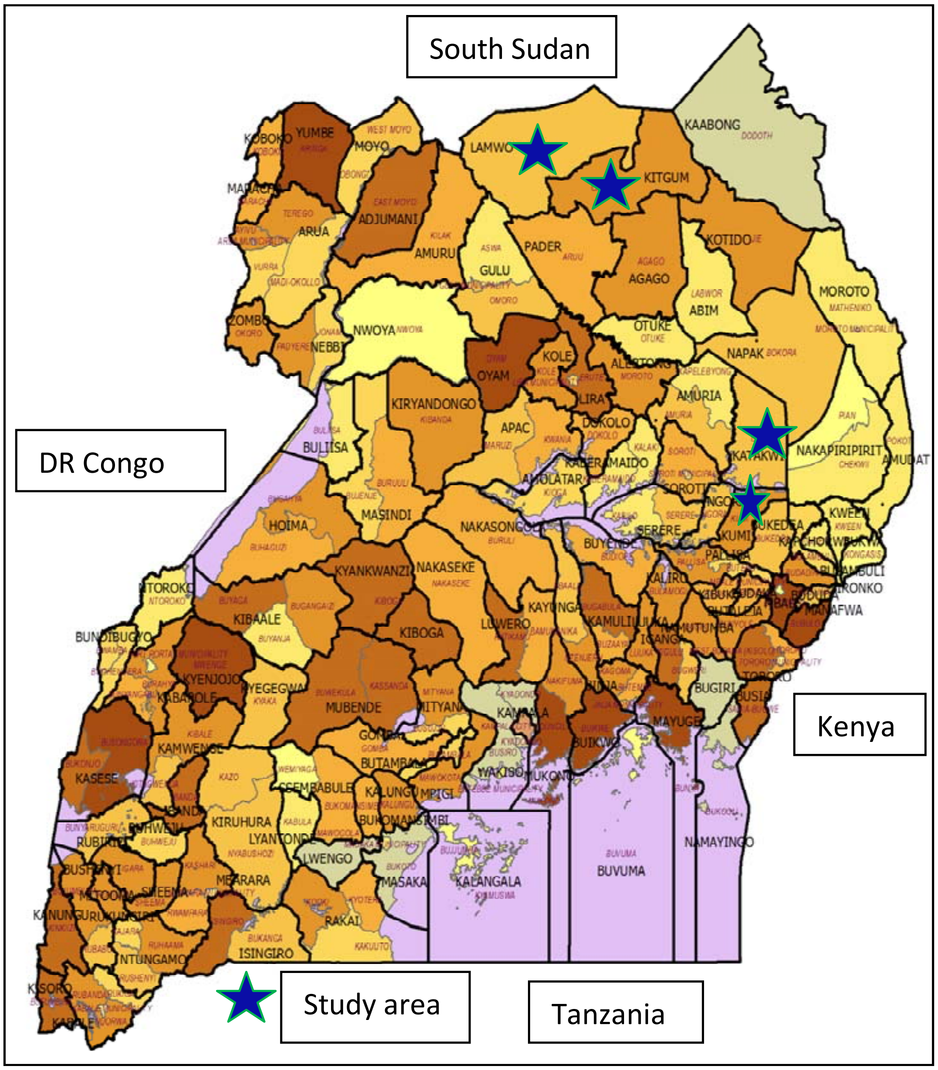

Figure 1. Map of Uganda showing the study area.

between disease severity and yield. A reduced regression model was developed to identify which disease parameters significantly affected yield. The yield was respondent variable, disease severity and incidence were the fixed effects and the district and region were the random effects of the mixed model analysis.

RESULTS

Demographic data about the age of the household head were collected and it was observed that the average age of the household heads was 47.85 years and the majority were in the range of 21-50 years old. In addition farmers were asked about the uses/importance of pearl millet in order to establish the significance of the crop to the farmers and results showed that most farmers cultivated pearl millet for food consumption (43.96%) followed by cash (35.53%) and brewing (17.22%). To a lesser extent some farmers barter the grain (1.47%) for other commodities while <1.00% of the farmers fed grains to poultry.

Disease symptoms and occurrence of ergot (Figure 2), smut (Figure 3), leaf blast (Figure 4) and rust (Figure 5) were observed in eastern and northern Uganda where the survey was conducted. These diseases occurred at different incidence and severity levels in the four districts. Generally, the diseases observed occurred at relatively high incidences of over 61% except for smut (26.76%), exserohilum leaf blight (8%) and cercospora leaf spot (7.5%) (Table 1). Results in Table 1 further show that rust (73.58%) caused by *Puccinia substriata* Ell. & Barth. *indica* Ramachar & Cumm. was the most prevalent disease in all the four districts surveyed followed by ergot (62.98%) caused by *Claviceps fusiformis* Loveless, blast (61.25%) caused by *Pyricularia grisea* (Cke.) Sacc. and smut (26.76%) caused by *Moesziomyces penicillariae* (Bref.) Vanky. The occurrence of rust (64.47 to 77. 15%)

Figure 2. Pearl millet panicle infected by ergot and smut.

Figure 4. Leaf blast.

Figure 3. Pearl millet panicles infected by smut.

Figure 5. Pearl millet rust disease.

was not significantly different (p=0.05) in all the four districts; statistically indicating that rust was distributed to almost the same extent in all the four study districts.

Occurrence of ergot (62.98%) and blast (61.25%) in the two regions was almost the same but significant variation existed within the districts. The ergot incidence

Table 1. Percentage incidences and severities of the common pearl millet diseases.

Region	District	%incidence						%severity						yield (Kg/ha)
		rust	ergot	blast	smut	exser	cerc	blast	ergot	rust	smut	Exser	cerc	
Eastern	Katakwi	77.15	80.92	62.26	28.08	15.00	5.00	67.67	60.15	37.56	17.18	10.00	2.00	484.83
	Kumi	76.78	12.93	29.80	16.34	2.00	0.00	43. 61	6.39	58.93	9.71	1.00	0.00	504.85
Northern	Kitgum	64.47	78.39	68.34	29.45	5.00	10.00	58.05	55.79	16.92	13.66	1.00	1.00	366.81
	Lamwo	75.91	79.68	84.59	33.18	10.00	15.00	64.14	47.68	19.73	19.50	5.00	3.00	514.97
	Mean	73.58	62.98	61.25	26.76	8.00	7.50	62.20	43.33	29.46	14.18	4.25	1.50	467.87
	Pvalue	0.05	0.00	0.00	0.95	0.10	0.07	0.01	0.00	0.03	0.00	0.40	0.68	0.13

Key: exser=exserohilum, cerc=cercospora.

significantly differed in the four districts ranging between 12.93% in Kumi district and 80.92% in Katakwi district. However, except for Kumi where the lowest ergot incidence was recorded, the other districts had almost the same high levels of ergot occurrence (78.39 to 80.92%). This shows that Kitgum, Katakwi and Lamwo can equally serve as hot spot areas for screening materials against ergot. The same trend was observed for leaf blast in all the four districts still there being a significant variation in the occurrence ranging from 29.80% in Kumi district to 84.59% in Lamwo district. Kitgum and Katakwi districts also had high occurrence of leaf blast greater than 62% and can thus also be hot spot areas for material screening against leaf blast. The smut, exserohilum and cercospora occurrences were low and not significantly different in all the four study districts.

Diseases severity significantly differed for blast, rust, ergot and smut but not for exserohilum and cercospora. For the significantly different diseases, leaf blast was the most severe disease (62.20%) followed by ergot (43.33%), rust (29.46%) and smut (14.18%) respectively. The blast severity significantly differed in the four districts with Kumi district having the lowest severity of 43.61% but this was still at above the resistance level of <10% level (Thakur et al., 2009). The ergot severity also differed in all the four districts. Except for Kumi district (6.39%) where farmers' materials were within the resistance range (≤10%), the ergot severity in Katakwi, Kitgum and Lamwo districts was above the susceptible level of ≥30% (Thakur et al., 1989). Both the highest and lowest ergot severities were observed in eastern region although the northern region had relatively high severities above 47%. Rust severity differed in all the four districts (p=0.03) but higher in eastern region (37.56 to 58.93%) than in northern region (16.92 to 19.73%). Kumi district had the highest rust severity of 58.93% although the same district had the lowest severity score for the other diseases. Smut severity (14.18%) was generally low compared with rust, blast, and ergot severity; but significantly differed at district level (9.71 to 19.50%). Still Kumi district had the lowest smut severity and Lamwo district the highest (Table 1). On the contrary, the cercospora and exserhilum severities were lowest of all the diseases with no significant variation in all the districts.

Grain yield did not differ significantly (p=0.13) in all the districts although the lowest and the highest were observed in the northern region. Katakwi and Kitgum districts had relatively low grain yields when compared with Kumi and Lamwo districts. The average yield of 467.87 Kg ha^{-1} observed in the study is very low compared with the potential grain yield of 3000 Kg ha^{-1} realized from research experiments.

The low yield observed was partly due to the combined effect of the observed diseases as shown by the significant regression of yield against disease severity (Table 2) and the negative correlation of yield against the disease severity and incidence (Table 3). The null hypothesis of diseases having no significant effect on yield was tested and results (Table 2) indicate a rejection of the null hypothesis; implying that the major diseases had a significant effect on farmers' grain yield. A backward model reduction was done to establish which model parameters significantly contributed to the tested model. Basing on the adjR2 (Table 2) it was observed that percentage smut incidence, percentage rust incidence, percentage ergot severity, percentage blast severity, and percentage rust severity were the most important parameters in reducing farmers' pearl millet grain yield. The reduced model further shows that generally disease severity was more important than incidence in explaining the low

Table 2. Regression variance of severities and incidences of major diseases on yield.

Source of variation	Sum of Squares	df	Fvalue	Pvalue	%R^2	%adjR^2	Stderror
			Full model				
Regression	3.585	8	2.863	**0.006***	15.70	10.20	0.39563
Residual	19.253	123					
Total	22.838	131					
			Reduced model				
Regression	3.565	6	3.853	**0.001***	15.30	**12.00**	0.39178
Residual	19.273	125					
Total	22.838	131					

*significant at p=0.05. Reduced model parameters; %smut incidence, %rust incidence, %ergot severity, %blast severity, %rust severity.

Table 3. Severity correlations of the common diseases and grain yield.

Variable	Yield	smut severity	blast severity	ergot severity	rust severity	p-value
smut severity	-0.05	1	0.19	0.25	-0.25	0.261
blast severity	-0.11	0.19	1	0.03	0.06	0.104
ergot severity	-0.23	0.25	0.03	1	-0.38	**0.003***
rust severity	-0.06	-0.25	0.06	-0.38	1	**0.045***

*significant at 5%.

grain yield 467.87 Kg ha^{-1} realized by farmers. However, the low adjusted R^2=12.00% accounts for a low percentage of the parameters explaining the model. This may indicate that there may be other factors, not considered in the study, contributing to the observed low grain yield.

DISCUSSION

The major diseases observed in pearl millet were leaf blast, leaf rust, ergot and smut. Except leaf blast, the other three diseases were also reported by Girgi et al. (2006) among the major diseases causing severe damage on pearl millet. Leaf blast has emerged as one of the components of the complex organisms that cause blights on pearl millet (Wilson and Hanna, 1992) and the only blights disease that has gained breeding-for-resistance attention (Hanna et al., 1988). Until recently leaf blast was of economic importance in the southern coastal plains of the USA where it affected green forage and digestible dry matter (Wilson and Gates, 1993). However, it has become a serious disease of pearl millet in India (Lukose et al., 2007; Sharma et al., 2013) which is the world's largest producer of the crop (Gupta et al., 2012). It was a widely distributed foliar disease equally found in eastern and northern Uganda. The incidence range (29.80 to 84.59%) observed in locally adapted materials was almost equal to that (20 to 80%) reported on hybrids in India (Rai et al., 2012). In the current study, pearl millet leaf blast had the highest severity range (43.61 to 67.67%) and a non-significant negative correlation (r= -0.11) with yield. However, Wilson and Gates (1993) reported a severity range of 3 to 35% with a significant negative correlation to dry matter yield; confirming that leaf blast actually has a significant effect in reducing pearl millet yield. The high severity and incidence observed may be a combined result of farmers' materials being susceptible and high plant density; as broadcasting was the sole planting method practiced by farmers resulting in high plant density and dense canopy. Wilson and Gates (1993) noted that dense canopy reduces circulation and sunlight penetration, resulting in high moisture retention, a condition promoting the blast pathogen, *Pyricularia grisea*, survival. The leaf blast pathogen has also been reported to have varying pathotypes, those in the USA being different from those in India (Gupta et al., 2012); indicating that studies should be done to identify whether pathotype variation exists in Uganda in order to develop effective resistant material.

Reports about rust show that the disease is widely distributed in countries that grow pearl millet but of low occurrence in the Sahelian zone. Rust has become one of the major pearl millet diseases (Gupta et al., 2012) affecting forage and fodder quality and substantially reducing grain yield (Lakshmana et al., 2010) through reduction of the photosynthetic area of the infected leaves (Wilson et al., 1996). The high rust incidence (73.58%) observed in the pearl millet growing districts covered in the study shows that the disease is also important in Uganda. There being no significant variation in the high rust incidence (p=0.05) indicates that rust was equally distributed and thus important in all the four districts surveyed. The importance is shown by the relatively high average severity (29.46%) and being in the susceptible range (21 to 30%) (Sharma et al., 2009; Wilson et al., 1996). Rust severity in northern Uganda was within the moderately susceptible range (11 to 20%) while in the east farmers' materials were highly susceptible (>30%) based on the Sharma et al. (2009) description of rust reaction. The variation in severity may be attributed to variation in the environmental factors like time of planting and the variation in resistance level in the germplasm planted by the farmers. Pearl millet being a late planted crop in Uganda and rust also being severe late in the season, the crop growth and development coincides with high level of rust prevalence. This may explain the high severity and incidences in all the pearl millet growing fields surveyed; disease progress being checked only by inherent resistance.

Ergot, also a widely distributed pearl millet disease in Africa, but of no importance in other continents like America, was another common disease with direct negative correlation to yield. The presence of ergot in Uganda was first reported in the early 1980s (Rachie and Majmudar, 1980) and since then no studies about this disease have been reported in Uganda but in Ghana ergot was reported as one of the most important diseases causing considerable pearl millet yield loss (Nutsugah et al., 2006). The wide spread and severity of ergot observed in Uganda calls for immediate action due to the health risk of producing alkaloids that cause ergotism in humans and other animals that consume contaminated grains (Thakur and King, 1988). This study showed that ergot occurred in northern and eastern Uganda with high incidence (62.98%) and severity (43.33%) except Kumi district. Thus, all the three districts can serve as hot spots for screening materials against ergot in Uganda. The high levels in addition to its health hazards make it a dangerous disease for the pearl millet consumers in Uganda.

Smut is also a widely distributed panicle disease which was identified during the current study but information about the disease in Uganda is scanty. Wilson (1995) reported that smut infects pearl millet when sporidia suspended in rain water or dew infiltrates in to the boot. Though smut occurred at low incidence and severity in the farmers' fields compared with other diseases, the rate was generally above the 10% severity level described for materials as being resistant (Rai and Thakur, 1996). This makes it a potential threat to causing epidemics (Wilson et al., 1990). Thus attention should also be put on smut when screening for resistance to other diseases. Fortunately, screening for smut can be done concurrently with that of ergot as studies done by Rai and Thakur (1995) showed that smut resistant lines were also resistant to ergot.

Other diseases occurring at very low frequencies from the pearl millet were Cercospora leaf spot, and Exserohilum spp. The observed low frequencies of these fungi may be due to the plant growth stage at which the study was done. Wilson (2002) observed a change in the frequencies and type of fungi that infected the pearl millet from boot stage to hard dough stage. Note should be made that downy mildew and striga, some of the most destructive constraints of pearl millet (Kumar and Manga, 2010) reported in the horn of Africa (Esele, 2002) were not observed in any of the 140 fields surveyed.

Conclusion

The study results show that ergot, rust, leaf blast and smut are the major pearl millet diseases in Uganda and thus research should focus on these diseases especially ergot, leaf blast and rust. The results also show that downy mildew and striga spp are not important pearl millet production constraints in Uganda since they were not identified in any of the one hundred and forty pearl millet fields visited. Among the panicle diseases much focus should be on ergot due to its high incidence and severity and the health risk it poses in producing alkaloids that cause ergotism in humans and animals; whereas for the foliar diseases focus should be on rust due to its direct effect on forage and grain yields. Kumi district had very low disease incidence and severity except for rust; making it a hot spot for screening materials against rust. The ergot, blast and smut can be screened in Katakwi, Kitgum and Lamwo districts except Kumi.

Conflict of Interest

The authors have not declared any conflict of interest.

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