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Research Article

Impact of different nucleus tuber sizes on growth, yield, and physiology attributes of potato production

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Abstract

Potato is the most important short-season annual herbaceous crop. Small nucleus tuber seeds are difficult to germinate and emerge in the field. This research evaluated how potato nucleus tuber size impacts seed production and plant development. We used the Randomized Complete Block Design (RCBD) in the first week of June to seed six potato nucleus tuber sizes: T1 (0.47 g), T2 (0.84 g), T3 (2.0 g), T4 (5.0 g), T5 (10 g), and T6 (25.0 g). Plants were 30 cm apart, and rows were 76 cm apart. All treatments significantly differed in terms of days to first germination, germination percentage, flowering, physiological maturity, number of main stems per plant, tuber weight, marketable tuber yield, size of large tuber, tuber starch content, and total starch yield. However, the interaction between treatment and environment had no effect on marketable tuber yield. This research found that treatment T1 had substantial outcomes in germination (22.5), blooming (67.5), and physiological maturity (107.1). Larger tubers T6 (25.0 g) contain more buds, which increases germination percentage (%), number of main stems, plant height, yield, and physiological parameters, outperforming other treatments. This research found that seed tuber size affects crop development. Plants from bigger seed tubers performed better than those from smaller seeds.

Keywords: Gilgit; *in vitro* plantlets; mini tubers; nucleus seeds; potatoes

Introduction

The potato, scientifically known as *Solanum tuberosum* L., belongs to the Solanaceae family. It is an annual herbaceous crop with a short growing season that provides a high caloric yield in a short time. It is a cash crop and a low-cost food source crop, after wheat, rice, and maize (Naz *et al.*, 2024). An estimated 359,071,407 metric tons of potatoes are produced worldwide every year on 16,494,810 ha of land (Asnake *et al.*, 2023). Pakistan's potato crop is very important, grown on 0.310 million hectares of land and produces 7.9 million

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metric tons of potatoes every year. Crop productivity is low in Pakistan due to biotic and abiotic stressors, but the main cause is a shortage of superior seeds at the right time and price for farmers. Pakistan spends approximately 120 million USD annually on importing potato seed for the cultivation of 15,000 acres (Dogar *et al.*, 2023). During the process of field propagation, however, some disease-free plants may become contaminated with diseases. Propagation material can be damaged by bacterial, fungal, and viral contamination; hence, it is often required to be replaced. However, some disease-free plants can get infections during field propagation. Viral, fungal, and bacterial contamination may damage propagation material; thus, it must be replaced generally (Al-Hussaini *et al.*, 2015). Therefore, it is necessary to multiply disease-free plants or tubers using in vitro techniques, and there is a need for enhanced tissue culture propagation methods to attain this objective. The tissue culture plant produces micro-tubers and mini tubers of potato seed. Mini tubers may be stored for months and planted in the field, making them easier to handle than in vitro plants. Thus, micro-tubers increase seed potato formation (Mamiya *et al.*, 2020). Mini tubers are cultivated in controlled environments, such as greenhouses or screenhouses particularly intended for this purpose, using plantlets produced in vitro. Subsequently, these mini tubers are deployed into the field. Potato farmers received mini tubers that had been planted in seed potato farms and propagated for 2–5 years before being delivered to potato growers (Boubaker *et al.*, 2023).

The use of potato seeds directly in field conditions presents a challenge in terms of germination and emergence, primarily due to their small size. There are significant factors that influence the generation of potato seed material, including the yield of mini-tubers from micro-plants, and a lot of variables contribute to the number of mini-tubers, including the density of plants, the length of their growth period, and their genetic makeup (Öztürk and Dumanoğlu, 2021). Several biometric parameters, including plant height, the number of compound leaves, and the number of stems, were shown to influence the number of mini tubers produced by each plant. This was discovered by researchers at the Central Scientific Research Institute of Potato in India (Filippova *et al.*, 2021). The output of mini-tubers from micro-plants affects potato seed material production, along plant density, growth time, and genetic composition. This study aims to improve the income and food security of smallholder farmers by identifying the optimal seed tuber size for the economical production of potatoes, focusing on the morphological and physiological effects of various nucleus seed sizes across different environmental locations.

Materials and Methods

This research was conducted in the tissue culture laboratory at the National Institute for Genomics and Advanced Biotechnology (NIGAB), National Agricultural Research Center (NARC), and field experiments were conducted at two different locations in Gilgit, i.e., Babusar and Naltar, during the cropping season of 2023–24. *In-vitro* plants of "Asterix" were taken out of nutrient media. First washed thoroughly with distilled water and then treated with fungicide (5 g/l), shifted to trays, and kept in a greenhouse for 2 weeks. In this last step of tissue culture, these plants were transferred to a screen house for tuberization. Among these nucleus tubers, six different tuber sizes were selected for field experiments to investigate the effect of potato nucleus tuber on the yield of plants as shown in Table 1. Six potato nucleus tuber sizes were sown in the first week of June using RCB Design with three replications at different locations with plant-to-plant 30 cm and row-to-row 76 cm. Each treatment consisted of 90 tubers, 30 tubers in each block and each block contained 3 rows 10 tubers in each. To attain accurate results, uniform cultural practices were used for all treatments for every replication. The plants were watered as per need.

Table 1. List of treatments under two different locations

Treatments	Tuber weight	Treatments	Tuber weight
T1	0.47 g	T4	5.0 g
T2	0.84 g	T5	10.0 g
T3	2.0 g	T6	25.0 g

Morphological parameters

Days to first germination were recorded by counting the days from the date of tuber sowing to days to the first germination date. Germination percentage was measured by dividing the number of plant emergence by the number of tubers sown with the help of the following formula:

$$\text{Germination percentage } = \frac{\text{Numberofplantemergence}}{\text{numberoftubersown}} \times 100$$

The plant height was determined by measuring the distance from the surface of the soil to the highest point of growth on 10 plants per plot using a meter rod when the plants reached physiological maturity. The number of primary stems per plant was determined by counting randomly selected plants from each plot at the stage of fifty percent flowering. The main stems are the parts that directly develop from the mother tuber and function as independent plants above the surface of the soil. Days to maturity were calculated from the date of sowing to the date of maturity of potato plants. We measured the average height of ten plants per plot from the soil surface to the top-most growing point at physiological maturity using a meter rod.

Yield parameters

After harvesting the crop, tubers per plant were counted from randomly selected 10 potato plants from each plot and then their average was used for the final analysis. Single tuber weight (g) was measured for each randomly selected plant tuber on the digital balance. For tuber yield (t/ha), all tubers from each plot were weighed and changed into tons per hectare. Marketable tuber yield (t/ha) was calculated by weighing all the tubers that were free from disease, defects, cracks, and other physiological disorders and not underweight (100 g) per net plot area and converting them into tons per hectare. Unmarketable tuber yield (t/ha) was measured by weighing all tubers other than marketable from each plot and converting them into tons per hectare. The weight of large and small tubers (g) was weighed in grams for each randomly selected plant and then averaged for data analysis.

Physiological parameters

<u>Tuber starch content (g/100 g)</u>

The percentage of tuber starch contents was measured from the specific gravity using the formula:

$$\text{Starch percentage} = 17.546 + 199.07\ (\text{specific gravity} - 1.0988)$$

<u>Total starch yield (t/h)</u>

Total starch yield was weighted in tonnes per hectare for each randomly selected plant.

<u>Tuber dry matter content</u>

Five tubers were chopped into one-to-two-centimeter cubes and dried 200 g subsamples from thoroughly mixed chopped tubers were in an oven at 800 °C for three days in two paper bags until a constant weight was attained. Then each variety's dry matter percentage was calculated.

Specific gravity

First, a sample of tuber was weighed in air, and then it was re-weighed in water to determine specific gravities.

$$\text{Specific gravity} = \frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}}$$

Data analysis

Data analysis was done using Statistix 8.1 software and a two-way randomized complete block.

Results

Morphological parameters

The maximum value of days of first germination was recorded for T6 (25 g) at the Naltar plantation (100%), while the minimum value of treatment and location interaction was recorded for T1 (0.47 g) on the Babusar plantation, as shown in Table 2. Days to flowering were counted when 50% of the plant populations in each plot bloomed. The maximum value of days to flowering was recorded in T1 under Naltar environmental conditions (68 days). The minimum value of treatment and location interaction was recorded for T6 (25 g) under Babusar environmental conditions (Figure 1 and Table 2). The number of days to physiological maturity was counted when the hauls of 50% of the plant population per plot turned yellowish or showed senescence. The maximum value of days to maturity was recorded for T2 (0.84 g) under the Naltar plantation (109.33), while the minimum value of treatment and location interaction was recorded for T6 (25 g) under the Babusar plantation (Table 2). The number of main stems per plant was counted from randomly selected plants from each plot at 50% flowering. Only stems that directly grew from the mother tuber and acted as independent plants above the soil were considered the main stems. Stems branching from other stems above the soil were not considered main stems. The maximum number of main stems was recorded for treatment 6 (25.0 g tuber size) under the Babusar plantation (4.34), while the minimum value of treatment and location interaction was recorded for treatment 1 (tuber size 0.47 g) under the Naltar plantation, as shown in Table 3. Maximum plant height was recorded for T6 (25.0 g) under Naltar plantation (74.77 cm), while the minimum value of treatment and location interaction was recorded for T1 (0.47 g) under Naltar plantation (Table 3).

Table 2. Mean table for number of days for germination, germination percentage (%), and days to the flowering of various tuber sizes under two different locations

Treatment	No. of days for germination			Germination percentage (%)			Days to flowering		
	Babusar	Naltar	Mean	Babusar	Naltar	Mean	Babusar	Naltar	Mean
T1 (0.47 g)	24.00^{a}	21.00^{bc}	22.50^{A}	67.33^{d}	78.33^{c}	72.83^{C}	67.00^{abc}	68.00^{a}	67.500^{A}
T2 (0.84 g)	21.33^{b}	20.67^{bcd}	21.00^{B}	83.33^{bc}	96.67^{a}	90.00^{B}	64.34^{de}	67.67^{ab}	66.00^{AB}
T3 (2.0 g)	20.66^{bcd}	20.66^{bcd}	20.66^{BC}	90.00^{ab}	97.33^{a}	93.67^{AB}	63.67^{de}	65.67^{bcd}	64.67^{BC}
T4 (5.0 g)	20.00^{bcd}	19.33^{d}	19.67^{C}	96.67^{a}	95.00^{a}	95.83^{AB}	63.00^{ef}	65.34^{cd}	64.17^{C}
T5 (10.0 g)	20.33^{bcd}	19.66^{cd}	20.00^{BC}	98.33^{a}	99.00^{a}	98.67^{A}	62.34^{efg}	64.00^{de}	63.17^{C}
T6 (25.0 g)	19.66^{cd}	19.66^{cd}	19.67^{C}	98.33^{a}	100.00^{a}	99.17^{A}	60.67^{g}	61.34^{fg}	61.00^{D}
Mean	21.00^{A}	20.17^{B}		89.00^{B}	94.39^{A}		63.500^{B}	65.34^{A}	
Treatment (T)	**			**			**		
Locations (L)	*			*			**		
T*L	NS			NS			NS		

Data represent the mean values (n=10), LSD test was applied among the locations. Smaller letters differ significantly from each other's ($p>0.05$)

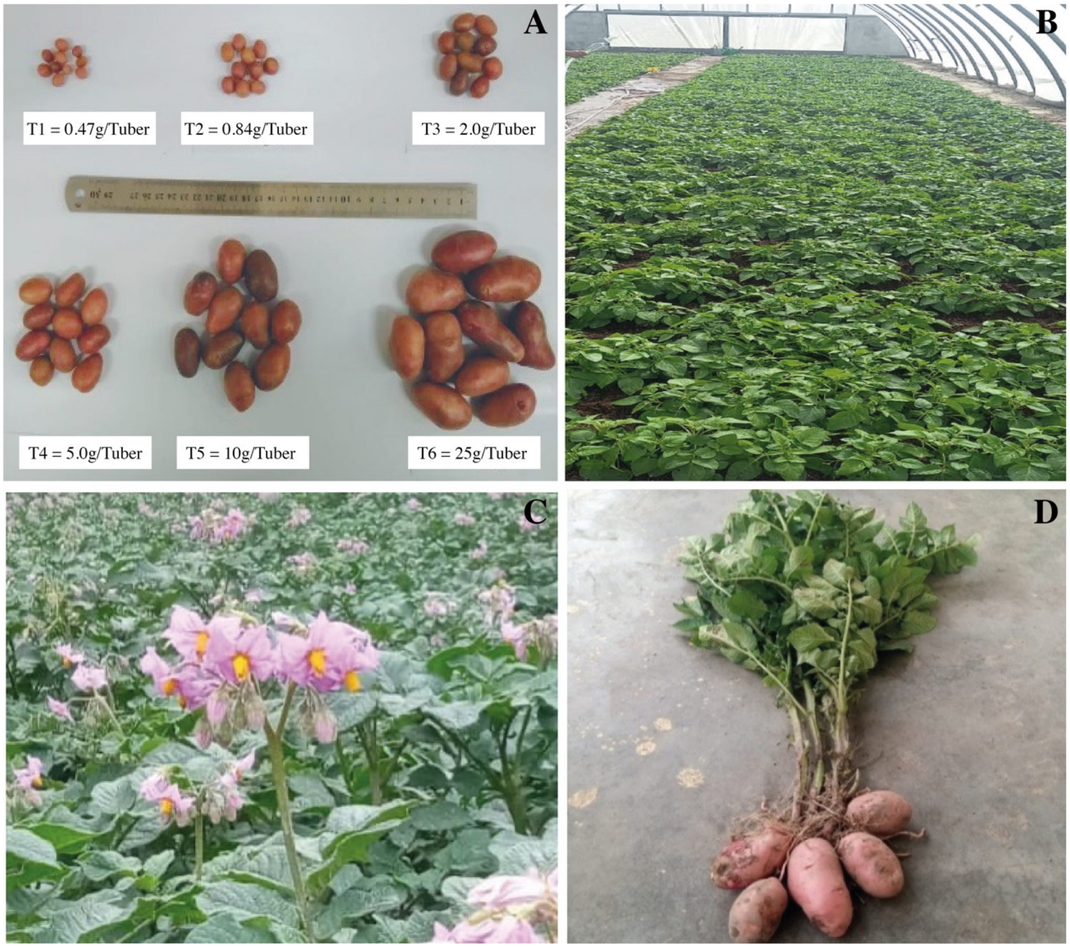

Figure 1. (A) Used different sizes of tubers after measuring; (B) Transplanting in screen house two different locations. (C) Vegetative propagations of plants in the flowering stage. (D) Harvesting Tubers from screen houses (E) Tuber data was recorded after the harvesting stage

Table 3. Mean table for days to physiological maturity, number of main stems, and plant height (cm) of various tuber sizes under two different locations

Treatment	Days to physiological maturity			Number of main stems			Plant Height (cm)		
	Babusar	Naltar	Mean	Babusar	Naltar	Mean	Babusar	Naltar	Mean
T1 (0.47 g)	105.33^{bc}	109.00^{a}	107.17^{A}	1.80^{gh}	1.57^{h}	1.48^{D}	52.10^{fg}	49.00^{g}	50.55^{D}
T2 (0.84 g)	104.57^{bc}	109.33^{a}	107.00^{A}	2.67^{ef}	2.20^{fg}	2.43^{C}	54.30^{cd}	56.33^{efg}	55.31^{C}
T3 (2.0 g)	105.34^{bc}	108.34^{a}	106.83^{A}	2.87^{de}	2.50^{ef}	2.68^{C}	58.23^{de}	55.73^{ef}	56.98^{C}
T4 (5.0 g)	104.34^{bc}	106.00^{b}	105.17^{B}	3.57^{bc}	3.57^{de}	3.17^{B}	65.67^{c}	64.13ab^{c}	64.90^{B}
T5 (10.0 g)	103.67^{c}	104.67^{bc}	104.17^{B}	3.77^{bc}	3.27^{cd}	3.51^{B}	68.40^{bc}	63.40^{cd}	65.90^{B}
T6 (25.0 g)	103.34^{c}	104.00^{bc}	103.67^{B}	4.34^{a}	3.90^{ab}	4.12^{A}	72.46^{a}	74.77^{ab}	73.62^{A}
Mean	104.44^{B}	106.89^{A}		3.17^{A}	2.70^{B}		62.24^{A}	60.18^{A}	
Treatment (T)	**			**			**		
Locations (L)	**			**			NS		
T*L	NS			NS			NS		

Data represent the mean values (n=10), LSD test was applied among the locations. Smaller letters differ significantly from each other's (p>0.05).

Yield parameters

The maximum number of tubers per plant was recorded for T6 (25 g) tuber size under the Babusar plantation (11.80), while the minimum value of treatment and location interaction was recorded for treatment 1 (0.47 g) under the Naltar plantation (5.46) (Table 4). The mean value of Babusar plantations for tuber weight ranged from 60.80 to 84.07 g. The mean value of tuber size and location ranged from 60.80 to 126.63 g. Maximum tuber weight was recorded for T5 (10 g) under the Naltar plantation (126.63 g), while the minimum value of treatment and location interaction was recorded for T2 (0.84 g) under the Babusar plantation (Table 4). Babusar plantations for tuber yield ranged from 20.10 to 36.46 t/ha; Naltar plantations for tuber yield ranged from 23.93 to 37.23 t/ha. Maximum tuber yield was recorded for T6 (25 g) under the Naltar plantation (37.23 t/ha), while the minimum value of treatment and location interaction was recorded for T1 (0.47 g) under the Babusar plantation (Table 4). Marketable tuber yield was not underweighted by 100 g per net plot area and converted into tonnes per hectare. Maximum marketable tuber yield was recorded for T6 (25 g) under the Naltar plantation (33.63 t/ha), while the minimum value of treatment and location interaction was recorded for T1 (0.47 g) under the Babusar plantation for marketable tuber yield (Table 5). The mean value of Babusar plantations for unmarketable tuber yield ranged from 1.70 to 3.40 t/ha. The mean value of treatments and location ranged from 1.70 to 3.60 t/ha. Maximum unmarketable tuber yield was recorded for T6 (25 g) under the Naltar plantation (3.60 t/ha). The minimum value of treatments and location interaction was recorded for T6 (25 g) under the Babusar location for unmarketable tuber yield (Table 5).

Table 4. Mean table for number of tubers per plant, tuber weight/tuber (g), and tuber yield (t/ha) of various tuber sizes under two different locations

Treatment	Number of tubers per plant			Tuber weight/tuber (g)			Tuber yield (t/ha)		
	Babusar	Naltar	Mean	Babusar	Naltar	Mean	Babusar	Naltar	Mean
T1 (0.47 g)	5.53^{d}	5.46^{c}	5.50^{C}	63.83^{c}	83.78^{abc}	73.81^{AB}	20.10^{h}	23.93^{g}	22.01^{F}
T2 (0.84 g)	5.53^{d}	8.20^{d}	8.20^{AB}	60.80^{c}	64.15^{c}	62.48^{B}	24.70^{g}	26.06^{fg}	25.38^{E}
T3 (2.0 g)	8.20^{bcd}	8.20^{bcd}	8.00^{A}	64.00^{c}	84.54^{abc}	74.27^{AB}	27.73^{ef}	30.20^{de}	28.96^{D}
T4 (5.0 g)	9.93^{ab}	6.93^{cd}	8.43^{B}	65.97^{c}	87.77^{abc}	76.87^{AB}	30.66^{d}	24.46^{bc}	32.56^{C}
T5 (10.0 g)	7.00^{bc}	9.13^{abc}	8.90^{AB}	84.07^{abc}	126.63^{a}	105.35^{A}	33.56^{c}	35.40^{abc}	34.48^{B}
T6 (25.0 g)	11.80^{a}	8.13^{bcd}	9.97^{A}	75.73^{bc}	117.73^{ab}	96.73^{A}	36.46^{ab}	37.23^{a}	36.85^{A}
Mean	8.72^{A}	7.61^{A}		69.07^{B}	94.10^{A}		28.87^{B}	31.21^{A}	
Treatment (T)	**			NS			**		
Locations (L)	NS			*			NS		
T*L	NS			NS			NS		

Data represent the mean values (n=10), LSD test was applied among the locations. Smaller letters differ significantly from each other's (p>0.05)

Table 5. Mean table for marketable tuber yield (t/ha) and unmarketable tuber yield (t/ha) of various tuber sizes under two different locations

Treatment	Marketable tuber yield (t/ha)			Unmarketable tuber yield (t/ha)		
	Babusar	Naltar	Mean	Babusar	Naltar	Mean
T1 (0.47 g)	17.03^{g}	21.53^{f}	19.28^{F}	3.40^{ab}	2.40^{abc}	2.90^{A}
T2 (0.84 g)	21.96^{f}	23.76^{ef}	22.86^{E}	2.73^{abc}	2.30^{abc}	2.51^{A}
T3 (2.0 g)	24.50^{def}	26.83^{de}	25.66^{D}	3.23^{ab}	3.36^{ab}	3.30^{A}
T4 (5.0 g)	27.53^{d}	31.03^{c}	29.28^{C}	3.13^{abc}	3.43^{ab}	3.28^{A}
T5 (10.0 g)	31.46^{bc}	32.10^{bc}	31.78^{B}	2.10^{bc}	3.30^{ab}	2.70^{A}
T6 (25.0 g)	34.76^{b}	33.63^{a}	34.19^{A}	1.70^{c}	3.60^{a}	2.65^{A}
Mean	26.211^{B}	27.66^{A}		2.71^{A}	3.06^{A}	
Treatment (T)	**			NS		
Locations (L)	**			NS		
T*L	**			NS		

Data represent the mean values (n=10), LSD test was applied among the locations. Smaller letters differ significantly from each other's (p>0.05)

Physiological parameters

The analysis of variance (ANOVA) of the potato tuber starch content, specific gravity, and tuber dry matter content showed non-significant differences among treatments and locations, while treatment and location interaction also showed non-significant differences (Table 6). Babusar plantations for tuber dry matter contents ranged from 21.96 to 24.50%. While Naltar plantation for tuber dry matter contents ranged from

21.41 to 24.53 %, the mean value of treatments and location ranged from 21.41 to 24.53 %. Maximum tuber dry matter content was recorded for T3 (2.0 g) under Naltar plantation (24.53%). While the minimum value of treatment and location interaction was recorded for T-1 (0.47g) under Naltar plantation (Table 6), specific gravities were measured by weighing a tuber sample in air and then re-weighing the sample in water. Babusar plantations for specific gravity ranged from 1.06 to 1.09. While Naltar plantations for specific gravity ranged from 1.08 to 1.10, the mean value of tuber size and location interaction ranged from 1.06 to 1.10. Maximum specific gravity was recorded for T4 under the Naltar plantation (1.10), while the minimum value of treatment and location interaction was recorded for treatment 1 (0.47 g) under the Babusar plantation, as shown in Table 6. The percentage of starch content under the Babusar plantation for tuber starch content (g/100g) ranged from 12.93 to 16.53 g/100g, while the mean value of the Naltar plantation for tuber starch content ranged from 14.40 to 16.80 g/100g. Maximum tuber starch content was recorded for T4 (5.0 g) under Naltar plantation (16.80 g/100g). The minimum value of treatments and location interaction was recorded for T3 (2.0 g) under the Babusar plantation (Table 6). Total starch yield (t/h) was weighted in tonnes per hectare for each randomly selected plant. The mean value of treatments (total starch yield) and location ranged from 2.45 to 5.85 t/h. The maximum total starch yield was recorded for T5 (10 g) under the Naltar plantation (5.85 t/h), while the minimum value of treatments and location interaction was recorded for T1 (0.47 g) under the Babusar plantation (Table 6).

Table 6. Mean table for tuber starch content (g/100 g), total starch yield (t/h), tuber dry matter content, and specific gravity of various tuber sizes under two different locations

Treatment	Tuber starch content (g/100 g)			Total starch yield (t/h)			Tuber dry matter content			Specific gravity		
	Babusar	Naltar	Mean	Babusar	Naltar	Mean	Babusar	Naltar	Mean	Babusar	Naltar	Mean
T1 (0.47 g)	13.07^{a}	16.00^{a}	14.53^{A}	2.45^{f}	3.86^{cdef}	19.28^{F}	23.08^{ab}	21.41^{a}	22.24^{A}	1.06^{b}	1.09^{a}	1.076^{B}
T2 (0.84 g)	16.13^{a}	14.50^{a}	15.35^{A}	3.96^{cdef}	3.81^{def}	22.86^{E}	21.96^{ab}	22.49^{b}	22.23^{A}	1.09^{a}	1.08^{ab}	1.09^{A}
T3 (2.0 g)	12.93^{a}	14.40^{a}	13.67^{A}	3.57^{ef}	4.34^{abcde}	25.66^{D}	23.05^{ab}	24.53^{ab}	23.79^{A}	1.07^{ab}	1.08^{ab}	1.08^{A}
T4 (5.0 g)	13.20^{a}	16.80^{a}	15.00^{A}	4.03^{bcdef}	5.78^{a}	29.28^{C}	24.50^{a}	21.95^{ab}	23.22^{A}	1.07^{ab}	1.10^{a}	1.09^{A}
T5 (10.0 g)	16.53^{a}	16.49^{a}	16.51^{A}	5.52^{abc}	5.85^{a}	31.78^{B}	24.23^{a}	22.26^{ab}	23.24^{A}	1.09^{a}	1.09^{a}	1.09^{A}
T6 (25.0 g)	14.60^{a}	15.33^{a}	14.97^{A}	5.32^{abcd}	5.68^{ab}	47.60^{A}	22.30^{ab}	23.18^{ab}	22.74^{A}	1.09^{ab}	1.09^{a}	1.09^{A}
Mean	14.41^{A}	15.60^{A}		4.1439^{B}	4.8894^{A}		23.19^{A}	22.64^{A}		1.08^{A}	1.09^{A}	
Treatment (T)	**			**			NS			NS		
Locations (L)	*			**			NS			NS		
T*L	NS			NS			NS			NS		

Data represent the mean values (n=10), and the LSD test was applied among the locations. Smaller letters differ significantly from each other's (p>0.05)

Association among morphological, physiological, and yield parameters

The yield of any crop is dependent on all the contributing traits. We check the association among morphological (GP, DF, DPM, NMS, NDG, PH), physiological (TDMC, TSC, TUSC, SG), and yield-related (TY, UTY, MTY, TW, NTPP) parameters (Figure 2). NMS showed an association with PH (r = 0.96), MTY (r = 0.90), TY (r = 0.79), TSC (r = 0.77), and GP (r = 0.74). Similarly, TSC showed an association with MTY (r = 0.93), SG (r = 0.81), NMS (r = 0.77), PH (r = 0.76), TW (r = 0.74), TY (r = 0.74), and TUSC (r = 0.70). This association was further confirmed through principal component analysis (Figure 3). TY, PH, NMS, GP, MTY, TSC, TW, SG, and TUSC were associated with each other. The treatment T6 was the most effective in both locations (Figure 3).

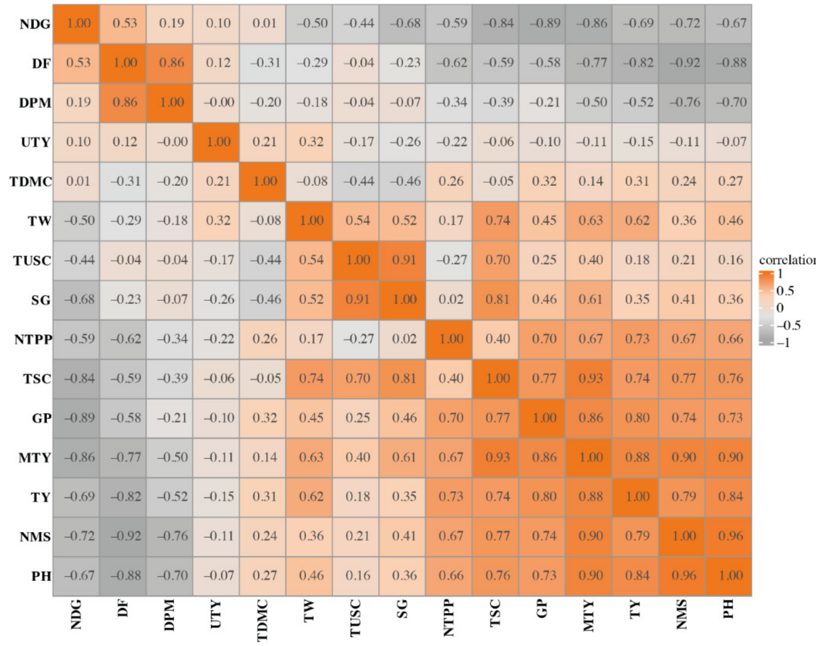

Figure 2. Correlation between potato traits

NDG = No. of day of germination, DF = Day to flowering, DPM = Day to physiological maturity, UTY = Unmarketable Tuber yield(t/ha), TDMC = Tuber dry matter content, TW = Tuber weight (g), TUSC = Tuber starch content, SG = Specific gravity, NTPP = Number of tubers per plant, TSC = Total starch content, GP = Germination percentage, MTY = Marketable Tuber yield (t/ha), TY = Tuber yield (t/ha), NMS = Number of main stem, PH = Plant height.

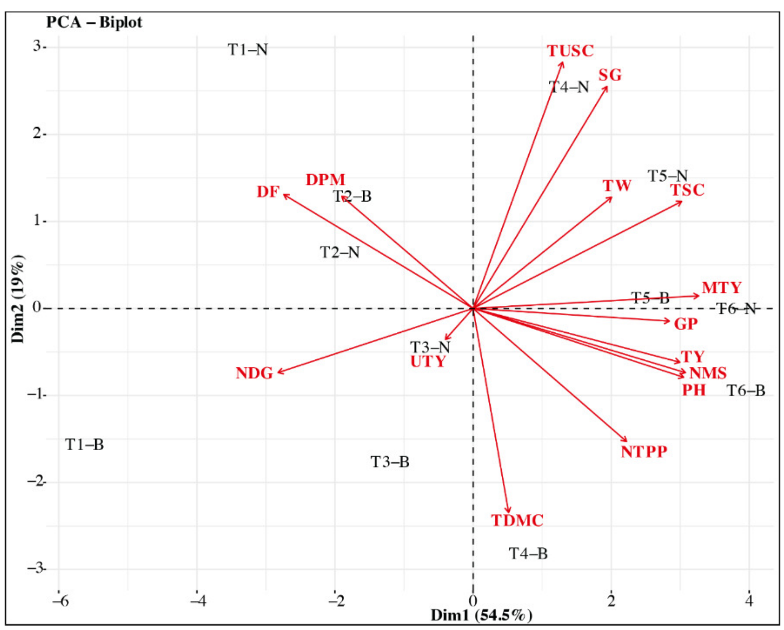

Figure 3. PCA biplot between potato traits under six treatments (T1 = 0.45 g, T2 = 0.84 g, T3 = 2.0 g, T4 = 5.0 g, T5 = 10.0 g, and T6 = 25.0 g) of two locations (Babusar = B and Naltar = N)

NDG = No. of day of germination, DF = Day to flowering, DPM = Day to physiological maturity, UTY = Unmarketable Tuber yield(t/ha), TDMC = Tuber dry matter content, TW = Tuber weight (g), TUSC = Tuber starch content, SG = Specific gravity, NTPP = Number of tubers per plant, TSC = Total starch content, GP = Germination percentage, MTY = Marketable Tuber yield (t/ha), TY = Tuber yield (t/ha), NMS = Number of main stem, PH = Plant height.

Discussion

Significant variations were observed in the potato yield trait and component analysis of variance (ANOVA) across treatments, location, and treatment-location interaction groups. In the Naltar plantations, the germination percentage, tuber weight (g/tuber), tuber yield (t/h), marketable tuber (t/h), and weight of large tuber (g) were all superior. In the Babusar plantations, the days to first emergence, number of main stems per plant, plant height, number of tubers per plant, unmarketable tuber (t/h), and weight of small tuber (g) were all superior. The analysis of variance (ANOVA) of the potato yield traits and their components showed highly significant differences among treatments, a significant difference in location, and a nonsignificant difference in the interaction between treatment and location. Some parameters showed better performances in Naltar plantations, such as germination percentage, tuber weight (g/tuber), tuber yield (t/h), marketable tuber (t/h), and weight of large tuber (g), while other morphological parameters, like days to first emergence, number of main stems per plant, plant height, number of tubers per plant, unmarketable tuber (t/h), and weight of small tuber (g), were better in Babusar plantations. In some cases, our findings are consistent with previous studies that have successfully used morphological traits such as tuber size and tuber weight to determine the effect of potato nucleus tuber size on plant development and seed yield (Muñoz-Rodríguez *et al.*, 2018). Potato tuber size is influenced by the number of days until first germination. So, large potato tubers take a minimum number of days to germinate, while small seed potato tubers take a maximum number of days to germinate. The current results align with the studies conducted by (Masarirambi *et al.*, 2012). These studies showed the number of days to seed germination is influenced by environmental factors such as tuber size, climatic conditions, and geographic locations. As tuber size increases, there is a marked decrease in days to germination. This effect is due to the fact that more carbon sources are available to germinate the potato plant. It is, therefore, essential to understand how tuber size affects germination days. A significant difference in seed tuber size from days to first germination or days to emergence was recorded (Chowdhury *et al.*, 2019).

Seed tubers' size affected crop establishment, therefore larger tubers had fewer days to first emergence. Compared to small to medium-sized seeds. According to Khan and Collin (2010), A higher percentage of big tubers germinate (Khan *et al.*, 2010). This was because mother tuber reserve material and metabolites determined germination percentage Because the germination % was determined by mother tuber reserve material and metabolites, this was the case (Kabir *et al.*, 2004; Naz, Umar*, et al.*, 2024). Larger seed tubers have more reserve material and initial meristematic potential (Aighewi *et al.*, 2015). It is also reported that earliness in flowering is controlled by factors including genetic and environmental factors (Zikhali and Griffiths, 2015). Large seed tubers took fewer days to blossom than medium to small tubers. Ebrahim et al. (2018) reported that a greater number of days to flowering was reported for small tubers (Ebrahim *et al.*, 2018). Tuber size significantly affects the days to physiological maturity. With increasing tuber size, the days to maturity decrease. Masarirambi *et al*. (2012) reported that at planting, large and extra-large seed tubers had longer and thicker sprouts, which accelerated crop growth (Masarirambi *et al.,* 2012; Noman and Azhar, 2023). While medium-sized tubers took the maximum number of days to mature (Duffy and Cassells, 2000), Gulluoglu and Arioglu (2009) explained the phenomenon of varying numbers of stems based on different sizes of tubers (Güllüoglu and Arıoglu, 2009). Large-size tubers contain a greater number of buds, resulting in a large number of mother stems, while small-size tubers contain a smaller number of mother stems, as per our findings. Our results are also correlate with (Kilonzi *et al.*, 2024). Greater numbers of sprouts were produced by larger seed tubers than by smaller ones, therefore producing more stems per plant. According to reports, the main stem count was much influenced by the size of the tuber; bigger tubers had more stems while smaller tubers had less, hence tuber size boosts the main stem count. Larger seed tubers were found to produce a greater number of sprouts than smaller seed tubers, resulting in a greater number of stems per plant. It is reported that the tuber size greatly affected the main stem number, with larger tubers having more stems and smaller tubers having fewer, and tuber size increases the main stem count (Tekalign and Hammes, 2005). The tuber size that Potato plants with large seed tubers grew higher than those with small tubers (Asnake *et al.,*, 2023). Large seed tubers produced more plant height than medium and small tubers by 4.9% and 8.9%, respectively. Plants grown from large seed tubers had more tubers per plant than those developed from small tubers (Singh *et al.*, 2023). Large seed tubers dominated the entire production. That could be due to giant tuber seeds having the most nutrient availability in the case of large tuber seeds. It is also reported in their results that seed tuber size significantly influences potato weight (Masarirambi *et al.,*, 2012). Plants with large seed sizes significantly increase the weight of potatoes and decrease in small seed sizes. Hence, yield performance was greatest with larger tubers. (Ebrahim *et al.,* 2018) reported that seed tuber size and varieties had a very highly significant influence on total tuber yield in tonnes per hectare. It is reported that larger tuber seeds yielded more marketable tubers increased photosynthesis efficiency and photo assimilation production (Nasir and Akassa, 2018). Ebrahim *et al*. (2018) reported that seed tuber size significantly affected unmarketable tuber yield (Ebrahim *et al.,*, 2018). The maximum unmarketable tuber yields were recorded from smaller seed tuber sizes, while the minimum unmarketable tuber yields were recorded from larger seed tuber sizes, and their results are parallel to our results.

The analysis of variance (ANOVA) of the potato tuber starch content, specific gravity, and tuber dry matter content showed non-significant differences among treatments and locations, while treatment and location interaction also showed non-significant differences. Total starch yield showed a highly significant difference for treatment and a significant difference for location. Mainly physiological parameters showed almost equal performances in both Naltar and Babusar plantations. When comparing treatments and locations using analysis of variance (ANOVA), there were no statistically significant changes in potato tuber starch content, specific gravity, or tuber dry matter content. Similarly, there were no significant changes when the interaction between treatment and location was investigated. Both the treatment and location parameters had a substantial impact on total starch yield. In terms of physiological assessments, the Naltar and Babusar plants were particularly equal (Ali *et al.*, 2024; Mariam *et al.*, 2023). Significant variation among different tuber sizes in tuber dry matter content was found (Mostofa *et al.*, 2019). Maximum dry matter content was obtained by large tuber sizes, and minimum dry matter content was obtained by smaller tuber seed sizes. It is reported that seed tuber size had a highly significant effect on tuber dry matter content (Ebrahim *et al.,*, 2018). Large seed tuber sizes produced the highest tuber dry matter content. Mostofa et al. (2019) reported significant differences among different tuber sizes based on the specific gravity of the tuber (Mostofa *et al.,*, 2019). The highest specific gravity (1.10 g/cm^3) of the tuber was exhibited by 5 g, and the lowest (1.06 g/cm^3) was exhibited by 0.47g. The relationship between specific gravity and tuber is not clear from the literature. Sawyer and Collin (1960) stated that potato tuber-specific gravity appeared to be related to tuber size; however, they found a relationship between varietal response and varietal-specific gravity (Sawyer and et al., 1960). Statistical variation among various seed tuber sizes for tuber starch content, which contrasts with my results (Hamunyela *et al.*, 2020; Regasa *et al.*, 2022). From their experiment, size increased with tuber size. Furthermore, an interaction between cultivar and tuber size was observed, implying that the magnitude of starch yield due to tuber size depends on the tuber seed size.

Conclusions

The study investigated the impact of potato nucleus tuber size on plant development and seed yield at Agricultural Research Gilgit's farms. Six different tuber sizes were sown using a randomized complete block design, with three replications at different locations. Results showed significant differences in days to first germination, germination percentage, flowering, physiological maturity, number of main stems per plant, tuber weight, marketable tuber yield, size of large tuber, tuber starch content, and total starch yield. It is concluded that T6 (25.0 g) showed the highest plant development and tuber yield among all six treatments. This result showed that the size of seed tubers influenced crop establishment; it followed those plants from larger seed tubers had better performance compared to smaller seeds.

Authors' Contributions

Conceptualization; MA, KA, and HA. Data curation; MA, HA, HS, RK. Formal analysis; MA, HA, IH, HS, and RK. Funding acquisition; KA. Investigation; HA and AN. Methodology; IH and AN. Project administration; KA. Resources; SA, AM, IH, and GMA. Software; HS, and RK. Supervision; KA. Validation; AM, and GMA. Visualization; HA. Writing - original draft; MA and HA. Writing - review and editing; KA and IH. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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