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Effect of seed source, size and treatment on potato growth and yield

Kigambo, M.[1*], Wasswa, P.[1], Obala, J.[2], Nakibuule, J.[1] and Mugisha, J[3]

[1]Department of Agricultural Production, Makerere University, P. O. Box 7062, Kampala, Uganda
[2]Department of Science & Vocational Education, Lira University, P. O. Box 1035, Lira, Uganda
[3]Department of Agribusiness & Natural Resource Economics, Makerere University, P. O. Box 7062, Kampala, Uganda

[*]Corresponding author: monicakigambo@gmail.com

Abstract

In Uganda, the capacity of certified potato seed production is too low to satisfy the demand; a gap that has been filled with low quality seed from informal sources. This study was set up to determine the effect of seed source, size, and treatment on potato growth, yield and incidence of late blight disease. Using a randomized complete block design in a split-split-plot arrangement, field trials were conducted at three locations in South-western Uganda for two consecutive seasons. Seed source was at 3 levels: farmer-saved, local market, and certified seed; seed size at 2 levels: large 35 to 55 mm and small < 35 mm; and fungicide seed treatment at 2 levels: untreated and treated. Results showed that certified seed significantly had the highest values for plant height (60.89 cm), plant emergence (88.60 %), and yield of medium-size (2.79 t/ha) and large-size tubers (3.59 t/ha) and total tuber yield (8.60 t/ha). Large-size seed exhibited significantly higher performance than the small-size seed for plant height (59.03 cm), main stems per plant (2.83), and total tuber yield (7.89 t/ha). Fungicide-treated seed showed significantly better performance than the untreated seed for total tuber yield (7.77 t/ha). However, the fungicide seed treatment had no significant effect on potato growth parameters, and late blight incidence. Integrating large-size certified seed with fungicide treatment considerably improved potato yields. In case of unavailability of certified seed, carefully selected large-size farmer-saved seed with fungicide dressing may be the next option.

Key words: Certified seed, farmer-saved seed, fungicide, seed quality, seed size, Uganda

Introduction

Potato (*Solanum tuberosum* L.), a temperate crop, cultivated mostly at high altitudes, is one of the world's most important crops (Lutaladio *et al.*, 2009). In Uganda, potato is grown by small-scale farmers for whom it makes a remarkable contribution as a pathway to food security as well as providing a quick source of income due to its high yielding capacity and short growing cycle (Mugisha *et al.*, 2017). Despite its potential, potato yields achieved in Uganda are lower than expected. For example, average yields obtained in 2017 were 4.19 t/ha (FAOSTAT, 2019), yet yield of about 25 t/ha are reportedly achievable (Namugga *et al.*, 2017). One of the key challenges is availability and access to quality seed. The certified seed potato produced in Uganda is inadequate (KaZARDI, 2014), and not readily available and accessible to small-holder farmers. This compels farmers to meet their seed requirements through unregulated informal sources such as farmer-saved (self-supply), local markets, and fellow farmers (Namugga *et al.*, 2017). The quality of informal seed is usually poor as a result of tuber-borne pathogens which accumulate over successive seasons of recycling, eventually resulting in lower yields (Gildemacher *et al.*, 2011). Although, usage of low quality seed from informal sources is reported as the primary potato yield reducing factor in Uganda (Kaguongo *et al.*, 2008; Aheisibwe *et al.*, 2015), there is meager information on the effect of seed from the informal sector on potato growth and yields.

Additionally, non-recommended small-size potato tubers (< 35 mm) have remained the most popular seed used by farmers in Uganda (Gildemacher *et al.*, 2009), with a traditional perception that "seed potato must be small". However, these tiny tubers are reported to produce few sprouts/stems and lack sufficient food reserves and moisture to support optimal growth (Burke, 2011). This is indicated to result in reduced yields compared to use of large-size seed tubers (Almeida *et al.*, 2016; Sadik *et al.*, 2018). However, in Uganda there is inadequate knowledge on the effect of seed size on potato productivity.

Furthermore, diseases lower the quality of potato seed. Among the potato diseases in Uganda, late blight, caused by the fungus *Phytophthora infestans*, which occurs in all main potato growing areas in the country is causing significant yield losses (Sedláková *et al.*, 2011). There is considerable literature indicating that fungicide seed treatment provides protection to the seed, sprouts and seedling against late blight attack thereby resulting in more plant stands, improved plant performance and yields (Rahman *et al.*, 2003; Haveri *et al.*, 2018). Currently, fungicide seed treatment is not a common practice in Uganda and information regarding its effect on potato productivity is lacking. This study assessed the effect of seed source, size, and treatment on potato growth, yield and incidence of late blight disease.

Materials and methods

Study areas

Field trials were conducted in the districts of Kabale (E 29.97621°, S 01.22977°), Rukiga (E 030.01781°, S 01.14570°) and Mbarara (E 030.71562°, S 00.55344°), in South-western Uganda. Kabale district, at an elevation of 1,865 metres above sea level (m.a.s.l), receives a mean annual rainfall of 1,656 mm, and average temperature ranges between 13°C to 23°C. Rukiga district, at an elevation of 1,764 m.a.s.l, receives a mean annual rainfall of 1,502 mm, and average temperature ranges between 14°C to 25°C. The elevation, mean annual rainfall, and average temperature ranges of Mbarara district are 1,430 m.a.s.l, 1,200 mm and 16°C to 28°C, respectively (Uganda National Meteorological Authority, https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/). The districts were chosen based on altitudinal gradient representation, potato production levels and the gravity of the seed quality problem in the region. The soil physical and chemical properties at each study site are shown in Table 1.

Seed collection, preparation, and other materials used

Seed potato of Rwangume, a widely adopted potato variety in Uganda (Namugga *et al.*, 2017) was collected from three common seed sources; farmer-saved, local market and from the National Research Institute, Kachwekano Zonal Agricultural Research and Development Institute (KaZARDI) mandated for potato research in Uganda. To obtain farmer-saved seed, a four-level, purposive, random-sampling procedure was followed. In this procedure, two major potato growing counties were chosen from Kabale district, the main potato growing district. In each county, two sub-counties were randomly chosen. One parish was randomly selected from each sub-county and two villages were also randomly picked from each parish. Ten potato farmers were randomly selected from each village to provide seed potato, giving a total of 80 farmers. Only farmers who had at least 5 kg of seed potato of Rwangume variety participated. For local market seed, seed potato was obtained from the major market(s) used by the farmers in the selected villages where farmer-saved seed was also collected. The seed from KaZARDI was certified quality seed and served as a positive control. The collected seed from each source was bulked together, sorted to remove the undesired and graded into small size (< 35 mm) and large size (35 to 55 mm) tubers (Burke, 2011). Half of the tubers obtained from each source and each size grade were then fungicide treated by dipping them in Victory 72 WP

Table 1. Soil physical and chemical soil properties at each study site

Site	BD (g/cm3)	pH	% OM	%N	AvP (ppm)	Exchangeable bases, Cmol kg^{-1}				% texture			
						K	Na	Mg	Ca	Sand	Clay	Silt	Texture
Mbarara	1.61	6.61	2.04	0.1	10.99	0.28	0.08	3.29	9.39	59	33	18	SC
Rukiga	1.47	5.95	2.59	0.18	2.61	0.23	0.05	1.81	5.75	47	25	28	SL
Kabale	1.44	6.64	2.81	0.15	6.69	0.29	0.09	2.05	10.27	43	41	16	SC
Critical values	1.55-1.65 (SC) 1.55-1.75 (SL)	5.5-7.0	1.5-3.0	0.12-0.25	15- 30	0.12-0.4	0.87	0.3-0.6	5.0-8.0				

BD = Bulk density; OM = Organic matter; %Nitrogen, AvP = Available phosphorus, K = Potassium; Na = Sodium; Mg = Magnesium; Ca = Calcium, SC = Sandy clay; SL = Sandy loam. Critical values for BD were based on Morris and Lowery (1988) while the rest of the critical values data were based on Tekalign *et al.* (1991)

(metalaxyl 80 g per kg and mancozeb 640 g per kg) suspension at a concentration of 50 g per 20 L for 1 to 2 minutes (method modified from Haveri *et al.*, 2018). To maintain the concentration used and to reduce the buildup of pathogens within the suspension hence reduce disease transmission among tubers, the fungicide suspension was divided into three portions. The fungicide portions were used subsequently after four potato dips in each.

Experimental design and field management

The experiment was run for two consecutive seasons: 2018B (second rains: September 2018 to January of 2019) and 2019A (first rains: February to June of 2019). The experimental factors were seed source: at 3 levels (farmer-saved, local market and certified seed); seed size: at 2 levels (large 35 to 55 mm and small < 35 mm) and fungicide seed treatment at 2 levels (untreated and treated). The factors were deployed in a split-split plot randomized complete block design with three replications, implemented in each site. Seed source was the main-plot factor, seed size the split-plot factor, and seed treatment the split-split-plot factor.

In each treatment plot measuring 3.5 m × 3.65 m, potato seed was planted in furrows of about 4 to 5 cm after band application of NPK (17:17:17) fertilizer at a rate of 23 g per tuber as recommended by KaZARDI. The recommended potato plant spacing of 0.75 m between rows and 0.3 m within rows as well as ridges of average height (17 cm) and width (59 cm) were used. Each plot consisted of five rows with 12 plants per row, giving a plant population of 60 plants per plot. The spacing between plots and adjacent replications was 1 m and 2 m, respectively.

Weeding and earthing up in order to suppress emerging weeds as well as prophylactic and curative spraying against insect pests using the insecticide Dudu-Ethoate 40® (Dimethoate) at the manufacturer's recommended rate of 40 ml per 20 L was used. Plants infected by bacterial wilt were rouged out whenever identified. Five weeks after emergence, a period when the protection from fungicide dressing at planting is over and data on that had been collected, a blanket application of fungicide Mistress® 72 WP (cymoxanil 8% and mancozeb 64%) at the manufacturer's recommended rate of 30 g per 20 L was used to safeguard the experimental plants.

Two weeks before harvesting, dehaulming was done using kitchen knives to promote hardening of the potato skin and reduce disease spread from the foliage to the tubers. Tubers were then removed by hand hoeing on dry (no rain) days taking care to avoid injuring the tubers.

Data collection

Data was collected on potato growth and yield parameters as well as late blight incidence. Data on plant height and leaf length was collected at 9 weeks after planting from 20 random plants from the three middle rows of each plot. Plant height was measured using a meter ruler from the soil surface to the tip of the top leaf found on the main stem when plant was pulled erect. Leaf length was measured from the stalk to apex of a fully grown middle leaflet using a meter ruler and was used to calculate the leaf area based on Firman and Allen (1988) formula below;

$$\log10\ (\text{leaf area, cm}^2) = 2.06 \times \log10\ (\text{leaf length, cm}) - 0.458$$

Data on plant emergence, late blight incidence and yield parameters was collected on all the plants from the entire plot. Plant emergence was determined by counting the number of emerged plants at 4 weeks after planting and expressed as a percentage using the formula adopted from Gunadi *et al*. (2011) below;

$$\text{Emergence (\%)} = (\text{No. of emerged plants} \div \text{Total plants planted per plot}) \times 100\%$$

Late blight incidence was determined by counting plants showing visible symptoms of late blight disease and expressed as a percentage using the formula adopted from International Potato Center (2006) below;

$$\text{Late blight incidence (\%)} = (\text{No. of infected plants} \div \text{Total number of plants per plot}) \times 100\%$$

At harvest, tubers were graded per plot as big tubers (> 55 mm), medium tubers (35 to 55 mm) and small tubers (< 35 mm) (Burke, 2011). The number of the different tuber grades per plot were obtained and expressed as percentages (100%) of the total number of tubers per plot. Furthermore, using a mechanical spring weighing scale with a bowl (Yongkang Zhengya, Zhejiang, China), the weight of the different tuber grades (kg) per plot were obtained and later aggregated to obtain total tuber weight (kg) per plot. The graded and total tuber weights were presented in tonnes per hectare (t/ha).

Data analysis

Data collected on different potato growth and yield parameters as well as late blight incidence was subjected to analysis of variance (three-way ANOVA) for a split-split-plot design for the different locations and seasons using GenStat 14th edition software. Seed source, size and treatment were the factors considered in the analysis. Significant treatment means were separated using Fisher's Least Significant Difference (LSD) test at 5% level of significance.

Results

Effect of seed source, size and treatment on incidence of late blight disease and potato growth parameters

Results indicated that solely, seed source significantly ($P < 0.05$) influenced plant height and plant emergence but not number of main stems and leaf Area (Table 2). Seed size significantly ($P < 0.05$) influenced plant height and number of main stems but not leaf area and plant emergence (Table 2). Seed treatment, alone, did not significantly ($P > 0.05$) influence any of the potato growth parameters, and late blight incidence (not presented). Seed source and seed treatment interacted significantly ($P < 0.05$) to influence plant emergence. Certified seed resulted in the tallest plants (60.89 cm), followed by farmer-saved seed (56.97 cm) while seed from the local market source resulted in the shortest plants (53 cm) (Fig. 1). The emergence of potato seedlings from different sources followed a similar trend (Fig. 2). Moreover, when potato seed from different sources were fungicide treated, the treated certified seed significantly resulted in the highest plant emergence at 88.6% while treated local market seed had the lowest emergence (81.3%) (Fig. 2). Seed size also interacted significantly ($P < 0.05$) with seed treatment to influence plant emergence and number of main stems. Though large-size seed treated with a fungicide had the most number of main stems per plant (2.83) higher than small-size untreated (2.09); it was not different from large-size untreated (2.64) (Fig. 3). Showing that size was the overriding factor; same for plant height where large had the tallest plants (59.03 cm) vs small-size seed with plants averaging 54.88 cm (Fig. 4).

Effect of seed source, size and treatment on potato yield parameters

Seed source significantly ($P < 0.01$) influenced all the studied yield parameters including the number of small-size tubers; yields of medium, large and total tubers; and the number of medium-size tubers and large-size tubers; and yield of small-size tubers (Table 3). Seed size significantly ($P < 0.01$) affected yield of small-size, medium-size and total tubers; as well as number of large-size tubers ($P < 0.05$) (Table 3). Seed treatment significantly influenced number of medium sized tubers and their yield, and total yield ($P<0.05$) (Table 3). The mean number of medium sized tubers under seed treatment was 22.93 as opposed to 20.15 in the untreated (LSD = 1.49); whereas the yield of total tuber yield was 7.77 t/ha as opposed to 7.25 t/ha in the untreated (LSD = 0.44)

The interaction between potato seed source and size influenced the number of large-size tubers; yield of medium-size, large-size and total tubers ($P < 0.05$) (Table 3). With regard to the number of small-size tubers, the means for certified, farmer-saved and local market sourced were 58, 68, and 74, respectively. This trend held for small-tuber yield, with the means for certified, farmer-saved and local market sourced

Table 2. F-statistics for the combined analysis of the effect of seed sources, seed size and seed treatment on potato growth parameters evaluated across three locations across South-western Uganda for seasons 2018B and 2019A

Source of variation	DF	F-statistics			
		Plant height (cm)	Number of main stems	Leaf Area (cm²)	Plant emergence (%)
Seed source	2	14.55*	0.51	6.51	8.85*
Seed size	1	57.17***	53.32***	2.75	4.69
Seed source*seed size	2	0.45	2.51	1.5	0.82
Seed treatment	1	0.1	0.01	0.77	0.00
Seed source*seed treatment	2	1.72	0.57	0.06	5.21*
Seed size*seed treatment	1	0.02	5.85*	0.31	5.99*
Seed source*seed size*seed treatment	2	0.19	0.4	0.03	2.84
Residual	2964				

***, **, * Indicate significance at P<0.001, P<0.01, and P<0.05, respectively. Values without asterisks are not significant; DF = degree of freedom

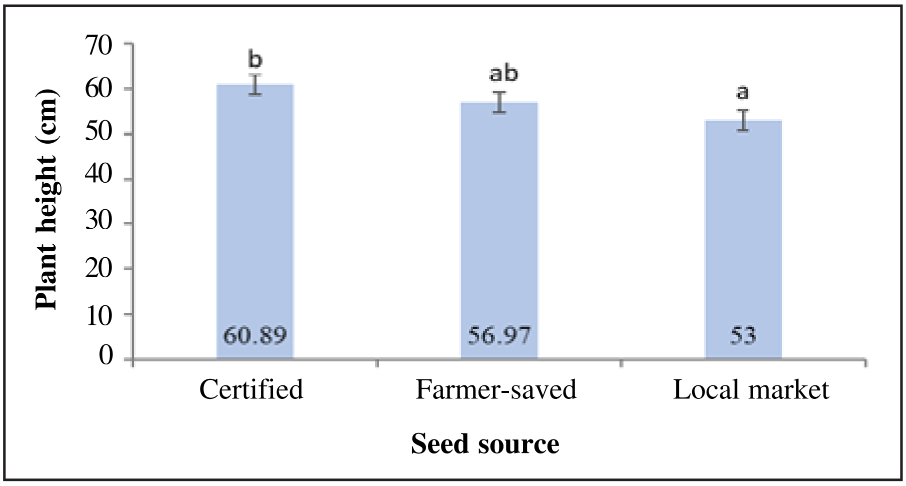

Figure 1. Effect of seed source on plant height (cm) of potato. Error bars represent standard deviation. Bars with the same letters are not significantly different.

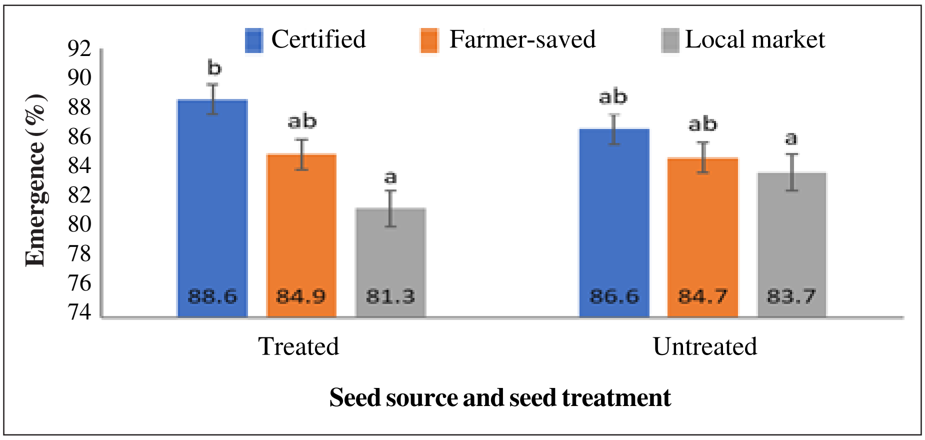

Figure 2. Potato emergence (%) as influenced by seed source and seed treatment. Error bars represent standard deviation. Bars with the same letters are not significantly different.

at 2.22, 2.41, and 2.93 t/ha, respectively. Irrespective of the seed size, certified seed resulted in the highest number of large-size tubers and highest yield of large and total tubers with the only exception being yield of medium size tubers where there was not much variation in the yield of the different seed sources (Table 4). Seed from the local market source generally resulted in the lowest values for potato yield parameters excluding total tuber yield accruing from large seed size, where total yield from local market source was higher than of the farm-saved source but still less than of certified seed (Table 4).

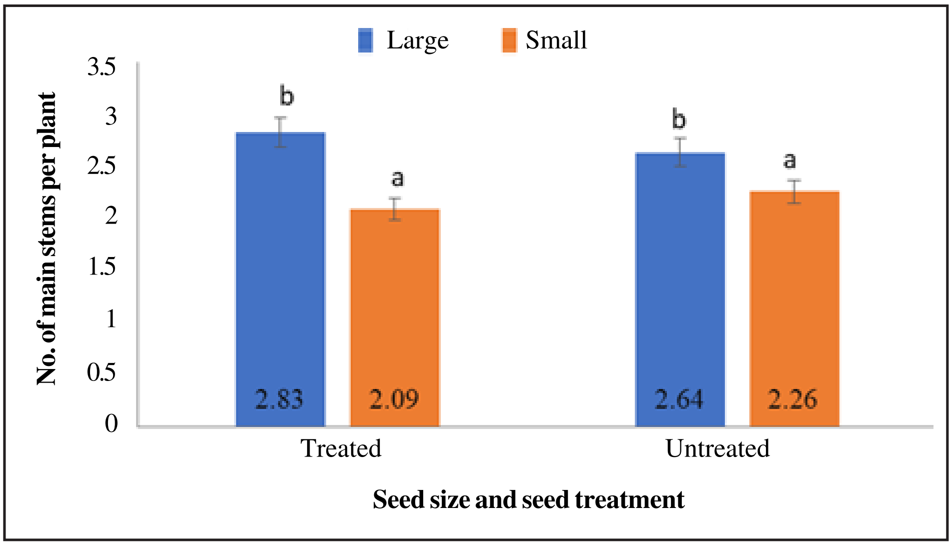

Figure 3. Number of main stems per potato plant as influenced by the interaction effect of seed size and seed treatment. Error bars represent standard deviation. Bars with the same letters are not significantly different.

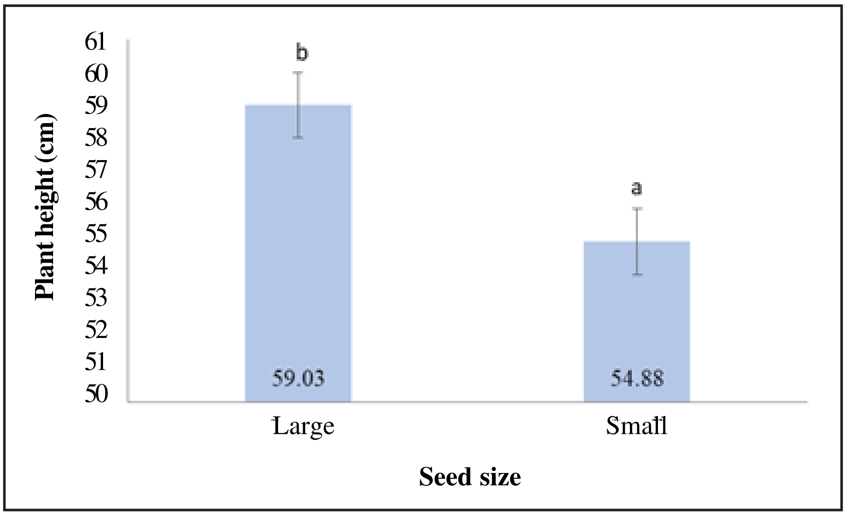

Figure 4. Effect of seed size on plant height (cm) of potato. Error bars represent standard deviation. Bars with the same letters are not significantly different.

Table 3. F-statistics for the combined analysis of the effect of seed sources, size and treatment on potato yield parameters evaluated across three locations across South-western Uganda for seasons 2018B and 2019A

Source of variation	DF	F-statistics						
		Number of small tubers (%)	Number of medium tubers (%)	Number of large tubers (%)	Yield of small tubers (t/ha)	Yield of medium tubers (t/ha)	Yield of large tubers (t/ha)	Total tuber yield (t/ha)
Seed source	2	137.73***	19.02**	32.64**	31.48**	68.57***	78.45***	115.1***
Seed size	1	0.92	0.57	6.5*	54.27***	22.33**	2.76	25.53**
Seed source*seed size	2	3.28	0.23	7.35*	5.07	12.99**	5.19*	8.31*
Seed treatment	1	1.78	16.37**	0.2	0.14	22.14***	1.04	6.69*
Seed source*seed treatment	2	1.72	0.01	5.61*	3.67	9.26**	1.33	2.04
Seed size*seed treatment	1	4.01	18.9***	1.26	5.88*	19.47***	1.01	1.87
Seed source*seed size*seed treatment	2	2.1	5.7*	1.32	0.02	2.74	1.93	2.45
Residual	156							

***, **,* Indicate significance at P<0.001, P<0.01, and P<0.05, respectively. Values without asterisks are not significant; DF = degrees of freedom

Table 4. Effect of seed source and seed size on number of large-size tubers as well as yield of medium, large and total tubers of potato evaluated across three locations for seasons 2018B and 2019A

Seed source	Number of large tubers (%)			Yield of medium tubers (t/ha)			Yield of large tubers (t/ha)			Total tuber yield (t/ha)		
	Large	Small	**Mean**	Large	Small	**Mean**	Large	Small	**Mean**	Large	Small	**Mean**
Certified	14.71	19.91	**17.31**	3.38	2.19	**2.79**	3.29	3.89	**3.59**	9.26	7.93	**8.60**
Farm saved	10.59	11.78	**11.19**	2.24	2.21	**2.23**	2.20	2.54	**2.37**	6.96	7.04	**7.00**
Local market	8.53	7.37	**7.95**	2.30	2.10	**2.20**	1.99	1.65	**1.85**	7.45	6.44	**6.95**
Mean	11.28	13.02	12.15	2.64	2.17	2.41	2.49	2.69	2.60	7.89	7.14	7.52
L.S.D			3.35*			0.31**			0.47*			0.49*

Values are means ± SD; ***, **,* Indicate significance at P<0.001, P<0.01, and P<0.05, respectively

Table 5. Effect of seed treatment and seed source on the number of large-size tubers and yield of medium-size tubers of potato evaluated across three locations for seasons 2018B and 2019A

Seed source	Number of large tubers (%)			Yield of medium tubers (t/ha)		
	Treated	Untreated	Mean	Treated	Untreated	Mean
Certified seed	15.68	18.94	**17.31**	3.14	2.42	**2.78**
Farmer-saved	11.48	10.89	**11.91**	2.45	2.00	**2.23**
Local market	8.85	7.04	**7.95**	2.16	2.24	**2.22**
Mean	**12.00**	**12.29**	**12.15**	**2.58**	**2.22**	**2.40**
L.S. D			**3.28***			**0.23****

***, **,* Indicate significance at P<0.001, P<0.01, and P<0.05, respectively

The interaction between potato seed source and seed treatment had a significant effect on number of medium-size tubers ($P < 0.01$) as well as yield of large -size tubers ($P < 0.05$) (Table 3). The highest response by different seed sources to fungicide treatment was in relation to yield of medium-size and large-size tubers recorded from treated certified seed, which had the highest values compared to informal sources (Table 5). Fungicide treatment enhanced the yield of medium-size tubers obtained from the farmer-saved seed by 0.45 t/ha; and for certified seed by 0.72 t/ha; the reverse was true for local market sourced seed. Fungicide treatment of farmer-saved seed produced an improvement in the number of large-size tubers from 10.89% in the untreated farmer-saved seed to 11.48% in the treated farmer-saved seed (Table 5).

The interaction between potato seed size and seed treatment had a significant effect on number of large tubers ($P < 0.001$), yield of medium tubers ($P < 0.001$) and yield of small tubers ($P < 0.05$) (Table 3). Plots with large-size treated seed consistently resulted in the highest number of medium-size tubers as well as highest yield of medium-size and small-size tubers (Table 6). Also consistently, treated seed resulted in the highest yield of medium-size tubers whatever the size of seed; for yield of small size tubers, this held for small size but not for large size seed (Table 6)

Discussion

Effect of seed source, size and treatment on late blight incidence and potato growth parameters

The results from this study showed that plant height and plant emergence were significantly different among the seed sources with certified seed resulting in the highest values whilst the lowest values were noted from the local market seed. Significant effect of seed source on growth parameters has been reported before for seed potato (Hussain *et al*., 2000; Gunadi *et al*., 2011 and Gomaa, 2014). This could be due to differences in the quality (physiological, physical, genetic and health status) of the seed tubers from the various sources. Though quality attributes are not presented in this study, personal observations showed that certified seed possessed characteristics of high-quality seed (few short, thick and strong sprouts; few diseased tubers; no wrinkles on tuber surface; larger seed size tubers and the highest genetic purity) when compared local market seed. Awad (2009) indicated that seed of high-quality maximizes use of the available resources, resulting in rapid germination, hasty shoot growth and eventually taller plants compared to low-quality seed. For plant emergence, certified seed is considered superior in emergence because such sprouts do not easily rot, resist rubbing off, and have a high vigor owing to the limited use of the starch reserves in the tubers during sprouting (Burke (2011). Additionally, local market

Table 6. Effect of seed treatment and size on the number of large-size tubers as well as yield of medium and small-size tubers of potato evaluated across three locations for seasons 2018B and 2019A

Seed size	Number of large tubers (%)			Yield of medium tubers (t/ha)			Yield of small tubers (t/ha)		
	Treated	Untreated	Mean	Treated	Untreated	Mean	Treated	Untreated	Mean
Large	24.94	19.18	**22.06**	2.98	2.29	**2.64**	2.68	2.84	**2.76**
Small	20.91	21.12	**21.02**	2.18	2.15	**2.17**	2.39	2.17	**2.28**
Mean	**22.93**	**20.15**	**21.54**	**2.58**	**2.22**	**2.40**	**2.53**	**2.50**	**2.52**
LSD			**3.47*****			**0.27*****			**0.21***

***, **,* Indicate significance at $P<0.001$, $P<0.01$, and $P<0.05$, respectively seed have been reported to be physiologically relatively older than for certified seed and hence poorer in emergence (Caldiz *et al*., 1996; Patel *et al*., 2008; Burke 2011). Moreover, Hasanuzzaman (2015) explained that mixed varieties that characterize local market sources often emerge at different times decreasing overall emergence.

With respect to seed treatment, the lack of a significant effect of the fungicide seed treatment on the potato growth parameters in sole treatment was probably due to the short-lived protection offered by the dressing; not long enough to provide a significant effect subsequent field infection. It is reported that the duration of protection by the fungicide to the treated seed varies from 10 to 14 days (Paulsrud *et al*., 2001) to 4-5 weeks (Kazda *et al*., 2005) after sowing depending on the climatic conditions. Additionally, the lack of a significant effect by the fungicide seed treatment on late blight incidence could be due to the presence of soil borne *Phytophthora infenstans* that the fungicide dressing could not protect against (Powelson *et al*., 2002; Seifu, 2017). Results of this study agree with the findings of Hervieux *et al*. (2001) who reported that seed treatment had no significant influence on the incidence of silver scurf on progeny potato tubers. In contrast, a number of researchers (Hartill, 1980; Wharton and Kirk, 2007; Rahman *et al*., 2003 and Haveri *et al*., 2018) reported that fungicides applied as seed treatment reduced late blight incidence in potato. Therefore, more comprehensive studies taking account of field soil borne pathogen inoculum may be vital. The positive results of fungicide treatment of certified seed with respect to plant emergence could be largely due to thorough seed selection and handling at the research station (KaZARDI) from which the certified seed was obtained.

Large-size seed resulted in significantly taller plants and more main stems per plant compared to small-size seed tubers. The better growth in terms of plant height could be due to the higher food and water reserves with large-size seed which supply sufficient nutrients and moisture to the growing plants consequently giving rise to a tall plant compared to small-size seed (Burke, 2011). Similar results were reported by Moonmoon *et al*. (2012) and Nasir and Akassa (2018) who indicated that plant height significantly increased with increasing seed tuber size. The enhanced growth as regards to more main stems per plant may be due to more eyes present in the large-size seed which consequently resulted in more main stems compared to small-size seed (Sadik *et al*., 2018). Kumar *et al*. (2015) indicated that the number of eyes is positively correlated to tuber size/surface area. These results also conform to the findings of previous studies (Patel *et al*., 2008; Almeida *et al*., 2016; Nasir and Akassa, 2018) who observed higher number of stems from larger-size seed tubers compared to smaller-size seed tubers.

Effect of seed source, size and treatment on potato yield parameters

In this study, certified seed exhibited superior performance compared to seed from the farmer-saved and local market sources for most of the potato yield parameters including total yield with exceptions for the number and yield of small-size tubers. O'brien and Allen (1992), Hussain *et al*. (2000), and Burke (2011) all reported significant differences in tuber numbers, graded and total tuber yield among different potato seed sources. This variation in yield parameters as a result of potato seed sources has been attributed seed quality, primarily the physiological age (developmental stage of a potato tuber which influences its production capacity) of the seed potato planted (Christiansen *et al*., 2006; Patel *et al*., 2008; Burke, 2011; Oliveira, 2015). The reason being that physiological age of seed potato influences parameters such as emergence, germination, plant height, number of stems, leaf area, number of leaves and canopy duration unto which tuber numbers and yields are associated with and dependent. Patel *et al*. (2008) and Burke (2011) mentioned that middle-aged seed potato, physiological ageing being majorly influenced by the storage conditions (temperature, humidity, light intensity) and not storage period, resulted in plants possessing maximum values of the above-named growth parameters occasioning to higher tuber numbers and yields than either young or too old potato seed. Certified seed, which is rigorously supervised and tested (Tindimubona *et al*., 2015), is more likely to meet the physiological age requirements for better performance with regard to potato yields. On the other hand, the relatively poor performance of seed from the informal sources, especially seed from the local market could be due to low quality of tubers attributable to the improper handling and storage practices (Kaguongo *et al*., 2008; Gildemacher *et al*., 2009).

In addition to seed source, seed size came out as a key factor, overriding treatment with regard to potato growth and yield. As mentioned earlier, this could be attributed to the higher food reserves in the superior large-size seed, which supplies sufficient nutrients to the growing plants consequently resulting in better growth and eventually high yields when large-size seed was used as planting materials compared to use of small-size seed (Patel *et al*., 2008; Burke, 2011; Almeida *et al*., 2016; Nasir and Akassa, 2018; Sadik *et al*., 2018). Uniquely, small-size seed resulted in significantly higher number of large-size tubers compared to large-size seed. Given that the number of potato tuber eyes is positively correlated to seed size, the fewer eyes in small-size seed could have resulted in fewer number of stems and tubers produced thus limiting the competition among stems and tubers for available resources shifting the size distribution to large-size tubers (Lung'aho *et al*., 2007; Kumar *et al*., 2015).

The better performance of fungicide treated in terms of total tuber yields could be explained by the protection the fungicide offers to the seed as well as the seedling at emergence when the plant is more susceptible to diseases that delays crop damage which significantly increases crop yields (Paulsrud *et al*., 2001). Furthermore, the fungicide effect could have reduced tuber decay (Wharton and Kirk, 2007), which was not measured in this study. As such, the positive effect of the fungicide on the planted tubers and emergence may have resulted in better yields. These observations agree with the findings of Rahman *et al*. (2003) and Adnan *et al*. (2015) who reported that fungicide seed treatment of potato tubers increased yields compared to the untreated control.

Conclusion

The study confirmed that certified seed was of superior performance compared to seed from informal sources (farmer-saved and local market). Large-size seed (35 mm to 55 mm) manifested in outstanding field performance compared to small-size seed (< 35 mm). Fungicide seed treatment though not able to influence late blight incidence on potato plants at the time it was measured, it significantly improved potato yield parameters compared to the untreated seed. Using large-size certified seed integrated with fungicide dressing considerably improved potato yields. Farmer-saved seed was better than local market sourced seed in terms of growth and yield of potato. Therefore, for improved potato productivity, farmers are prevailed upon to primarily use certified seed for potato production. However, in the event that certified seed is unavailable careful selection (clean, >35 mm size) alongside fungicide treatment of farm-saved seed can work as back up.

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