Physical Quality Characteristics 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 physical tuber quality characteristic. 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. All physical quality attributes of potato responded significantly (P < 0.01) for the main effect of variety and spacing. At Haramaya, Bubu had the higher geometric mean diameter (46.76 mm3) and surface area (6958 mm2) of tuber than the other varieties. Tuber sphericity was higher for Bubu (85.28%), Badhassa (86.54%) and Chiro (82.26%). At both locations, wider spacing of 75 cm x 30 cm, 60 cm x 30 cm and 60 cm x 25 cm gave the highest geometric mean diameter and tuber surface area. However, narrow spacing of 45 cm x 20 cm and 50 cm x 25 cm resulted in the higher sphericity of tuber.

Keywords: Inter and intra row spacing, Solanum tuberosum L., variety, geometric diameter, sphericity, surface area
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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).

Physical characteristics of agricultural products are the most important parameter in the design of grading, handling, processing and packaging systems. Among these physical characteristics, mass, volume, projected area, and centre of gravity are the most important ones in the handling systems (Peleg, 1985). Other important parameters are width, length, and thickness (Peleg, 1985). Knowledge of length, width, volume, surface area and centre location of mass may be applied in the designing of sorting machinery, in predicting surface needed when applying chemicals, shape factor (sphericity), and yield in the peeling operation (surface area) (Wright et al., 1986). Other characteristics worth of concentration are width, length, and thickness (Mohsenin, 1970; Peleg, 1985). Moreover, the appearance of fresh agricultural products is a primary criterion in making purchasing decisions (Kays, 1991).

When tubers are marketed for industrial processing, the portions of certain size-grades and the tuber shape play an important role (Haase et al., 2007). Therefore, the industry processing potatoes demands tubers grade > 50 mm for French fries and 40 to 65 mm for crisps. In this connection, the choice of cultivar for industry processing may also be an efficient agronomic measure to increase financial returns when high portions of larger tubers are required Zehra (2011). Tuber shape is an important characteristic in influencing peeling and trimming efficiency during processing (George et al., 2010). Potato tubers that are round (spherical) in shape have been shown to be suitable for crisps processing for most processors because they easily make the required crisp diameters (Kulkarni and Govinden, 1994; Kabira and Lemaga, 2006). The long and oval tubers, however, lend themselves easily for processing of French fries (Kabira and Lemaga, 2006; Abong’ et al., 2009).

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 quality attributes. Therefore, using the same spacing for all varieties may not lead to optimum tuber quality. Thus, this experiment was conducted with the objective of determining some physical quality attributes of potato cultivars under different spacing and growing conditions.

MATERIALS AND METHODS
Description of Experimental Sites
The study was conducted under rain-fed condition 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    | 0.65 cmolc 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 varieties (Bubu, Badhasa, Zemen and Chiro) which are widely cultivated in eastern Ethiopia.

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

| No | Variety | Year of release | Growth habit | Plant height (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 m²). 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. Untifungicidal 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 liter to control late blight disease. Phosphorus fertilizer was applied at the rate of 92 kg P₂O₅ ha⁻¹ was done by banding the granules of DAP (diammonium phosphate) (18% N, 46% P₂O₅) at the depth of 10 cm below and around the seed tuber at planting. Nitrogen fertilizer was applied at the rate of 111 kg N ha⁻¹ (Anonymous, 2004).

Data Collection and Measurements
Geometric mean diameter (Dg) (mm): The size of ten randomly selected tubers from each plot were measured as length, width and thickness using a digital caliper with an accuracy of 0.01 mm. The geometric mean diameter (Dg) was calculated by using the following equation as described by Mohsenin (1970) as cited by Shehzad et al. (2013): 

\[ Dg = (LWT)^{0.333} \]

Where, \( L \) is the length, \( W \) is the width and \( T \) is thickness of the tuber.

Sphericity of the tuber (\( \Phi \)) (%): Tubers sphericity was determined by the following formula as described by Ahmadi et al. (2008):

\[ \Phi = \left( \frac{Dg}{L} \right) \times 100 \]

Where, \( \Phi \) is sphericity of the tuber, \( Dg \) is geometric mean diameter and \( L \) is length

Surface area (S) (mm²): Tubers surface area was determined according to Baryeh (2001) by the following formula:

\[ S = \pi Dg^2 \]
Where, $S$ is surface area and $D_g$ is geometric mean diameter

**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 Tukey 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**

**Geometric mean diameter**

The main effects of variety and seed tuber spacing significantly ($P < 0.01$) affected geometric mean diameter of the tuber at both locations. However, variety and plant spacing did not interact to influence this parameter at both locations (Appendix Table 1, 2 and 3).

At Haramaya, Bubu had the highest geometric mean diameter (46.76 mm$^3$) than the other varieties; whereas the other varieties are in statistical parity with each other. However, at Hirna, Bubu, Zemen and Chiro had higher geometric mean diameters (50.49, 49.34 and 49.11 mm$^3$, respectively) while Badhasa had the lower (45.83 mm$^3$). This is because of the production of large-sized tubers by Bubu, Zemen and Chiro varieties which resulted in high geometric mean diameter. Increasing plant spacing significantly increased geometric mean diameter. Thus, in general, 75 cm x 30 cm, 60 cm x 30 cm and 60 cm x 25 cm spacing resulted in higher geometric mean diameters compared to 45 cm x 20 cm and 50 cm x 25 cm spacing. This is because large-sized tubers are produced in response to wider spacing than narrower spacing, consequently resulted in higher geometric mean diameters (Table 14). Habtamu (2013) indicated that geometric mean diameter of potato was significantly influenced by variety and growing environment.

**Sphericity of tuber**

The main effects of variety and spacing significantly ($P < 0.01$) affected sphericity of tubers produced at both locations and the mean results of the locations. However, the interaction effect of variety and spacing did not influence this parameter at both locations (Appendix Tables 1, 2and 3).

Mean result of the two locations showed that Bubu, Badhasa and Chiro are more spherical in shape as compared to Zemen. On the other hand, decreasing plant spacing significantly increased tuber sphericity. More spherical tubers were obtained from narrow spacing of 45 cm x 20 cm (94.09%) and 50 cm x 25 cm (89.38%) (Table 14). This is because at narrower spacing, small-sized tubers are produced which are more or less spherical in shape as compared to tubers that are produced in response to wider spacing, which are usually wide and large in size and oval in shape.

The t-test of sphericity of the overall mean of the two locations revealed a non-significant difference. This indicates that tuber sphericity did not influenced by varied environmental factors across the locations.

**Surface area**

Both the main effects of variety and plant spacing significantly ($P < 0.01$) influenced surface area of potato tubers at both locations. However, the interaction effect of variety and plant spacing did not influence this parameter at both locations (Appendix Tables 1, 2 and 3).

At Haramaya, Bubu had the highest tuber surface area (6958 mm$^2$), while the remaining varieties had the lowest surface area and were in statistical parity with each other. However, under Hirna condition, the varieties Bubu, Zemen and Chiro had higher surface area of (8055, 7676 and 7622 mm$^2$, respectively). Consistent with the results of this study, Habtamu (2013) observed significant varietal and location differences for surface area of potato tubers. Increasing seed tuber spacing significantly increased surface area of potato tuber. Thus, at both locations, spacing of 75 cm x 30 cm, 60 cm x 30 cm and 60 cm x 25 cm resulted in the highest surface area while spacing of 45 cm x 20 cm and 50 cm x 25 cm led to the lowest surface area (Table 14). This is because at wider spacing large-sized tubers are produced which have higher surface area due to less stiffer competition for resources whereas at narrow spacing small-sized tubers are produced due to stiffer competition for growth factors.
Table 3. Geometric mean diameter, sphericity and Surface area of potato tubers as influenced by the main effects of variety and spacing at Haramaya and Hirna during the 2013 main cropping season.

| Variety   | Geometric mean diameter (mm$^3$) | Sphericity of tuber (%) | Surface area (mm$^2$) |
|-----------|---------------------------------|-------------------------|-----------------------|
|           | Haramaya | Hirna | Haramaya | Hirna | Mean | Haramaya | Hirna | Mean | Haramaya | Hirna | Mean |
| Bubu      | 46.76a   | 50.49a | 85.58ab  | 84.99ab | 85.28a | 6958a   | 805 5a | 83.04 | 83.49 | 5369 | 7504 |
| Badhasa   | 37.64b   | 45.83b | 86.04a   | 87.04a  | 86.54a | 4588b   | 6663b | 6766ab |
| Zemen     | 37.55b   | 49.34ab| 78.39b   | 79.55c  | 79.97b | 4562b   | 7676ab |
| Chiro     | 41.14b   | 49.11ab| 82.14ab  | 82.37bc | 82.62ab| 5367b   | 7622ab |
| LSD (0.05)| 3.461    | 2.662  | 5.543    | 3.107   | 3.454  | 839.3   | 770.2 |
| F-test    | **       | **     | **       | **      | **     | **      | **     |
| CV%       | 11.5     | 7.4    | 9        | 5       | 5.6    | 21.1    | 13.9   |

| Spacing   | Geometric mean diameter (mm$^3$) | Sphericity of tuber (%) | Surface area (mm$^2$) |
|-----------|---------------------------------|-------------------------|-----------------------|
|           | 75 cm x 30 cm                      | 60 cm x 30 cm | 50 cm x 25 cm | 45 cm x 20 cm | 75 cm x 30 cm | 60 cm x 30 cm | 50 cm x 25 cm | 45 cm x 20 cm |
| 75 cm x 30 cm | 44.95a   | 52.56a   | 76.27c  | 71.27c  | 73.77c | 6506a   | 8682a |
| 60 cm x 30 cm | 43.35ab  | 49.23ab  | 77.81c  | 76.30d  | 77.05bc | 6073a  | 7651ab |
| 60 cm x 25 cm | 41.34abc | 48.91ab  | 81.38bc | 82.65c  | 82.02b  | 5433ab | 7569ab |
| 50 cm x 25 cm | 38.05bc  | 46.99b   | 87.86ab | 90.90b  | 89.38a  | 4632b  | 6975b |
| 45 cm x 20 cm | 36.15c   | 45.77b   | 91.87a  | 96.31a  | 94.09a  | 4199b  | 6643b |
| LSD (0.05) | 3.87     | 2.976    | 6.197   | 3.474   | 3.862   | 938.4  | 861.1 |
| F-test    | **       | **       | **      | **      | **     | **     | **     |
| CV%       | 11.5     | 7.4      | 9       | 5       | 5.6    | 21.1   | 13.9   |

Overall mean:
Location Mean 40.77 48.69 83.04 83.49 5369 7504
T-test NS NS NS ** NS
LSD (0.05) 1.5 2.181 391.4

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. NS = non-significant difference. LSD = Least significant difference; CV % = Coefficient of variation and NS = non-significant difference.

SUMMARY AND CONCLUSION
The experiment was conducted out at Haramaya and Hirna, Hararghe highlands of Eastern Ethiopia. Randomized complete black design in factorial arrangement was used with three replications which comprised of 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 45 cm x 20 cm) and four levels potato varieties (Bubu, Badhasa, Zemen and Chiro). All physical quality attributes of potato responded significantly (P < 0.01) for the main effect of variety and spacing. At Haramaya, Bubu had the higher geometric mean diameter (46.76 mm$^3$) and surface area (6958 mm$^2$) of tuber than the other varieties. Sphericity of tuber was higher for Bubu (85.28%), Badhasa (86.54%) and Chiro (82.26%). At both locations, the wider spacing of 75 cm x 30 cm and 60 cm x 30 cm and 60 cm x 25 cm gave the highest geometric mean diameter and tuber surface area. However, narrow spacing (high planting density) of 45 cm x 20 cm and 50 cm x 25 cm resulted in the higher sphericity of tuber.

Acknowledgement

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**APPENDIX TABLE**

**Appendix Table 1.** Mean squares from analysis of variance (ANOVA) for some tuber quality attributes at Haramaya site

| Variables               | Replication | Variety (V) | Spacing (S) | V x S | Error |
|-------------------------|-------------|-------------|-------------|-------|-------|
| Degrees of freedom      | 2           | 3           | 4           | 12    | 38    |
| Geometric mean diameter | 13.72       | 280.81**    | 159.6**     | 34.58ns| 21.93 |
| Sphericity of tuber     | 23.03       | 189.2*      | 531.58**    | 20.63ns| 56.22 |
| Surface area            | 960543      | 18926975**  | 11110773**  | 2073641ns| 1289236|

**Appendix Table 2.** Mean squares from analysis of variance (ANOVA) for some tuber quality attributes at Hirna site

| Variables               | Replication | Variety (V) | Spacing (S) | V x S | Error |
|-------------------------|-------------|-------------|-------------|-------|-------|
| Degrees of freedom      | 2           | 3           | 4           | 12    | 38    |
| Geometric mean diameter | 21.88       | 60.2***     | 80.4**      | 7.64ns| 12.97 |
| Sphericity of tuber     | 25.66       | 158.08***   | 1263.47**   | 21.75ns| 17.66 |
| Surface area            | 1772568     | 5268714**   | 7309073**   | 653607ns| 1085611|
Appendix Table 3. Mean squares from analysis of variance (ANOVA) for some tuber quality attributes for the mean of the two locations

| Variables                | Replication | Variety (V) | Spacing (S) | V x S   | Error |
|--------------------------|-------------|-------------|-------------|---------|-------|
| Degrees of freedom       | 2           | 3           | 4           | 12      | 38    |
| Geometric mean diameter  | 17.131      | 129.828**   | 113.796**   | 11.091ns| 7.262 |
| Sphericity of tuber      | 24.08       | 171.22**    | 854.88**    | 9.28ns  | 21.83 |
| Surface area             | 1317716     | 9528818**   | 8871981**   | 653603ns| 499052|