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Influence of Plant Spacing and Seed Tuber Size on Yield and Quality of Potato (*Solanum tuberosum* L.) in Central Ethiopia

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Abstract

Plant spacing and seed tuber size are important agronomic management practices in the production of potato. However, potato farmers in Ethiopia often use haphazard plant spacing and seed tuber sizes, which contribute to the low yield of the crop. A study was designed to elucidating the effect of varied plant spacing and seed tuber sizes on yield and quality of potato. Average tuber weight was significantly affected by combined effects of plant spacing and seed tuber sizes. The highest average tuber weight (119.61 g) was obtained from 35-45 mm seed tuber sizes and at 75 × 30 cm plant spacing treatment combinations. Total tuber yield and marketable tuber yield significantly affected by plant spacing and seed tuber size where the maximum marketable tuber yield (33.68 t ha^{-1}) and total tuber yields (34.38 t ha^{-1}) were obtained at spacing of 60 × 30 cm and 50 × 20 cm, respectively, while highest total and marketable tuber yields of 36.16 and 37.65 t ha^{-1}, respectively, obtained from large-sized tubers (>56 mm). The yield of Starch was significantly affected by seed tuber sizes but, did not influenced significantly on specific gravity and tuber dry matter content of potato. The use of medium plant spacing 60 × 30 cm under seed tubers size of 35-45 mm are recommended for potato production over than other seed tubers size and plant spacing combinations, farmers can use to get maximum yield.

Keywords: Plant spacing; Seed tuber size; Yield; Tuber quality

Introduction

Potato (*Solanum tuberosum* L.) is the most important vegetable crop, constituting the fourth most important food crop in the world [1,2]. It is most important tuber crops in Ethiopia that play key roles as a source of food and cash income for smallholder farmers [3].

Potato crop is graded as a high potential food security and cash crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly <120 days) compared to major cereal crops like maize [4,5]. The country has about 70% of the available agricultural land suitable for potato production [6]. Even though, the country is endowed with suitable climatic and edaphic conditions the annual production of potato in Ethiopia is low (about 775,503 tons) and the national average yield is 7 tons/ha, which is very low as compared to the world's average of 17 tons/ha [7].

A major production problem of potato that account for such low yields could be unavailability and high cost of seed tubers, lack of well adapted cultivars, inappropriate agronomic practices, diseases, insect pests and inadequate storage [8]. The optimizing of plant density is one of the most important agronomic practices of potato production, because it affects seed cost, plant development, yield and quality of the crop [9].

Farmers who grow potatoes frequently give less regard to optimal plant population. The possibility of securing high yield depends on proper consideration of optimum number of plants per unit area [10]. Narrow spacing increased the hectare yield and decreased the yield per plant. According to Rajadrai [11] the highest yield was obtained with large sized tubers planted in narrow spacing. However, the combination of large size seed tubers and narrow spacing produced many small size tubers of low market value.

In all areas of Ethiopia, there is no separate plot and management for ware and seed potato production. Mostly, potato tubers are sorted into ware and seed immediately after harvest. For most potato producers seed potato is usually considered as the by-product of ware potato [5]. Potato tubers are planted by smallholder farmers at narrow and erratic spacing, very small tuber sizes resulting in non-optimum plant population and seed tuber size that may result in low tuber yields and quality of tubers. The objective of this research study was to determine optimum tuber seed size and plant density for maximum yield production and tuber quality.

Materials and Methods

Description of the study area

The study was conducted under irrigation during the year 2014 cropping season in off season at Holetta central highlands of Ethiopia. Holetta is situated at an altitude of 2400 meters above sea level at 9°N latitude and 38°29`E longitude and is located 40 km West of Addis Ababa along the Ambo road. The average annual maximum and minimum temperature is 22.1 C° and 6.2 C° respectively. The soil type in the area is predominantly Nitosol which is characterized with average organic matter (AOM) content of 1.8%, Nitrogen 0.17%, Phosphorous 4.55 ppm and Potassium 1.12 Meq/100 gm of soil and pH 5.24 (HARC).

Experimental treatments and design

The treatments consisted of four tuber seed sizes in millimeter (mm) (25-34, 35-45, 46-55 and >56 mm) and five plants spacing (75 × 30 cm, 60 × 30 cm, 60 × 20 cm, 50 × 30 cm and 50 cm × 20 cm). The experiment was laid out as a completely randomized block design (RCBD) in a factorial arrangement and replicated three times per treatment.

Data collection and analysis

Data on yield, yield components and quality variables were collected and subjected to analysis of variance (ANOVA) using the General Linear Model of the SAS statistical package (SAS, 2007). All significant pairs of treatment means were compared using the Least Significant Difference Test (LSD) at 5% level of significance.

Results and Discussion

Average tuber weight (g)

From the analysis of the variance, seed tuber sizes and plant spacing showed highly signi icant difference ($p<0.01$) on average tuber weight (Table 1). Highest average tuber weight (119.61 g) was recorded for plants grown from 35-45 mm seed tuber sizes and at 75 × 30 cm plant spacing treatment combinations this might be due to medium seed tuber sizes produced of optimum number of stems and wider plant spacing had less resource competitions they get high potential of resources whereas lowest average tuber weight (55.91 g) was obtained at 50 × 20 cm plant spacing and >56 mm seed tuber sizes treatment combinations. The present result agreed with the inding of Berga et al.[4] that average tuber weight decreased with an increase in mother tuber size. Similarly, Zabihi-Mahmoodabad et al. [12] reported that increase in density probably causes the increase in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight. The production of higher average tuber weight at wider plant spacing as compared to closer plant spacing was also reported by other authors [9,13,14].

Tuber Size	Plant Spacing				
	75 × 30 cm	60 × 30 cm	60 × 20 cm	50 × 30 cm	50 × 20 cm
>56 mm	84.63c	76.86cd	66.69defg	63.36fgh	55.91h
46-55 mm	104.35b	76.44cd	71.09defg	69.93defgh	65.74efgh
35-45 mm	119.61a	105.16b	76.99cd	72.92def	66.99defg
25-34 mm	75.69cde	74.57cde	69.16efgh	62.06gh	63.75fgh
LSD/5%	11.55				
CV/%	9.03				

Table 1: Average tuber weight as influenced by the interaction factors of plant spacing and seed tuber size. Means followed by the same letter(s) within a row and column are not significantly different at 5% level of significance. LSD=least significant difference, CV=coefficient of variation.

Total tuber yield

Plant spacing and seed tuber size signi icantly ($p<0.05$) affected total tuber yield, but the two factors did not interact to in luence the parameter (Table 2). The results showed that maximum marketable total tuber yield (34.88 t ha^{-1}) was obtained at plant spacing of 60 × 30 cm whereas the lowest (31.25 t ha^{-1}) was obtained at 50 × 30 cm. Plants grown at plant spacing of 60 × 30 cm produced higher total tuber yield higher than plants spaced at 50 × 30 cm and 75 × 30 cm by about 9.53 and 10.30%, respectively. In this study, plants spaced at 60 × 30 cm, 60 × 20 cm and 50 × 20 cm produced total tuber yields that exhibited statistically non-signi icant difference. The maximum yield was obtained at closer plant spacing than wider plant spacing except plants spaced 50 × 30 cm. This might be due to attributed to efficient use of available soil nutrients and other growth factors in plants grown at closer plant spacing than wider plant spacing. This result consistent with Beukema and Van der-Zaag [15] indicated that increased yield at higher densities might be due to the ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches are being formed and tuber growth starting earlier. In other words, increased plant population increased yield due to more tubers being harvested per unit area of land.

Based on the result the highest tuber yield (37.65 t ha^{-1}) was obtained from large seed tuber sizes (>56 mm) whereas the lowest yield (24.26 t ha^{-1}) was obtained from small seed tuber sizes. The use of large seed tuber size as planting material to produce higher total tuber yield significantly exceeded that of 35-45 mm and 25-34 mm tuber sizes by about 7.63 and 55.19%, respectively. The results showed that total tuber yield increased when seed tuber sizes increased from small to large as planting materials. The significant difference on tuber yield this might be due to large seed tuber size attributed high amount of food reserves that produce highest tuber yields. This result agreed with the results reported by Rojoni et al. [16] that yield was increased with increasing seed tuber size. The highest gross tuber yield was recorded in large seed size while the lowest was in small seed size. Gulluogl and Arıoglu [13] also indicated that small seeds gave the lowest tuber yield per plant due to increasing competition stem m^2 density, whereas large tubers encountered the least competition and gave the highest tuber yield per plant at same stem density.

Marketable tuber yield

Plant spacing and seed tuber size signi icantly ($p<0.05$) in luenced marketable tuber yield (Table 2). Highest marketable tuber yield (33.68 t ha^{-1}) was obtained in response to planting the tubers at the spacing of 60 × 30 cm whereas the lowest marketable tuber yield was recorded at the spacing of 50 × 30 cm. Plant spacing of 60 × 30 cm produced higher marketable yield than 50 × 30 cm and 75 × 30 cm plant spacing by about 12.04 and 9.53%, respectively. Plant spacing of 60 × 30 cm, 60 × 20 cm and 50 × 20 cm produced marketable tuber yield per hectare without significant difference. At closer plant spacing had efficient use of soil nutrients and other resources which led to produce high marketable tuber yield. Related results reported by Tesfa [17] that closer spacing of 50 × 25 cm and 60 × 25 cm recorded higher marketable tuber yield while wider spacing of 80 cm × 30 cm and 75 cm × 30 cm observed with lower marketable tuber yield. Similarly, Khalafalla [18] marketable yield increased at closer spacing high yielder than wider row spacing.

Signi icantly maximum marketable yield (36.16 t ha^{-1}) was obtained from larger seed tuber size whereas the lowest marketable tuber yield (27.62 t ha^{-1}) was obtained from small seed tuber size (Table 2). Large seed tuber sizes produce high yield than medium and large seed tuber sizes this might be due to the presence of high number of eyes which attributed to the production of many stems and had high amount food reserves that leads to produce high yield. his result consistent with Rojoni et al. [16] also suggested that high food reserves in large seed tubers produce higher yield through increase vegetative growth of plants and rapid development of tubers. Similarly, Allen and Wurr [19] reported that total yield increases with increase in seed tuber sizes. Unmarketable tuber yield: Plant spacing had signi icant (p<0.01) affected unmarketable tuber yield. However, the main factor of seed tuber size and the two interactions did not in luence unmarketable tuber yield (Table 2). he highest unmarketable tuber yield (1.79 t ha^{-1}) was obtained at closer plant spacing (50 × 20 cm) whereas the lowest unmarketable tuber yield was recorded at wider plant spacing (75 × 30 cm). In this study, plants spaced at 60 × 30 cm, 60 × 20 cm and 50 × 30 cm produced unmarketable tuber yields that exhibited statistically non-signi icant difference (Table 2).

The result showed that plants grown at closer spacing produced highest unmarketable tuber yield than plants grown at wider plant spacing. The significant difference in unmarketable tuber yield due to plant competition; at closer plant spacing had high competition of plants for growth factors due to high number plant per unit area than wider plant spacing which led to produce high number of under size tubers which was high unmarketable tuber yield. This result agreed with the results reported by Frezgi [20] that closest spacing which resulted in significantly higher yield of small tubers as the consequence of higher competition between plants. Tesfa [17] also indicated that at closer plant spacing produced high yield of unmarketable tubers than wider plant spacing. Plant spacing increases from 50 cm × 25 cm to 80 cm × 30 cm, the unmarketable tuber yield reduced.

Spacing	Parameter		
	MTY	UMTY	TTY
75 cm × 30 cm	30.49bc	0.76c	31.25b
60 cm × 30 cm	33.68a	1.20b	34.88a
60 cm × 20 cm	32.66ab	1.33b	33.99a
50 cm × 30 cm	30.06c	1.40b	31.47b
50 cm × 20 cm	32.68ab	1.79a	34.47a
LSD/5%	2.1	0.34	2.23
Tuber Size			
>56 mm	36.16a	1.49	37.65a
45-55 mm	34.74ab	1.3	35.96ab
35-45 mm	33.81b	1.22	34.98b
25-34 mm	22.95c	1.17	24.26c
LSD/5%	1.96	ns	1.99
CV/%	7.69	31.47	8.13

Table 2: Total and Marketable yields (t ha^{-1}) as influenced by plant spacing and seed tuber size.

Effect of plant spacing and seed tuber size on tuber size distribution

Tuber yield of large size (>75 g): he main factors of plant spacing, and seed tuber size had highly signi icantly (p<0.01) affected on yield of larger tuber sizes. However, the interaction factors of plant spacing and seed tuber size did not in luence on yield of larger tuber sizes (Table 3). he highest yield of large tuber size was recorded (17.06 t ha^{-1}) was obtained at wider plant spacing (75 × 30) whereas the lowest yield (11.72 t ha^{-1}) was obtained at closer plant spacing (50 × 30 cm). he results showed that when plant spacing increased closer plant spacing to wider plant spacing the yield of large tuber size was increased. his might be due to wider plant spacing had slight competition between plants for nutrients and growth factors than closer plant spacing which lead to produce high yield of large tuber sizes. his result agreed with the results reported by Khalafalla [18] that produce large size tubers increased with spacing increase but closer spacing produced more small size tubers.

Medium seed tuber size (35-45 mm) 14.82 t ha^{-1} gave higher yield of large tuber size which was more than small seed tuber size by about 29.39%. Similarly, >56 mm seed tuber size and 46-55 mm seed tuber size exceeded that of 25-34 mm seed tuber size by about 29.80 and 31.85%, respectively. Plants grown from medium seed tuber size did not produced high yield of large tuber sizes which were statistically difference from plants grown from large seed tuber size (>56 mm) (Table 3). Medium and large seed tuber sizes had produced highest yield of large tuber size than small seed tuber sizes. This result might be due to medium and large seed tuber sizes had higher food reserves that had high potentials to produce high yield of large tuber sizes than small seed tuber sizes. This result is in consistent with the finding of Gulluogl and Arroglu [13] Seed tuber size significantly affected on tuber yield. Both tuber yields per plant and per hectare consistently increased with increasing seed size. Similarly, Masarirambi et al. [21] and Khalafalla [18] reported that Seed size significantly affected tuber yield. Large seed tubers maintained higher yield than small seed tuber sizes. Mean tuber yield decreased as seed size decreased from large tubers to small tubers.

Tuber yield of medium size (39-75 g): he analysis of variance showed that the main factors of seed tuber size and plant spacing had highly signi icant (p<0.01) in luenced on yield of medium tuber size, but the two factors did not interact to in luence the parameter (Table 2). Plants grown at 60 × 20 cm plant spacing produced signi icantly maximum yield of medium tuber sizes than wider plant spacing (75 × 30 cm) which was more than by about 43.79%. Plant spacing of 60 × 30 cm, 60 × 20 cm, 50 × 30 cm and 50 × 20 cm produced yield of medium tuber sizes without signi icant difference (Table 3). At closer plant spacing had high yield of medium tuber sizes than wider plant spacing. When plant density increased the yield of medium tuber sizes was increased. his result might be due to higher number of plants per unit area produced at closer plant spacing than plants at wider spacing which lead to produced high yield of medium tuber size. his result agreed with the inding of Tesfa [17] reported maximum yield of medium size tubers was recorded for closer spacing (50 × 25 cm) whereas the lowest yield of medium size tuber was observed with wider (80 × 30 cm) plant spacing.

Use of large seed tuber sizes (>56 mm) in potato production had high potential of producing highest yield of medium tuber sizes whereas small seed tuber sizes produced the lowest yield of medium tuber sizes. Large seed tuber size (>56 mm) 12.18 t ha^{-1} was produced significantly the highest yield of medium tuber size than 35-45 mm and 25-34 mm seed tuber sizes by about 12.68 and 88.17%, respectively. Large seed tuber size (>56 mm) did not significantly difference with medium seed tuber size (46-55 mm) to produce high yield of medium tuber sizes (Table 2). When increased seed tuber size used for planting material from small to large seed tuber sizes the yield of medium seed tuber size also increased. This result might be due to the presence of high number of eyes on large seed tubers than small seed tuber sizes consequently produced high yield of medium tuber sizes. Related study was reported by Khalafalla [18] that tuber number m^2 increased with increasing seed tuber weight.

Tuber yield of small size (25-38 g): he main factors of plant spacing, and seed tuber size had signi icant ($p<0.01$) affected on yield of small tuber size. However, the interaction factors of seed tuber size and plant spacing did not in luence yield of small tuber size (Table 3). he highest yield of small tuber sizes was obtained at closer plant spacing (50 × 20 cm) which was higher yield by about 17.90, 23.67, 48.29 and 66.48% at plant spacing of 50 × 30 cm, 60 × 20 cm, 60 × 30 cm and 75 × 30 cm, respectively (Table 3). he general trend showed that as planting spacing reduced from 75 × 30 cm to 50 × 20 cm the yield of small tuber sizes was also increased. his result might be due to the high number of plants produced per unit area at closer plant spacing that results strong competition between plants for nutrients and growth factors and leads to the production of high yield of small tuber size. his result agrees with the inding of Tesfaye et al. that reported the highest number of small tubers was obtained at closer plant spacing whereas the lowest number of small potato tubers was found at wider plant spacing [22].

Spacing	Parameter		
	Small Tuber Size (25 g-38 g)	Medium Tuber Size (39 g-75 g)	Large Tuber Size (>75 g)
75 cm × 30 cm	5.46d	7.97b	17.06a
60 cm × 30 cm	6.12cd	11.10a	16.46a
60 cm × 20 cm	7.35bc	11.49a	13.82b
50 cm × 30 cm	7.71b	10.63a	11.72c
50 cm × 20 cm	9.09a	11.46a	12.13bc
LSD/5%	1.25	1.59	1.99
Tuber Size			
>56 mm	8.98a	12.59a	14.59a
45-55 mm	7.74b	12.18a	14.82a
35-45 mm	6.84b	10.69b	16.28a
25-34 mm	5.04c	6.67c	11.24b
LSD/5%	1.12	1.42	1.79
CV/%	21.14	18.29	16.98

Table 3: Tuber yield (t ha^{-1}) of Belete variety in different tuber sizes on the basis of tuber weight as influenced by plant spacing and seed tuber size. Means followed by the same letter(s) within a column are not significantly different at 5% level of significance. LSD=least significant difference, CV=coefficient of variation.

The use of different seed tuber sizes as planting materials had significant influence on yield of small tuber size. Maximum yield of small tuber size was obtained from the use of larger tuber seed sizes (>56 mm) as planting materials. The use of large seed tuber size as planting materials produced highest yield of small tuber size which exceeded plants grown from 46-55 mm, 35-45 mm and 25-34 mm tuber seed sizes by about 16.02, 31.29 and 78.17%, respectively (Table 3). Medium seed tuber size (35-45 mm) did not exhibit statistically difference with medium seed tuber size (46-55 mm) in producing yield of small tuber sizes. As the seed tuber size increased from small to larger seed tuber size the yield of small tuber sizes was also increased. This result might be due to the production of higher number of main stems per hill in plants grown from large tuber sizes that exerts high competition of resources between stems and tubers which leads to production of high yield of small tuber size. This result agreed with the finding of Lung'aho et al. [23] big seed tubers will result on the production of too many stems and tubers, which will compete for growth factors in the soil and become too small. Rajadrai [11] also indicated that number of tubers per plant increased with increasing seed tuber size and large size seed tubers produced significantly more number of tubers over small size seed tubers.

Influence of plant spacing and seed tuber size on tuber quality

Starch content: he production of starch per hectare was highly signi icantly ($p<0.01$) in luenced by the seed tuber size use as planting materials However, plant spacing and the interaction of seed tuber size and plant spacing did not in luence this parameter. Highest starch yield (8.07 t ha^{-1}) was obtained from plants grown from large seed tuber sizes whereas the lowest (5.45 t ha^{-1}) was obtained from plants grown from small seed tuber sizes (Table 4). Large seed tuber size (>56 mm) did not produce signi icantly different starch yield than medium seed tuber sizes (35-45 mm and 46-55 mm) (Table 11). Production of starch yield per hectare increased as the seed tuber size increased used for planting. his due to large seed tuber sizes had high amount food reserves which led to produce high starch yields.

Specific gravity of tubers (g/cm^3): Specific gravity which is an expression of density is the most widely accepted measurement of potato quality. Plant spacing, and seed tuber size recorded had high specific gravity of tubers which is between 1.11 to 1.13 g/cm^3. As a result, the main factors of plant spacing and seed tuber size are grouped under high specific gravity grades, which is acceptable for processing. The main factor of plant spacing and seed tuber size did not affect tuber specific gravity (Table 4). This might be due to the fact that most quality traits of potato including tuber specific gravity are controlled by genetic factors rather than the tuber size and plant spacing or other environmental factors [24,25]. In this study, only one variety (Belete) was used as experimental material specific gravity parameter was not affected by the planting material (tuber sizes) and plant spacing. The result agrees with the findings of Tesfaye indicated that plant spacing did not significantly affected tuber specific gravity. Similarly, Bikila et al. [26] also reported that tuber specific gravity was not affected by inter and infra row spacing.

Tuber dry matter content (%): The main factor of plant spacing and seed tuber size had no significant difference on dry matter content of tubers (Table 4). Dry matter content is an important quality determinant in potato processing and its higher content (>20%) allow lesser oil uptake, desirable texture and enhanced yield in the finished products [22,27,28]. Similarly, Kabira and Berga [29] reported that tuber dry matter contents of more than 20% are acceptable. In this study, maximum and minimum tuber dry matter recorded were 23.92% and 23.47% respectively indicating that both plant spacing and seed tuber size did not significantly affected tuber dry matter content of potato. The present result is in harmony with the findings of Tesfaye who confirmed that plant spacing did not significantly affected tuber dry matter content of potato.

Spacing	Parameter		
	SG	TDM	Starch yield t ha^{-1}
75 cm × 30 cm	1.13	23.65	7.02
60 cm × 30 cm	1.12	23.49	7.88
60 cm × 20 cm	1.12	23.59	7.21
50 cm × 30 cm	1.12	23.92	7.55
50 cm × 20 cm	1.11	23.79	7.02
LSD/5%	ns	ns	ns
Tuber Size			
>56 mm	1.11	23.47	8.07a
45-55 mm	1.12	23.82	8.087a
35-45 mm	1.12	23.78	7.73a
25-34 mm	1.12	23.68	5.45b
LSD/5%	ns	ns	0.95
CV/%	1.73	5.84	17.55

Table 4: Specific gravity, dry matter content, tubers sphericity, and total starch yield per hectare as influenced by plant spacing and seed tuber size. Means followed by the same letter (s) within a column are not significant different at 5% level of significance. LSD=least significant difference, CV=coefficient of vitiation.

Summary and Conclusion

In conclusion, the result of this study have revealed that plant spacing of 60 cm × 30 cm, 60 cm × 20 cm and 50 cm × 20 cm resulted in the production of higher marketable tuber yields than the other spacing. However, the amount of seed to cover a given area has to be considered the spacing of 60 × 30 cm plant more appropriate than the other two spacing for tuber yield production. Similarly, large (>56 mm) seed tuber sizes produced maximum marketable tuber yields than small and medium (35-45 mm) seed tuber sizes but medium tuber seed sizes (35-45 mm) were appropriate for tuber yield production by considering the seed tuber costs.

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