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African Journal of Plant Science

Full Length Research Paper

Distribution and farmers' knowledge on Fusarium wilt (Race 1) in cropping systems of Uganda

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The study aimed at understanding the spatial distribution of Fusarium wilt (FW) in different banana growing regions, ascertain the effect of management practices and plantation age on FW incidence, as well as investigate farmers' knowledge regarding the symptoms and spread of FW in Uganda. Individual interviews were conducted in 119 farms using a pre-tested questionnaire and field observations during a survey in major banana growing regions. Results indicate that FW is widely distributed across the banana growing areas with more occurrences (70%) in Kapchorwa district and majority of respondents (63.4%) reported increasing disease prevalence. A chi-square test performed revealed significant association between FW incidence and plantation age with more incidences (51.6%) recorded in older plantations (>20 years of establishment) than newly (1-5 years) established ones (11.1%). FW incidence was significantly associated with plantation management with higher incidences (86.9%) recorded in well managed plantations. Half of interviewed farmers could explain and distinguish symptoms associated with FW from other diseases, but only 38.4% of these could tell how the disease spreads; thus, a need for more concerted efforts in building the capacity of farmers to identify the symptoms and spread of FW for effective management program. We identified preliminary evidence that field abandonment is sometimes used as a last option for coping up with FW. Understanding the mechanism behind this requires more detailed research as well as establishing how farmers are managing FW culturally.

Key words: Fusarium wilt, farmers' knowledge, spatial distribution, Uganda.

INTRODUCTION

Banana and plantain are one of the major staple foods for over 50% of the population in Uganda (Karamura et al., 2012). In addition, banana is considered a key food security crop and a source of income for resource poor farmers. Uganda has the highest global per capita consumption levels of banana, estimated at 0.4-0.7 kg per day (FEWS NET, 2017). Seventy percent of the bananas grown in Uganda are consumed locally and the rest is sold on the domestic market to generate household income (UBOS, 2019). Depending on genome,

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banana serves several purposes, for instance; AAA (Cavendish, Gros Michel and East African Highland Bananas-EAHBs) are majorly used as deserts and cooking respectively, AAB (Pisang Awak, Silk and Pome) are grown for preparing juice and desert, AB (Sukali Ndizi, Kisubi) for dessert, ABB (Bluggoes) and AAAA (FHIAs mainly, 03, 17, 21, 23 and 25) for juice, desert and cooking. Therefore, the production of banana is demand-driven with the EAHBs also locally known as "matooke/cooking type", the most cultivated ones (Karamura et al., 2012). However, in the recent years, investing in dessert varieties especially Gros Michel is becoming lucrative and has become major export commodity not only in Uganda but in East Africa and the world. According to Fruitrop (2016), the global production of Gros Michel is at 14910.16 tonnes; of this, 4.1% come from East Africa mainly: Uganda (352.8 tonnes), Tanzania (173.1 tonnes), Burundi (86.496 tonnes), Kenya (72.1 tonnes) and Rwanda (70 tonnes).

Despite its importance, banana productivity has remained low (6.3 t ha^{-1} yr^{-1}) compared to the potential yield of 70 tonnes/ha/year obtained on station under proper management practices (Nalunga et al., 2015). Pests and diseases, declining soil fertility and drought stress are among the major factors attributing to this yield gap in Uganda (Nyombi, 2013; Tinzaara et al., 2014). Among the most devastating diseases is Fusarium wilt (FW), also known as Panama disease. It has been reported among diseases posing substantial threat to banana production especially to the dessert varieties (Karangwa et al., 2018; Kangire et al., 2000; Tushemereirwe et al., 2004).

FW has caused almost more than 60% in the field losses (Buregyeya et al., 2020). FW is a soil borne fungus caused by *Fusarium oxysporum* f. sp *cubense* (Foc). At present, four races of Foc have been documented (Mostert et al., 2017). These include race 1 that causes manifestation of the disease in Gros Michel (AAA), Silk (AB), Pome (AAB) and Pisang Awak (ABB), race 2 which attacks Bluggoe (ABB), race 3 that attacks *Heliconia* species and tropical race 4 (TR4) which attacks mainly Cavendish (AAA) varieties and all varieties susceptible to race 1 and 2 (Mostert et al., 2017; Dita et al., 2018), Race 1 has remained problematic to non-Cavendish varieties as recent surveys in Mozambique still confirm the status quo (Viljoen et al., 2020). Although this classification still holds, there is a growing concern yet to be confirmed that TR4 does not necessarily affect all species susceptible to Race 1 (Molina personal communication). The race system of *Foc* classification has been proven to be insufficient in distinguishing different *Foc* isolates from different parts of the world and therefore the Vegetative Compatibility Group (VCG) system has been used (Mostert et al., 2017). Currently, only race 1 has been reported in Uganda mainly on Gros Michel, Sukali Ndizi and Pisang awak under the VCGs 0124, 0125, 0128, 01212,01220 and 01222 (Karangwa et al., 2018; Tushemereirwe et al., 2004).

Since being identified in Uganda in 1952 (Leaky, 1970) entire fields of dessert banana varieties of Bogoya (Gross Michel), Kayinja (Pisang Awak), Sukali Ndizi and Kisubi (Ney Poovan) have almost been wiped out (Tushemereirwe et al., 2004). Fusarium wilt symptoms include wilting of the old leaves, splitting at the corm base, the xylem becomes reddish brown, plugged, thus hindering water and nutrient transport as the plant eventually dies (Ploetz, 2015a; Viljoen et al., 2017). Initially, yellowing of the leaves begins with the margin advancing towards the midrib and the petioles becomes brown and buckles, pseudostem splits above, discoloration of the corm and dead leaves hang around the pseudostem appearing like a skirt (Viljoen et al., 2017; Thangavelu et al., 2020). Expression of such symptoms has been widely used to identify Banana Fusarium wilt and collect samples for further laboratory characterisation and hence (Karangwa et al., 2018; Viljoen et al., 2017).

Foc can survive in the soils for more than 20 years as hard-cased chlamydospores, making it very difficult to eradicate (Ploetz, 2015b; Dita et al., 2018). Management of Fusarium wilt in other parts of the world where the Cavendish industry is grossly affected by the virulent TR4 has been through attempts at use of fungicides and chemicals, soil fumigation and complete destruction of Foc-infected plants (Viljoen et al., 2019). Most of these methods have proven expensive and unsustainable (Veena et al., 2014). Fusarium wilt being a soil borne disease needs to be sustainably managed (Dita et al., 2018).

For sustainable management of the disease, especially with the imminent threat of the presence of TR4 in neighbouring Mozambique in 2013, there is need to monitor diseases progress, understand how farmers are managing the disease as well documenting current knowledge about the same basing on community perception for an informed and participatory breeding program. Such information in Uganda is limited. The last study with closely related information was by Kangire et al. (2000); it is more than 20 years now and certainly a lot has changed. For instance, there are growing unsubstantiated claims that Fusarium wilt is more prevalent in well managed than abandoned plantations, others argue that Fusarium wilt is common in older plantations than recently established ones. In addition, knowledge about the spatial distribution of FW in Uganda is limited yet such information in vital in understanding disease pressure to map out hot spot experimental areas (Madden and Hughes, 1995), sampling program for disease losses (Liu et al., 2015) and determining areas where concerted management efforts should be put (Ristaino and Gumpertz, 2000). Information on spatial patterns of FW has been widely studied (Meldrum et al., 2013; Gudero et al., 2018; Liu et al., 2015; Heck et al., 2021) in other countries not Uganda.

Table 1. Percentage of respondents by gender and level of education.

Demographic characteristics	Number	Percent
Gender		
Male	75	63.0
Female	44	37.0
Total	119	100.0
Level of education		
Completed primary	44	37.0
Completed secondary	8	6.7
Completed university	10	8.4
Completed tertiary/vocational	30	25.2
Never went to school	27	22.7
Total	119	100.0

Therefore, this study aimed at: (1) understanding the distribution (spatial and within *Musa* spp.) and status of FW based on symptomatology within major banana growing areas, (2) investigate what is known by farmers in regard to symptom identification and spread and (3) ascertain the effect of plantation age and management practices on Fusarium wilt.

MATERIALS AND METHODS

The study used two different tools, namely: (1) individual interviews, (2) field observation based on symptomatology.

Individual interviews

Farmers from major banana producing areas of eastern, central and western Uganda were selected based on having at least 5 mats (a mat refers to collection of banana plants interconnected to original plant) of FW susceptible varieties. The sample was stratified according to altitude differences: (1) districts at high altitude (1450-1950), (2) districts at medium altitude (1200-1450 masl), and (3) districts at low altitude (1000-1200 masl). A total of 119 farmers were selected from four districts with contrasting altitudes namely, Kapchorwa, Isingiro, Kabarole and Sironko for high altitude; Ntungamo, Rubirizi, Rakai and Mukono for medium altitude; Mbale, Masaka, Luweero; and Kayunga for lower altitude. For each district, three sub counties were randomly selected and ten respondents with at least 5 mats of FW susceptible varieties chosen per sub county. Banana growing households distant from each other by at least five km with acreage between 0.5-20 were selected. The farmers were interviewed using an open-ended questionnaire aimed at generating data on demographic characteristics, plantation history, and knowledge about Fusarium wilt (FW), as well as information on resistance on grown banana varieties/clones.

Field observation

Following a Fusarium wilt disease symptom and management manual by Viljoen et al. (2017), a transect walk was conducted in plantation for each individual respondents to identify the presence or absence of FW symptoms on desert bananas (diseases incidence). For each plantation, symptomatic plants as explained by Viljoen et al. (2017) were split and checked for discoloration of the corm to confirm the presence of the disease on desert bananas, and upon this confirmation, the number of mats affected were counted and recorded.

Data analysis

Data were subjected to three packages for analysis: (1) Quantum GIS to develop maps on spatial distribution of the disease in study areas (2) Stata Version 15 (Stata Corporation. 2003) and Microsoft excel for inferential and descriptive statistics mainly means and frequencies as well as testing for associations between variables. Qualitative data was consolidated and disaggregated using queries to generate required tables for analysis. The filter function of Microsoft Excel was employed to eliminate outliers and check for wrong entries. The cleaned data was subjected to Pivot Table function of Microsoft and Stata version 15 for descriptive and inferential statistics. The chi-square test was performed to test the association between Fusarium wilt incidence and management status of banana plantations. All tests on inferential statistics were conducted at 95% confidence level.

RESULTS

Demographic factors within selected banana growing regions of Uganda

According to the individual interviews, male (63%) still dominates banana production as compared to their female counterpart (37%). On appropriateness of information provided, most farmers (77.3%) had completed primary school and above. However, 22.7% of the respondents engaged in banana farming had never received any formal education. It was interesting to note that university graduates owned a notable number of plantations 8.4%. Nevertheless, farmers who never went to school were reported (Table 1).

Table 2. Mean land size and period spent under banana production by respondents.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Age of respondent	119	41.1	11.5	19	72
Period grown banana (years)	119	25.2	9.3	2	50
Estimated total land area (acres)	119	4.3	5.5	0.3	35
Area under banana	119	2.8	4.8	0.3	30

Table 3. Plantation characteristics.

Characteristics	Number	Percent
Plantation age (years)		
1-5	25	21
6-10	13	10.9
11-15	19	16
16-20	6	5.0
>20	55	46.2
Not sure	1	0.8
No. of varieties on farm		
1-2	2	1.68
3-5	16	13.45
6-8	53	44.54
9-11	28	23.53
12-14	19	15.97
>14	1	0.84

Farmers' experience on growing banana and land size allocated to banana

Interviewed farmers had an average land size of 4.3 acres with some farmers owning up to 35 acres of land. Land ownership may not necessarily mean banana production; so to understand this, an interview was held to discern amount of land allocated to banana, and it was revealed that majority (66.3%) allocate their land to banana production. The interviewed farmers were majorly small-scale banana farmers with average banana acreage of 2.8 although very small pieces of 0.3 acres were recorded. Nevertheless, some farmers had scaled up banana production to 30 acres. Among these, the youngest was 19 years and the oldest 72, with an average age for all at 41. Additionally, all farmers had at least two years' experience in growing banana with an average experience at 25 years. The results also indicated that some farmers had grown banana for 50 years (Table 2).

Plantation characteristics in interviewed banana production areas

An assessment to understand plantation age revealed that majority (46.2%) were old plantations established 20 years and above. Albeit a notable number of new plantations were reported (21%), of these 5 were established after abandoning those severely hit by FW. It was also reported that majority of farmers (44.5%) prefer growing a mixture of varieties as opposed to pure stands of a single variety (1.7%) (Table 3).

Distribution and status of FW in selected banana growing regions

Spatial distribution

Symptoms associated with FW were widespread within selected banana growing areas with more prevalence in the eastern region of the country (Figure 2). There was a significant difference ($p < 0.05$) between FW incidence and districts. Generally, FW was more prevalent in eastern Uganda with Kapchorwa district showing highest incidence (70%), followed by Mbale (60%), and Sironko (60%) (Figure 2). Results further indicated that altitude did not have a significant contribution on FW incidence as this is evidenced by occurrence of high disease incidences in districts at high, medium and low altitudes.

Distribution of FW symptoms within Musa* spp. *according to farmers' perspective

EAHBs continue to be the dominant banana subgroup

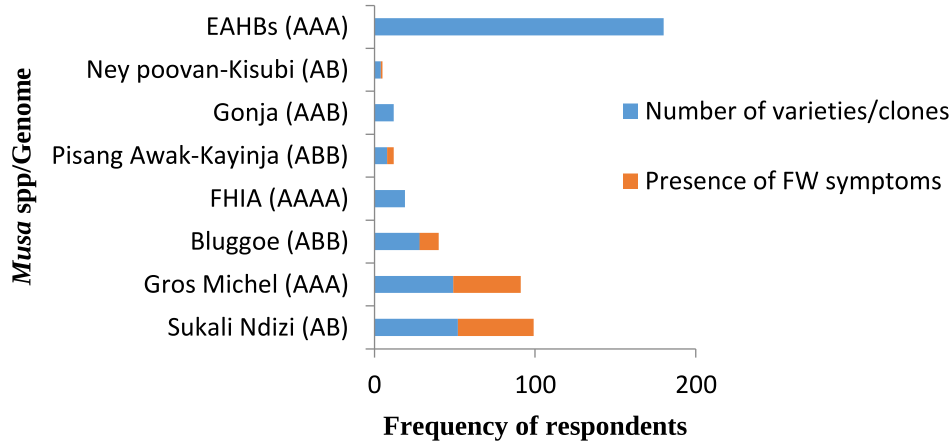

Figure 1. Frequency of distribution of FW within banana subgroups.

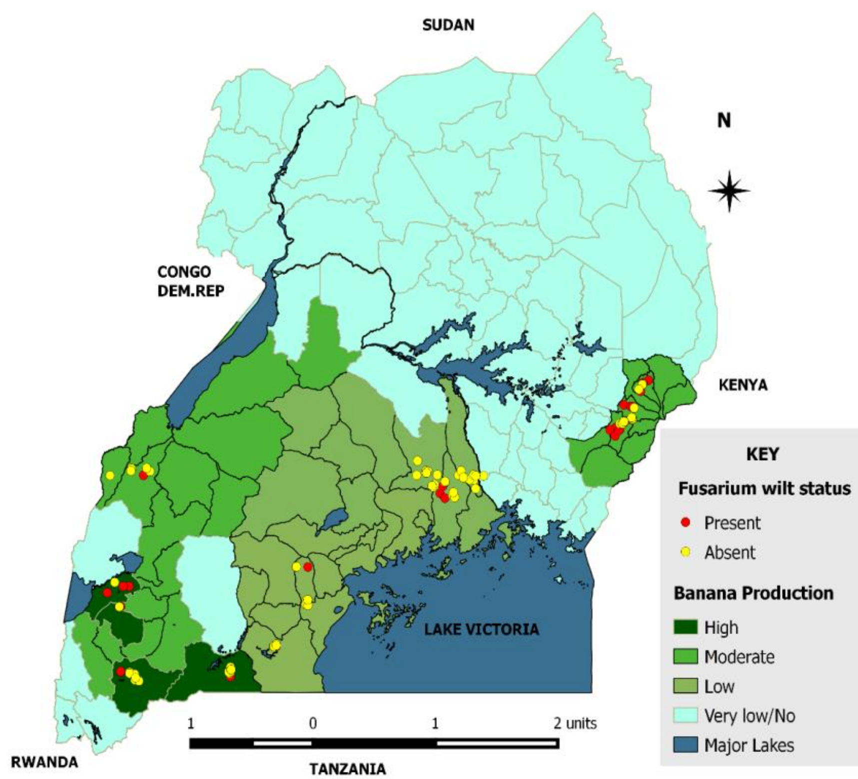

Figure 2. Spatial distribution of FW in major banana growing areas of Uganda.

grown in Uganda. Farmers' perception according to resistance, ranked Sukali Ndizi (AB) as the most susceptible *Musa* species followed by Gros Michel (AAB) and Bluggoe (ABB). Symptoms associated with FW were more observed in Sukali Ndizi and Gros Michel (Figure 1). Results further indicated that all clones of Pisang Awak (ABB) genome were reported susceptible and neither did any single farmer report symptoms associated with FW on FHIA (AAAA), Gonja (AAB) and KM5 (AAA) nor were such symptoms observed on the same varieties.

Status of FW in sampled banana growing areas

Symptoms associated with FW symptoms were observed in only 34.5% of the surveyed area. Out of these, more than 40% mats were infected, and the disease was

Table 4. Status of FW on farmer fields.

Status	Number	Percentage
Fusarium wilt status		
Present	41	34.5
Absent	78	65.5
Proportion Fusarium wilt infected mats (%)		
<10%	2	4.9
10-40% mats	21	51.2
40-70% mats	18	43.9
Farmer knowledge about Fusarium wilt progress		
Increasing	26	63.4
Decreasing	5	12.2
Constant	4	9.8
Not sure	6	14.6

Table 5. Farmer knowledge on the disease spread and symptoms of FW.

Knowledge	Number	Percentage
Ever heard about FW		
Yes	67	43.7
No	52	56.3
Farmer knows typical symptoms of FW		
Knows symptoms	57	50.0
Is mixed up with other diseases	8	7.0
Has no knowledge on symptoms of Fusarium wilt	49	43
Farmer knowledge about FW spread		
Knows spread	44	38.9
Has no knowledge on spread of Fusarium wilt	5	4.4
Confused with other diseases	64	56.6

reported increasing by majority (63.4%) of respondents (Table 4).

Understanding farmers' knowledge in regard to FW symptom identification and spread

In phytopathology, the design of an effective and efficient diseases management program depends on clear understanding of symptoms, spread and survival mechanism. We investigated to ascertain if farmers know typical symptoms of FW, how it spreads and how possible to manage it.

Farmers' knowledge on symptom identification and spread of FW

In a detailed interview, farmers were requested to explain the symptoms exhibited in FW infected plants and probed to reveal if such symptoms are not confused with Banana Xanthomonas Wilt (BXW) or other biotic stresses. Half of the respondents (50%) explained typical symptoms of FW (Table 5). Nevertheless, farmers still confuse FW with BXW and other disorders. For instance, farmers in Rubirizi district reported corm discoloration in EAHBs, yet these are known to be resistant to FW (Viljoen et al., 2017; Arinaitwe et al., 2019) (Plate 1). Understanding the spread of FW still remains a paradox to farmers, majority (56.6%) had no knowledge about the spread and only 38.9% could clearly describe the spread by associating it with soil movement from infected site'.

Effect of management practices and plantation age on FW incidence

A chi-squared test performed to test the association

Plate 1. Corm 'like' discoloration symptoms observed on EAHBs in Rubirizi District. Farm 1: At 1453 masl, Long: 300648.6 Lat: 2027.8; Farm 2: At 1457 masl, Long: 300657.2 Lat: 2019.6; Farm 3: At 1442 masl, Long: 300606.7 Lat: 1635.6.

Table 6. Association between FW incidence with plantation age and management.

Fusarium wilt Incidence	Plantation age (Years)					Plantation management status		
	1-5	**6-10**	**11-15**	**16-20**	**>20**	**Good**	**Fairly**	**Poor**
Present	4.0^d	1.0	3.0	1.0	31.0	29.2^d	1.80	6.0
	7.1^c	3.2	6.7	2.4	20.6	86.49^c	10.00	2.7
Absent	14.0	7.0	13.0	5.0	**20.0**	**50.50**	3.10	10.5
	10.5	4.7	9.9	3.5	30.4	73.44	1.56	25.0
Not sure	0.0	0.0	1.0	0.0	1.0	2.40	0.50	0.1
	0.4	0.2	0.3	0.1	1.0	100.00	0.00	0.0
Total	18.0	8.0	17.0	6.0	52.0	82.00	5.00	17.0
	$X^2(8) = 20.37$; *p value* = 0.009					$X^2(4) = 12.64$; *p value* = 0.013		

X^2 =Chi-square value with (8) degrees of freedom tested at 95% confidence level; d =Observed frequency and c =Expected frequency.

between FW incidence and management status of banana plantations was significant ($p < 0.05$) (Table 6). Remarkably, more incidences (86.5%) of FW were found in well managed farms (weeded, pruned, de-suckered with corms removed) than fairly managed (10%) and poorly/nearly abandoned farms (2.7%). Results further indicated a significant relationship ($p < 0.05$) between FW incidence and plantation age with highest incidences observed in older plantations established more than 20 years ago (Table 6).

DISCUSSION

Demographic factors within banana growing regions of Uganda

Fusarium wilt remains one of the most devastating diseases in several banana growing regions of the world and thus a global threat to banana production (Ploetz, 2015b; Kema et al., 2020). In this study, we identified the spatial distribution of FW in the banana growing areas and within banana subgroups, ascertained the effect of management practices and plantation age on FW incidence, as well as investigated how much information is known by farmers in regard to the symptoms and spread of FW in Uganda. Results showed that more males (63%) are involved in banana production than female (37%) in the major banana growing areas. The higher involvement of males in banana production suggest that men (males) are the likely more responsible for cash crops management than women as the latter mainly provide labour, although both males and females could be involved in decision making on the farms for increased income (Bjornlund et al., 2019; Rietveld et al., 2018).

Attaining formal education has been strongly correlated with adoption of management practices (Kikulwe and

Asindu, 2020; Ebewore, 2016). In our study, 22.7% of the respondents had never attained any formal education, implying that management practices devised to curtail Fusarium wilt, need to be simplified in a more user-friendly manner and employ practical means like farmer field schools. It was interesting to discover in this study that a notable number (8.4%) of university graduates owned banana farms and were engaged in daily management of plantations. It is envisaged that the future of agriculture lies in the hands of youths, as the need for youths into agriculture has been documented (Irungu et al., 2015; Mukembo and Edwards, 2020). In Uganda, the call for more youths in agriculture has been emphasized in the National Development Plan phase 3 (NDP III) (National Planning Authority, 2020). Finding ten youths already in banana farming in Uganda is evident to show that the country is on the right trend.

Findings further reveal that banana farmers had an average land size of 4.3 acres with about 66.3% allocated to banana production. Banana is a major food security crop accounting for much of farmers' income and is more profitable than annual food crops such as maize, sweet potatoes and cassava and thus the most important food crop in the country (Kiiza et al., 2004; Nyombi, 2013). The study was represented by farmers with depth in responding to questions related to banana farming as showcased by the average experience in banana production of 25.4 years, with some farmers recorded to have spent 50 years in this business.

Distribution (spatial and within *Musa* spp.) and status of FW based on symptomatology within major banana growing areas

Data on spatial distribution of Fusarium wilt remains scanty. This makes it difficult to map out hot spot experimental areas, sampling program for disease losses, and conducting cost benefit analysis studies on available management options for Fusarium wilt as highlighted by Staver et al. (2020). This study revealed a wide spatial distribution of symptoms associated with FW disease in all altitudes agrees with Gudero et al. (2018). However, there was a significant difference (p < 0.05) between FW incidence and districts. Kapchorwa, (a district on high altitude, 1950 masl) expressed highest incidence of symptoms associated with FW. The wide distribution of FW agrees with however, the results of altitude and FW contradicts with Karangwa et al. (2016) who reported high symptoms associated with FW at low altitudes. In Kapchorwa, it was observed normal for germplasm exchange between farmers; this traditional exchange of planting materials (sometimes infected) from one field to a healthy one could be the underlying reason for higher incidences of symptoms associated with FW observed in Kapchorwa.

Interestingly, no symptoms of FW were observed in sampled districts within low altitude (Kayunga and Luweero). There is a high likelihood that other factors apart from altitude contributed to this finding. For instance, Kayunga was the district where Banana Xanthomonas Wilt (BXW) was first observed in the early 2000's, with an impact that was unbearable and that forced farmers to uproot any symptomatic plant and mats, most of these mats were never recovered/ replanted, but rather the land was diversified to other income generating activities (Tushemereirwe et al., 2001). It is envisaged that, continued removal of infected plants could have reduced the inoculum and also reduce population of susceptible varieties, which is in agreement with Tushemereirwe et al. (2004).

In this study, we also found that the EAHBs were the most cultivated *Musa* species followed by Sukali Ndizi (AB), and Gross Michel (AAA), indicating their economic importance and consumer preferences (Figure 1). For instance, among deserts, Sukali Ndizi (AAB) is the most popular because of its compact bunch, short fingers and very sweet flavour when ripe (Gold et al., 2002). Farmers' perception according to resistance ranked Sukali Ndizi (AB) as the most susceptible *Musa* species followed by Gross Michel (AAB) and Bluggoe (ABB). In addition, all clones of Pisang Awak (ABB) genome were reported susceptible and with resistance to FW on FHIA (AAAA), Gonja (AAB) and KM5 (AAA). Our findings are consistent with Kangire et al. (2000) who reported that Sukali Ndizi (AB) variety is very much susceptible to FW. The findings are also consistent with Tushemereirwe et al. (2001) who reported that the FHIA varieties are resistant.

Results also showed that the least grown *Musa* species were Kayinja (ABB) and Kivuuvu (AB). Despite the low production of Kayinja and Kivuuvu, the contribution by the two in banana production system should not be underestimated. For example, Kayinja produces more juice for beer production as compared to the indigenous beer locally known as "*Mbidde*" whereas Kivuuvu is preferred in some areas for cooking compared to EAHBs due to low production costs (Bagamba et al., 2006). However, during an epidemic of Banana Xanthomonas wilt in an area, Kayinja and Kivuuvu are the first to be infected (Tushemereirwe et al., 2001). Thus, their susceptibility has tremendously contributed to reduction in mat stands and given that both varieties are susceptible to the two diseases, the decline in mat stands is highly likely to continue unless proper management strategies are reinstated.

Understanding farmers' knowledge regarding FW symptom identification and spread

Like other diseases, FW can effectively be managed when accurate diagnosis of the diseases through symptomatology and other DNA based methods are correctly done (Dita et al., 2018). Farmers normally rely

Plate 2. A field abandoned due to FW infection.

on symptoms for understanding the disease and devise management strategies. We investigated to ascertain how much is known about symptoms and spread of FW and found out that 50% of the respondents could explicitly explain typical symptoms of FW without confusing it with other *Musa* spp. diseases such as BXW, of which only 38.9% could understand how the disease spreads. This shows that limited information occurs on identification and spread. FW spread was predominantly confused with BXW as evidenced by farmers practicing removal of male inflorescence and stating that FW was spread through same by the bees, while others were strongly disinfecting tools after cutting a susceptible plant. It is known that being a soil-borne pathogen, dispersal for FW takes place by passive movement of soil particles and spores in soil propagules at short and long distance mainly by water runoff and (or) animals (Dita et al., 2018). The knowledge gap for symptom identification and spread could be one of the underlying factors for continuous spread of FW in sampled areas and more research needs to be directed towards this direction to build the capacity of farmers in understanding symptoms and spread so that they can attach meaning to management practices proposed.

Effect of management practices and plantation age on FW incidence

The study also revealed that plantation age plays a significant role in incidences of FW disease. The highest incidences of FW were observed in older plantations established more than 20 years ago. The effect of plantation age on disease incidence in banana has not received enough attention; nevertheless, scanty studies have been conducted (Mobambo et al., 1996; Karangwa et al., 2016). While conducting a study on distribution and incidence of banana Fusarium wilt in East and Central Africa, Karangwa et al. (2016) found out that plantation age was significantly associated with FW incidence with prevalence more pronounced in plantations of 10-30 years. This is consistent with our findings. Although this interaction has not adequately been investigated, it could be linked with the long duration that the pathogen stays in soil (Stover, 1972). This means that plantations which are already infected will remain as secondary inoculants for a long period. Therefore, as the field becomes old, more and more pathogens could accumulate in the soil if proper soil management practices such as sterilization, application of bio control, soil amendments are not performed over time (Ploetz, 2015b).

The chi-square conducted revealed an association between Fusarium wilt and management, with higher incidences in well managed plantations, than poorly/nearly abandoned plantations. Well managed plantations involve several agronomy practices for instance mulching and weeding (sometimes with a hoe). These encourage continuous soil disturbance which promotes movement of spores in infected sites (Alabouvette, 1986). For this reason, more incidences are more pronounced in well managed plantations than poorly/nearly abandoned ones which receive less soil disturbance. For the first time, our study reports field abandonment as one of the managements practices used in Uganda (Plate 2). It was reported that instead of cutting down entire plantation, abandoning the field and still harvest a substantial yield is a better option. According to FAO (2019), this practice has been commonly used in Philippines as a worst-case Fusarium wilt management practice. Understanding the mechanism behind this claim will require further research involving field experiments but could also be linked with the concept of suppressive soils being left undisturbed. Alabouvette (1986) reported the role of soil microflora in supressing FW. The author asserts that soils abundant with micro-organisms tend to have a suppressive effect, probably poorly managed or abandoned fields receive minimal disturbance thus encouraging more microbial growth which significantly contribute to soil suppression. In addition, abandoned plantations could be more nutrient-rich due to high microbial activity, and recently, Nowembabazi et al. (2021) revealed the enormous importance of nutrients especially potassium in reducing FW incidence in apple bananas.

Conclusion

The study revealed a notable number of growing university graduates in banana production. Fusarium wilt in banana is widely distributed in the major banana growing areas of Uganda with Kapchorwa district showing the highest incidences. According to farmers, Sukali Ndizi (AB), Gross Michel (AAB) and Bluggoe (ABB) were ranked susceptible to FW in that order whereas FHIA (AAAA), Gonja (AAB) and KM5 (AAA) were considered resistant. The disease was reported to be increasing by the majority, and the drivers for this increment were majorly limited knowledge on the spread that encourages management practices similar to BXW as well as traditional exchange of germplasm especially dessert ones. At least, half of the interviewed farmers know how to separate symptoms associated with FW from other banana diseases especially BXW. However, a majority are still challenged with understanding how the disease spreads and how it can be managed. Fusarium wilt symptoms were more pronounced in older plantations with 20 years from date of establishment and such symptoms are common within well managed plantations. Also, higher incidences of FW wilt observed in older plantations as well as well managed plantations need to be further investigated. Interestingly in this study, we found out field abandonment as a strategy for managing already infected field. This study predisposes array of research in near future, for instance the effect of intercrops in supressing FW, a detailed study on how farmers are managing FW in Uganda, understanding the mechanism of field abandonment in managing FW as well as the role of variety mixtures in supressing FW.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessing production constraints, management and use of pearl millet in the Guinea Savanna Agro-ecology of Ghana

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The adoption of new and high yielding pearl millet (*Pennisetum glaucum* (L.) R. Br.) varieties can be boosted if they correspond to farmers' preferences and answer the constraints prevailing in the production environments. Therefore, the focus of this study was to assess production constraints, farmers' preferences and choices of varieties among pearl millet cultivating farmers using participatory rural appraisal (PRA) in the guinea savanna agro-ecological zone of Ghana where the crop is grown. Data collection was through mixed methods of focus group discussion (FGD) and individual interviews with 295 (45 for FGD and 250 for individual interviews) farmers covering 45 communities. Results indicated that the major constraints of production included low yields, bird damage, poor soils, erratic rainfall, downy mildew disease, head insects, and early maturity. Majority of pearl millet farmers depend on own seed source due to lack of access to and low knowledge of improved seeds. Breeding for high grain yield, earliness, resistance to downy mildew disease and bird attack varieties were the leading traits of preference that research should focus on. It is therefore anticipated that breeding program would integrate the product profiling proposed in this work for enhance adoption of new pearl millet varieties in Ghana.

Key words: Participatory rural appraisal, constraint, pearl millet Guinea savanna, Ghana.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.), is one of the most extensively cultivated cereals in the world, ranking sixth after rice, wheat, maize, barley and sorghum in terms of area under cultivation (Khairwal et al., 2007). Rai and Yadav (2013) contends that at least 30 million hectares of land is cultivated with pearl millet to feed about 100 million people in the world, mostly those are subsistent from Africa and Asia. From the great north, the crop was introduced and cultivated at Ntesero in Ghana around 1250 B.C. (Davies, 1968).

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Pearl millet is predominantly grown in Upper East, Upper West and Northern regions as a subsistent crop. Pearl millet is well adapted to the short and erratic rainfall, high temperature and low soil fertility that characterize northern Ghana (Dietz et al., 2004; Asante, 2004). The crop can produce high grain yield under stressful environments with high nutrient quality (Burton, 1985). Northern Ghana constitutes 40% of the total land area of Ghana and is the main food basket in terms of grain cereals in the country (MoFA, 2019). The Upper East region is noted for the cultivation of the early maturing type of pearl millet (Asungre et al., 2015; Kanton et al., 2015), which matures within 65-70 days from sowing, making it gain the accolade as the ‘poor man’s crop’ or ‘hunger breaker’. This is because it is often the first cereal crop to be harvested during the main season, thus serving as a food security crop during mid-July to late August each year. Apart from its main use as a food crop for traditional dishes such as *Tuo-Zafi*, *Maasa*, and porridges for the people in Ghana, the stalks are used variously as fodder, roofing, fencing material or source of saltpetre for cooking traditional food.

Yield of pearl millet on farmers’ fields in Ghana are below 1.0 t ha^{-1} even though research shows that yields can be as high as 2.1 t ha-1 as was shown in a dossier presented to the National Variety Release and Registration Committee (NVRRC) in 2015 when Ghana was preparing to release five candidate genotypes. In 2010, 177,000 ha of arable land were cultivated with pearl millet with a total grain yield of 219,000 metric tons (MoFA, 2011). Maize (*Zea mays* L.) and Cowpea (*Vigna unguiculata* L. Walp.) are fast replacing pearl millet leading to a decline in its production. The decline is also attributed to continuous recycling of seed of landraces by majority of the peasant farmers (Sugri et al., 2013a,b). Unlike pearl millet, which can fit well into any cropping system, Maize and Cowpea lend themselves to a mono-cropping system for higher yields and crop performance. However, a review of the state of plant and genetic resources for food and agriculture suggests that Ghana could be under threat of food security if this trend continues (Bennett-Lartey and Oteng-Yeboah, 2008). Genetic erosion due to the replacement of many crop varieties by a few more competitive or close substitutes is another threat to food security, especially in Ghana where recent agricultural policy intervention (Planting for Food and Jobs) rely on the promotion of maize, cowpea, rice and soybean to the neglect of sorghum and pearl millet (Sugri et al., 2013a,b).

The grain of pearl millet contains appreciable amounts of micronutrients especially Fe and Zn compared with cereals such as maize, rice, wheat and sorghum (Dwivedi et al., 2012). Preliminary findings on Ghanaian pearl millet landraces show that they are rich in many of the micronutrients needed for human health and development (Tortoe et al., 2019). For instance, the protein content (11%) of pearl millet is not only high, but of exceptionally good quality; the lysine content is reported to be 3.68 mg g^{-1} protein compared to 2.24 mg g^{-1} for wheat, 3.36 mg g^{-1} for rice, 3.0 mg g^{-1} for maize, and 3.2 mg g^{-1} for sorghum (Tortoe et al., 2019). Earlier works in other parts of the world indicated that pearl millet accounts for 19 to 63% of the Fe and 16 to 56% of the Zn intake from all food sources (Rao et al., 2006a, b).

It has been reported that there is an increase in variety development and release in Ghana in recent times as a result of increased investments in agricultural research (Etwire et al., 2013). However, the adoption of many of these new improved varieties, especially pearl millet, in Ghana has been very low due to lack of awareness and weak seed delivery systems. Furthermore, very little research work has been done on pearl millet value chain and the major production constraints facing the rural farmer who depend on dishes prepared from pearl millet for their micronutrients, energy and protein sources. The purpose of this participatory rural appraisal (PRA) study was, therefore, to help identify the production constraints, cropping systems, sources of seed for millet farmers as well as the role millet plays in their daily requirement of micronutrients, among others.

MATERIALS AND METHODS

Scope of the study and sampling process

This study covered three pearl millet growing districts each in Upper East, Northern and Upper West regions of Ghana (Table 1). A multi-stage sampling process was deployed for the study to reflect the ecological and socio-economic environments in the pearl millet growing regions. The first level was a purposive selection of the three regions known for the cultivation of pearl millet in Ghana. This was followed by random selection of three districts in each region and five communities in each district. Data collection was through mixed methods of focus group discussion (FGD) and questionnaire for individual face-to-face interview. The FGD was held at the district level where three pearl millet farmers were randomly selected from each of the five selected communities. At the community level five farmers were selected, except Garu district where 10 farmers were randomly selected for the individual face-to-face interviews. A total sample size was 295 respondents comprising of 45 for FGD and 250 for individual interviews (Table 1). The sample size for the face-to-face interview was arrived at following the formula (Equation 1) proposed by Sugri et al. (2017).

$$\mathrm{N} = \frac{Z_2 \times PQ}{D_2} \qquad (1)$$

Where N = total number of farmers to be interviewed, Z = Confidence level of 95% (standard deviation of 1.96), P = estimated prevalence of farmers in the study area (80%), Q = 1-P, and D = margin of error of 5%. Even though this formula resulted in 245.8, the total sample size was adjusted to 250 respondents. Information captured using these tools included socio-demographic characteristics of the farmers, scale of pearl millet production, seed source, production operations, utilization,

Table 1. Number of farmers that participated in the FGD and individual interview sessions.

Region	District	Name of Community	No. of persons for FGD	No. of Individual respondents
Upper East	Garu	Napaadi, Denugu, Nomboko, Kparimboaka, Barboaka	15	50
	Telansi	Dapoore, Zoog, Gorogo, Pusu- Namongo, Yameriga	-	25
	Builsa North	Chansa, Siniansi, Naasa, Kalijiisa, Bilinsa	-	25
Upper West	Jirapa	Duori-Guo, Duori-Naakpari, Duori-Kpaguori, Sigti-Baanari, Jeffisi	-	25
	Lawra	Bompari, Orbili, Tabier, Pavuu, Dozuuri	-	25
	Sisala East	Tanvieli, Kroboi, Chinchang, Kassana, Pouri	15	25
Northern	Sawla-Tuna-Kalba	Yipala, Kpongiri, Dorlepari, Kpongiri No.2, Kpankpansuga	-	25
	Chereponi	Jakpa, Namalku, Gbalo, Songbana, Tusunga	-	25
	Bunkpurugu	Kpentaung, Kauk/Jagouk, Tojing, Gbetmongpaak, Nanyiar Paak	15	25
Total			45	250

Table 2. Gender distribution of respondents across the selected districts in Northern, Upper East and West regions of Ghana.

Region	District	Gender distribution of respondents			
		Male	%	Female	%
Upper East	Builsa North	22	88.00	3	12.00
	Garu	42	84.00	8	16.00
	Talensi	22	88.00	3	12.00
Upper West	Jirapa	21	84.00	4	16.00
	Lawra	16	64.00	9	36.00
	Sisala East	25	100.00	0	0
Northern	Bunkpurugu	25	100.00	0	0
	Chereponi	16	64.00	9	36.00
	STK*	19	76.00	6	24.00
	Total	208	83.20	42	16.80

*= Saula-Tuna-Kalba.

marketing, constraints and benefits derived from millet cultivation.

The Statistical Package for Social Sciences (IBM SPSS 26) was employed in analysing the data for statistical inferences and conclusions. The results were then presented in tables and graphs for interpretations.

RESULTS

Gender distribution

A majority of the respondents were men (208) constituting 83.20% while 16.80% (42) were women from all the regions (Table 2). The Upper East region recorded more men (86%) compared with Upper West and Northern region (82.7% and 80%), respectively, as respondents. At the district level, Sisala East district in Upper West region and Bunkpurugu district in Northern region recorded none of the respondents being women; while Builsa North and Talensi districts in the Upper East region each had 3 women.

Age, family size, marital status and educational level of respondents

A majority of the respondents across the regions were within the age of 40 to 60 years, followed by those below 40 years and then those above 60 years (49.6, 36.4, and 14%, respectively). Upper West did not only record the highest number of respondents below 40

Table 3. Age, marital status, and family size of respondents in Northern, Upper East and West regions of Ghana.

	Region of respondents			Total (%)
	Northern	Upper east	Upper west	
		Age (%)		
Below 40 years	38.70	29.00	44.00	36.40
40-50 years	36.00	39.00	25.30	34.00
50-60 years	12.00	12.00	24.00	15.60
Above 60 years	13.30	20.00	6.70	14.00
		Family size (%)		
1 to 5	16.00	14.00	9.30	13.20
6 to 10	54.70	50.00	34.70	46.80
11 to 15	20.00	23.00	34.70	25.60
16 to 20	8.00	8.00	10.70	8.80
Above 20	1.30	5.00	10.70	5.60

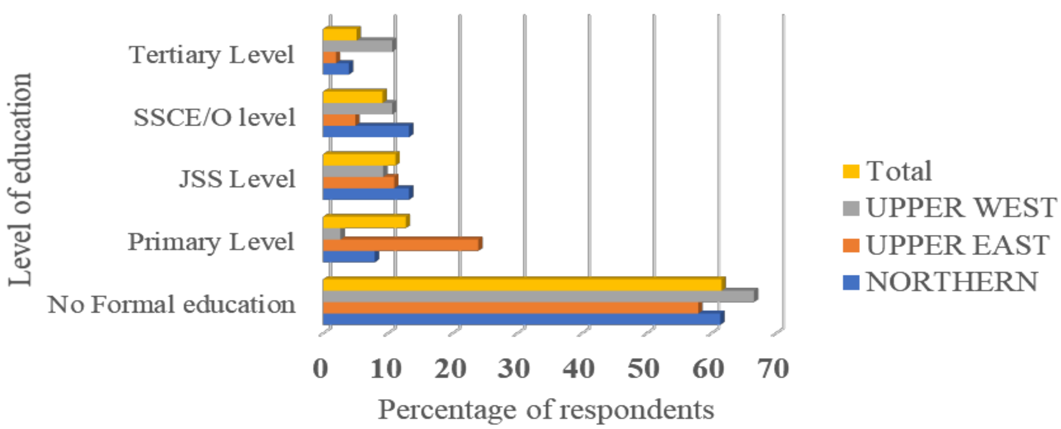

Figure 1. Educational status of respondents in the study area of northern Ghana.

years (44%) but also recorded the least number of those above 60 years (6.7%), indicating that a youthful population in the region are engaged in Agriculture compared with the other regions. Upper East region recorded the highest percentage of respondents being in the 40 to 50 years age range (39%), and was closely followed by the Northern region with 36%. In terms of family size, 46.08% (117) of the respondents had 6-10 members in a family (Table 3). Large family sizes were in the Upper West region with higher numbers coming from all the ages except 1-5. Upper East recorded the smallest family size, except for those with family size above 20 where it recorded a higher number than the Northern region (3 and 1.3%, respectively). Across the regions, only 5.60% of the respondents recorded more than 20 people living in a family.

While a majority of the respondents (61.6%) did not have a formal education, only 5.20% had a tertiary level education (Figure 1). The overall results revealed a decreasing trend from no formal education to tertiary level. Except for Northern and Upper West regions, the same trend was observed for the Upper East region.

Pearl millet yields and its influencing factors

Figure 2 shows the average pearl millet yields from farmer fields. Results indicated that 166 farmers, representing 66.40%, of those interviewed across the regions reported yields between 1 and 3 maxi bags ac^{-1} (0.25-0.75 t ha^{-1}), with few of them (11.20%) achieving yields above 6 bags ac^{-1} (1.50 t ha^{-1}). Eighty-nine percent of farmers in Upper East region reported yields between 1 and 3 maxi bags (0.25-0.75 t ha^{-1}) of millet on

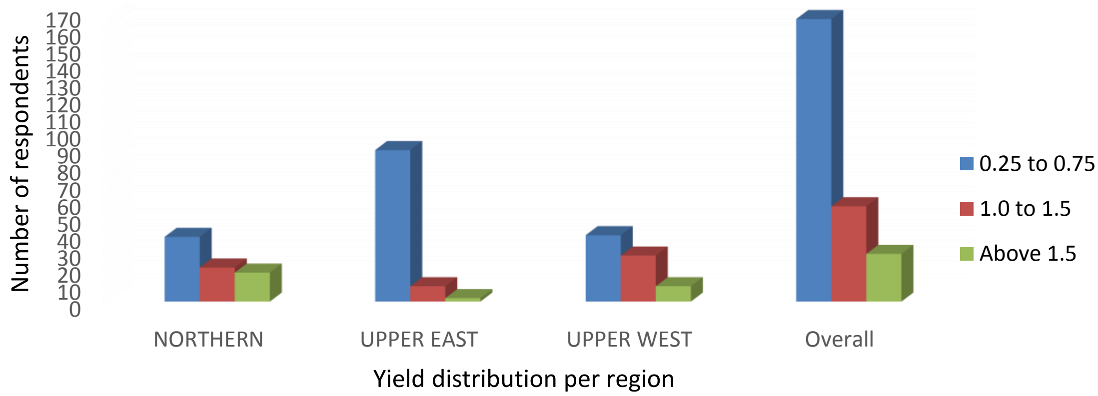

Figure 2. Average yield per hectare for millet on farmers' fields in the study area.

Table 4. Experience of respondent in the cultivation of pearl millet in their communities.

Period	Frequency	Percent
1 to 5	66	26.4
6 to 10	46	18.4
11 to 15	21	8.4
16 to 20	40	16
>21	77	30.8

average. Half of the respondents in the Northern and Upper West regions (38 and 39, respectively) reported yields below 400 kg ac^{-1} (1.0 t ha^{-1}); though others reported yields above 600 kg ac^{-1} (>1.50 t ha^{-1}). More farmers (17) in the Northern region tend to record higher yields (>600 kg ac^{-1}) than those in the Upper East region.

Farmers' experience in pearl millet cultivation

Results indicated that 31% of the respondents have been cultivating pearl millet for at least 21 years, 26% for 1 to 5 years; while only 8% have been growing the crop for at most 15 years (Table 4). Again, 18 and 16% of the respondents have been cultivating pearl millet between 6 and 10 years and 16 and 20 years, respectively.

The study also revealed that an overwhelming majority of the respondents (60.4%) own more than 3 acres (>1.5 ha) of farmland; while 20% own less than one acre (Table 5). Sixty-eight percent of the farmers in the Northern region and 73% in Upper East region owned more than 1.5 ha of farmland. The results show that 72.8% of the respondents dedicated at least 25% of their farmland to pearl millet production each year; while 45.2% dedicated 25 to 50% of their farmland to pear millet production (Table 5). Again, 46.7% each of farmers in Northern and Upper West regions and 43% in Upper East region dedicate between 25 and 50% of their available crop land to pearl millet cultivation

Pearl millet cropping systems in northern Ghana

Results show that the majority of farmers in the regions practice intercropping, which is mainly cereal and cereal intercrop patterns (Table 6). For instance, 78.8% (first four from Table 6) of the farmers in the study area practice cereal intercropping, with only 21.2% growing sole cereals. It was found that 32% of the farmers performing intercropping grow early millet-late millet as part of an intercrop; and early millet-sorghum intercrop is the subsequent, which accounts for 24% of the farmers. Less than 1% of farmers grow early millet-maize intercrop. It was found that 80% of the farmers in Upper East region, 42.7% in Northern region and 41.3% in Upper West region practice early millet-late millet and early millet-Sorghum intercropping.

Trait preference by pearl millet farmers

The results show that farmers have varied agronomic trait preferences in pearl millet production (Table 7). Across regions, a majority of the respondents considered yield

Table 5. Farm size and proportion used for pearl millet cultivation in northern Ghana as indicated by the respondents.

Farm size	Number and percentage of respondents						Overall	
	Northern		Upper east		Upper west			
	Number	%	Number	%	Number	%	Total count	%
<1 acre	4	5.33	5	5.00	11	14.67	20	8.00
1-3 acre	20	26.67	22	22.00	37	49.33	79	31.60
> 3 acres	51	68.00	73	73.00	27	36.00	151	60.40
	Proportion of farms under pear millet cultivation							
<25	9	12	21	21	38	50.67	68	27.2
25-50	35	46.67	43	43	35	46.67	113	45.2
51-75	24	32	28	28	1	1.33	53	21.2
76-100	7	9.33	8	8	1	1.33	16	6.4

Table 6. Types of Pearl millet cropping systems commonly practiced in the regions.

Cropping system	Region of respondents							
	Northern		Upper EAST		UPPER WEST		Overall	
	Number	%	Number	%	Number	%	Total count	%
1 (EM/LM)	14	18.67	51	51.00	18	24.00	83	33.20
2 (EM/S)	18	24.00	29	29.00	13	17.33	60	24.00
3 (LM/S)	28	37.33	8	8.00	16	21.33	52	20.80
4 (EM/M)	1	1.33	1	1.00	0	0	2	0.80
Sole	14	18.67	11	11.00	28	37.33	53	21.20
Total	75	100	100	100	75	100	250	100.00

EM = early millet, LM = late millet, S = sorghum, M = maize.

Table 7. Number of respondents and their preferred pearl millet traits by regions.

Trait preferred	Northern	Upper east	Upper west	Total	Proportion
Tillers (many/few)	5	5	8	18	7.2
Plant height	6	9	5	20	8.0
Maturity (Early)	10	15	15	40	16.0
Seed colour (Ivory)	6	1	9	16	6.4
Disease and pest	14	17	13	44	17.6
Seed colour (gray)	-	8	-	8	3.2
Panicle length	5	10	-	15	6.0
Grain yield	25	30	25	80	32.0
Panicle shape	4	4	-	8	3.2
Seed size	-	1	-	1	0.4
Total	75	100	75	250	100

-Not mentioned by respondents.

(32%) and downy mildew disease incidence (17.6%) as the two main agronomic traits of importance. Early maturity was considered as the third most preferred trait across regions (16%). The trend is the same for the individual regions. However, seed colour and size were not mentioned as preferred traits in Northern and Upper West regions. Panicle length and shape were also not considered as preferred traits in the Upper west region.

Table 8. Major constraints to pearl millet production in Ghana.

Constraint	Ranking of individual constraints			Mean rank	FGD rank
	Northern	Upper east	Upper west		
Low yields	1	1	1	1	1
Lack of improve seed	1	1	1	1	1
Erratic rainfall	2	2	3	2.3	1
Low Soil Fertility	-	2	5	3.5	2
Downy mildew	2	1	2	1.7	2
Bird destruction	3	1	5	3	2
Striga Infestation	5	3	-	4	-
Head insects	3	5	-	4	-
Land availability	2	4	5	3.7	2
Lack of capital for inputs	2	3	2	2.3	-
Ease of threshing	5	5	4	4.7	-
Lodging	-	3	3	3	-
Labour for operations	-	-	-	-	3
Storage for long periods	-	-	-	-	5

-Not mentioned as constraint, 1 = most important, 2-4 = intermediate, 5 = least important.

Table 9. Farmers' source of pearl millet seed supply for cultivation.

Source	Frequency	Percent
Own	210	84
Friends	14	5.6
Market	19	7.6
Input dealers	1	0.4
Research	5	2
MOFA/NGO	1	0.4
Total	250	100

Constraints to pearl millet production in Ghana

Low yields, and lack of improved seeds were ranked highest (ranked 1) in all regions, an indication that these two constraints were the driving force for improved and increased production and productivity in pearl millet (Table 8). Apart from low yields and lack of improved seeds, downy mildew and bird destruction were also ranked as important constraints in the Upper East region. The least important constraints in the Northern region were striga infestation and ease of threshing; while in the Upper East, land availability and ease of threshing were mentioned. Low soil fertility, bird destruction and land availability were the least important constraints in Upper West region. Striga infestation and low soil fertility were ranked low by farmers in the regions. In fact, in Upper West region, striga did not feature at all as a constraint; while in the Northern and Upper East regions it was ranked 5 and 3, respectively. During the FGD meeting, it was realized that improved seed, low yields and erratic rainfall pattern were ranked as the most critical constraint to pearl millet production across the agro-ecological zone. This was closely followed by downy mildew disease, low soil fertility, bird destruction and land availability with a rank of 2; while storage was ranked as the least of the critical variables.

An overwhelming majority of the pearl millet farmers (84%) recycle their seed; while 5.6 and 7.6% got their seed from friends and the open market, respectively (Table 9). Again, 2% of the respondents depended on research institutions; whereas, 0.4% depended on input dealers and MoFA/NGO for seed.

Pearl millet consumption among respondents

A majority of respondents (62.00%) rely mostly on pearl millet meals as food for their families (Table 10). Ninety-six

Table 10. Farmer knowledge and willingness to use millet.

Item	Yes	Percent	No	Percent
Knowledge of Improved millet use	55	22.00	195	78.00
Willingness to use improved seed	241	96.40	9	3.60
Willingness to purchase improved seed	200	80.00	50	20.00
Sale of part of produce harvested	143	57.20	107	42.80
Growing millet with enhanced grain Zn and Fe	243	97.20	7	2.80
Willingness to increase production	240	96.00	10	4.00
Feeding children with Millet based products	155	62.00	95	38.00

Table 11. Correlation of some critical variables affecting pearl millet production in northern Ghana.

Variable	Respondent age	Gender distribution	Family size	Grain yield	Farm size	Years in cultivating	Percent of farm for millet cultivation
Respondent age							
Gender distribution	0.021ns	1.000					
Family size	-0.013ns	0.025ns	1.000				
Grain yield	-0.085ns	-0.006ns	-0.008ns	1.000			
Farm size	0.160*	-0.059ns	-0.113ns	.076ns	1.000		
Years in cultivating	0.497**	-0.032ns	-0.006ns	-0.062ns	0.265**	1.000	
Percent of farm for millet cultivation	0.080ns	-0.043ns	-0.152*	0.077ns	0.387**	0.098ns	1.000

**,* = significant at P<0.001, P<0.01 levels respectively, ns = not significant (P = 0.05).

percent (96%) of the population were ready to increase their current level of pearl millet production provided that the major constraints to production were addressed, including lack of improved seed relative to potential levels of increase. Whilst 96.4% of the population were willing to use improved seed generally, 80% were ready to purchase improved pearl millet seed for cultivation. Again, 97.00% of the respondents were willing to grow improved pearl millet seed with enhanced grain iron (Fe) and zinc (Zn) contents, even though a majority (78.00%) had no knowledge of any improved pearl millet seed in the system.

Correlation of some production variables

Correlation among some of the most critical variables shows significant association amongst them (Table 11). For instance, age of respondent, farm size and the number of years the respondent has been cultivating pearl millet were significantly positively correlated. While the size of farm land positively and significantly (p<0.001) influenced the proportion used for pearl millet cultivation, family size negatively and significantly influenced the proportion of land allotted to pearl millet production among farm families. However, gender distribution and grain yield did not significantly associate with the each other as well as the other variables.

DISCUSSION

The results showed that at least a majority of the respondents are pearl millet farmers, and thus have gained experience in its production. The current study revealed that pearl millet is an important part of the daily meals of majority of people of northern Ghana where it is eaten at least once every week. If the prevailing constraints such as lack of, and access to, improved seed, land availability among others were addressed; pearl millet crop farmers can increase their current level of production. Cereal crop production in northern Ghana is gender sensitive. A majority of peasants in northern Ghana are men because of land ownership characteristics (Sugri et al., 2017). This condition affects women's access and use of agricultural lands for the crop of their choice. The situation becomes even worse where the family size is large, which is typical of Northern and Upper East regions (Sugri et al., 2017).

Pearl millet, one of the main cereal crops in Ghana, has a yield potential of between 2,000 kg ha^{-1} for OPVs and up to 3,600 kg ha^{-1} for hybrids. However, the currents trends, as revealed in this study, show that yield range of 250-750 kg ha^{-1} is achieved on farmers' fields. There is, therefore, the need to explore the variations for possible yield increases in the locally available genotypes. According to earlier reports, pearl millet production in the country has seen a decline over the year (GSS, 2018, 2019; MoFA, 2019) and has been attributed to use of an indigenous landrace, which tends to be low yielding in low soil fertility; and the situation has become more problematic by substitution of pearl millet for crops such as maize and soybeans by some crop farmers. It is therefore, imperative to consider taking advantage of the existing genetic variations in some of the pearl millet landraces for improvement in the breeding programme in Ghana; since knowledge of the genetic variability, heritability and association among economic traits in existing local varieties is a pre-requisite for selection and development of a well-adapted variety for target environments (Afribeh et al., 2006; Jalata et al., 2011). Fortunately, many of the pearl millet farmers in Ghana have been cultivating it for over 20 years, as shown by the current study, and are therefore endowed with sufficient knowledge in the cultivation of the crop. Again, many of these farmers also own their own farmlands; hence, they do not entertain any fears of losing their investment to any landowner. Thus, they have dedicated a portion of their farmland, often not more than 2 ha, to pearl millet cultivation on a sustainable base. This confirms earlier reports that a majority of Ghanaian farmers own less than 2 ha of agricultural land on which most of their crops are cultivated annually (Bawa, 2019; GSS, 2018; Sugri et al., 2017; Tetteh et al., 2016). To address the limitation of land for production, a majority of farmers in the regions practice mixed cropping or intercropping. This was confirmed by this current study, which indicated that about 90% of the farmers in the Upper East region, in particular, practice early millet-late millet and early millet-sorghum intercropping systems; even on their limited available agricultural land that does not support mechanization, due to the area dedicated for such crops. Agricultural intensification is thus high among the farmers as a way to maximize returns as well as a form of insurance against unfavourable seasons that may affect some crop yields.

The education level of most of the peasant farmers of northern Ghana is very low causing many to shift into economic ventures such as farming, which does not often require high educational standards before one engages in its practices. This has led to northern Ghana being the labour hub for most agricultural activities, not only up north but also for many of the agricultural activities in southern Ghana. A majority of the respondents in the present study are in the productive age-group and were married. This, however, has negative effects on the living standards and the environment as reports suggest that people with high level of education are expected to have more income, and an enhanced livelihood, compared with those with little or no education (Nkegbe et al., 2017). Productive agricultural soils stand to be at risk of abuse by less educated farmers who have less chances of adopting soil conservation measures aimed at increased crop production (Tefera and Tefera, 2014).

High grain yield was the most preferred trait, followed by disease tolerance, many tillers, medium plant heights, and finally seed size as the least preferred trait across all regions. Farmers have their preferred traits in crops they cultivate, as reported in the current study, and are likely to hold on to a crop variety for a long time, if it serves the purpose. However, downy mildew disease is the most serious challenge of pearl millet farmers causing yield loss as high as 40% across the West African sub-region (Wilson et al., 2008). Therefore, breeding for high grain yield, earliness, and downy mildew control is important for the breeding program since these are the leading preferred traits of pearl millet as revealed in the present study.

As stated earlier, low yields due to low soil fertility or diseases, and lack of improved seeds are the driving forces against improved and increased production and productivity of pearl millet in Ghana. Earlier reports revealed that there is a lack of outlets for farmers to access improved seeds of released crop varieties (Etwire et al., 2013). Susceptibility to downy mildew disease was hampering the use of improved crop varieties in northern Ghana (Afribeh et al., 2006; Akromah et al., 2008; Asungre et al., 2015; Kanton et al., 2015). This causes many farmers to resort to recycled, or own saved seed, for sowing (Etwire *et al.*, 2013; Sugri *et al.*, 2013a). It must be pointed out that *Striga* weed resistance is one of the most preferred traits by pearl millet farmers (Dawud et al., 2017). However, in the current study this did not feature prominently as a constraint, probably since early maturing pearl millet in Ghana is usually harvested (latest in August) before *Striga* emergence in September.

Product profile development for pearl millet

From the participatory studies carried out in the pearl millet growing regions, it came to light that the production of this crop is plagued with many constraints. A product profile has thus been proposed as a way to ameliorate some of the identified constraints in the short-term period (Table 12). The way to achieve this lies in two prongs, which are breeding and introduction. The first step is to initiate contacts with the international centre like the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for available advanced breeding lines or varieties for screening for the specific traits and possible release to farmers. Aside from this, the pearl millet breeding programme of the Council for Scientific

Table 12. Proposed product profile for pearl millet based on some constraints identified.

Constraint	Target Trait	Bench mark	Target for next 5 years
Low grain yields	High yielding OPVs and Hybrids	OPVs (<1 t ha^{-1}), hybrids (<1.5 t ha^{-1})	15–50% increase in yield for both OPVs and hybrids
Downy mildew	DM resistance/tolerance	1 MD resistant variety released by SARI in 2015	Increase number to at least 3 in the next five years
Bird destruction	Bristles, Compact heads	1 variety released by SARI in 2015	Increase number to at least 5 in the next five years
Head insects	Bristles, Compact heads	2 varieties released by SARI in 2015	Increase number to at least 5 in the next five years
Early maturing	Earliness (65–75 days to harvest maturity)	4 Early maturing varieties released by SARI in 2015	Increase number to at least 5 in the next five years
Plant lodging	Height (1.8–2.5 m tall)	One available in Ghana and released by SARI in 2015	Increase number to at least 5 in the next five years
Nutrition	Enhanced levels of micronutrients in grain	2 among those released in 2015 have levels above 40 mg g^{-1}	25-75% increase in yield for both OPVs and hybrids

OPVs = open pollinated varieties; DM = Downy mildew; SARI = Savanna Agricultural Research Institute.

and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI), will have to target these traits with urgency to come out with varieties that can fit in the agro-ecology of northern Ghana.

Conclusion

The cultivation of pearl millet in northern Ghana continues to serve as a stop-gap and source of food security measure against hunger of many subsistence farmers, as it is often harvested during periods of food shortage in many households in the area. However, over 90% of these farmers depend on their own saved seed-source due to lack of access to improved seeds and insufficiency of high yielding varieties that can replace existing landraces. Traits such as high yielding, early maturity, and tolerance to downy mildew disease were identified by farmers as important for improvement of pearl millet production to take advantage of the huge nutritional benefits that can be accrued from the consumption of pearl millet food products. The fact that there is a decline in the production of pearl millet in the country calls for a deliberate effort by the relevant stakeholders targeting these farmers with the available technologies such as improved varieties for improved production and productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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