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Full Length Research Paper

Evaluation of wheat cultivars for slow rusting resistance to leaf rust (*Puccinia trticina* Eriks) in Ethiopia

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Leaf rust (*Puccinia triticina* Eriks) is the most common rust disease of wheat in wheat-producing areas of Ethiopia. The use of cultivars with durable resistance is the most economical way of controlling the disease. Field experiments were conducted at Ambo Plant Protection Research Center, Ethiopia during 2013 to 2014 main cropping seasons to reveal variability for field based slow rusting resistance to leaf rust among 18 improved wheat cultivars grown in Ethiopia. Parameters used as criteria to identify slow rusting included final rust severity (FRS), coefficient of infection (CI), relative area under disease progress curve (rAUDPC) and infection rate (Inf-rate). Among these parameters, FRS, CI and rAUDPC were found to be reliable to assess slow rusting in the cultivars. The results revealed that wheat cultivars Pavon 76, Africa Mayo, Bonny, Galili, Qulqulu, Hawi and Senqegna had low disease severities (< 30%) with moderately susceptible reactions, lower rAUDPC values (>30%) and CI (< 20) and were identified to have good level of slow rusting resistance. Cultivars Kubsa, Galama and PBW 343 had moderate values for slow rusting parameters and were identified as possessing moderate level of slow rusting. The slow rusting cultivars identified from the current study can be used for further manipulation in wheat improvement programs.

Key words: Leaf rust, *Puccinia triticina*, resistance, slow rusting, wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the major food crops in the world. It is used by more than one-third of its population as a staple food (Kumar et al., 2011). Ethiopia is the largest wheat producer in sub-Saharan Africa (FAOSTAT, 2014). The current total area devoted to wheat production in Ethiopia is estimated to be over 1.6 million hectare (CSA, 2015). Despite the large area under wheat, average yield in Ethiopia is estimated around 2.54 t ha^{-1} which is far less than potential yields of 8 to 10 t ha^{-1} (CSA, 2015). The low productivity is partially attributed to the prevalence of wheat rust diseases and lack of durable resistant variety. Leaf rust caused by the pathogen *Puccinia triticina* Eriks has been an important disease of wheat in most wheat growing areas of Ethiopia

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Table 1. Description of the wheat cultivars used for evaluation of slow rusting resistance.

S/N	Cultivar	Year of release	Source center
1	Africa Mayo	1960	Kenya
2	Bonny	1967	Kenya
3	Pavon-76	1982	KARC /EIAR
4	Kubsa	1995	KARC/EIAR
5	Galama	1995	KARC/EIAR
6	PBW 343	1995	CVRC/India
7	Medawalabu	1999	SARC\OARI
8	Hawi	1999	KARC/EIAR
9	Senkegna	2005	ADARC/ARARI
10	Mellenium	2007	KARC\EIAR
11	Qulqulu	2009	HU
12	Galil	2010	Hazera Genetics Ltd
13	Kekeba	2010	KARC\EIAR
14	Danda'a	2010	KARC/EIAR
15	Shorima	2011	KARC/EIAR
16	Hoggana	2011	KARC/EIAR
17	Jefferson	2012	Fedis/OARI
18	Huluka	2012	KARC/EIAR
19	Morocco(Sucpt.ck)		

(Badebo et al., 2008). It is the most prevalent type of rust, which causes yield losses up to 70% on susceptible cultivars (Draz et al., 2015). The best alternative to reduce loss from such a disease would be to use resistant cultivars.

To date, more than 70 leaf rust resistance genes are identified in wheat however most of the genes are race-specific that confer resistance in a gene-for-gene manner (McIntosh et al., 2012; Park et al., 2014). Wheat varieties relying on race-specific resistance often lose effectiveness within a few years by imposing selection for virulent leaf rust races (Bolton et al., 2008; Draz et al., 2015). Due to non-durability of resistance in cultivars that contain only specific major genes for resistance, recent breeding programs have focused on developing cultivars with adult plant resistance or slow rusting.

Slow rusting resistance is a type of resistance that is both race non-specific and durable (Sawhney, 1995; Priyamvada et al., 2011). It is polygenic and effective against a broad range of leaf rust races (Parlevliet, 1985; McIntosh et al., 1995; Herrera-Foessel et al., 2007). Slow rusting resistance is characterized by a slow epidemic build up despite a high infection type indicating a compatible host-pathogen relationship (Parlevliet and van Ommeren, 1975; Priyamvada et al., 2011). In wheat only a small group of leaf rust resistance genes are known as slow rusting genes such as *Lr67* (Dyck and Samborski, 1977), *Lr34* (Singh and Gupta, 1992), *Lr46* (Singh et al., 1998) and *Lr68* (Herrera-Foessel et al., 2012).

Although several studies have been carried out to assess leaf rust resistance in different wheat genotypes in Ethiopia, many of them were based on race specific resistance. The present study was thus designed to assess the levels of slow rusting resistance in some commercial bread wheat cultivars to leaf rust under field conditions.

MATERIALS AND METHODS

To evaluate 18 released bread wheat cultivars (Table 1) for their slow rusting resistance to leaf rust field experiments were conducted during 2013 and 2014 main cropping seasons (June to October) at Ambo Plant Protection Research Center (Ambo PPRC). Ambo PPRC is found at an altitude of 2147 m above sea level. The annual average temperature and rain fall is 27.5°C and 1077.68 mm, respectively. Wheat cultivar Morocco which is considered to lack resistance genes to the leaf rust pathogen was used as a comparative control in the experiments.

The experiments were laid out in randomized complete block design (RCBD) with three replications. Each plot consisted of 6 rows with a size of 1 m × 1.5 m and a spacing of 1 m between blocks and 0.5 m between plots. The inter row spacing was 0.3 m. To ensure uniform spread of inoculum and for sufficient disease development during the trial periods susceptible wheat cultivar Morocco was planted a week earlier around the experimental areas. Artificial inoculation was carried out by spraying spreader rows with mixture of isolates prevalent in the area using an ultralow volume sprayer after sunset. This took place twice when most plants were at the stem elongation. The recommended fertilizer rates (41/46 kg N/P_2O_5 ha^{-1}) and seed rates 150 kg ha^{-1} was used.

Disease assessment

Slow rusting of the wheat genotypes was assessed through final rust severity (FRS), coefficient of infection (CI), area under disease

Table 2. Final rust severities and coefficient of infections of leaf rust on the cultivars tested.

Varieties	2013 cropping season		2014 cropping season	
	FRS	**CI**	**FRS**	**CI**
Pavon 76	5MS	4	10 MS	8
Kekeba	2R	0.8	3.5 MR	1.4
Dendea	5R-MR	1.5	5 MR	2
Shorima	2R-MR	0.6	5 R-MR	1.5
Huluka	0R	0	0 R	0
Hoggana	0R	0	0 R	0
Kubsa	30MS	24	40 MS	32
Galama	28MS	22.4	35 MS	28
Madawalabu	10MR	4	10 MR	4
Africa Mayo	10MS	8	22.5 MS	18
Millenium	5R-MR	1.5	10 MR	4
PBW 343	35MS	28	40 MS	32
Bonny	10MS	8	22.5 MS	18
Galil	5MS	4	10 MS	8
Qulqulu	5MS	4	5 MS	4
Jefferson	5R-MR	1.5	10 MR	4
Hawi	10MS	8	22.5 MS	18
Senkegna	5MS	4	10 MS	8
Morocco	60S	60	70S	70

FRS = Final rust severity; CI = Coefficient of infection; R = Resistant; R-MR = Resistant to moderately resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

progress curve (AUDPC) and infection rate (inf-rate).

Disease severity was assessed by estimating the approximate percentage of leaf area affected using modified Cobb scale (Peterson et al., 1948) on all tillers of 10 randomly selected and pre-tagged plants of the central four rows of each plot and the mean of the ten plants was considered as the value for a plot. Disease severity was taken three times at twenty days interval starting when leaf rust levels on Morocco reached 50% severity. The host plant response to infection was scored according to Roelfs et al. (1992).

Average coefficient of infection (CI) was calculated by multiplying the percentage severity and the constant value assigned to each reaction type (Saari and Wilcoxson, 1974). The constant values were considered as R=0.2, R-MR = 0.3, MR = 0.4, MS = 0.8 and S = 1.

Area under disease progress curve (AUDPC) was calculated by using the formula suggested by Wilcoxson et al. (1975).

$$\text{AUDPC} = \sum_{i=1}^{n} [0.5\,(x_i + x_{i+1})]\,[t_{i+1} - t_i].$$

Where, x_i = the average coefficient of infection of i^{th} record, X_{i+1} = the average coefficient of infection of i+1th record and $t_{i+1} - t_i$ = Number of days between the i^{th} record and i+1th record, and n = number of observations.

Apparent infection rate (Inf-rate) as a function of time was also calculated from the three disease severity observations as a severity of leaf rust infection at the time of rust pustules appearance and every twenty days thereafter. It was estimated using the following formula adopted by Van der Plank (1963).

$$\text{Inf-rate} = 1/t\ (\ln x/1-x)$$

Where x = the percent of severity divided by 100; t = time measured in days. The apparent infection rate is the regression coefficient of ln x/1-x on t.

Data analysis

Relative forms of the epidemiological parameters were generated by comparing the respective values of each entry with the susceptible variety Morocco. Coefficient of correlation was done using SPSS software (SPSS, 2005) to determine the relationship between disease parameters.

RESULTS AND DISCUSSION

Final rust severity

There was wide variation in the leaf rust severities ranging from 0 to 60% during the 2013 cropping season at the Ambo PPRC. Diverse field reactions ranging from resistance (R) to susceptible (S) responses were observed at the trial. The final rust severities of the cultivars and their infection types are presented in Table 2.

Final rust severity represents the cumulative result of all resistance factors during the progress of epidemics (Parlevliet and van Omeren, 1975). Based on final rust severity, the tested wheat cultivars were grouped into two groups of slow rusting resistance, that is, high and moderate levels of partial resistance having 1-30 and 31-

50% FRS, respectively. During the 2013 cropping season seventeen wheat cultivars displayed disease severities of up to 30%. Of these eight had resistant to moderately resistant (R-MR) field reactions while nine showed moderately susceptible (MS) responses. On the other hand, cultivar PBW 343 was included in the second group with 35% final rust severity and MS field response. Despite the heavy leaf rust disease pressure during 2014 cropping season, 7 wheat cultivars, including Pavon 76, Africa Mayo, Bonny, Galili, Qulqulu, Hawi and Senkegna remained in the first group, exhibiting final rust severities ranging from 1 to 30%, with compatible (MS) responses and are of great importance to achieving effective breeding for durable resistance to leaf rust (Parlevliet, 1988; Nzuve et al., 2012). According to Nzuve et al. (2012), the available resistance genes in these materials overcame the leaf rust virulence in the field and led to statistically low disease severities despite the compatible host-pathogen reactions. Previously, Ali et al. (2007), Li et al. (2010), Tabassum (2011) and Safavi (2012) also used final rust severity to assess slow rusting behaviour of wheat lines. On the other hand Kubsa, Galama and PBW 343 showed final rust severities between 31 and 50% in 2014 cropping season and were regarded as possessing moderate levels of slow rusting resistance.

Cultivars, Huluka and Hoggana showed immune responses in both seasons. The immune response on these cultivars could be as a result of hypersensitive responses; resistance often breaks down due to the development of new races of the pathogen. A suitable breeding strategy like the use of inter-specific and remote crosses or even the direct transfer of these resistances through backcrosses could be used to improve the adopted but highly susceptible wheat varieties being grown in Ethiopia (Bartos et al., 2002). On the other hand, the susceptible check, Morocco, displayed the highest disease severities of 60 and 70% with completely susceptible (S) responses during 2013 and 2014 cropping seasons, respectively, indicating that an acceptable epidemic pressure was established over the seasons for field experiments.

Coefficient of infection

The data on disease severity and host reaction were combined to calculate CI (Table 2). According to Ali et al. (2009), lines with CI values of 0-20, 21-40, 41-60 were regarded as possessing high, moderate and low levels of slow rusting resistance, respectively. In the present study, all the test genotypes except Kubsa, Galama and PBW-343 showed CI values between 0 and 20 in both seasons and were designated as having a high level of slow rusting. It was, therefore, concluded that these cultivars had a great potential to be used as a resistance sources against leaf rust. Cultivars Kubsa, Galama and PBW-343 had CI values of 21 to 40, designated as having moderate levels of slow rusting resistance. In the seasons, only the susceptible check had a CI value of more than 40. Many earlier researchers such as Patil et al. (2005); Pathan and Park (2006) and Draz et al. (2015) also appraised slow rusting resistance to wheat leaf rust using coefficient of infection and reported the presence of different partial resistance conferring genes in wheat lines.

Area under disease progress curve

Disease progress curve is a better indicator of disease expression over time (Van der Plank, 1963). Therefore, selection of cultivars having lower AUDPC values is acceptable for practical purposes. The tested wheat cultivars were categorized into two distinct groups for slow rusting resistance, based on the AUDPC values. Wheat cultivars exhibiting AUDPC values up to 30% of the check were grouped as having high level of partial resistance, consisted of 15 and 16 wheat cultivars during 2013 and 2014 cropping seasons, respectively; while those having AUDPC values to 70% of the check were grouped as moderately resistant cultivars, included Kubsa, Galama and PBW 343 in 2013 and Kubsa and Galama during 2014 cropping season (Table 3).

Of the wheat cultivars under group one, cultivars Pavon-76, Africa Mayo, Bonny, Galil, Qulqulu, Hawi and Senqegna showed MS types of infection in the field. According to Parlevliet (1988), Brown et al. (2001), Singh et al. (2005), and Kaur and Bariana (2010) the cultivars which had MS infection type may be carrying durable resistance genes, such as slow rusting resistance. These wheat cultivars first shown rust infection and sporulation but the final host reaction was characterized as chlorotic and necrotic lesions. Subsequently, the disease progression remained slower and highly retarded among these cultivars. Such partially resistant lines could highly delay evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in normal circumstances (Schafer and Roelfs, 1985; Ali et al., 2008; Tsilo et al., 2010). Likewise, despite the MS infection type exhibited on moderately slow rusting cultivars, leaf rust developed slowly as indicated by their AUDPC values. None of the tested cultivars was marked as having susceptible field response. Other researchers have also reported variation among different wheat lines for slow rusting resistance to leaf rust using AUDPC (Patil et al., 2005; Draz et al., 2015).

Infection rate

The maximum mean disease progress rate (Inf-rate = 0.12) was observed on the cultivar Hawi in 2013 cropping season, while the maximum infection rate of 0.170 was observed on the cultivar Galama in 2014 (Table 3).

Table 3. AUDPC and Infection rates of leaf rust on the cultivars tested.

Varieties	2013 cropping season			2014 cropping season		
	AUDPC	rAUDPC	Inf-rate	AUDPC	rAUDPC	Inf-rate
Pavon 76	40	6.67	0.082	88	12.57	0.088
Kekeba	0	0.00	0.019	7	1.00	0.046
Dendea	20	3.33	0.081	10	1.43	0.032
Shorima	8	1.33	0.044	20	2.86	0.073
Huluka	0	0.00	0.000	0	0.00	0.000
Hoggana	0	0.00	0.000	0	0.00	0.000
Kubsa	320	53.33	0.064	360	51.43	0.169
Galama	300	50.00	0.053	340	48.57	0.170
Madawalabu	44	7.33	0.082	40	5.71	0.083
Africa Mayo	100	16.67	0.037	190	27.14	0.089
Millenium	20	3.33	0.081	28	4.00	0.157
PBW 343	400	66.67	0.052	210	30.00	0.084
Bonny	88	14.67	0.084	130	18.57	0.058
Galil	40	6.67	0.082	66	9.43	0.078
Qulqulu	40	6.67	0.082	36	5.14	0.091
Jefferson	16	2.67	0.081	48	6.86	0.058
Hawi	84	14.00	0.120	178	25.43	0.091
Senkegna	40	6.67	0.082	58	8.29	0.066
Morocco	600	100.00	0.119	700	100.00	0.130

AUDPC = Area under disease progress curve; rAUDPC = Relative area under disease progress curve; Inf-rate = Infection rate.

Table 4. Correlation coefficients (r) for disease parameters of leaf rust on wheat cultivars at Ambo, 2013 cropping season.

Parameter	2013 cropping season			2014 cropping season		
	FRS	CI	AUDPC	FRS	CI	AUDPC
FRS	1			1		
CI	0.990**	1		0.989**	1	
AUDPC	0.993**	0.983**	1	0.972**	0.982**	1
Inf-rate	0.311	0.305	0.237	0.579**	0.520*	0.570**

******Significance level at P ≤ 0.01; *****significance level at P ≤ 0.05.

Cultivars Huluka and Hoggana showed a constant disease severity, thus showing no increase per unit time with an Inf-rate value of 0 in both seasons. The disease progress rate of certain lines was more than the susceptible cultivar, Morocco in the seasons due to the fact that disease scoring was initiated when disease severity was already 50% on the susceptible check. Hence, the actual infection rate for Morocco may even be more. Besides, infection rate in the present study did not distinguish cultivars with different level of slow rusting with regard to other parameters. Similarly, the more variation in infection rate among the tested cultivars than the other slow rusting parameters is partly because infection rate is a regression coefficient with larger error variance. Therefore infection rate in the present study seemed to produce unreliable estimates of slow rusting resistance when compared with FRS, CI and AUDPC. Similar results were found for rusts of wheat (Rees et al., 1979; Broers, 1989; Ali et al., 2008; Safavi et al., 2013).

Correlation between slow rusting parameters of wheat leaf rust

A positive and highly significant correlation of FRS with CI (r = 0.990) and AUDPC (r = 0.993) was found during 2013 cropping season (Table 4). Strong correlation coefficients of 0.989 and 0.972 were also observed between FRS with CI and AUDPC during the 2014 cropping season, respectively. The high correlation coefficient was also observed between AUDPC and CI in both seasons; r = 0.983 during the 2013 main season and r = 0.982 during the 2014 cropping season. These strong correlations agreed with the results of Qamar et al. (2007); Ali et al. (2008); Safavi et al. (2010) and Shah et al. (2010). Although positive correlations were observed between infection rate and other disease parameters, the relationship between the variables was weak in the season. Similarly, relatively low correlations were observed between infection rate and the other disease parameters in 2014 cropping season. This indicates that although severity or the area under the disease progress curve was increasing, the rate of infection reduced as epidemic progressed because less healthy plant tissue was available for additional infections (Freedman and Mackenzie, 1992).

Since, FRS, CI and AUDPC had strong positive correlations in the present study; selection of lines having final disease score less than 30%, CI between 0 to 20 and rAUDPC less than 30% with MS responses is normally accepted for practical purposes. Feasibility of measuring slow rusting resistance under field condition preferably by low final ratings and CI have been reported previously by Safavi et al. (2013) and Hei et al. (2014). Singh et al. (2007) also reported that field selection of the slow rusting trait preferably by low rAUDPC and terminal ratings along with CI, is feasible where greenhouse facilities are inadequate. Accordingly, wheat cultivars Pavon 76, Africa Mayo, Bonny, Galili, Qulqulu, Hawi and Senqegna with highly slow rusting resistance characteristics: FRS 0-30% with MS field responses, CI 0-20 and rAUDPC less than 30% were identified for resistance breeding. Of these cultivars Pavon 76 and Hawi were postulated to have combinations of major gene resistance genes *Lr1*, *Lr10* and *Lr 13,* and *Lr2c*, *Lr23*, *Lr27+31*, respectively (Mebrate et al., 2008). The presence of both major and minor genes in these cultivars is of paramount importance since the combined effects of several genes give the cultivar a wider base of disease resistance (Roelfs et al., 1992). Cultivars Kubsa, Galama and PBW 343 had FRS 31 to 50% with MS field responses, CI value ranging from 21 to 40 and rAUDPC between 31 and 70% and were regarded as moderately slow rusting (Table 2). Cultivar Kubsa was postulated to have major gene resistance gene *Lr44* while Galama was postulated to have a combination of major gene resistance genes *Lr23* and *Lr37* (Mebrate et al., 2008). The highly slow rusting and moderately slow rusting wheat cultivars identified in the present study were supposed to be having genes for varying degrees of slow rusting and may be used for further genetic manipulation in wheat improvement programs. Singh et al. (2004) have also reported that genotypes in both group 1 and 2 could have durable resistance controlled by more than one gene which can serve as good parents for breeding.

Conclusion

The wheat cultivars showed variation in resistance reaction, ranging from immunity to slow rusting resistance. Most of the evaluated cultivars exhibited better performance under high disease pressure shown by susceptible check. Cultivars Pavon 76, Africa Mayo, Bonny, Galili, Qulqulu, Hawi and Senqegna exhibited lower levels of FRS (< 30% with MS responses), coefficient of infection (< 20) and rAUDPC less than 30% indicating a high level of slow rusting resistance. Three wheat cultivars Kubsa, Galama and PBW 343 had moderate level of slow rusting resistance in the seasons. The correlations among the field based slow rusting parameters were highly significant. The slow rusting cultivars identified from this study with better levels of slow rusting resistance may be exploited for durable resistance in Ethiopian wheat breeding program. However, further testing for stability over years and locations for leaf rust along with other desirable characters must be made before approval.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Bridging the gap in quality and quantity of seed potatoes through farmer managed screen houses in Uganda

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Quality seed potato is a key factor in enhancing potato yields in Uganda. Available disease-free seed potato accounts for less than 5% of the whole potato seed market demand in Uganda leaving 95% as seed availability gap. This study was conducted to explore the potential of using farmer managed screen houses to alleviate the seed potato availability gap that exists in Uganda. Six screen houses of 7 m × 14 m each with capacity of 1620 plants were set up, three (3) screen houses in Bukimbiri, one (1) in Kisoro, one (1) in Hamurwa and one (1) in Maziba sites. All the sites were managed by trained six famers. Sterilized soil was used to reduce the incidence of pathogens and to ensure that clean mini-tubers were produced. Seed production was done in 2015 for two consecutive seasons (A and B). From the 6 screen houses, a total of 107,638 clean mini-tubers were generated across the sites for both seasons. At multiplication ratio of 1: 9 the generated mini-tubers have the potential of generating 968,742 tubers. This would reduce on existing seed gap for the next season. It was noted during the study that mini-tuber production, vigour and rate of growth varied significantly (P<0.001) across the varieties with 'Rwangume' achieving the highest yield in terms of tuber number per plant and height, compared to other 4 varieties (Kiningi, Rwashaki, Kachpot 1 and Victoria). This study showed that production of disease free mini-tuber at farmer level is possible using screen house technology and has a potential of reducing the seed availability gap through production of quality seed that can be accessed by other farmers.

Key words: Seed potato, seed gap, farmer screen houses.

INTRODUCTION

The potato (*Solanum tuberosum* L.) is the third most important food crop in the world after rice and wheat in terms of human consumption (CIP, 2014, Gastelo et al., 2014). More than a billion people worldwide eat potato,

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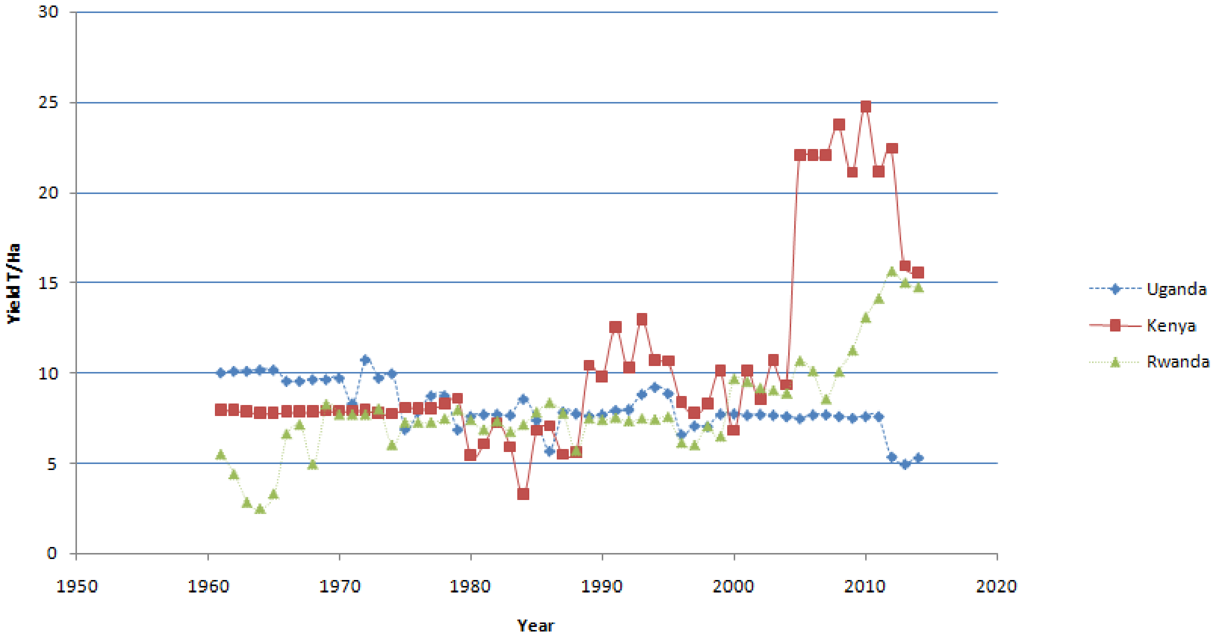

Figure 1. Potato tuber yield (T/ha) in Uganda vis-à-vis other East African countries. Source: FAOSTAT (2014).

and global total crop production exceeds 300 million metric tons (FAOSTAT, 2014). The world average potato production is about 17 t ha^{-1}, while direct consumption as human food is 31.3 kg per capita (kg/year) (FAOSTAT, 2014). Worldwide, Asia and Europe are the world's major potato producing regions, accounting for more than 80% of world production while Africa is the least, accounting for about 5%. North America is the clear leader in productivity at more than 40 t ha^{-1}, followed by Europe at 17.4 t ha^{-1} while Africa lags at about 10 t ha^{-1} (FAOSTAT, 2014). In Africa, the top ten potato producers in descending order are Egypt, Malawi, South Africa, Algeria, Morocco, Rwanda, Nigeria, Kenya, Uganda, and Angola (Muthoni et al., 2011). Potato yields in Uganda have stagnated between 5 and 7.5 t/ha at farmers level while on-station, yields go as high as 20T/HA (Figure 1) (FAOSTAT, 2014).

Lack of quality basic seed potato by farmers is widely recognized as a key constraint to potato production in Uganda and other East African countries (Aheisibwe et al., 2015). In potato production, the quality of seed potatoes planted is an important determinant of the final yield and quality (Lanteri and Quagliotti, 1997). If farmer saved seed potatoes are used for several cropping cycles, without renewing the seed lot from a reliable source, seed-borne diseases cause severe yield and quality losses (Gildemacher et al., 2009). The potential demand for seed potatoes is estimated at 239,328 tones (Aheisibwe et al., 2015). However, availability of disease-free seed potato is less than 5% of the whole potato seed market demand in Uganda which is normally produced by Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) (KAZARDI, 2014). (Figures 2 and 3).

Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) has been spearheading the country’s seed potato production using *in vitro* derived mini-tubers for multiplication to basic level in Uganda. Despite these significant advancement good quality seed remains a scarce commodity (Aheisibwe et al., 2015) and other approaches of farmer managed quality production systems are hence needed to bridge the seed gap (Kinyua et al., 2008). International Potato Centre recommends the use of tissue culture and mini-tubers production through aeroponics technology and use of screen houses as approaches that can quickly multiply quality seed potatoes (Farran and Mingo-Castel, 2006; Gildemacher et al., 2009).

Efforts to bridge the seed availability gap were initiated in a collaborative arrangement between International Fertilizer Development Centre (IFDC) and National Agricultural Research organization (NARO) to empower the smallholder potato farmers to be self-sufficient in good quality mini-tuber seed production using *in vitro* plantlets that are grown in screen houses for generation of mini-tubers. . This strategy was sought that it would have significant impact in reducing the seed availability gap and complementing the efforts put forward by the national potato program. In addition, the health of the seed produced through this process is assured since the seed is generated under sterile soils and is further supported by testing for latent bacterial wilt infection (Chindi et al., 2014). The production of mini-tubers at farm level would reduce the number of field multiplication

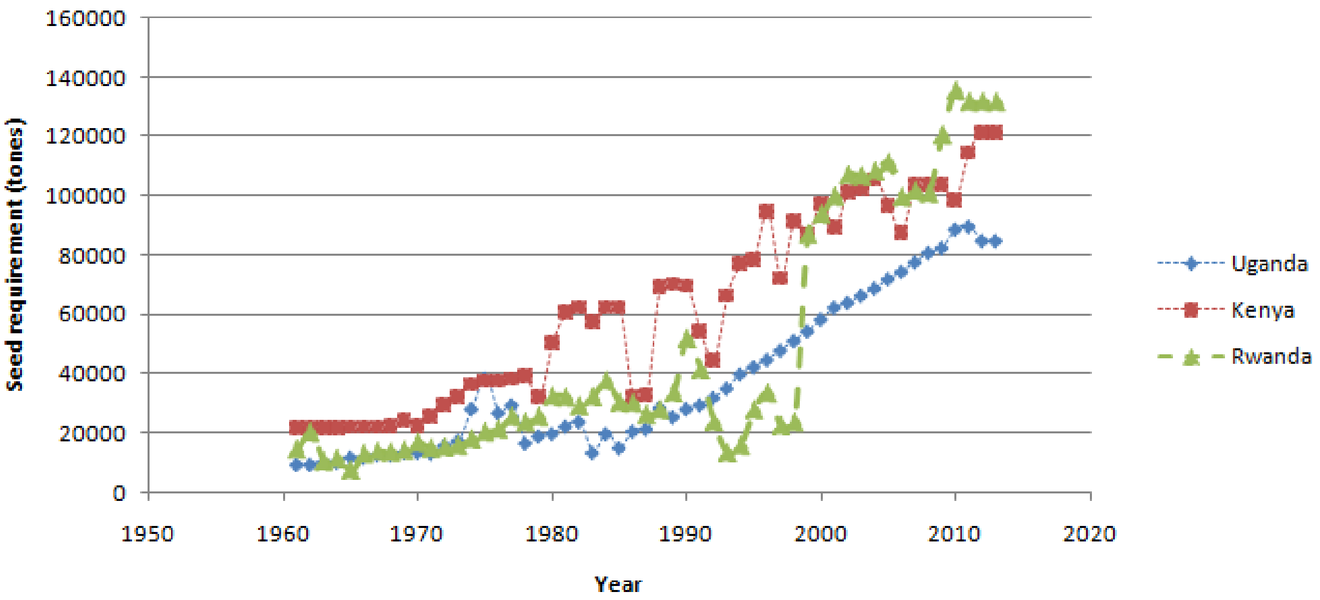

Figure 2. Seed supply requirements from 1960 2013: Source: FAOSTAT, 2014.

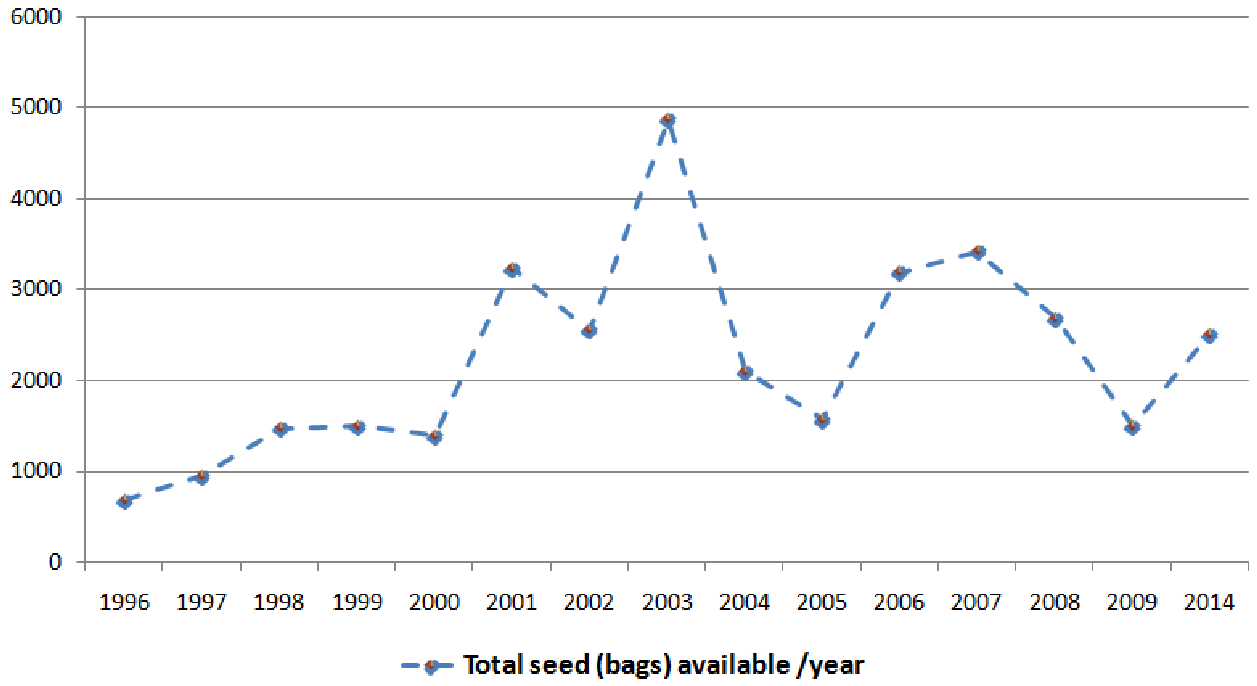

Figure 3. Total quality seed (100kg bags) supplied per year from national potato program and seed multipliers. Source: KAZARDI (2014).

cycles needed to generate enough seed for distribution and would lower the degree of transmission of seed-borne diseases (Mbiyu et al., 2012). Therefore, the objective of this study was to explore the potential of generating quality seed potatoes using farm managed screen houses.

MATERIALS AND METHODS

Generation of tissue culture potato plantlets

Potato *in vitro* plantlets for planting in screen houses were generated in tissue culture laboratory at KAZARDI and availed for planting to the farmers. Tissue culture plantlets were micro

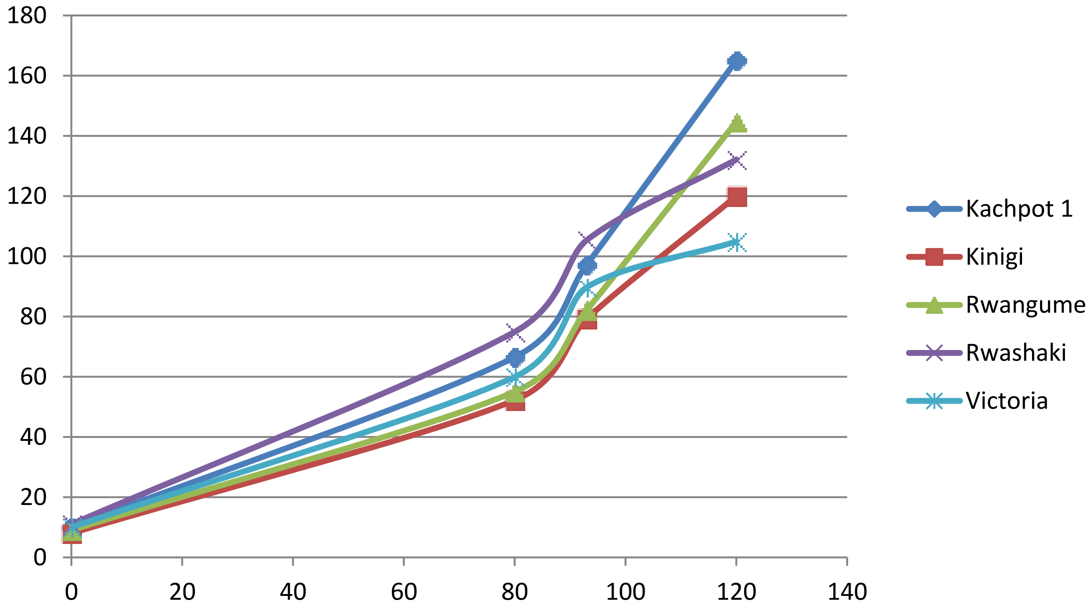

Figure 4. Growth in height (cm) performance of different potato varieties at Kisoro town farmer screen house.

propagated using a modified protocol on MS media according to Fite et al. (2013).

Construction of screen houses and sitting of the screen houses

Six screen houses of dimension 7 meters wide × 14 m long each with capacity of 1620 potato plantlets were built in partnership with the IFDC and farmers for production of quality seed potato. Four (4) screen houses were established in Kisoro district (3 in Bukimbiri sub county and 1 in Kisoro town) while 2 were constructed in Kabale district (1 in Hamurwa and 1 in Maziba sub county). Water tanks of capacity 2000 L were installed at each site to enable constant supply of water for irrigation to the plants.

Crop management and data collection

The six farmers that hosted the screen houses were trained in mini-tuber production focusing on handling of tissue culture potato plantlets, soil sterilization, screen house maintenance, establishment and management of potato crop in screen house, and post-harvest handling (storage and management) of mini-tubers by scientists from Kachwekano ZARDI. Following the training, the *invitro* plantlets of different varieties ('Kiningi', 'Rwangume', 'Rwashaki', 'Victoria' and Kachpot 1) were given to farmers and left to be managed by the farmers in the screen houses. Plantlets (64 *Invitro* plantlets) were put in each planting box containing mixed sterile soils (loam and sand soil in ration of 3: 1) and supplemented with inorganic fertilizer NPK (17:17:17) Each box served as a replicate for the variety and four boxes were used per variety in each screen house allocation of varieties to planting boxes was done randomly The plants were managed following standard agronomic practices. Data were collected on growth vigour, using a scale of 1-9 (Rykaczewska, 2013), the height of the plants and mini-tuber yield per variety and tuber number per plant was collected for 2 seasons of 2015 (A AND B).

Data analysis

Statistical methods

Analysis of variance was performed on growth vigour, height of the plant and mini-tuber number using Genstart computer package 11 edition. Mean comparisons were conducted using Fisher's Least Significant Difference (LSD~=0.05). The sources of variability used in the statistical model were treatment (variety), the blocks (replicates) and the experimental error.

RESULTS AND DISCUSSION

Performance of different potato varieties under farmer managed screen houses

The growth rate of the five different varieties was noted to be low in the first 50 days after transplanting in the screen house for all the test sites and later peaked with peak growth rate observed at 80 days after transplanting (Figures 4 to 7). Slow growth rate at the start was due to the fact that the plantlets was introduced from the tissue culture laboratory to the screen house, hence was undergoing physiological adjustment in acclimatizing to the new environment in the screen house. Varieties planted in Bukimbiri sites (1, 2 and 3) were noted to have shorter height in range of 65 to 96 cm for the period of 109 to 114 days after transplanting while in Kisoro town and Maziba sites, the test varieties were taller with maximum height noted to range from 100 to 192 cm (Figure 4 to 7) observed from 108 to 120 days after transplanting. The potato plant vigour of the test varieties also varied within the varieties and across the sites.

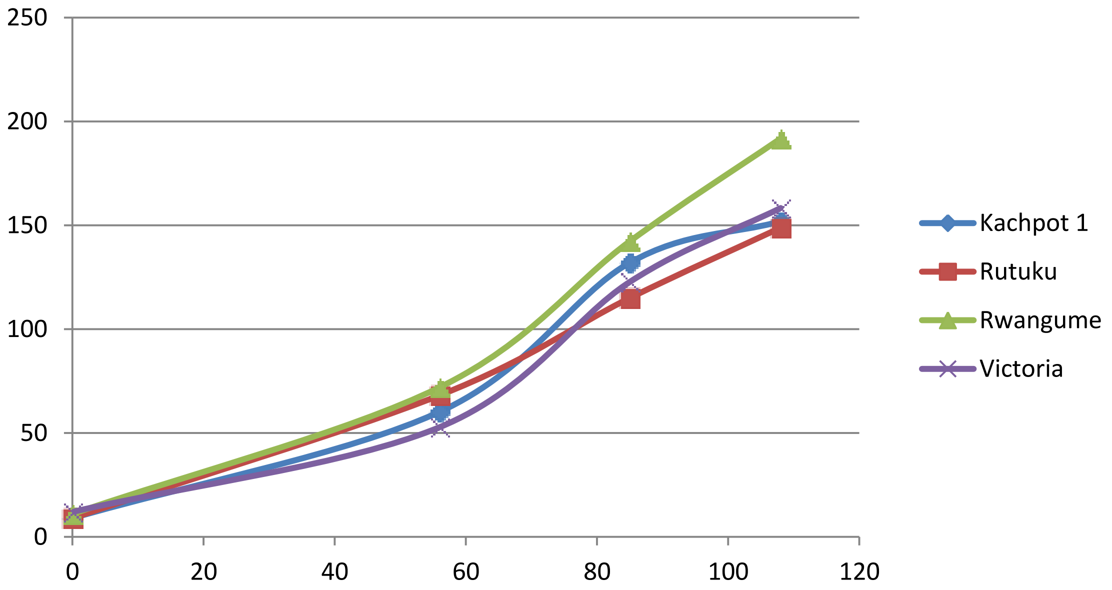

Figure 5. Growth in height (cm) performance of different potato varieties at Maziba farmer screen house.

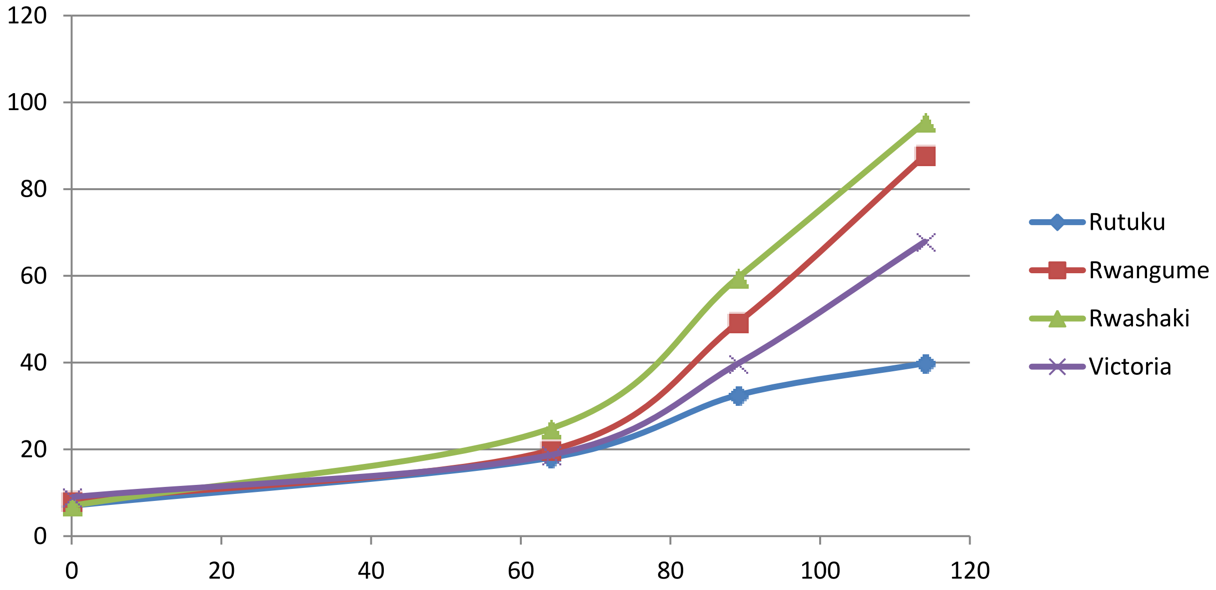

Figure 6. Growth in height (cm) performance of different potato varieties at Bukimbiri site 1 farmer screen house.

Plants at Kisoro town site were the most vigorous, followed by Bukibiri-2, Maziba, Bukimbiri-3. The plant vigour of the varieties varied across the sites. Kiningi was most vigorous at Kisoro town screen house compared to other varieties. Kachpot 1 was least vigorous compared to all the varieties tested. The vigour of potato is dependent on the physiological potential during establishment, emergence and development of plants. The plant vigour in this study was seen as an important aspect since it determines the materials future productivity that is conditioned genetically, physiologically and ecologically (Oliveira, 2015). The growth performance of the potato plants was seen to influence the production capacity and overall potato mini-tube yields. The plant vigour and stem length (height) varied significantly different ($P<0.05$) (Tables 1 and 2). This was largely dependent on genotype, phenological age and environmental conditions especially temperature during the growth stages of potato. This is similar to the work done by Oliveira (2015) and also supported by Lanteri

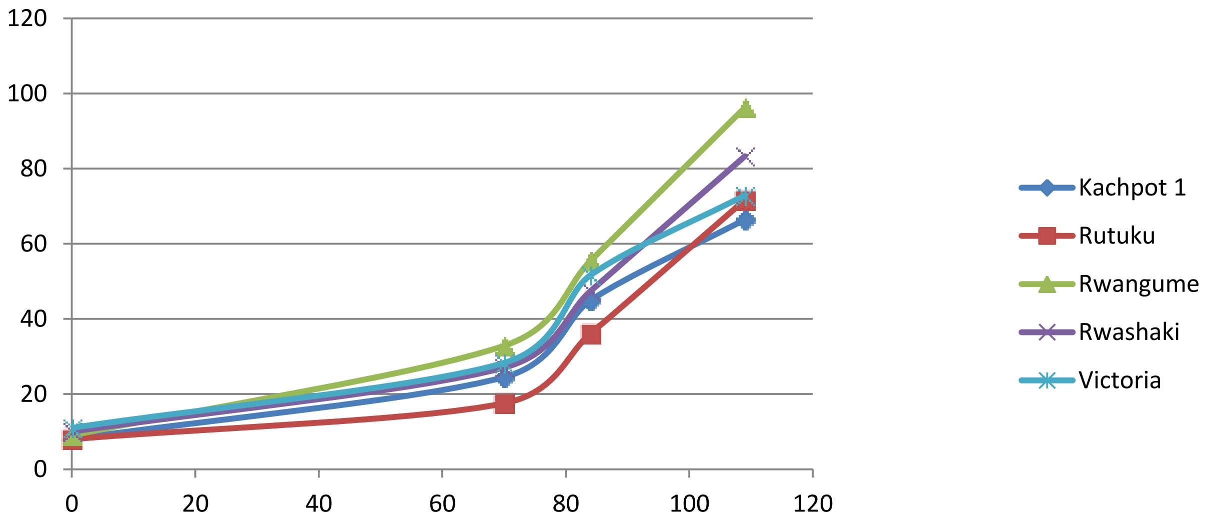

Figure 7. Growth in height (cm) performance of different potato varieties at Bukimbiri site 2 farmer screen house.

Table 1. Potato growth vigor performance of different varieties ranked based on Kruskal Wallis model.

Variety	Size	Mean rank
Kachpot 1	200	728.8
Kinigi	60	1017.2
Rutuku	388	767.76
Rwangume	358	885.19
Rwashaki	179	904.87
Victoria	449	784.5

Degrees of freedom = 5; Chi-square probability < 0.001.

Table 2. Potato growth vigor performance as influenced by farmer screen house site.

Location	Size	Mean rank
Hamurwa	120	689.89
Bukimbiri-1	240	516.59
Bukimbiri-2	336	967.93
Bukimbiri-3	298	731.62
Maziba	340	788.9
Kisoro town	300	1058.51

Degrees of freedom = 5; Chi-square probability < 0.001.

and Quagliotti (1997). The temperature or thermal-time accumulated by the potato during the growing period is known to influence the plant performance. These factors explain the variability observed in respect to potato plant vigour and height under different farmer managed since the different screen houses were established in different districts.

The study also showed a positive relation between growth vigour and overall tuber yield/plant (Figure 8). Variety Rwagume yielded highest with 13 tubers per plant followed by Victoria (9 tubers /plant), Rutuku (7 tubers/plant) and Kachpot 1 (5 tubers/plant). Average yield per plant across the sites ranged from 5 to 15 tuber per plant with Bukimbiri-2 being the highest (15 tubers/plant). A total of 107,638 tubers were produced during 2015 A and B season across the six sites with an average yield of 10 tubers per plant (Tables 3 and 4) The generated tubers upon one cycle of field multiplication by the farmers at a rate of 1:9 would generate significant number of seed tubers (968,742 tubers) that can reduce on the existing seed gap in Uganda. However, to achieve this it would depend on growing season since tuber yield is dependent of genotype and growing condition (Struik and Wiersema, 1999).

Seed quality assurance

The mini-tubers harvested in 2015A and B seasons were indexed for the presence of bacterial wilt pathogen (*Ralstonia solanacearum*) using NCM-ELISA method and results showed that all the collected mini-tuber samples from the screen house were negative for the bacterial wilt pathogen which is always a major concern in seed production as put forward by Kinyua et al. (2001). This indicated that seed produced using this method is completely clean and satisfies the quality standards for certification. The supply of this seed to other farmers would reduce on the gap in quality and quantity of seed potatoes in the Uganda.

Conclusion

Multiplication of potato mini-tubers using screen houses

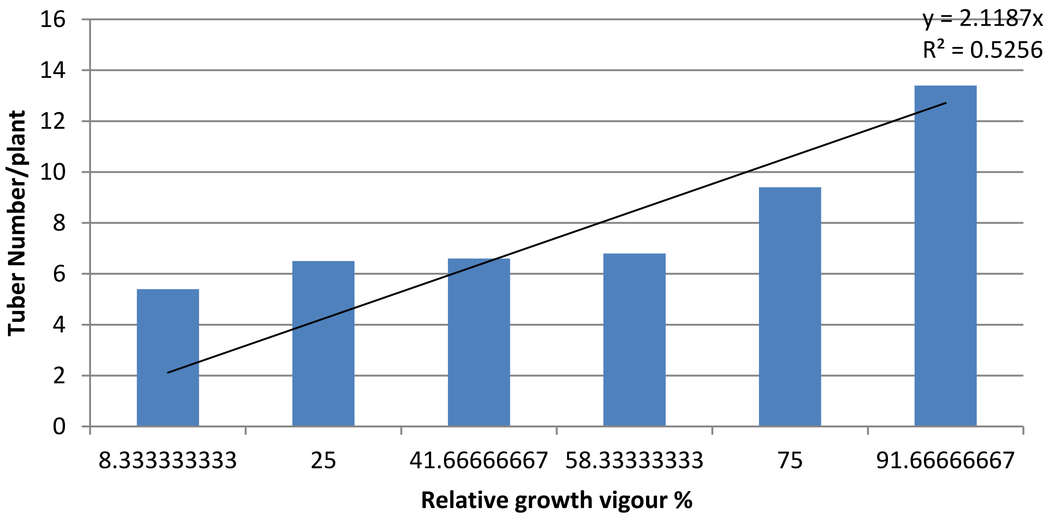

Figure 8. Probability plot of tuber number as influenced by growth vigour.

Table 3. Mini-tuber yield number per variety across different sites and seasons.

Screen house	Variety						
	Kachpot 1	**Kinigi**	**Rutuku**	**Rwangume**	**Rwashaki**	**Victoria**	**Grand total**
Season 2015A mean			**9142**	**6861**		**11580**	**27883**
Hamurwa			691	4715		2351	7757
Bukimbiri-2			4782	2146		4103	11031
Maziba			3969			5126	9095
Season 2015B mean	**3849**	**1758**	**5722**	**42995**	**7171**	**18260**	**79755**
Hamurwa	1170		451	1979		346	3946
Bukimbiri-1			938	10813	2111	5069	18931
Bukimbiri-2	831		1681	9785		7011	19308
Bukimbiri-3	732		1961	7685	3399	2319	16096
Maziba	752		691	3511		2556	7510
Kisoro Town	364	1758		9222	1661	959	13964
Grand mean	**3849**	**1758**	**11195**	**49856**	**7171**	**29840**	**107638**
F.Pr				<0.001			
LSD				**102.1**			

Table 4. Mini-tuber yield per plant for different varieties across different sites and seasons.

Screen house X season	Varieties						
	Kachpot 1	**Kinigi**	**Rutuku**	**Rwangume**	**Rwashaki**	**Victoria**	**Grand mean**
2015A mean			**6.7**	**10.9**		**7.7**	**7.9**
Hamurwa			7.2	10.4		5.6	7.8
Bukimbiri-2			7.1	12.7		8.0	8.1
Maziba			6.2			9.4	7.8
2015B mean	**5.4**	**6.5**	**6.8**	**14.0**	**6.6**	**10.9**	**10.4**
Hamurwa	4.9		4.8	5.5		3.1	4.9
Bukimbiri-1			6.1	19.3	7.0	16.0	14.2
Bukimbiri-2	8.8		9.2	18.6		15.7	15.4
Bukimbiri-3	6.3		7.9	19.7	6.9	11.4	11.3

Table 4. Contd.

Screen house X season	**Varieties**						
	Kachpot 1	**Kinigi**	**Rutuku**	**Rwangume**	**Rwashaki**	**Victoria**	**Grand mean**
Kisoro Town	3.7	6.5		12.9	5.6	7.9	9.2
Grand mean	**5.4**	**6.5**	**6.8**	**13.4**	**6.6**	**9.4**	**9.6**
F.pr	<0.001						
LSD	1.978						

has demonstrated a potential of alleviating the gap in seed quality and quantity seed potato that will contribute on reducing the seed availability gap in Uganda. This study has shown that seed production using screen house technology is possible at farm level.

Conflicts of Interests

The authors have not declared any conflict of interests.

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