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Quality of Potato (Solanum tuberosum L.) Tubers as Influenced by Cultivar and Plant Spacing in Eastern Ethiopia

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Abstract
A field experiment was conducted at Haramaya and Hirna during the main cropping season of 2013 to determine the appropriate plant spacing for potato cultivars in relation to tuber quality. The treatments consisted of five seed tuber spacing between ridges and seed tubers (75 cm x 30 cm, 60 cm x 30 cm, 60 cm x 25 cm, 50 cm x 25 cm and 45 cm x 20 cm) and four potato varieties (Bubu, Badhassa, Zemen and Chiro). The experiment was laid out as a randomised complete block design with three replications. The analyzed data results showed that the main effect of variety significantly ($P < 0.01$) affected almost all quality parameters of the crop and some of them responded significantly for the main effect of spacing. However, variety and plant spacing did not interacted to significantly influence most quality parameters at both locations except for specific gravity and total starch content. Mean result of the two locations indicated that Bubu had significantly higher specific gravity (1.106). In addition to variety, the highest specific gravity was recorded at the spacing of 75 cm x 30 cm (1.088), 60 cm x 30 cm (1.088) and 60 cm x 25 cm (1.086). At Hramaya, a significantly higher tuber dry matter content was recorded for Bubu (28.41%). At Hirna, Bubu, Badhasa and Chiro varieties had the highest tuber dry matter contents of 31.44%, 29.39% and 27.63%, respectively. Mean result of the locations showed that Bubu had higher total starch content (18.94 g/100g) than the other varieties. In terms of spacing, the highest total starch contents were recorded for spacing of 60 cm x 30 cm (15.44 g/100g), 75 cm x 30 cm (15.36 g/100g) and 60 cm x 25 cm (14.92 g/100g). Mean results of the two location showed that tubers of Chiro, Zemen and Bubu had higher pH (6.079, 6.036 and 6.01, respectively). At both locations, Bubu had the highest total soluble solids while Chiro and Zemen had the lowest.
Keywords: Inter and intra row spacing; *Solanum tuberosum L.;* cultivar, specific gravity; dry matter content; total starch content; pH

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a crop of major economic importance worldwide. On a global scale, potato is the fourth most cultivated food crop after wheat, rice, and maize (FAOSTAT, 2012). The relatively high carbohydrate and low fat content of potato makes it an excellent energy source for human consumption (Dean, 1994).

The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist (Pankhurst, 1964). The country has about 70% of the available agricultural land suitable for potato production (Gebremedhin *et al*., 2008). Even though, the country is endowed with suitable climatic and edaphic conditions the annual production of potato in Ethiopia is low (about 525, 657 metric tons) and the national average yield is 7.2 tons/ha, which is very low compared to the world's average of 16.4 tons/ha (FAOSTAT, 2012).

Specific gravity which is an expression of density is the most widely accepted measurement of potato quality. Specific gravity is the measure of choice for estimating dry matter and starch content and ultimately for determining the processing quality of potato varieties (Tesfaye *et al.,* 2013). These are very important to the potato processor because they affect the quality and yield of the processed product. They also affect processing costs because the oil absorption rates during frying are related to dry matter levels. Factors that influence potato yield and quality include cultivar, soil type, weather conditions, water management, plant population, seed piece size, pests and diseases (Khalafalla, 2001).

Plant spacing should depend on type of variety, fertility status of soil, plant architecture or growth habit etc. Potato varieties also differ on growth habit and other quality attributes. Therefore, using the same spacing for all varieties may not lead to optimum tuber quality. In view of this, this experiment was conducted with the objective of determining the quality of potato cultivars under different spacing and growing conditions.

MATERIALS AND METHODS

Description of Experimental Sites

The study was conducted under rain-fed conditions during the 2013 main cropping season at Haramaya and Hirna districts, in eastern and western Hararghe zones of the Oromia Regional State in Ethiopia, respectively.

Table 1. Description of the experimental sites

Characteristics /features	Haramaya Site	Hirna Site
Latitude	9° 26' North latitude	9° 12' North latitude
Longitude	42° 3' East longitude	41° 4' East longitude
Altitude	2015 masl	1870 masl
Mean annual rainfall	760 mm	990 to 1010 mm
Soil type	well-drained deep alluvial	vertisol
Organic carbon content	1.15%	1.75%
Total nitrogen content	0.11%	0.18%
Available Phosphorus content	18.2 mg kg $soil^{-1}$	32 mg kg $soil^{-1}$
Exchangeable potassium	0.65cmolc kg $soil^{-1}$	0.68 cmolc kg $soil^{-1}$
Soil pH	8.0	7.09
Sand content	63%	27%
Silt content	20%	28%
Clay content	17%	45%

Source; Belay *et al.*, 1998, Tamire, 1973, Simret, 2010, HURC, 1996, Nebret, 2011

Description of Experimental Materials

The experiment was conducted with four improved potato cultivars (Bubu, Badhasa, Zemen and Chiro) which are widely cultivated in eastern Ethiopia.

Table 2. Description of the potato varieties used for the experiment

				Plant height	Area of adaptation	
No	Variety	Year of release	Growth habit	(cm)	Altitude (metres above sea level)	Rainfall (mm)
1	Bubu	2011	Erect	66.8	1650-2330	700-800
2	Badhasa	2001	Erect	50-55	1700-2000	700-800
3	Zemen	2001	Erect	55-60	1700-2000	700-800
4	Chiro	1998	Semi-erect	60	1600-2000	700-800

Source: MoARD (2012).

Treatments and Experimental Design

The experiment consisted of four improved potato varieties (Bubu, Badhasa, Zemen and Chiro) and five seed tuber spacing between rows (ridges) and between plants (75 cm x 30 cm, 60 cm x 30 cm, 60 cm x 25 cm, 50 cm x 25 cm and 45 cm x 20 cm). The treatments were laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. Gross plot size was 3.6 m x 4.0 m (14.4 m^2). The spacing between adjacent plots was 1.0 m and the spacing between adjacent blocks was 1.5 m.

Management of the Experiment

The experimental fields were cultivated by a tractor and then levelled, after which ridges were made by hand. Well-sprouted medium sized seed tubers were planted according to the specified treatments. Cultivation, weeding and harvesting were done at the appropriate time. Untifengicidal chemical (Mancozeb 80% WP) was applied on 15 days interval at the rate of 1.5 kg ha^{-1} diluted at the rate of 40 g per 20 litre to control late blight disease.

Application of phosphorus fertilizer at the rate of 92 kg P_2O_5 ha^{-1} was done by banding the granules of DAP (diammonium phosphate) (18% N, 46% P_2O_5) at the depth of 10 cm below and around the seed tuber at planting. The blanket N recommendation is 111 kg N ha^{-1} (Anonymous, 2004).

Data Collection and Measurements

Specific gravity of tubers (gcm^{-3}): Tuber specific gravity was measured using the weight in air and weight in water method (Gould, 1995).

$$\text{Specific Gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

Tuber dry matter content (%): Five potato tubers were randomly selected from each plot, chopped into small 1-2 cm cubes, mixed thoroughly, and two sub-samples each weighing 200 g was weighed. The dry matter percent was calculated according to the formula of William and Woodbury (1968).

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100\%$$

Total starch content (g/100 g): The percentages of starch was calculated from the specific gravity as follows: Starch (%) =17.546 + 199.07 × (specific gravity - 1.0988) (Talburt and Smith 1959 as cited by Yildrim and Tokuşoğlu, 2005).
pH measurement: The pH of the raw potato tuber samples was determined using a method as described by Pardo *et al.* (2000). The pH was measured in the juice obtained after washing, crushing, and extracting the juice of the sample tubers using a pH meter.
Total soluble solids (^{0}Brix): The Brix of the raw potato samples was determined using the method as described by Pardo *et al.* (2000) with a hand refractometer.

Data Analysis
The data were subjected to analysis of variance (ANOVA) using the General Linear Model of the SAS statistical package (SAS, 2007) version 9.1. All significant pairs of treatment means were compared using Tulkey Test at 5% level of significance. T-test was conducted to determine differences between the two locations in the performance of the potato varieties to plant spacing. F-test was computed for determining homogeneity of variance for the locations.

RESULTS AND DISCUSSION

Specific gravity
Analysis of the mean specific gravity of the two locations showed that the main effects of both variety and spacing significantly ($P < 0.01$) affected it (Table 3). However, the main effect of spacing and interaction effect of variety and spacing did not affect specific gravity at both locations (Appendix Tables 1 and 2).

Mean results of the locations indicated that tubers of Bubu had significantly higher specific gravity (1.106) while tubers of the other varieties had lower values of specific gravity, which were in statistical parity. In addition to variety, the highest specific gravity was recorded at the spacing of 75 cm x 30 cm (1.088), 60 cm x 30 cm (1.088) and 60 cm x 25 cm (1.086) while the lowest specific gravity was recorded at 45 cm x 20 cm (1.082) and 50 cm x 25cm (1.082) spacing (Table 3). In this study, all cultivars had a specific gravity higher than 1.070, indicating that they are suitable for chip making.

Dry matter content
At both locations, the main effect of variety significantly ($P < 0.01$) affected dry matter percent (Table 3). However, the interaction effect of variety and plant spacing did not affect this parameter at both locations (Appendix Tables 1 and 2).

At Hramaya, a significantly higher tuber dry matter content was recorded for Bubu (28.41%). At Hirna, Bubu, Badhasa and Chiro varieties had the highest tuber dry matter contents (31.44%, 29.39% and 27.63%, respectively) (Table 3). This may be due to genetic differences among the varieties, according to Burton (1966) who reported that genetic differences among varieties play a role in their ability to produce high solids. At Haramaya, increasing seed tuber spacing significantly increased tuber dry matter content of potato. Thus, the wider spacing of 75 cm x 30 cm and 60 cm x 30 cm resulted in higher dry matter contents while the narrow spacing of 45 cm x 20 cm and 50 cm x 25 cm resulted in lower dry matter content (Table 3).

Total starch content
Mean result of the locations showed that the main effects of both variety and spacing significantly ($P < 0.01$) affected total starch content. However, the main effect of spacing and the interaction effect of spacing and variety did not influence total starch content at both locations (Appendix Tables 1 and 2).

Mean result of the locations showed that Bubu had higher total starch content (18.94 g/100g) than the other varieties. In terms of spacing, the highest total starch contents were recorded for spacing of 60 cm x 30 cm (15.44 g/100g), 75 cm x 30 cm (15.36 g/100g) and 60 cm x 25 cm (14.92 g/100g) while the lowest was recorded for the spacing of 45 cm x 20 cm and 50 cm x 25 cm (Table 3). The starch content plays very important roles in the quality of potato products and varies with potato cultivars. Potatoes with higher starch content are well suited for food use, processing or starch manufacture (Liu *et al.,* 2003).

pH
The mean results of the two locations indicate that the main effects of variety affect pH and spacing did not affect pH. Variety and spacing did not interact to influence pH of raw potato tubers at both locations (Appendix Tables 1 and 2).

Mean results of the two location showed that tubers of Chiro, Zemen and Bubu had higher pH (6.079, 6.036 and 6.01, respectively) while those of Badhasa had lower pH (5.977) (Table 4). This finding is in agreement with the findings of Nourian *et al.* (2002) who reported that pH of raw potatoes is usually around 6.0. Corroborating the results of this study, Elfnesh *et al.* (2011) also reported that there was a highly significant difference in pH

among cultivars grown at Haramaya, Kulubi and Langie.

Total soluble solids

The main effect of variety significantly ($P < 0.01$) affected total soluble solids at both locations and the mean of the locations. However, the main effect of spacing and the interaction effect of variety and spacing did not influence total soluble solids at both locations (Appendix Tables 1 and 2).

At both locations, Bubu had the highest total soluble solids while Chiro and Zemen had the lowest (Table 4). According to Rex (1989), Brix equals to percent of sucrose and varies directly with plant quality. The refractive index of potato varies from poor 3^0Brix, average 5^0Brix, and good 7^0Brix as long to excellent 8^0 Brix (Rex, 1989).

Table 3. Specific gravity, Dry matter content (%) and Total starch content (g/100g) of potato tubers as influenced by the main effects of variety and seed tuber spacing at Haramaya and Hirna during the 2013 main cropping season.

	Tuber specific gravity (g/cm^3)			Dry matter content (%)		Total starch content (g/100g)		
Variety	Haramaya	Hirna	Mean	Haramaya	Hirna	Haramaya	Hirna	Mean
Bubu	1.100a	1.112a	1.106a	28.41a	31.44a	17.72a	20.16a	18.94a
Badhasa	1.086b	1.075b	1.080b	26.17b	29.39ab	15.00b	12.78b	13.89b
Zemen	1.078b	1.076b	1.077b	24.70b	26.37b	13.33b	13.03b	13.18b
Chiro	1.078b	1.076b	1.077b	24.92b	27.63ab	13.37b	13.06b	13.21b
LSD (0.05)	0.0119	0.00884	0.002887	1.121	3.605	1.78	1.76	0.575
F-test	**	**	**	**	*	**	**	**
CV%	1.11	1.1	0.4	5.8	17	16.2	16.1	5.3
Spacing								
75cm x 30cm	1.088	1.088	1.088a	28.61a	31.29	15.4	15.33	15.36a
60cm x 30cm	1.089	1.088	1.088a	27.04ab	30.49	15.58	15.3	15.44a
60cm x 25cm	1.087	1.084	1.086ab	26.05bc	28.99	15.23	14.62	14.92ab
50cm x 25cm	1.081	1.083	1.082b	24.51cd	26.78	13.99	14.38	14.19b
45cm x 20cm	1.081	1.082	1.082b	24.04d	25.99	14.07	14.17	14.12b
LSD (0.05)	0.0141	0.00988	0.003228	1.253	4.031	1.99	1.968	0.642
F-test	NS	NS	**	**	NS	NS	NS	**
CV%	1.11	1.1	0.4	5.8	17	16.2	16.1	5.3
Overall mean								
Location	1.0853	1.0848		26.05	28.71	14.85	14.76	
T-test	NS			**		NS		
LSD (0.05)	0.00438			1.335		0.871		

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level. LSD = Least significant difference; CV% = Coefficient of variation, NS= non-significant difference.

Table 4. pH and total soluble solid of potato as influenced by the main effects of variety and spacing at Haramaya and Hirna during the 2013 main cropping season.

	pH			Total soluble solid (^{0}Brix)	
Variety	Haramaya	Hirna	Mean	Haramaya	Hirna
Bubu	5.941ab	6.078	6.010ab	6.463a	6.780a
Badhasa	5.898b	6.057	5.977b	5.660b	5.987b
Zemen	6.069a	6.002	6.036ab	4.963c	5.693bc
Chiro	6.093a	6.064	6.079a	4.923c	5.280c
LSD (0.05)	0.1259	0.078	0.0712	0.3835	0.4645
F-test	**	NS	*	**	**
CV%	2.8	1.7	1.6	9.4	10.6
Spacing					
75 cm x 30 cm	6.091	6.038	6.065	5.729	6.042
60 cm x 30 cm	5.968	6.062	6.015	5.525	5.908
60 cm x 25 cm	6.012	6.042	6.027	5.583	6.183
50 cm x 25 cm	5.95	6.056	6.003	5.517	5.667
45 cm x 20 cm	5.982	6.053	6.018	5.158	5.875
LSD (0.05)	0.1407	0.087	0.0796	0.4288	0.5193
F-test	NS	NS	NS	NS	NS
CV%	2.8	1.7	1.6	9.4	10.6
Overall mean					
Location	6	6.05		5.503	5.935
T-test	NS			**	
LSD (0.05)	0.0521			0.2094	

Means followed by the same letter within a column for the main effects of variety and plant spacing are not significantly different at 5% level of significance. ** = significant at 1% probability level, * = significant at 5% probability level. LSD = Least significant difference; CV% = Coefficient of variation and NS= non-significant difference.

SUMMARY AND CONCLUSION

The experiment was carried out at Haramaya and Hirna, Hararghe highland of Eastern Ethiopia. Randomized complete black design in factorial arrangement was used with three replications comprising five levels of plant spacing (75 cm x 30 cm, 60 cm x 30 cm, 60 cm x 25 cm and 50 cm x 25 cm and 45cm x 20cm) and four levels potato varieties (Bubu, Badhassa, Zemen and Chiro). Almost all quality attributes of potato responded significantly ($P < 0.01$) for the main effect of variety and some of them responded significantly for the main effect of spacing. The response of specific gravity, dry matter content and total starch content to the main effect of variety influenced significantly ($P < 0.01$). In the present investigation, Bubu had the highest the specific gravity (1.1), dry matter content and total starch content (18.94 g/100g). On the other hand, the highest the specific gravity and total starch contents were obtained from seed tuber spacing of 75 cm x 30 cm, 60 cm x 30 cm and 60 cm x 25 cm. At Haramaya, the highest dry matter contents were recorded from seed tuber spacing of 75 cm x 30 cm (28.61%) and 60 cm x 30 cm (27.04%). The relatively higher pH of raw potato tuber was recorded for Zemen (6.04), Chiro (6.08) and Bubu (6.01).

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Appendix Table

Appendix Table 1. Mean squares from analysis of variance (ANOVA) for 6 potato quality attributes at Haramaya site

Variables	Replication	Variety (V)	Spacing (S)	V x S	Error
Degrees of freedom	2	3	4	12	38
Specific gravity	0.0001245	0.0016121**	0.0001764ns	0.000188ns	0.0001463
% Dry matter content	1.973	43.396**	41.811**	2.19ns	2.299
Total starch content	4.932	63.887**	6.99ns	7.449ns	5.799
% Peel content	13.595	54.168**	5.736ns	5.786ns	4.78
pH	0.00585	0.13651**	0.03706ns	0.05151ns	0.029
Total soluble solids	0.7539	7.8707**	0.5312ns	0.3746ns	0.2691

Appendix Table 2. Mean squares from analysis of variance (ANOVA) for 6 potato quality attributes at Hirna site

Variables	Replication	Variety (V)	Spacing (S)	V x S	Error
Degrees of freedom	2	3	4	12	38
Specific gravity	0.0001016	0.0049141**	0.0000851ns	0.0000709ns	0.000143
% Dry matter content	48.03	62.99*	72.67ns	45.37ns	23.79
Total starch content	4.026	194.74**	3.373ns	2.808ns	5.668
% Peel content	3.817	19.255*	10.85ns	7.839ns	4.431
pH	0.05235	0.01673ns	0.00114ns	0.00991ns	0.01104
Total soluble solids	0.008	6.0206**	0.4481ns	0.6602ns	0.3948