



Growth and Quality Responses to Plant Spacing in Potato (*Solanum tuberosum* L.) Varieties

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was conducted during winter season of 2020 at Experimental Farm of Vegetable Sciences, DAV University, Jalandhar to study the growth and quality responses to plant spacing in potato (*Solanum tuberosum* L.) varieties. Experimental material consisted of four varieties (Kufri Pukhraj, Kufri Jyoti, Kufri Badshah, Kufri Chandramukhi) sown at three spacings (70 cm x 20 cm, 60 cm x 20 cm, 50 cm x 20 cm) and laid in Factorial Randomized Block design with three replications. Observations on number of leaves per plant at 30 DAS, number of leaves per plant at 60 DAS, number of leaves per plant at 90 DAS, Plant height (cm) at 30 Days After Sowing (DAS), Plant height (cm) at 60 DAS, Plant height (cm) at 90 DAS, average tuber weight (g), number of tuber plant, marketable tuber yield per plot (kg), unmarketable tuber yield per plot (kg), tuber yield per plot (kg), TSS, ascorbic acid (mg/100g), starch content (%) and dry matter content (%) were recorded. Analysis of Variance (ANOVA) revealed significant effect of spacing, varieties and their interaction for all the characters under study. It was observed that plants sown at spacing S₁ (70 cm x 20 cm) resulted in superior performance for most of the traits studied. Among cultivars, desirable results were observed in V₁ (Kufri Pukhraj). Considering the interaction of varieties and spacing it was concluded that Kufri Pukhraj sown at a spacing of 70 cm x 20 cm can result in superior performance with respect to growth, yield, and quality parameters of potato.

Keywords: *Plant spacing; randomized block design; plant height.*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) popularly known as 'king of vegetables' occupies a preponderant place in the food of many countries by the surface which it occupies, the jobs which it provides and the volume of production which it generates. It is most important vegetable crop, constituting the fourth most important food crop in the world. 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. India in particular and Asia in general are showing rapid growth in potato production. Potato is highly remunerative crop of Punjab and has large area cover. During the fiscal year 2020- 21, the volume of potato produced across India accounted for over 48 million metric tons. With a projected population increase of 19% by 2050, India faces a tremendous challenge to increase production of all food crops, including potatoes, to meet future demands [1].

Potatoes are grown across India under diverse agro-climatic conditions in almost all states except the coastal belt. Nearly 82% of potatoes are grown in northern India, in the vast Indo-Gangetic Plain (IGP) during short winter days from October to February/March. Since the Central IGP has milder winters, agriculture intensification is high, and farmers frequently cultivate three crops in a year. Punjab is known as the 'Seed Bowl' of the country because of absence or low presence of aphids during October. Potato varieties suited to the country's climate - hot summers and short winters - are grown on the Indo-Gangetic plain during the short winter days from October to March, while some year-round production takes place in relatively high altitude areas in the south and Northern hills.

There are many factors that affect yield and quality of specific vegetables which include fertilizer application, cultural practices, soil type, sowing method and cultural practices etc. The population of plant which is dependent on the spacing affects the growth and yield of vegetables. In case of spacing the yield is poor due to the improper spacing [2]. The use of spacing in crop production is very important, because it reduces competition between plants and weeds. Increased spacing reduces the number of plants per hectare thus affecting the yield. However decreased spacing increases plant population and yield per unit area up to a

certain limit, beyond which the yield decreases due to limitation in natural resources required for plant growth. Overcrowding of seedlings or plant in a particular area or spot may lead to increased competition among adjacent plants for available essential growth resources like sunlight, space, water and nutrient, as well as for aerial space for canopy formation which affects plant growth, yield and quality [3]. In the potato factors which influence yield and quality are cultivar, plant population, soil type, weather conditions, water management, fertilization, seed piece size, pests and diseases [4]. Planting density strongly affects yield and it is assumed that higher planting densities can result in more tubers and yield per square meter. Bussan et al., [5] and Creamer et al. [6], argued that optimizing plant density was one of the most important practices in potato production management, as it affects seed cost, plant development, yield and the quality of the crop. Plant population studies in potato are thought to be never out dated because newly developed cultivars have unique tuber characteristics and evolving industries constantly come up with new tuber size requirements [7]. In view of importance of the crop and role of spacing in its production the present study was planned and executed to study the response of plant spacing on growth and quality of potato.

2. MATERIALS AND METHODS

The present investigation was carried out at the Experimental Farm of Faculty of Agricultural Sciences, DAV University, Jalandhar during winter season of 2020-2021. The experiment was laid out in Factorial Randomized Block Design (FRBD) with the three replications. The experiment material consisted of four varieties viz., Kufri Pukhraj, Kufri Jyoti, Kufri Badshah, Kufri Chandramukhi and three spacings viz., 70 cm x 20 cm, 60 cm x 20 cm and 50 cm x 20 cm. The organic manure (Farm Yard Manure) and inorganic fertilizers (150kg/ha N, 100kg /ha P₂O₅ and 100kg/ha K₂O) were applied in the experimental field and the cultural practices were done as per the package of practices of Punjab Agricultural University. Before planting, sprouted seed tubers of potato were dipped in the solution of Dithane M-45 @ 2.5 g l⁻¹ for 20 minute in a tray to avoid any external and internal fungal infection. Each solution was used only three times for dipping sprouted tuber lets. The treated tubers were planted on ridges at a spacing depending upon the respective treatments. The observations on number of leaves per plant at

30, 60 and 90 DAS, Plant height (cm) at 30, 60 and 90 DAS, average tuber weight (g), number of tuber plant, marketable tuber yield per plot (kg), unmarketable tuber yield per plot (kg), tuber yield per plot (kg), TSS, ascorbic acid (mg/100g), starch content (%) and dry matter content (%) were recorded as per the methods given by Ranganna, 1977 and analyzed statistically. The statistical analysis of data recorded during the course of investigation for all the characters was done by analysis of variance method for factorial randomized block design described by Panse and Sukhatme [8].

3. RESULTS AND DISCUSION

3.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) revealed significant differences among plant spacing and varieties for all the traits while, the interaction between varieties and spacing showed significant differences for all the characters except TSS and dry matter content (%) (Table 1).

3.2 Number of Leaves per Plant at 30DAS, 60 DAS and 90DAS

Perusal of data (Table 2) revealed maximum number of leaves per plant at 30 DAS (11.22) in V_4 (Kufri Chandramukhi) which was statistically at par with V_1 (Kufri Pukhraj) which produced (9.89) leaves per plant. Minimum number of leaves per plant (6.55) observed in V_2 (Kufri Jyoti) was statistically at par with V_3 (Kufri Badshah) producing (8.22) leaves per plant at 30

DAS. Among spacing, maximum number of leaves per plant at 30 DAS (9.50) was observed in plants sown at S_1 (70 cm x 20 cm) which was statistically at par with the number of leaves per plant (9.16) observed in plants sown at S_3 (50 cm x 20 cm). Minimum number of leaves per plant (8.25) was observed in S_2 (60 cm x 20 cm) which was statistically at par with leaves of plants at 30 DAS sown at S_3 (50 cm x 20 cm) (9.16). Number of leaves per plant at 30 DAS showed significant differences in interaction between varieties and spacing. Table 2.1 depicted that maximum number of leaves per plant (12.67) in $V_4 \times S_1$ (Kufri Chandramukhi x 70 cm x 20 cm) which was statistically at par with $V_4 \times S_3$ (Kufri Chandramukhi x 50 cm x 20 cm) (12.00). Minimum number of leaves per plant (6.00) was observed in $V_2 \times S_2$ (Kufri Jyoti x 60 cm x 20 cm) which was statistically at par with $V_2 \times S_3$ (Kufri Jyoti x 50 cm x 20 cm) and $V_2 \times S_1$ (Kufri Jyoti x 70 cm x 20 cm) which produced 7.00 and 7.67 leaves per plant at 30 DAS respectively. At 60 DAS maximum number of leaves per plant (40.77) were observed in V_1 (Kufri Pukhraj) which was statistically at par with V_4 (Kufri Chandramukhi) which produced (40.44) leaves per plant. Minimum number of leaves per plant (36.55) was observed in V_2 (Kufri Jyoti) which was statistically at par with V_3 (Kufri Badshah) which produced (38.22) leaves per plant at 60 DAS. Among spacing, maximum number of leaves per plant (40.17) was observed in plants sown at S_1 (70 cm x 20 cm) which was statistically at par with the number of leaves per plant (39.17) observed in plants sown

Table 1. Analysis of variance for growth and yield parameters of potato

Observations	MSS Factor A	MSS Factor B	MSS Factor A x B
Number of leaves per plant at 30 DAS	36.92*	5.02*	3.35*
Number of leaves per plant at 60 DAS	35.48*	19.00*	7.37
Number of leaves per plant at 90 DAS	34.55*	20.36*	8.22*
Average tuber weight (g)	9602.83*	1,429.45*	5,752.24*
Plant height (cm) at 30 DAS	8.15*	4.14*	15.76*
Plant height (cm) at 60 DAS	171.00*	151.08*	80.31*
Plant height (cm) at 90 DAS	9.88*	8.44*	20.29*
Number of tuber per plant	259.45*	9.46*	13.14*
Marketable yield per plot (kg)	103.41*	24.15*	18.16*
Unmarketable yield per plot (kg)	0.82*	0.43*	0.24*
Tuber yield per plant (g)	5719.75*	5278.71*	3532.43*
Tuber yield per plot (kg)	1.85*	1.71*	1.15*
TSS	3.75*	0.91*	0.19*
Ascorbic acid (mg/100g)	147.47*	23.002*	28.12*
Starch Content (%)	7.22*	4.96*	7.11*
Dry matter content (%)	15.38*	9.17*	6.69*

Factor A = Varieties; Factor B = Spacing

Table 2. Effect of varieties and spacing on growth parameters of Potato

Treatment	Number of leaves per plant at 30 DAS	Number of leaves per plant at 60 DAS	Number of leaves per plant at 90 DAS	Plant height (cm) at 30 DAS	Plant height (cm) at 60 DAS	Plant height (cm) at 90 DAS
Varieties						
V ₁	9.89	40.77	60.77	26.97	56.89	68.67
V ₂	6.55	36.55	56.55	25.77	61.22	67.22
V ₃	8.22	38.22	58.22	24.73	66.22	66.11
V ₄	11.22	40.44	60.33	26.36	66.77	67.44
CD (5%)	1.06	1.38	1.43	0.99	5.49	1.48
SE (d)	0.51	0.66	0.68	0.47	2.63	0.07
Plant spacing						
S ₁	9.50	40.17	60.17	26.56	66.16	68.25
S ₂	8.025	37.67	57.67	25.93	59.08	67.25
S ₃	9.16	39.17	59.17	24.73	62.25	66.58
CD (5%)	0.94	1.20	1.25	0.85	4.76	1.28
SE (d)	0.44	0.57	0.59	0.41	2.28	0.62

Table 2.1. Interaction effect of varieties and spacing on growth parameters of potato

Varieties/Plant spacing	Number of leaves per plant at 30 DAS			Number of leaves per plant at 60 DAS			Number of leaves per plant at 90 DAS			Plant height (cm) at 30 DAS			Plant height (cm) at 60 DAS			Plant height (cm) at 90 DAS		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
V ₁	9.67	10.00	10.00	42.33	40.00	40.00	62.33	60.00	60.00	28.10	27.09	25.71	64.33	53.33	53.00	71.33	68.00	66.67
V ₂	7.67	6.00	6.00	37.67	36.00	36.00	57.67	56.00	56.00	27.26	23.84	26.21	67.33	50.66	65.66	68.33	65.66	67.67
V ₃	8.00	8.00	8.66	38.00	38.00	38.67	58.00	58.00	58.67	26.42	26.48	23.30	68.33	66.00	64.33	68.00	68.00	66.11
V ₄	12.67	9.00	12.00	42.67	36.67	42.00	62.67	56.67	62.00	24.45	28.90	23.20	64.66	66.33	66.00	65.33	67.33	69.66
CD (5%)	1.85			2.40			2.48			1.71			9.52			2.56		
SE (d)	0.88			1.15			1.47			0.83			4.56			1.22		

Table 3. Effect of varieties and spacing on yield and quality parameters of potato

Treatments	Average tuber weight (g)	Number of tuber per plant	Marketable yield per plot (kg)	Unmarketable yield per plot (kg)	Tuber yield per plant (g)	Tuber yield per plot (kg)	TSS (°B)	Ascorbic acid (mg/100g)	Starch Content (%)	Dry matter content (%)
Varieties										
V ₁	107.71	30.10	13.86	0.16	161.00	2.90	4.94	21.11	13.90	17.10
V ₂	67.35	25.12	9.85	1.45	110.60	1.99	3.87	12.19	12.26	15.81
V ₃	67.14	21.57	6.47	1.24	105.00	1.89	3.53	12.87	12.11	14.26
V ₄	27.70	17.45	13.15	0.89	123.00	2.22	3.62	15.48	11.99	16.93
CD (5%)	19.45	1.17	1.59	0.19	36.00	0.65	0.29	2.50	0.86	1.61
SE (d)	9.31	0.56	0.76	0.09	17.25	0.31	0.14	1.19	0.41	0.77
Plant spacing										
S ₁	79.00	24.47	9.92	0.89	148.05	2.06	3.99	15.58	13.30	16.96
S ₂	66.14	23.52	12.14	1.33	107.10	1.93	3.71	16.69	12.11	15.89
S ₃	57.29	22.69	13.04	1.26	119.70	0.25	4.26	13.94	12.22	15.22
CD (5%)	16.84	1.01	1.38	0.17	31.17	0.56	0.25	4.33	0.74	1.39
SE (d)	8.07	0.48	0.56	0.08	14.94	0.27	0.12	2.07	0.59	0.66

Table 3.1. Interaction effect of varieties and spacing on yield parameters of potato.

Varieties/Plant spacing	Number of tuber per plant			Marketable yield per plot (kg)			Unmarketable yield per plot (kg)			Average tuber weight (g)			Tuber yield per plant (g)			Tuber yield per plot (kg)		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
V ₁	29.40	31.53	29.37	14.47	13.21	13.91	0.61	0.62	1.18	159.35	137.54	26.25	197.40	67.20	123.20	3.55	1.21	1.89
V ₂	24.67	26.20	24.50	4.43	11.22	13.91	1.10	1.58	1.66	48.57	50.68	102.81	113.40	121.80	110.60	2.04	2.19	1.74
V ₃	19.60	19.30	25.80	6.28	5.40	7.22	1.24	1.03	1.46	79.18	53.15	59.12	126.00	92.40	105.00	2.27	1.66	1.73
V ₄	17.10	17.06	18.20	12.14	13.15	14.15	0.89	1.33	1.26	28.90	23.20	31.01	155.40	147.00	161.00	2.79	2.64	3.25
CD (5%)		2.03			2.76			0.34		33.68			62.35			1.12		
SE (d)		0.97			1.32			1.16		16.14			29.87			0.53		

Table 3.2. Interaction effect of varieties and spacing on quality parameters of potato

Varieties/Plant spacing	TSS			Ascorbic acid (mg/100g)			Dry matter content (%)			Starch Content (%)		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
V ₁	4.90	4.41	5.48	21.58	25.24	16.50	18.64	18.36	14.29	15.92	13.82	11.96
V ₂	4.03	3.37	4.20	15.66	10.59	10.33	15.23	15.99	16.20	12.77	11.54	12.46
V ₃	3.50	3.43	3.66	12.17	13.48	12.47	15.17	13.75	13.32	13.93	10.55	11.87
V ₄	4.76	3.63	3.70	12.41	17.47	16.47	18.24	15.47	15.22	10.58	12.53	12.86
CD (5%)	NS			4.33			NS					
SE (d)	0.24			2.07			1.33					

at S_3 (50 cm \times 20 cm) while, significantly minimum number of leaves per plant (37.67) was observed in S_2 (60 cm \times 20 cm). Among interactions, maximum number of leaves per plant (42.67) were observed in $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) which was statistically at par with $V_{1 \times S_1}$ (Kufri Pukhraj \times 70 cm \times 20 cm) (42.33), $V_4 \times S_3$ (Kufri Chandramukhi \times 50 cm \times 20 cm) (42.00), $V_{1 \times S_2}$ (Kufri Pukhraj \times 60 cm \times 20 cm) (40.00) and $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm) (40.00). Minimum number of leaves per plant (36.00) was observed in $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) which was statistically at par with $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm) and $V_{2 \times S_1}$ (Kufri Jyoti \times 70 cm \times 20 cm) which produced 37.00 and 36.67 leaves per plant at 60 DAS respectively. Maximum number of leaves per plant at 90 DAS (60.77) was observed in V_1 (Kufri Pukhraj) which was statistically at par with V_4 (Kufri Chandramukhi) which produced (60.44) leaves per plant. Minimum number of leaves per plant (56.56) was observed V_2 (Kufri Jyoti) which was statistically at par with V_3 (Kufri Badshah) producing (58.22) leaves per plant. Among spacing, maximum number of leaves per plant (60.17) was observed in plants sown at S_1 (70 cm \times 20 cm) which was statistically at par with the number of leaves per plant (59.17) observed in plants sown at S_3 (50 cm \times 20 cm). Minimum number of leaves per plant (57.67) was observed in S_2 (60 cm \times 20 cm) which was significantly lowest than other spacing. Among interaction effects at 90DAS, maximum number of leaves per plant (62.67) was observed in $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) which was statistically at par with $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) (62.33). Minimum number of leaves per plant (56.00) was observed in $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) and $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm) which was statistically at par with $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) (56.67), $V_2 \times S_1$ (Kufri Jyoti \times 70 cm \times 20 cm) (57.67), $V_3 \times S_1$ (Kufri Badshah \times 70 cm \times 20 cm) (58.00) and $V_3 \times S_2$ (Kufri Badshah \times 60 cm \times 20 cm) (58.67).

The wider spacing results in maximum number of leaves per plant at 30 DAS, 60 DAS and at 90 DAS. The reduced spacing caused increased population density which might have promoted plant competition for sunlight, nutrients, water and space. The findings corroborates with the findings of earlier researchers viz., Mvumi et al., [9]; Mangani et al., [10] and Takele et al., [11] who observed higher number of leaves with increased plant spacing in potato. Significant

variations among varieties for number of leaves per plant could be due to their genetic makeup differences. Similar results were obtained by earlier researchers viz., Mangani et al. [10] in potato. Interaction effects of varieties and spacing were also significant for number of leaves per plant indicating the influence of spacing on varieties for the number of leaves per plant. The results are in line with the findings of Mvumi et al [9]; Mangani et al [10]; Takele et al., [11].

3.3 Plant Height (cm) at 30DAS, 60 DAS and 90DAS

Effect of varieties and spacing on plant height (cm) at 30DAS, 60 DAS and 90DAS has been presented in table 2. Plant height at 30 DAS was observed maximum (26.97 cm) in V_1 (Kufri Pukhraj) which were statistically at par with plant height of V_4 (Kufri Chandramukhi) (26.36 cm). Minimum plant height (24.73 cm) was observed in V_3 (Kufri Badshah) which was significantly lowest than all the varieties. Among spacing, maximum plant height (26.56 cm) was observed in plants sown at S_1 (70 cm \times 20 cm) which was statistically at par with the plant height (25.93 cm) observed in plants sown at S_2 (60 cm \times 20 cm). Minimum plant height (24.73 cm) was observed in S_3 (50 cm \times 20 cm) which was significantly lowest than height of plants sown in other spacing. Interaction effect of varieties and spacing at 30DAS, 60 DAS and 90DAS has been presented in table 2.1. Plant height at 30 DAS showed significant differences in interaction between varieties and spacing. Maximum plant height (28.90 cm) was observed in $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) which was statistically at par with $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm), $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) and $V_2 \times S_1$ (Kufri Jyoti \times 70 cm \times 20 cm) which produced plant height at 30 DAS to the tune of 28.10 cm, 27.09 cm and 27.26 cm, respectively. Minimum plant height (23.20 cm) was observed in $V_4 \times S_3$ (Kufri Chandramukhi \times 50 cm \times 20 cm) which was statistically at par with $V_3 \times S_3$ (Kufri Badshah \times 50 cm \times 20 cm), $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) and $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) which produced 23.30 cm, 23.84 cm and 24.45 cm, respectively tall plants at 30 DAS.

Data depicted that at 60 DAS maximum plant height (66.67 cm) was observed in V_4 (Kufri Chandramukhi) which was statistically at par with plant height of V_3 (Kufri Badshah) (66.22 cm) while, V_1 (Kufri Pukhraj) produced shortest

plants with the plant height of (56.89 cm) which was statistically at par with V_2 (Kufri Jyoti) having 61.22 cm plant height. Among spacing tallest plants (66.17 cm) were observed at S_1 (70 cm \times 20 cm) which was statistically at par with the plant height of plants spaced at S_3 (50 cm \times 20 cm) (62.25 cm). Among interaction effects of varieties and spacing, it was maximum (68.33 cm) in $V_3 \times S_1$ (Kufri Badshah \times 70 cm \times 20 cm) which was statistically at par with all the interactions effects except $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) (53.33 cm), $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm) (53.00 cm) and $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) (50.67 cm). Minimum plant height was observed in $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) which produced plants with the plant height of (50.67 cm) which was statistically at par with plant height observed in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) and $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm) which produced (53.33 cm) and (53.00 cm) tall plants, respectively.

At 90 DAS, V_1 (Kufri Pukhraj) produced tallest plants (66.67 cm) which were statistically at par with V_4 (Kufri Chandramukhi) and V_2 (Kufri Jyoti) which produce (67.44 cm) and (67.22 cm) tall plants, respectively. Among spacing, tallest plants (68.25 cm) were observed when sowing was done at a spacing of S_1 (70 cm \times 20 cm) which was statistically at par with plants sown at a spacing of S_2 (60 cm \times 20 cm) having plant height of (67.25 cm). Interaction effect of varieties and spacing for plant height at 90DAS was maximum (71.33 cm) in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) which was statistically at par with the plants sown in interaction of $V_4 \times S_3$ (Kufri Chandramukhi \times 50 cm \times 20 cm) which produced 69.67 cm tall plants. Shortest plants (65.33 cm) were observed in $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) which were statistically at par with plant height of $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) (65.67 cm), $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) (67.33 cm), $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm) (67.67 cm) and $V_3 \times S_3$ (Kufri Badshah \times 50 cm \times 20 cm) (66.11 cm).

Increase in plant height with increase in plant spacing was observed in the experiment at 30 DAS, 60 DAS and 90 DAS. This could be due to reduced plant competition for sunlight, water and nutrients in wider spacing. The results are in conformity with the study done by Barry et al [7] who stated that decreased spacing resulting in increased population density, increase the plant competition for nutrients, water and space

resulting in short plant height in potato. Similar results were also observed by Arega et al [12] in potato, Hussain et al (2013) in tomato and Idoko et al (2015) in sweet potato.

Varietal response towards plant height was significantly different at 30 DAS, 60 DAS, 90 DAS. These differences are likely due to varietal differences associated with their canopy structure and growth habit. Simongo et al., [13] attributed differences in stem height to the differences that the cultivar had in canopy structure. The Canopy structure has an effect on photosynthesis as it increases the rate at which incoming solar radiation is intercepted. This occurs when the canopy has features that increase photosynthesis like erect leaves. Overall a canopy that has higher photosynthetic rate will have a higher growth rate and stem growth. The results were in agreement with the finding of Mangani et al. [10]. Interaction effect of varieties and spacing on plant height at 30 DAS, 60 DAS, 90 DAS indicates the strong influence of spacing on varietal response. It was maximum when spacing was wider. The results are in agreement with earlier researchers Viz., Zamil et al (2010) and Arega et al [12] who observed taller plants when plant spacing was increased in potato.

3.4 Average Weight of Tuber (g)

The data pertaining to effect of varieties and spacing on average weight of tuber (g) is presented in Table 3. It was revealed that average weight of tuber was maximum (107.76g) in V_1 (Kufri Pukhraj) which was significantly superior to all other varieties. Minimum average weight of tuber (27.70g) was produced by V_4 (Kufri Chandramukhi) which was significantly lowest than all other varieties. Among spacing, maximum average weight of tuber (79.00g) was observed in S_1 (70 cm \times 20 cm) which was significantly highest among all other spacings. Minimum average tuber weight (57.29g) was observed when spacing was S_3 (50 cm \times 20 cm) which was statistically at par with average weight of tubers of plants sown at S_2 (60 cm \times 20 cm) (66.14g). Among interaction effects of varieties and spacing, maximum average weight of tuber (159.35g) was observed in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) which was statistically at par with the average tuber weight observed in $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) producing (137.54g) average tuber weight. Minimum tuber weight (23.20g) was observed in interaction $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) which

was statistically at par with tuber weight observed in $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm) (26.25g), $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) (31.01g), $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) (50.68g), $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm) (102.81g) and $V_3 \times S_2$ (Kufri Badshah \times 60 cm \times 20 cm) (53.15g) (Table 3.1).

Average tuber weight showed a decreasing trend with decrease in inter row spacing. This could be due to decreased plant competition due to increased plant spacing. Similar results were obtained by earlier researchers Viz ., Zabihi et al., [14]; Arega et al [12]; and Dagne et al., [15] in potato who also observed significant effect of spacing on tuber weight and more tuber size was observed with increased spacing. Significant varietal response in terms of tuber size weight could be due to their different genetic makeup. Significant interaction effect of varieties and spacing for average tuber weight indicates the role spacing in determining the tuber weight. The results are in line with the finding of Zabihi et al., [14]; Arega et al., [12] and Dagne et al ., [15].

3.5 Number of Tubers per Plant

Data on number of tubers per plant as affected by varieties and spacing is presented in Table 3. Persual of data revealed that V_1 (Kufri Pukhraj) produced maximum number of tubers per plant (30.10) which was significantly highest than other varieties. While, minimum number of tubers per plant (17.06) was observed in V_4 (Kufri Chandramukhi) which was significantly lowest than other varieties. Among spacing S_1 (70 cm \times 20 cm) resulted in maximum number of tubers per plant (24.47) which were significantly superior than other spacing. Minimum number of tuber per plant (22.69) was observed in spacing S_3 (50 cm \times 20 cm) which was statistically at par with the number of tuber per plant observed in S_2 (60 cm \times 20 cm) producing 23.52 tuber per plant.

Number of tubers per plant showed significant differences in interaction between varieties and spacing. It was maximum (31.53) when plants were sown in interaction $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) which was statistically at par with $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) (29.40) and $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm) (29.37). $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) produced minimum number of tuber per plant (17.06) which was statistically at par with the tubers per plant produced by plants

sown in interaction $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) (17.10) and $V_4 \times S_3$ (Kufri Chandramukhi \times 50 cm \times 20 cm) (18.20) (Table 3.1).

Significant differences for number of tubers per plant was observed among spacing and varieties and their interaction effects . It was observed that number of tubers per plant reduced with increased plant spacing . Arega et al , [12] also reported that with increased plant spacing there was decreased number of tubers per plant. Significant influence of plant spacing on important yield and yield contributing traits in potato was also observed by Zabihi et al., [14]. Varied response of different varieties with respect to number of tubers per plant was also observed by earlier researchers Sultana and Shahiduzzam [17] in sweet potato. Interaction effect of varieties and spacing was also found significant for number of tuber per plant by Mvumi et al [9] in sweet potato.

3.6 Marketable Yield per Plot (kg)

The data pertaining to marketable yield per plot as affected by varieties and spacing is presented in Table 3. Maximum marketable yield per plot (13.86 kg) was observed in V_1 (Kufri Pukhraj) which was statistically at par with V_4 (Kufri Chandramukhi) producing marketable yield per plot to the tune of 13.15 kg. V_3 (Kufri Badshah) produced minimum marketable yield per plot (6.48 kg) which was significantly lowest than all other varieties. Among spacing, maximum marketable yield per plot (13.05 kg) was observed in S_1 (70 cm \times 20 cm) which was statistically at par with the marketable yield per plot (12.14 kg) of plants sown at a spacing of S_2 (60 cm \times 20 cm). Minimum marketable yield per plot (9.92 kg) was observed at S_3 (50 cm \times 20 cm) which was significantly lowest than all other varieties. Interaction effect of varieties and spacing was significant for marketable yield per plot. Maximum marketable yield per plot was observed in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) which was statistically at par with $V_4 \times S_3$ (Kufri Chandramukhi \times 50 cm \times 20 cm), $V_1 \times S_3$ (Kufri Pukhraj \times 50 cm \times 20 cm), $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm), $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm), $V_4 \times S_2$ (Kufri Chandramukhi \times 60 cm \times 20 cm) and $V_4 \times S_1$ (Kufri Chandramukhi \times 70 cm \times 20 cm) which resulted in marketable yield per plot to the tune of (14.15 kg), (13.91 kg), (13.91 kg), (13.27kg), (13.15 kg) and (12.14kg), respectively.

Significant interaction effect of varieties and Spacing for marketable yield per plot was also observed by earlier researchers Mangani et al., [10]. There was increased marketable yield with wider spacing. Due to minimum competition at wider spacing, plants absorbed the significantly available resources and intercepted more light. This increased their photosynthetic efficiency for higher photo assimilates production and ultimately result in increased marketable yield. The results are similar to the finding of Khalafalla et al [4] in sweet potato and Takele et al [11] who also observed higher marketable yield with wider spacing in potato and Ara et al., [17] and Ahrbha et al., [18] in tomato. Marketable yield per plot (kg) varied significantly among varieties. It was maximum in Kufri Pukhraj which also showed maximum average tuber weight and number of tubers per plant. The variable response of varieties for marketable yield per plot attribute to their genetic makeup. The findings are in line with the results of earlier reserchers Mangani et al., [10] and Tessema et al., [19] in potato.

3.7 Unmarketable Yield per Plot

Data presented in (Table 3) showed that maximum unmarketable yield per plot (1.45kg) was produced by V_2 (Kufri Jyoti) which was significantly highest among all the varieties. However minimum marketable yield per plot (0.16kg) was observed in V_1 (Kufri Pukhraj) which was significantly lowest among all varieties. Plants sown in spacing S_1 (70 cm \times 20 cm) resulted in minimum unmarketable yield per plot (0.89 kg) which was significantly lowest than other spacing. Maximum unmarketable yield per plot (1.27kg) was observed in S_3 (50 cm \times 20 cm) which was statistically at par with the unmarketable yield of plants (1.13kg) sown at a spacing of S_2 (60 cm \times 20 cm).

Interaction effect of varieties and spacing (Table 3.1) revealed that minimum unmarketable yield per plot (0.61kg) was observed in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) which was statistically at par with the unmarketable yield per plot produced by $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) (0.62kg) and $V_4 \times S_1$ (Kufri Chandramukhix 70 cm \times 20 cm) (0.89kg). Maximum unmarketable yield per plot (1.66kg) was observed in $V_2 \times S_3$ (Kufri Jyoti \times 50 cm \times 20 cm) which was statistically at par with $V_2 \times S_2$ (Kufri Jyoti \times 60 cm \times 20 cm) (1.58 kg) and $V_3 \times S_3$ (Kufri Badshah \times 50 cm \times 20 cm) (1.46 kg).

Unmarketable yield responded significantly for varieties, spacing and their interaction. It was minimum for plants sown at 70 cm \times 20 cm spacing. The results are in conformities in findings of Takele et al., [11] and Arega et al., [12] who also observed more number of undersized, diseased and deformed tubers in closer spacing. Unmarketable yield was also significantly influenced by the varieties which could be due to their genetic makeup. The results are in line with the findings of Tessema et al., [19] in potato. Significant interaction effect of varieties and spacing for unmarketable yield indicates the importance of spacing in decreasing unmarketable tubers in potato. It was reported higher in closer spacing. Similar results were observed by Mangani et al., [10].

3.8 Tuber Yield per Plant (g) and Per Plot (kg)

Tuber yield per plant as affected by varieties and spacing (Table 3) depicted that maximum tuber yield per plant (161.00 g) and per plot (2.90 kg) was observed in V_1 (Kufri Pukhraj) which was significantly highest than all other varieties. Minimum tuber yield per plant (105.00 g) was observed in V_3 (Kufri Badshah) which was statistically at par with V_2 (Kufri Jyoti) producing (110.60 g) tuber yield per plant while tuber yield per plot was significantly minimum (1.89kg) in V_2 (Kufri Jyoti). Among spacing, maximum tuber yield per plant (148.05 g) and per plot (2.66 kg) was observed in spacing S_1 (70 cm \times 20 cm) which was significantly highest than all other spacings. Minimum tuber yield per plant (107.10 g) and per plot ((1.93 kg) was observed in S_2 (60 cm \times 20 cm) which was statistically at par with tuber yield of plants sown in S_3 (50 cm \times 20 cm) (tuber yield per plant 119.70 g) and (tuber yield per plot 2.05 kg). Interaction effect of varieties and spacing on tuber yield per plant and per plot (Table 3.1) revealed maximum tuber yield per plant (197.40 g) and per plot (3.55 kg) in $V_1 \times S_1$ (Kufri Pukhraj \times 70 cm \times 20 cm) which was statistically at par with $V_4 \times S_3$ (Kufri Chandramukhix 50 cm \times 20 cm), $V_4 \times S_1$ (Kufri Chandramukhix 70 cm \times 20 cm) and $V_4 \times S_2$ (Kufri Chandramukhix 60 cm \times 20 cm) which produced 161.00 g, 155.40 g and 147.00g, tuber yield per plant and 3.25 kg, 2.79 kg and (2.64 kg) tuber yield per plot, respectively. Minimum tuber yield per plant (67.70g) and was tuber yield per plot was produced by $V_1 \times S_2$ (Kufri Pukhraj \times 60 cm \times 20 cm) which was statistically at par with the tuber yield per plant in all the interaction except $V_1 \times S_1$, $V_4 \times S_3$, $V_4 \times S_1$ and $V_4 \times S_2$.

Tuber yield per plant and per plot revealed similar trend for different spacing and varieties and their interaction. It was observed highest with wider spacing (70 cm × 20 cm) where as lowest at medium spacing. This could be attributed to the compensation effect of closer spaced plants than the wider spaced plants by more number of tubers per plants and more average tuber weight which resulted in high tuber yield of potato per plant leading to higher tuber yield per plot. Masarirambi et al., (2012); Lamessa and Zewdu [20]; Szarvas et al., [21] and Takele et al., [11] also studied the effect of spacing on yield of potato and concluded that at wider spacing yield was more than narrow spaced plants in potato and in sweet potato [22]. Significant differences for tuber yield per plant and per plot among different varieties was also observed by earlier researchers, Habtamu et al., [23], Eatan et al., [24], and Tessema et al., [19] in potato. Significant interaction effect for total yield per plant and plot among varieties, spacing and their interaction was also observed by Mangani et al., [10]. Higher yield in Kufri Pukhraj was also reported by Dash et al., [25].

3.9 TSS (Total Soluble Solids)

Data representing the effect of varieties and spacing on TSS (Table 3) revealed that V_1 (Kufri Pukhraj) resulted in maximum TSS (4.93^0B) which was significantly highest among all the varieties. Minimum TSS (3.53^0B) was observed in V_3 (Kufri Badshah) which was at par with TSS of V_4 (Kufri Chandramukhi) (3.62^0B). Among spacing, plants sown at a spacing of S_3 (50 cm × 20 cm) produced maximum TSS (4.26^0B) which was significantly highest than all other spacing. Minimum TSS (3.71^0B) was observed in plants sown at S_2 (60 cm × 20 cm) which was significantly lowest than all the spacing. Interaction effect of varieties and spacing on TSS was non significant.

Significant effect of spacing on TSS content was also observed by earlier researchers viz., Koodi et al [26], Narayan et al., [27] in potato and Gohawar and Ughade., [28] in beet root. Varieties also varied significantly for TSS content in research conducted by Abbasi et al., [29].

3.10 Ascorbic Acid (mg/100g)

Data representing the effect of varieties and spacing on ascorbic acid (Table 3) depicted that maximum ascorbic acid (21.11 mg/100g) was observed in V_1 (Kufri Pukhraj) which was

significantly highest than all varieties. Minimum ascorbic acid (12.19mg/100g) was observed in V_2 (Kufri Jyoti) which was statistically at par with V_3 (Kufri Badshah) (12.88 mg / 100g). Among spacing, S_2 (60 cm × 20 cm) resulted in maximum ascorbic acid content (16.70 mg / 100g) which was statistically at par with S_1 (70 cm × 20 cm) (15.59 mg/100g). Table 3.2 reveals that among interaction effects of varieties and spacing maximum ascorbic acid (25.24 mg / 100 g) was observed in $V_1 \times S_2$ (Kufri Pukhraj × 60 cm × 20 cm) which was significantly higher than all the interaction effects except $V_1 \times S_1$ (Kufri Pukhraj × 70 cm × 20 cm) which resulted in ascorbic acid content to the tune of (21.58 mg / 100g). Minimum ascorbic acid (10.33mg/100g) was observed in $V_2 \times S_3$ (Kufri Jyoti × 50 cm × 20 cm) which was statistically at par with the ascorbic acid content of $V_2 \times S_2$ (Kufri Jyoti × 60 cm × 20 cm) (10.59), $V_4 \times S_1$ (Kufri Chandramukhi × 70 cm × 20 cm) (12.40mg/100g), $V_3 \times S_3$ (Kufri Badshah × 50 cm × 20 cm) (12.47 mg/100g) and $V_3 \times S_1$ (Kufri Badshah × 70 cm × 20 cm) (12.70 mg / 100 g).

Ascorbic acid is one of the important antioxidant present in potato. It plays major role in preventing diseases related to aging. Effect of varieties, spacing and their interaction was significant for ascorbic acid content. It was reported to be high in wider plant spacing. Narayan et al., [27] and Koodi et al., [26] also observed higher ascorbic content at wider spacing on tomato and sweet potato, respectively. Varietal differences for ascorbic acid content was also observed by Valcarcel et al., (2015) and Quequezana et al., [30] in potato. Significant differences among interaction of spacing and variety was also observed Narayan et al., [27] in tomato.

3.11 Dry Matter Content (%)

Perusal of data (Table 3) revealed maximum dry matter content (17.10%) in V_1 (Kufri Pukhraj) which was statistically at par with the dry matter content observed in V_4 (Kufri Chandramukhi) (16.93%) and V_2 (Kufri Jyoti) (15.81%). Minimum dry matter content (14.26%) was observed in V_3 (Kufri Badshah) which was statistically at par with dry matter content observed in V_2 (Kufri Jyoti) (15.81%). Among spacing, maximum dry matter content (16.96%) was found in plants sown at a spacing of S_1 (70 cm × 20 cm) which was statistically at par with dry matter content observed in plants sown at S_2 (60 cm × 20 cm) (15.89%). Interaction effect of varieties and

spacing on dry matter content was non significant.

Dry matter content is overriding factor governing the quality of potato. It determines the culinary quality of potato. A higher content is more desirable as it allows lesser oil uptake, desired texture and enhanced yield in finished products. A wider spacing resulted in higher dry matter content. The present findings are harmony with the finding of Getachew et al., [31] and Mangani et al., [10] in potato. Significant role of genetic makeup as depicted by the significant variation among different varieties for dry matter content was also advocated by Abebe et al., [32] and Tessema et al., [19] in potato.

3.12 Starch Content (%)

Starch content significantly varied with varieties and spacing. Table 3) showed maximum starch content (13.90%) in V₁ (Kufri Pukhraj) which was significantly highest than all other varieties. Minimum starch content (11.99 %) was observed in V₄ (Kufri Chandramukhi) which was statistically at par with V₂ (Kufri Jyoti) (12.25) and V₃ (Kufri Badshah) (12.12 %). among spacings, S₁ (70 cm × 20 cm) resulted into maximum starch content (13.30%) which was significantly highest than all other spacing. Plants sown at S₂ (60 cm × 20 cm) spacing resulted in minimum starch content (12.11 %) which was statistically at par with the starch content (12.23 %) of the plants sown at S₃ (50 cm × 20 cm).

Effect of interaction between varieties and spacing on starch content showed that V₁ × S₁ (Kufri Pukhraj × 70 cm × 20 cm) resulted in maximum starch content (15.92 %) which was significantly highest than other interaction effects. Minimum starch content (10.58 %) was observed in V₄ × S₁ (Kufri Chandramukhi × 70 cm × 20 cm) which was statistically at par with V₃ × S₂ (Kufri Badshah × 60 cm × 20 cm) (10.59%), V₂ × S₂ (Kufri Jyoti × 60 cm × 20 cm) (11.54%), V₃ × S₃ (Kufri Badshah × 50 cm × 20 cm) (12.47%) and V₃ × S₁ (Kufri Badshah × 70 cm × 20 cm) (11.96%) (Table 3.2).

Wider spacing resulted in higher starch content which might be due to favorable conditions created by spacing by way of enhancing the availability of major nutrients. The present results are in close conformity with the finding of Koodi et al., [26] in Sweet potato and Dagne et al., [15] in potato. Varietal differences for starch

content was also observed by Abebe et al., [32] and Jatav et al., [33] in potato. Interaction effect of varieties and spacing also indicates the influence of spacing. It was reported higher in wider spacing. The results are in line with the findings of Koodi et al [26] and Dagne et al. [15].

4. CONCLUSION

The discussion mentioned earlier about the effect of spacing on growth, yield and quality traits of potato boils down to one fact that spacing plays an important role in deciding the performance of cultivars in terms of growth, yield and quality traits. Among all the varieties studied Kufri Pukhraj performed best for growth, yield and quality traits. Spacing 70 cm x 20 cm favored growth, yield and yield and quality traits while, narrow spacing 50 cm × 20 cm has manifested the undesirable results. Thus it can be concluded that Kufri Pukhraj performed better when planted at 70 cm × 20 cm in Jalandhar region. In order to arrive at field recommendation, the experiments on potato under the same treatments need to be conducted for more crop season.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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