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Effect of plant density and varieties on seed size potato tuber production and fresh tuber yield

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ABSTRACT

Farmers in Munshiganj region are using different spacing below or above the national recommendation depending on the purpose of planting either for seed tuber or consumption due to lack of recommended plant spacing. Therefore, an experiment was conducted at the Tuber Crops Research Sub-Centre (TCRSC), Bangladesh Agricultural Research Institute (BARI), Munshiganj during 2023-24 with four types of spacing like S_1=75cm x 30cm, S_2=60 cm x 25cm (Control), S_3=50cm x 20cm and S_4=30cm x 15cm under four varieties viz. V_1=BARI Alu-25, V_2=BARI Alu-37, V_3=BARI Alu-62 and V_4=BARI Alu-79 with a view to find out suitable spacing for seed size potato tuber (28-40mm) production and fresh tuber yield in Munshiganj region. Results showed that the maximum (61.96%) seed size (28-40mm) potato tuber (% number) was produced by treatment combination V_1S_4 which was statistically at par V_1S_3 and statistically similar withV_3S_4, V_4S_3, V_3S_3 etc. Closer spacing is more suitable for seedsize potato tuber production than wider spacing. In case yield, the maximum tuber yield (35.27 t/ha) was obtained from treatment combination V_4S_4 which was statistically similar to V_3S_4, V_1S_4, V_1S_3 etc. Therefore, considering the seed size potato tuber production, final yield and yield contributing characters sowing of potato BARI Alu-25, BARI Alu-37, BARI Alu-62, BARI Alu-79 with closer spacing (30cm x 15cm) may be practiced to cultivate seed size potato tuber in our country.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crops in the world. In volume of production, it ranks fourth in the world after maize, rice and wheat, with an estimated production area of 18.9 million hectares (Naz et.al., 2011). Among root crops, potato ranks first in volume produced and consumed, followed by cassava, sweet potato, and yam (FAO, 2004). Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops and extensively grown in Munshigonj region. Crop production could be increased either by improving the inherent genetic potential of the crop or through application of better agronomic management, such as use of optimum plant density. One of the most important management practices for potato production is plant spacing. It depends on type of variety, fertility status of soil, plant architecture or growth habit etc. Potato varieties also differ on growth habit and other attributes. Therefore, using the same spacing for all varieties may not lead to optimum tuber yields. One of the main economic problems in the production of high-quality seed potatoes is their cost to end users. The cost of seed represents the greatest proportion of the total production cost and account for 30 to 50% of the total production expenses depending on the country or region (Kabir et al., 2004; Karim et al., 2010). Seed tuber size is an important factor to decide the seed rate per unit area because it affects total yield and graded or marketable tuber yields (Singh and Kushwah, 2010 and Dagne et al., 2019). Seed rate depends on the size of tubers used in potato planting. Appropriate seed tuber size has

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very important implication on potato production. The farmers prefer to use a different production system rather than recommended practice by research organization namely Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Gazipur. Farmers are used to use imported seed and have to buy a box of 50 (Fifty) kg seed potato at minimum 8000/- (Eight thousand taka). They plant cut tuber with densely maintaining spacing (40 cm x 15 cm) in addition to high dosages of fertilizer application (DAE, Munshiganj). Farmers think that planting whole tuber means misuse of seed potato and maintaining wider spacing is misuse of land. On the contrary, TCRC recommends whole tuber potato seed maintaining 60 mm x 25 cm spacing and less use of fertilizer. Plant spacing and seed tuber size are important agronomic management practices in the production of potato. Optimizing plant density is one of the most important agronomic practices for potato production, because it affects seed cost, plant development, yield and quality of the crop (Bussan et al., 2007). The yield of seed potato can be maximized at higher plant population (closer spacing) or by regulating the number of stems per unit area and to certain extent by removing the haulm earlier during the maturity (O'Brien and Allen, 2009). (Rahemi et al., 2005) reported that the effect of intra-row spacing on yield of potatoes was significant especially at 20 cm intra-row spacing, which showed 36.85% yield increment as compared to 30 cm intra-row spacing. Intra-row distance of 20 cm increased total tuber number and weight, and tuber weight per plant and the marginal return rate increased by 13% when intra-row distance decreased from 35 to 25 cm. The possibility of securing high yield depends on proper consideration for optimum number of plants per unit area. Availability of 40-50g tubers for planting is problem as it constitutes 20-25% of total seed production. Under the circumstance, farmers have option either use higher seed rate or optimize seed rate by cutting seed tubers. The ideal spacing and planting density are those that maximize marketable yield without unduly increasing costs. In order to achieve this, seed size and planting geometry must be exploited as these two components determine the amount of seed required per hectare for optimum population. Potato production and productivity is low due to several constraining factors such as inappropriate planting materials, prevalence of disease and pests, poor soil fertility (Menza et al., 2014), variability in climatic patterns, shortage of water, shortage of agricultural input, and poor post-harvest handling practices (Tesfaye et al., 2011). Potato plant has a multiplication rate ranging from 1:10 to 1:15. The seed is a costly and critical input in potato production and it alone accounts about 36-38% percent of the total cost of cultivation (Peer, 2013 and Raghuvanshi, 2018) in potato production. The situation of increase in seed cost further increases and becomes prime most factors in the cultivars, which produces the large size tubers. There is an acute shortage of small size (10-20g) healthy seed tubers during planting season of the potatoes. The tuber size profile can be reduced or expanded by altering inter and intra row seed spacing (Kumar et al., 2009). When potatoes are grown for seed, cultural practices need to be used in order to maximize the production of seed size tubers (Sanli, 2015). If farmers plant seed size (28-40mm) whole tuber with maintaining 60 cm x 25 cm there will be no chance of misuse of seed potato and land. The outcome will be very helpful for the farmers as insects and diseases free healthy seed size (28-40 mm) potato will be ensured by the farmer's own self. Farmers in the study area (Munshiganj, Bangladesh) are using different spacing below or above the national recommendation depending on the purpose of planting either for consumption or for seed tuber due to lack of recommended inter and intra-row spacing. Hence, it is important to maintain appropriate plant population per unit area to have high yield, marketable size and good quality of seed tuber. Even though different research is done in different parts of the country on potato plant density, the condition is not studied in Munshiganj. This study was therefore conducted to determine the best inter and intra-row spacing for optimum tuber seed yield and quality of potato seed tuber at Munshiganj, Bangladesh.

MATERIALS AND METHODS

Study location and experimental design

The experiment was conducted during the potato growing season of 2023–24 at the research field of the Tuber Crops Research Sub-Center (TCRSC), Bangladesh Agricultural Research Institute (BARI), located in Munshiganj. The research site is situated between 23°22′ N latitude and 90°28′–90°36′ E longitude. The TCRSC, Munshiganj, lies within Agro-ecological Zones (AEZ) 8, 9, 10, 12, and 16, with soil pH ranging from 5.2 to 7.5. The experimental design was a randomized complete block design (RCBD Factorial) with three replications. The study focused on optimization of plant density for seed size potato production with four potato varieties viz.: BARI Alu-25, BARI Alu-37, BARI Alu-62 and BARI Alu-79.

Planting Material and Plot Layout

The treatments consisted of four potato cultivars (V_1= BARI Alu-25, V_2= BARI Alu-37, V_3= BARI Alu-62 and V_4= BARI Alu-79) and four plant spacing between rows and plants, respectively: (S_1= 75 cm x 30 cm, S_2= 60 cm x 25 cm (Control, recommended spacing by TCRC), S_3 = 50 cm x 20 cm and S_4=30 cm x 15 cm). Generally, 60 cm × 25 cm spacing is being followed for table as well as for seed potato cultivation in Bangladesh, so S_2 (60 cm × 25 cm) served as control. The experiments were laid out in RCBD in a factorial arrangement and replicated three times.Uniformly sized, disease-free, well-sprouted whole tubers of the selected potato varieties were planted on November 20, 2023. Each experimental plot measured 3.0 m × 3.0 m.

Fertilization and soil management

The following fertilizers were applied: urea at 325 kg/ha, TSP at 220 kg/ha, MoP at 300 kg/ha, gypsum at 100 kg/ha, Zinc Sulphate at 14 kg/ha, and Boric Acid at 12 kg/ha. Additionally, cow dung was applied at 10 t/ha during the final land preparation. A full dose of TSP, MoP, gypsum, zinc sulphate, and boric acid, along with half of the urea, was applied in furrows at planting. The remaining half of the urea was top-dressed 30 days after planting (DAP).

Crop management

Irrigation, weeding, earthing up, and other intercultural operations were carried out as needed to ensure optimal crop growth. To control soil-borne insects such as ants, mites, cutworms, and aphids, Eco-furan was applied at 15 kg/ha during the final land preparation. Admire (0.2%) was sprayed in three installments at 45, 60, and 70 DAP to manage insect pests. For disease prevention, particularly against late blight, the crops were alternately sprayed with Cleanzeb and Dithane-M-45 (0.2%) five times at 30, 40, 50, 60, and 70 DAP.

Harvest and sample collection

Final harvesting was done on the 27th February, 2024. Data were taken on, plant height at 45 & 60 DAP, number of stem per hill at 45 & 60 DAP, foliage coverage (%) at 45 & 60 DAP, plant vigor (1-10) Scale at 45 & 60 DAP, tuber Grade (% by number) & (% by weight), Total tuber number/m^2 at 95 DAP, tuber fresh yield ton per hectare (t/ha), marketabletuber fresh yield ton per hectare (t/ha), non-marketable tuber fresh yield ton per hectare (t/ha) at 95 DAP and seed multiplication rate for tuber number and weight.

$$\text{Seed multiplication rate} = \frac{\text{Total tuber yield by number and weight/ha}}{\text{Seed rate by number and weight/ha}}$$

Statistical analysis

Significant tests were made by analysis of variance for Randomized Complete Block Design in factorial arrangement. The collected data on various parameters were statistically analyzed using the Statistix 10 software program. Mean values were compared using the least significant difference (LSD) test at the 1% or 5% level of probability.

RESULTS AND DISCUSSION

The results obtained from the experiment are presented and discussed character wise:

There was significant variation was found among the treatments in plant height (cm), number of stem/hill, foliage coverage (%), plant vigor (1-10 scale at 45 and 60 DAP (Table 1).

Plant height at 45 DAP

At 45 DAP; the highest plant height (60.00 cm) was recorded in V_4S_1, which was statistically at par with V_1S_1, V_1S_2 and V_2S_1 whereas the lowest plant height (39.67cm) was observed in V_2S_4 treatment combination (Table 1).

Plant height at 60 DAP

At 60 DAP; the highest plant height (80.33 cm) was recorded in V_1S_1, which was statistically similar to V_2S_1, V_1S_1, V_4S_1 etc. whereas the lowest plant height (56.87cm) was observed in V_3S_4 treatment combination (Table 1). The increase in height may be due to better availability of nutrients; water and sun light since plants in wider spacing have less competition and grow more shoots. But, densely populated plants show intensive competition which leads to decrease in plant height. The result of the experiment was in line with the findings of (Zamil et al., 2010) who reported that the widest spacing enhances growth and height of the plant which was significantly different from narrow spacing. They reported that significant effect of spacing on plant height; as a result of availability of wider inter row spacing for growth factor (Gebre and Giorgis, 2001).

Number of stem/hill at 45 DAP

The interaction effect between variety and spacing on number of stem/hill at 45 DAP was significant (Table 1). The highest (5.33) stem per hill was recorded from V_1S_1 which was statistically similar to V_1S_2, V_4S_1 and V_4S_2 whereas the minimum (3.00) number of stem per hill was recorded in V_3S_4 (Table 1).

Number of stem/hill at 60 DAP

The treatment V_4S_1 produced the maximum (6.00) number of stem per hill at 60 DAP which was statistically similar to V_4S_2 whereas the minimum (2.60) number of stem per hill was recorded in V_3S_4 (Table 1) (Masarirambi et al., 2012) conducted on four levels of seed tuber size and plant population, and reported significant differences in the number of main stems per plant across four seed sizes.

Foliage coverage (%) at 45 DAP

The maximum foliage coverage (93.33%) was found in V_4S_4 which was at par with V3S4 whereas the lowest foliage coverage (65.00%) was found from the treatment V_3S_1 (Table 1).

Foliage coverage (%) at 60 DAP

The maximum foliage coverage (95.33%) was found in V_4S_4 which wasstatistically similar to V_4S_3, V_1S_3 and V_1S_4 whereas the lowest foliage coverage (77.33%) was found from the treatment V_1S_1 (Table 1).

Plant vigor at 45 DAP (1-10 scale)

The maximum plant vigor (8.67) was observed in V_4S_1 treatment combination which was statistically similar with V_4S_2 and V_4S_4 whereas the minimum (6.0) plant vigor was noted in V_3S_1 (Table 1)

Plant vigor at 60 DAP (1-10 scale)

The maximum plant vigor (9.33) was observed in V_1S_2 treatment which was statistically similar with V_4S_4, V_1S_4 etc whereas the minimum (8.00) plant vigor was noted in V_1S_1 which was statistically at par with V_4S_2 (Table 1).

Tuber grade (% by number) at 95 DAP

There was significant variation was found for all the treatments in the tuber grade (<28mm, 28-40mm, 40-55mm and >55mm) (Table 2). V_2S_4 treatment combination produced the highest (23.00%) smaller sized tuber like <28mm whereas the lowest smaller sized tuber (9.41%) was found from V_3S_1 (Table 2). Narrower distance increases undersize and small tubers (Akasa et al., 2014 and Mangani et al., 2015; Dawinder et al., 2020). This confirms the present result where closer spacing gave higher small tuber than wider spacing. This result agrees with the finding of (Tesfaye et al., 2012) who reported that 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.

Table 1: Effect of plant density and varieties onplant height, number of stem per hill, foliage coverage (%) and plant vigor (1-10 scale) 45 & 60 DAP

Variety x Spacing	Plant height (cm) at 45 DAP	Plant height (cm) at 60 DAP	Number of stem per hill at 45 DAP	Number of stem per hill at 60 DAP	Foliage coverage (%) at 45 DAP	Foliage coverage (%) at 60 DAP	Plant vigor (1-10 scale) at 45 DAP	Plant vigor (1-10 scale) at 60 DAP
V_1S_1	59.53a	80.33a	5.33a	4.67cd	63.33g	77.33h	6.00e	8.00c
V_1S_2	55.33a	68.20c-f	4.33ab	4.00de	66.67fg	84.33e-h	6.33de	9.33a
V_1S_3	50.00b-e	66.33d-g	4.00bc	3.53ef	80b-e	93.00abc	6.67cde	8.67abc
V_1S_4	44.33efg	61.47fgh	3.47bcd	3.40ef	86.67ab	93.67abc	6.67cde	9.00ab
V_2S_1	55.67a	76.67ab	3.87bcd	4.00de	71.67efg	83.33fgh	6.67cde	8.67abc
V_2S_2	50.00b-e	69.07b-f	3.47bcd	3.20fg	76.67cde	87.00c-f	7.33a-e	8.67abc
V_2S_3	45.00efg	68.93b-f	3.20bcd	3.03fg	85.33abc	91.67a-d	7.67a-d	9.00ab
V_2S_4	39.67g	65.00efg	3.07cd	2.67g	92.33a	94.33ab	8.33ab	9.00ab
V_3S_1	55.33ab	69.80b-e	4.00cd	4.00de	65.00g	79.67gh	6.00e	8.33bc
V_3S_2	50.00b-e	62.67e-h	3.60bcd	3.00fg	75.00def	88.00b-f	7.00b-e	8.67abc
V_3S_3	46.00d-g	58.67gh	3.33bcd	3.00fg	84.67a-d	88.33a-f	8.00abc	9.00ab
V_3S_4	42.67fg	56.87h	3.00d	2.60g	92.00a	91.00a-e	7.67a-d	8.67abc
V_4S_1	60.00a	74.67abc	4.33ab	6.00a	63.33a	78.33gh	8.67a	9.00ab
V_4S_2	52.33bcd	73.67a-d	4.33ab	5.67ab	75.00def	85.00d-g	8.33ab	8.67abc
V_4S_3	48.67c-f	75.33abc	3.60bcd	5.00bc	85.33ab	91.67a-d	8.00abc	8.67abc
V_4S_4	53.67abc	74.47abc	3.60bcd	5.00bc	88.33ab	95.33a	8.33ab	9.00ab
Level of significance	**	**	*	**	**	**	**	*
CV (%)	7.87	7.07	19.17	10.35	7.46	4.86	12.55	6.36

Means bearing same letter (s) do not differ significantly at 1 or 5% level of probability by LSD
*= Significant at 5% level of probability,
S_1=75cm x 30cm, S_2=60 cm x 25cm, S_3=50cm x 20cm and S_4=30cm x 15cm
V_1=BARI Alu-25, V_2=BARI Alu-37, V_3=BARI Alu-62 and V_4=BARI Alu-79

The maximum (61.96%) seed size (28-40mm) tuber grade was produced by V_1S_4 treatment combination which statistically at par V_1S_3 and statistically similar with V_3S_4, V_3S_3 and V_4S_3 whereas the minimum (41.50%) seed size (28-40mm) tuber grade was produced by V_2S_2 which was statistically similar V_1S_1, V_1S_2, V_3S_2, V_4S_1 etc. to (Table 2). The highest (37.03%) tuber grade 40-55mm was found from treatment combination V_1S_1 while the lowest tuber grade 40-55mm (16.25%) was found from treatment combination V_2S_4 (Table 2). In case large sized tuber >55mm, the maximum (11.01%) was produced by V_4S_1 whereas the lowest (2.92%) was produced by treatment combination V_2S_4 (Table 2).

Tuber grade (% by weight) at 95 DAP

The variation due to effect of treatment combination for the entire tuber grade (<28mm, 28-40mm, 40-55m and >55mm) was found significant (Table 2). The highest (6.46%) smaller size potato tuber (<28mm) was produced by treatment combination V_1S_4 whereas the lowest smaller sized tuber (2.08%) was found from V_3S_1 (Table 2). The maximum (49.14%) seed size (28-40mm) tuber grade was produced by V_3S_4 which statistically at par withV_4S_4 whereas the minimum (22.25%) seed size tuber grade 28-40mm was produced by V_1S_1 (Table 2). The highest (56.66%) tuber grade 40-55mm was found from treatment combinationV_1S_1 while the lowest tuber grade 40-55mm (29.89%) was found from treatment combinationV_4S_1 (Table 2). In case large sized tuber >55mm, the maximum (33.08%) was produced by V_4S_1 whereas the lowest (7.20%) was produced by treatment combinationV_1S_4 (Table 2). The above findings for tuber grade (% by number) and (% by weight) at 95 DAP are in agreement with (Getachew et al., 2013) who concluded that tuber bulking of individuals at closer spacing were reduced and resulting in small tubers. (Khalafalla et al., 2001) also found closer spacing to result in smaller tuber sizes. Therefore, different varieties have different capacities of producing different tuber sizes based on number of tubers that a particular variety can set. Similar results also proposed by (Kushwah and Grewal 1990) and when the density of plant will increased the size of tuber was decreased. Reducing the plant population resulted in an increase in large sized tubers and this applied to all the four varieties. This may be because of few sinks available per unit area that resulted in less competition between the individuals at low plant densities. More resources where channeled to each individual tuber at low density plantings resulting in a high number of large sized tubers. In other studies (Güllüoglu and Arıoglu 2009) larger numbers of large sized tubers occurred when a wider spacing was used because of availability of growth requirements for the growth of the tubers.

Table 2: Effect of plant density and varieties on tuber grade at 95 DAP

Variety x Spacing	(% by number)				(% by weight)			
	<28mm	28-40mm	40-55mm	>55mm	<28mm	28-40mm	40-55mm	>55mm
V_1S_1	14.97c	42.68c	37.03a	5.32bc	2.61cd	22.25d	56.66a	18.48abc
V_1S_2	19.48ab	46.57c	27.79a-d	6.15abc	3.32a-d	24.24cd	49.95ab	22.48ab
V_1S_3	16.46abc	61.52a	18.69def	3.33bc	2.42cd	39.18a-d	46.82ab	11.58bc
V_1S_4	18.80ab	61.96a	17.49ef	1.74c	3.63a-d	36.28a-d	53.18a	7.20c
V_2S_1	22.383ab	47.04bc	22.30c-f	8.27ab	6.46a	32.00abcd	37.48b-e	24.08ab
V_2S_2	21.43ab	41.50c	30.39abc	6.67abc	5.05abc	28.48bcd	45.87abc	20.60abc
V_2S_3	21.553ab	45.71c	29.62abc	3.13c	4.24abc	36.62a-d	46.63abc	12.50bc
V_2S_4	23.007a	53.36abc	20.71b-f	2.92c	5.94ab	41.87ab	38.75b-e	13.44bc
V_3S_1	19.41ab	39.35c	34.60ab	6.63abc	2.08d	26.08bcd	52.10a	19.75abc
V_3S_2	16.82abc	43.18c	33.30ab	6.71abc	2.66cd	28.99bcd	47.48ab	20.87abc
V_3S_3	15.02bc	53.20abc	27.22a-e	4.56bc	3.18bcd	33.73a-d	44.88a-d	18.22abc
V_3S_4	15.93abc	60.86ab	19.63c-f	3.58bc	4.62abc	49.14a	32.08de	14.17bc
V_4S_1	15.97abc	45.96c	27.06a-f	11.01a	3.38a-d	33.65a-d	29.89e	33.08a
V_4S_2	14.09bc	52.71abc	26.62a-f	6.58abc	3.57a-d	35.76a-d	38.18b-e	22.49ab
V_4S_3	16.36abc	55.35abc	22.06c-f	6.23abc	3.31a-d	40.34abc	36.08b-e	20.28abc
V_4S_4	19.04ab	61.24ab	16.25f	3.467bc	5.99ab	47.90a	33.10cde	13.02bc
Level of significance	*	*	**	*	*	*	**	*
CV (%)	31.28	16.97	25.22	56	49.44	30.03	18.96	49.01

Means bearing same letter (s) do not differ significantly at 1 or 5% level of probability by LSD
*= Significant at 5% level of probability,
S_1=75cm x 30cm, S_2=60 cm x 25cm, S_3=50cm x 20cm and S_4=30cm x 15cm
V_1=BARI Alu-25, V_2=BARI Alu-37, V_3=BARI Alu-62 and V_4=BARI Alu-79

Total tuber number per m^{2}at 95 DAP

The results of total number of tuber (ha-1) as influenced by interaction effect of plant density and varietiesis presented in (Table 3). The highest (97.97) total tuber number per m2 was recorded at V_4S_4 treatment combination i.e. planting density (30 cm x 15 cm) and BARI Alu-79 which was statistically similar with V_3S_4 and the lowest (42.97) number was observed at low planting density (75 cm x 50 cm) with BARI Alu-25. All cultivars produced their maximum tuber numbers at the closer spacing than the wider one and there were gradual increments (Table 3). The total number of tubers per unit area increased linearly with increasing density. This is in agreement with Mangani et al. (2015); Arega et al. (2018); Dagne et al. (2019). However, the total number of tubers per stem decreased with increasing seed size and reduced spacing.

Average fresh tuber weight (g)

Significant variation was observed due to interaction effect of different types of varieties and spacing for average fresh tuber weight (g) (Table

3). The maximum mean tuber weight (58.50 g) was recorded from V_4S_1treatment combination which was statistically similar with V_4S_1. The smallest average fresh tuber weight (35.38 g) was recorded V_2S_4 which was statistically similar with V_1S_4, V_3S_4 and V_4S_4. Increase in density probably increased competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, resulted in decline of mean tuber weight. This result is in line with that of Ali (1997), who found higher average fruit weight at wider spacing as compared to closer spacing. Berga and Caesar (1990) also reported that stem number per plant and tuber number per plant are positively related, however, average tuber weight increased with wider spacing.

Tuber fresh yield (t/ha) at 95 DAP

Significant variation was observed due to interaction effect of different types of varieties and spacing for tuber fresh yield (t/ha) (Table 3). The maximum tuber yield (35.27 t/ha) was obtained from treatment combination V_4S_4 which was statistically similar to V_3S_4, V_1S_4,V_4S_3, V_1S_3 etc. whereas the lowest (18.28 t/ha) tuber fresh yield was produced by V_2S_1 which was statistically similar to V_1S_1 (Table 3). This result consistent with (Beukema and Van der-Zaag, 1990) 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. (Zebenay, 2015) also reported that the production of total number of tubers per hill increased as plants grown at narrow plant spacing and decreased at wider plant spacing. The genotype determines tuber number, tuber size and yield potential for any given cultivar (Wang, 2008). Varietal difference may occur for seed size tuber production as the cultivars vary in maturity and their bulking capacity. The increased yield was attributed to more tubers produced at the higher plant population per hectare although average tuber size was decreased because of increased inter-plant competition at closely spaced plants leading to more unmarketable tuber yield. At closer spacing there is high number of plants per unit area which brings about an increased ground cover that enables more light interception, consequently influencing photosynthesis. It is therefore, very likely that substantial increases in rate of land coverage and thereby tuber yield could be achieved by dramatically increasing the stem density per unit area. The present result agrees with the findings of (Zabihi et al., 2011) who reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and tuber quality. Increase in plant density led to decrease in mean tuber weight but number of tubers and yield per unit area were increased. In terms of seed tuber percentage, Multa was the best (72.60%) followed by Ailsa (71.82%) and Dheera (71.74%) under Bangladesh conditions (Mahmud et al., 2009). This indicates the variation in tuber bulking ability in different genotypes resulting in variation in proportion of seed size tubers among different varieties.

Marketable fresh tuber yield (t/ha) at 95 DAP

Significant variation was observed due to interaction effect of different types of varieties and spacing for marketable tuber fresh yield (t/ha) (Table 3). The maximum (30.22 t/ha) marketable tuber yield was obtained from treatment combination V_4S_4 which was statistically similar to V_3S_4, V_1S_4, V_1S_3 etc. whereas the lowest (11.10 t/ha) marketable tuber fresh yield was produced by V_3S^1 which was statistically similar to V_1S_1 (Table 2). This result is supported by the results of experiments done in Sudan, which revealed that marketable tuber yield of close in-row spacing of 15 cm and 25 cm increased and out-yielded wider (35 cm) spacing by 26 % (Khalafalla, 2001).

Non-marketable fresh tuber yield (t/ha) at 95 DAP

Significant variation was observed due to interaction effect of different types of varieties and spacing for non-marketable tuber fresh yield (t/ha) (Table 3). The maximum (7.17 t/ha) marketable tuber yield was obtained from treatment combination V_2S_1 which was statistically similar to V_2S_4, V_1S_4, V_4S_4 etc. whereas the lowest (1.19 t/ha) non-marketable tuber fresh yield was produced by V_3S_1 which was statistically similar to V_1S_1 (Table 3). This could be attributed to the facts that, under narrower spacing, a higher proportion of undersized tubers are produced, which are unmarketable. FrezgiAsgedom (2007) also reported that closest spacing resulted in significantly higher yield of small-sized tubers as the consequence of stiffer competitions between plants for resources such as moisture, nutrients, and light.

Seed multiplication rate (SMR)

Significant variations in seed multiplication rate (SMR) were recorded due to interaction effect of different types of varieties and planting density for tuber number. The highest (14.69) seed multiplication rate for tuber number was found from V_4S_4 treatment combination whereas the lowest (6.44) SMR was recorded from V_1S_1 treatment combination. For weight, interaction effect of different types of varieties and planting density was found significant. The maximum (17.64) SMR was recorded from the treatment combination V_4S_4 and the minimum (9.14) SMR was recorded from V_2S_1 (Table 3).

Table 3: Effect of plant density and varieties on total tuber number/m^2, total fresh tuber yield (t/ha), marketable fresh tuber yield (t/ha), non-marketable fresh tuber yield (t/ha) and seed multiplication rate for tuber number and weight at 95 DAP

Variety x Spacing	Total tuber number/m^2	Average fresh tuber weight (g)	Total fresh tuber yield (t/ha)	Marketable fresh tuber yield (t/ha)	Non-marketable fresh tuber yield (t/ha)	Seed multiplication rate for tuber number	Seed multiplication rate for tuber weight
V_1S_1	42.97h	51.07ab	22.06ef	19.16cd	2.90cd	6.44h	11.03efg
V_1S_2	49.85gh	48.47a-d	24.24c-f	20.55abc	3.69a-d	7.48gh	12.12d-g
V_1S_3	68.07def	46.46a-d	31.11a-d	28.43ab	2.69cd	10.21def	15.56a-d
V_1S_4	82.48bc	39.80bcd	32.19abc	28.16abc	4.03a-d	12.37bc	16.09abc
V_2S_1	43.52h	42.19bcd	18.28f	11.10d	7.17a	6.53h	9.14g
V_2S_2	59.89fg	43.89a-d	25.42c-f	19.82bcd	5.61abc	8.98fg	12.710c-g
V_2S_3	65.48ef	40.71bcd	26.35b-e	21.64abc	4.71abc	9.82ef	13.18b-f
V_2S_4	80.84bcd	35.38d	28.26a-e	21.67abc	6.59ab	12.07bcd	14.13a-f
V_3S_1	43.85h	49.31a-d	21.55ef	20.36abc	1.19d	6.58h	10.78fg
V_3S_2	48.96gh	50.51abc	24.46def	21.51abc	2.95cd	7.35gh	12.23d-g
V_3S_3	74.33cde	42.29bcd	30.48a-d	26.95abc	3.52bcd	11.15cde	15.24a-d
V_3S_4	92.85ab	36.67bcd	33.63ab	28.51ab	5.12abc	13.93ab	16.82ab
V_4S_1	47.19gh	58.50a	25.60c-f	21.85abc	3.75a-d	7.08gh	12.80c-f
V_4S_2	59.93fg	48.62a-d	29.11a-e	25.15abc	3.96a-d	8.99fg	14.56a-e
V_4S_3	70.336c-f	44.25a-d	31.04a-d	27.37abc	3.68a-d	10.55c-f	15.52a-d
V_4S_4	97.97a	36.01cd	35.27a	30.22a	6.65ab	14.69a	17.64a
Level of significance	**	*	**	*	*	**	**
CV (%)	12.82	19.94	16.61	23.66	48.43	12.62	15.94

Means bearing same letter(s) do not differ significantly at 1 or 5% level of probability by LSD
*= Significant at 5% level of probability,
S_1=75cm x 30cm, S_2=60 cm x 25cm, S_3=50cm x 20cm and S_4=30cm x 15cm
V_1=BARI Alu-25, V_2=BARI Alu-37, V_3=BARI Alu-62 and V_4=BARI Alu-79

CONCLUSION

The results of growth parameters and yield parameters were influenced by the interaction effect of plant density and varieties. All varieties had higher yields of small-sized tubers when they were combined with lower plant densities; however the yield reduced as spacing was widened.The result clearly indicated the maximum seed size (28-40 mm) tuber number (% by number) was recorded from variety BARI Alu-25 with spacing of 30 cm x 15 cm followed by variety

BARI Alu-62, BARI Alu-79 and BARI Alu-37. In conclusion, the result of this study have revealed that plant at the variety i.e. BARI Alu-25, BARI Alu-37, BARI Alu-62 and BARI Alu-79 with spacing of 30 cm × 15 cm resulted in the production of higher seed size (28-40 mm) and marketable tuber yields than the other spacing which was followed by spacing (50 cm x 20 cm). The highest (14.69) seed multiplication rate for tuber number was found from V_4S_4 treatment combination whereas the lowest (6.44) SMR was recorded from V_1S_1 treatment combination. For weight, the maximum (17.64) SMR was recorded from the treatment combination V_4S_4 and the minimum (9.14) SMR was recorded from V_2S_1 Therefore, considering the seed size potato tuber production, seed multiplication rate, marketable fresh tuber yield and yield contributing characters sowing of potato BARI Alu-25, BARI Alu-37, BARI Alu-62, BARI Alu-79 with closer spacing (30cm x 15cm) may be practiced to cultivate seed size potato tuber in our country which will be very helpful for the farmers to adopt the research practice for potato cultivation with whole tuber sowing with appropriate spacing.

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