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Research article

Planting Date and Varietal Impact on Growth and Yield of Potato

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ABSTRACT

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Identification of suitable planting dates for improved agricultural yield is challenging due to climate change. An experiment was conducted in Damada, Dadeldhura, to evaluate the performance of potato varieties at various planting dates. The study was conducted in a factorial randomized complete block design where four varieties: MS-42.3, Khumal Seto-1, Cardinal, and, Desiree were in factor A and three planting dates (10th February, 20th February, and 1st March) were in factor B; altogether 12 treatments were replicated thrice. The analysis of variance revealed significant variations in the yield among the varieties, planting dates, and their interactions. Among the varieties, Desiree took the longest time (24 days) for emergence, while Khumal Seto-1 emerged early (21 days) on all planting dates. The plant height, number of branches, and leaves were significantly higher for Khumal Seto-1 when planted on 1st March. Among the varieties, the highest yield was recorded in Khumal Seto-1 with 46.32 t/ha, when planted on 20th Feb, followed by MS-42.3 (38.15 t/ha) planted on 1st March. The lowest yield was recorded in Desiree (17.05 t/ha) when planted on 1st March. However, Khumal Seto-1, Cardinal, and Desiree produced higher yields on 20th Feb except for MS-42.3, which produced higher yields on 1st March. The results showed significant differences in total tuber number, average weight, and yield of potato tubers at different planting dates and varieties. Among the three planting dates, Khumal Seto-1 yielded the highest average production (40.84 t/ha), with a peak yield (46.32 t/ha) observed when planted on 20 February. Although this clone achieved the highest overall yield, its performance was significantly influenced by planting date, with lower yields when planted too early or late. This highlights the critical role of both varietal selection and optimal planting timing in improving food security in Dadeldhura's hilly agroecology.

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important vegetables and starch-supplying crops, belonging to the Solanaceae family. This crop is also known for its high production per unit area and has a relatively short cropping cycle (90-120 days) among vegetables commonly cultivated in Nepal (NPRP). Potato produces the highest dry matter, and edible protein, and fulfills food requirements to a greater extent among major food crops (Balpande et al. 2019). It consists mainly of water (80%), protein (2%), and carbohydrates (18%), with significant amounts of minerals and vitamins B and C (Qasim et al. 2013). Nepal's diverse agroecological conditions allow for year-round potato cultivation. According to the Ministry of Agriculture and Livestock Development, the major districts of potato cultivation are; Jhapa, Kavrepalanchok, Bara, Ilam, and Makwanpur. Potatoes are grown across all 77 districts, with altitudes ranging from 100 to 4400 masl (Gainju et al. 2019). Potatoes contributed approximately 6.34% to AGDP and ranked fifth in area coverage (198,256 ha), second in total production (3,410,829 mt), and first in total productivity (17.20 mt/ha) among food crops in Nepal (MoALD 2023).

Potatoes have higher productivity and economic value compared to rice, wheat, and maize, making them a viable option for enhancing rural health and nutrition. In Nepal, potatoes are considered a major component of meals, particularly in the hills and mountains, because they enrich the human diet, although in the terai region, they are utilized as a vegetable. Potato thrives in the mid-hills throughout the spring and autumn, high hills and mountains in the summer, and terai and low hills in the winter. The crop's lifespan varies with altitude and is longer at higher elevations (Thapa 2022, Oli et al. 2022). In Nepal, the National Potato Research Program (NPRP) spearheads research to develop improved potato varieties tailored to diverse agroecologies from the Terai plains to high hills. The program's efforts include breeding for disease resistance, enhanced nutritional quality, and adaptability to different altitudes. In addition, NPRP provides seed tuber through seed certification and disseminates best agronomic practices. This work helps address challenges such as climate variability and pest pressure, thereby improving productivity and reinforcing food security and rural livelihoods in Nepal's agricultural sector (NPRP 2023). Various varieties, including Cardinal, Kufri, Sinduri, Khumal Rato-2, Khumal Seto-1, and, Desiree are majorly grown in Nepal (Joshi et al. 2020). Factors affecting potato growth, development, and productivity include climate, improved varieties, quality of seed, planting time, spacing, soil nutrition, irrigation, weed management, and pest and disease control (Gainju et al. 2019).

Planting time significantly affects crop emergence, growth, longevity, and tuber production. Variations in day and night temperatures, photoperiod, and photosynthetically active radiation affect growth and yield (Singh et al. 2022). Planting the right variety at the right time offers benefits such as protection against late blight diseases, optimal utilization of nutrients, sunlight, and moisture, and adaptation to climatic conditions. For successful potato production, high-yielding varieties and area-specific adaptations are crucial. Choosing a variety suited to local climatic conditions can mitigate yield losses in potatoes (Oli et al. 2022). In Nepal's mid-hill zone (1,000–1,800 masl), farmers typically plant potatoes in mid-February to early March, just after the last frost and before the onset of the pre-monsoon rains (Upadhyay and Timilsina 2020). Kufri Jyoti, Khumal Seto-1, Cardinal, and Desiree are some of the popular varieties that are cultivated in the mid-hills of Nepal (Technical Study Nepal 2024). According to local farmers, despite commercial cultivation efforts, potato production in Dadeldhura has faced challenges due to factors such as the unavailability of quality seed tubers and high-yielding varieties, frost damage, inappropriate planting times, diseases, pests, and lack of irrigation (personal communication, February 6th).

Potato tuberization is highly photoperiod-sensitive, with short days (<14 h) inducing stolon swelling and tuber initiation, while long days can delay bulking (Cristina et al. 2014). For instance, Desiree and Cardinal are classified as early-maturing, typically initiating tubers ~25 days after emergence under standard conditions, and are expected to bulk quickly even if the photoperiod becomes less inductive (Struik 2007). MS-42.3 represents a medium-duration group, with intermediate stolon formation and yield stability across both long and short days (Luitel and Bhandari 2023). Khumal Seto-1 is a medium-late type, often requiring ~35 days to tuber initiation and favoring shorter days later in the season for maximum bulking (Struik 2007). Limited research on varieties and planting times was done. Therefore, by selecting these four varieties across the maturity spectrum, and by imposing three planting dates (10 Feb, 20 Feb, 1 Mar), our factorial RCBD is designed to capture planting date and variety interactions, fill the existing research gap in mid-hill agronomy, and provide locally-relevant recommendations for maximizing tuber yield in Dadeldhura's prevailing climate.

Materials and Methods

Site and planting materials

The study was conducted in Damada-06, Dadeldhura district, Nepal (29°20'54.54"N, 80°35'57.51"E, 1655 masl), having clay loamy soil (pH 6.5). A factorial randomized complete block design (RCBD) was used to evaluate the performance of four potato varieties MS-42.3, Khumal Seto-1, Cardinal, and Desiree under three different planting dates: February 10, February 20, and March 1, 2024. These varieties were selected based on their suitability for the hilly agroecological conditions of Dadeldhura and their availability at the time of the study. The experiment consisted of 12 treatment combinations; each replicated three times in 2.4 m × 1.5 m plots. Plots were spaced 0.3 m apart, with 1 m separating replications.

The selected varieties differed in skin color and maturity period: MS-42.3 has dark blue skin and matures in 100–120 days; Khumal Seto-1 is pale yellow and matures in approximately 110 days; Desiree is an early-maturing variety (90–120 days) with shiny red skin and pale-yellow flesh; and Cardinal is a large, light red-skinned variety maturing in around 90 days (AITC 2022). Healthy, 25 g tubers were planted at 60 cm × 25 cm spacing. Potatoes were planted on 10 Feb, 20 Feb, and 1 Mar 2024 in an open field condition.

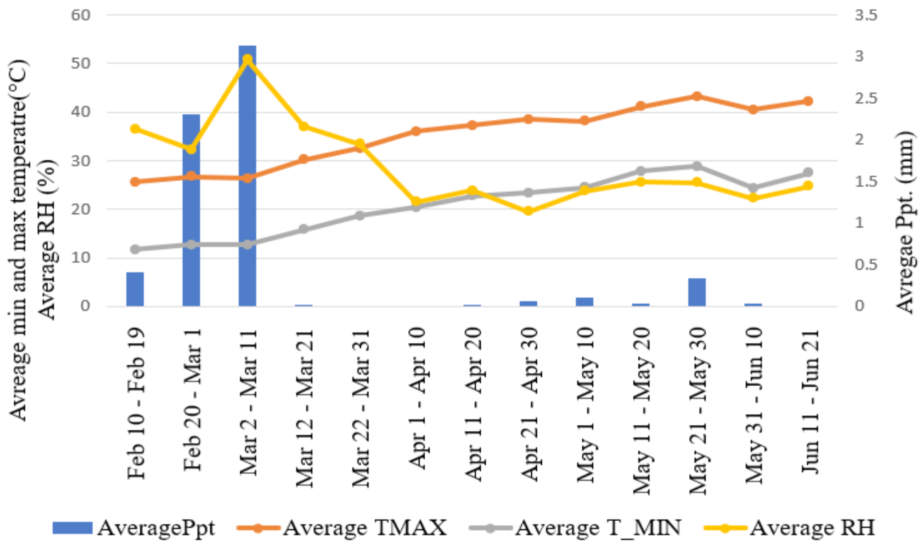

Figure 1. Meteorological conditions during the experiments. In the figure; Ppt, precipitation; TMAX, maximum temperature; TMIN, minimum temperature; RH, relative humidity

Between February 10 and May 23, the weather data reveals marked fluctuations in precipitation, temperature, and humidity over ten-day periods. Precipitation was highest in early March, averaging 4.74 mm from March 1 to 10, before dropping sharply to nearly 0.01 mm by late April. Maximum temperatures climbed steadily from around 25.06 °C in mid-February to 40.66 °C by late May, and minimum temperatures rose from 10.62 °C to 26.10 °C over the same timeframe. Relative humidity peaked at 43.06% in early March but then declined to approximately 20% by late April and early May, indicating drier conditions. Overall, this data illustrates the seasonal shift from cooler, wetter early spring to hotter, drier conditions as summer approaches.

Field cultivation

The cultivation practices involved applying a recommended dose of 100:100:60 ($N:P_2O_5:K_2O$) kg/ha along with 20 t/ha organic manure as recommended by NPRP. Each plot was applied 0.012 t/ha farmyard manure (FYM), 52.5 g urea (46% N), 81 g Di-ammonium Phosphate (DAP) (18% N, 46% P2O5), and 37.5 g Muriate of Potash (K2O) as a basal dose. The first weeding and earthing up were performed 50 days after sowing (DAS), followed by a second at 20 DAS. Initial irrigation was applied at 10 DAS, with subsequent irrigation at 15-day intervals starting at 45 DAS. The final irrigation was done 15 days before the harvest. Aphids and cutworms were managed using a foliar spray of Chlorpyriphos 50% + Cypermethrin 5% EC (2 ml/L), while zinc (2 g/L) was applied to address micronutrient deficiencies. Dehaulming was carried out 5 days before the harvest to ensure proper skin formation and prevent re-growth or virus infection. For Desiree and Cardinal, dehaulming was done at 90 DAS (both are early varieties, so dehaulming is recommended one week before harvest), while for MS-42.3 and Khumal Seto-1, it was at 100 DAS. Manual harvesting was followed for 5 days after dehaulming, occurring at 95 DAS for Desiree, 100 DAS for Cardinal, and 110 DASP for MS-42.3 and Khumal Seto-1. After harvesting, the produce was graded according to their size; marketable (> 25 g) and unmarketable (< 25 g).

Data collection and analysis

Eight representative plants, excluding border plants, were randomly chosen from each plot, and data were collected from tagged plants at 45 DAS and every 15 days until physiological maturity. Growth parameters measured, days to first 50% and 80% emergence, plant height, number of stems per hill, number of leaves per plant, and number of branches per plant. Yield traits included the number of tubers per hill, average tuber weight per hill, number of marketable, unmarketable, and infected tubers per square meter, and total data were organized in MS-Excel 2016 and analyzed using R for Windows (version 4.4.2, R Foundation for Statistical Computing). Duncan's Multiple Range Test (DMRT) was used to compare treatment means at a 5% significance level.

Results

Growth characters

Days to plant emergence

The days to plant emergence varied significantly between different potato varieties and planting dates. Khumal Seto-1 emerged the fastest among the four varieties, sprouting at 21 days and reaching 50% population by 27.11 days and 80%

at 32.44 days (but not significantly different from MS42.3). Desiree, on the other hand, required the most time to emerge, taking 24 days but the plant emergence data on Desiree and Cardinal were not significantly different. Planting dates also had a significant impact on emergence. Delayed planting on March 1 resulted in early emergence at 17.75 days, followed by 50% at 23.75 days and 80% at 29.67 days. These variations demonstrate the influence of both genetic and environmental factors on potato emergence (Table 1).

Plant height

Plant height varied significantly depending on variety and planting date. MS-42.3 produced the tallest plants (64.50 cm), whereas Desiree produced the shortest (47.01 cm). Planting dates also had an impact on plant height, as taller plants were observed when potatoes were planted on March 1st. This is likely due to an increase in temperatures as compared to February, which speeds up growth processes like photosynthesis and cell elongation. These data imply that both genetic and environmental factors influence plant height (Table 1).

Number of branches per hill

Khumal Seto-1 had the highest number of branches, with an average of 25.34, whereas Desiree had substantially fewer, averaging 14.09. Planting dates also had an impact on a number of branches. Potatoes planted on March 1 developed more branches than those planted earlier, most likely because of the higher temperatures (18-20 °C) associated with later planting. In contrast, earlier planting at cooler temperatures (12-15 °C) caused slower development thus resulting in fewer branches (Table 1).

Number of leaves per hill

The number of leaves on potato plants was significantly influenced by both variety and planting date. Khumal Seto-1 had the highest leaf count (93.41), indicating luxuriant development, whereas Desiree had the lowest leaf count (31.99) (Table 1). Planting on March 1st produced the highest leaf counts, as an increase in temperature encouraged greater growth and more leaves (Begum et al. 2015).

Number of stems per hill

The number of stems per hill differed significantly. The largest stem number was observed in MS-42.3 (4.59), followed by Khumal Seto-1, which was comparable to Cardinal. Desiree had the lowest number of stems per hill (3.66) (Table 1).

Table 1. Growth parameters as influenced by varieties and planting dates of potato

Treatments	**1st v emergence**	**50% emergence**	**80% emergence**	**Plant height (cm)**	**Branches per hill (number)**	**Leaves per hill (number)**	**Stems per hill (number)**
Varieties							
MS-42.3	21.22^{c}	27.22^{b}	33.00^{b}	64.50^{a}	16.23^{c}	52.02^{b}	4.59^{a}
Khumal Seto-1	21.00^{c}	27.11^{b}	32.44^{b}	63.21^{a}	25.34^{a}	93.41^{a}	3.75^{b}
Cardinal	22.44^{b}	29.66^{a}	35.00^{a}	51.66^{b}	17.01^{b}	49.10^{c}	3.73^{b}
Desiree	24.00^{a}	29.55^{a}	35.44^{a}	47.01^{c}	14.09^{d}	31.99^{d}	3.66^{b}
SEM (±)	0.17	0.20	0.20	0.54	0.24	0.46	0.17
LSD	0.50	0.61	0.59	1.59	0.72	1.36	0.51
Date of planting							
10th February	27.08^{a}	33.91^{a}	38.58^{a}	52.68^{c}	15.50^{c}	51.50^{c}	3.92^{a}
20th February	21.66^{b}	27.50^{b}	33.67^{b}	56.87^{b}	17.85^{b}	56.93^{b}	3.88^{a}
1st March	17.75^{c}	23.75^{c}	29.67^{c}	60.24^{a}	21.16^{a}	61.46^{a}	4.00^{a}
SEM (±)	0.14	0.18	0.17	0.47	0.21	0.40	0.15
LSD	0.43	0.52	0.51	1.38	0.62	1.18	0.44
CV%	2.32	2.20	1.80	2.88	4.07	2.46	13.43

SEM: Standard error of the mean, LSD: Least significant difference, CV: Coefficient of variance, ns: non-significant, *: $p \leq 0.05$, ** $p \leq 0.01$, ***: $p \leq 0.001$

Interaction effect of varieties and date of planting on growth parameters

The interaction effect of variety and planting date on days to emergence in potatoes was significant. Khumal Seto-1, planted on March 1st, emerged early (28.33 days), achieved 80% plant population in 37.33 days and Desiree, took the longest time (40.67 days) to emerge (Table 2). The variety and planting date had a significant impact on plant height. Khumal Seto-1 had the highest plant height (69.39 cm) when planted on March 1st, while Desiree had the lowest (43.30 cm) on February 10th. The highest plant height of Khumal Seto-1, planted in early March, likely had suitable climatic conditions that utilized the food reserve in the tuber perfectly, to support strong sprouting and emergence, which is crucial for early growth (Haverkort and Verhagen 2008). The highest numbers of branches were observed in Khumal Seto-1 (28.58) when planted on March 1st, while Desiree had the fewest (13.00) when planted on February 10th. The number of leaves produced per plant varied by variety and planting date. Khumal Seto-1 had the highest number of leaves (104.88) per plant when planted on March 1st, while Desiree had the lowest (28.16). A significant interaction effect was found between variety and planting date on the number of stems per hill in potatoes. The highest number of stems per hill was counted in MS-42.3, planted on February 10th, while the lowest number was recorded in Khumal Seto-1, planted on February 20th (Table 2).

Table 2. Interaction effect of varieties and planting dates on different growth parameters in potato

Treatments	**Days to emergence**	**Plant height(cm)**	**Branches per hill (number)**	**Leaves per hill (number)**	**Stems per hill (number)**
MS-42.3 × 10th Feb	37.00^{c}	59.39^{cd}	13.79^{f}	47.24^{f}	4.95^{a}
Khumal Seto-1 × 10th Feb	37.33^{c}	58.52^{d}	22.08^{c}	74.21^{c}	3.50^{bcd}
Cardinal × 10th Feb	39.33^{b}	49.52^{fg}	13.12^{f}	52.83^{e}	3.33^{d}
Desiree × 10th Feb	40.67^{a}	43.30^{h}	13.00^{f}	31.75^{i}	3.91^{bcd}
MS-42.3 × 20th Feb	32.33^{e}	65.41^{b}	15.62^{e}	56.95^{d}	4.45^{ab}
Khumal Seto-1 × 20th Feb	31.67^{e}	61.72^{c}	25.37^{b}	101.16^{b}	3.25^{d}
Cardinal × 20th Feb	35.33^{d}	53.08^{e}	16.70^{e}	51.67^{e}	4.12^{abcd}
Desiree × 20th Feb	35.33^{d}	47.27^{g}	13.70^{f}	36.06^{h}	3.70^{bcd}
MS-42.3 × 1st March	29.67^{f}	68.70^{a}	19.29^{d}	51.88^{e}	4.37^{abc}
Khumal Seto-1 × 1st March	28.33^{g}	69.39^{a}	28.58^{a}	104.88^{a}	4.50^{ab}
Cardinal × 1st March	30.33^{f}	52.39^{ef}	21.20^{c}	42.80^{g}	3.75^{bcd}
Desiree × 1st March	30.33^{f}	50.47^{ef}	15.58^{e}	28.16^{j}	3.37^{cd}
SEM (±)	0.35	0.94	0.42	0.80	0.30
LSD	1.03	2.76	1.25	2.36	0.89
F-test	**	**	***	***	*
CV%	1.80	2.88	4.07	2.46	13.43

SEM: Standard error of the mean, LSD: Least significant difference, CV: Coefficient of variance, ns: non-significant, *: $p \leq 0.05$, ** $p \leq 0.01$, ***: $p \leq 0.001$

Yield parameters

Average number of tubers per hill

Khumal Seto-1 produced the highest number of tubers per plant (18.90), whereas Cardinal produced the lowest (9.06), despite having larger tubers than Desiree. Planting dates also had an impact on tuber production, as early planting on February 10th exposed plants to chilly temperatures (as shown in Figure 1), delaying growth and reducing tuber formation. In contrast, planting in late February or early March gave superior growing circumstances, resulting in a larger number of tubers (Table 3).

Weight of tubers per hill

Varieties significantly affected the weight of tubers per hill, while the planting date had no significant effect. MS-42.3 (580 g) and Khumal Seto-1 (570 g) had the highest tuber weights per hill, followed by Cardinal (0.45 kg), which was comparable to Desiree (0.39 kg) (Table 3).

Tuber yield

Varieties and planting dates showed a significant effect on potato tuber production. The maximum yield was recorded in Khumal Seto-1 (40.84 t/ha), followed by MS-42.3 (37.23 t/ha) and Cardinal (29.70 t/ha), with Desiree having the lowest yield (19.10 t/ha). Varieties such as MS-42.3 and Khumal Seto-1 produced the highest tuber weights per hill, contributing to a better yield per hectare. Khumal Seto-1 also had the highest number of tubers per hill, which contributed to its greater total output (Table 3). Desiree and Cardinal had lower yields because their tubers were fewer and smaller, also both of them are early bulking varieties and low yielders as compared to MS-42.3 and Khumal Seto-1 (Banjade et al. 2019).

Number and weight of tubers per plant

The number and weight of tubers showed significant variation among varieties. Khumal Seto-1 (10.33) produced the highest number of unmarketable tubers (<25 gm) while, Cardinal produced the lowest (3.45), which is likely due to genetic differences influencing tuber size and quality (Haile et al. 2015). For marketable tubers (>25 gm), MS-42.3 produced the highest (8.13), followed closely by Khumal Seto-1 (8.07), while Cardinal (4.26) and Desiree (4.21) yielded the lowest. The highest weight per plant (580 g) was recorded from MS-42.3, and the lowest was recorded from Desiree (393 g) (Table 3).

Number of tubers by grade basis

The harvested potatoes were categorized as marketable (> 25 g) or unmarketable (< 25 g). Among the varieties, MS 42.3 yielded the highest number of marketable tubers (8.13), while Desiree produced the fewest (1.26). Regarding planting dates, the second date (20 February) resulted in the greatest average number of marketable tubers (6.33), whereas the first date (10 February) yielded the fewest (5.89). In the unmarketable category, Khumal Seto-1 had the highest count of small tubers (10.33), and Cardinal the lowest (3.45). Additionally, late planting increased the production of unmarketable tubers (7.12 g compared to earlier planting) (Table 3).

Table 3. Different yield and quality parameters as influenced by varieties and planting dates of potato

Treatments	Number of tubers per hill	Weight of tubers per hill (g)	Total tuber yield (t/ha)	Unmarketable tuber number (<25gm)	Marketable tuber number (>25gm)
Factor A (Varieties)					
MS-42.3	15.19^{b}	0.58^{a}	37.23^{b}	6.19^{b}	8.13^{a}
Khumal Seto-1	18.90^{a}	0.57^{a}	40.84^{a}	10.33^{a}	8.07^{a}
Cardinal	9.06^{d}	0.45^{b}	29.70^{c}	3.45^{d}	4.26^{b}
Desiree	10.05^{c}	0.39^{c}	19.10^{d}	4.58^{c}	4.21^{b}
SEM (±)	0.24	0.01	1.00	0.15	0.19
F -test	***	***	***	***	***
LSD	0.71	0.05	2.95	0.46	0.58
Factor B (Date of planting)					
10th February	12.34^{c}	0.49^{a}	31.31^{b}	5.80^{b}	5.89^{a}
20th February	13.02^{b}	0.50^{a}	34.56^{a}	5.49^{b}	6.33^{a}
1st March	14.54^{a}	0.49^{a}	29.29^{b}	7.12^{a}	6.27^{a}
SEM (±)	0.21	0.01	0.87	0.13	0.17
F -test	***	Ns	**	***	ns
LSD	0.61	0.04	2.56	0.39	0.50
CV%	5.49	10.58	9.54	7.68	9.62

SEM: Standard error of the mean, LSD: Least significant difference, CV: Coefficient of variance, ns: non-significant, *: p≤0.05, ** p≤0.01, ***: p≤0.001

Interaction effect of varieties and date of planting

The interaction between varieties and planting date had a clear impact on tuber yield. When potatoes were planted on February 20, they benefited from almost perfect tuber-initiation weather: daytime highs averaged about 25 °C, nighttime lows hovered around 10 °C, and nearly 54 mm of rain fell over the following ten days. Under these conditions, Khumal Seto-1 produced 46.3 t/ha, MS-42.3—36.58t/ha, Cardinal—34.1 t/ha, and Desiree produced—20.9 t/ha. In contrast, the February 10 planting faced low temperatures (around 6.5 °C) and only 12 mm of rain, which slowed stolon growth and reduced yields. Delayed planting on March 1 exposed young tubers to daytime temperatures climbing to 27–28 °C with scant rainfall (around 8 mm), inducing heat stress that further limited bulking, except in MS-42.3, which still reached 38.2 t/ha under those warmer conditions (Table 4). Detailed temperature and precipitation records are provided in the Materials and Methods section.

Table 4. Interaction effect of varieties and planting dates on tuber yield in potato

Treatments	Varieties			
	MS-42.3	**Khumal Seto-1**	**Cardinal**	**Desiree**
Planting dates				
10th February	36.58bc	37.46bc	31.81c	19.37de
20th February	36.96bc	46.32a	34.06bc	20.88de
1st March	38.15b	38.75b	23.22d	17.05e
SEM (±)	1.74			
F -test	*			
LSD	5.12			
CV%	9.54			

SEM: Standard error of the mean, LSD: Least significant difference, CV: Coefficient of variance, ns: non-significant, *: $p \leq 0.05$

Discussion

The variation in emergence among potato varieties and planting dates can be due to genetic traits and environmental factors. Given that potato is a short-duration crop and day length is critical for tuberization, understanding the bulking behavior of these varieties is essential (Lamsal et al. 2022). For instance, early-maturing varieties like Desiree and Cardinal, medium-duration varieties like MS-42.3, and medium-late varieties like Khumal Seto-1 have different growth characteristics. The minimum temperature for potato sprout emergence should be 13-18 °C, with relative humidity ranging from 50-80% (Wheeler et al. 1989). Sprout emergence is markedly delayed at temperatures below 10 °C and inhibited above 24 °C, with optimum rates between 20–25 °C (Struik 2007). Our 10th February planting, exposed to below 10 °C temperature, showed the slowed sprout extension (Firman et al. 1992). By 20th February, temperature started to get warmer (15–18 °C) and 54 mm of rain perfectly matched the 15–20 °C range. However, the higher emergence rate on 1st March as compared to the other two planting dates could be attributed to favorable temperature (>25 °C) and soil moisture (Thongam et al. 2017). The variation in plant height among different varieties can be attributed to genetic differences (Oli et al. 2022). Genetic variation in plant height is influenced by the interplay of growth-related genes and plant hormones such as gibberellins, auxins, and cytokinins. These hormones regulate various aspects of plant development, including cell elongation, division, and differentiation, thereby affecting overall plant stature (Wang and Irving 2011). The plant height is influenced by environmental factors, such as optimal temperature (20-25 °C), initial food reserve, and clonal characteristics. The lower the temperature (below 10 °C), the slower the vegetative growth (Begum et al. 2015), which initially resulted in lower plant height in early planting.

The increase in the number of leaves at late planting was due to the increase in daytime temperature; (around 30 °C) while the night temperature stayed around 18 °C (see Figure 1) (Berry and Bjorkman 1980). That causes our potato plants to produce the most leaves, about 62 per plant (Table 1). Warmer days like these bring temperatures closer to the optimal range for photosynthesis, enhancing the activity of enzymes that fix carbon into sugars (Hermida-Carrera et al. 2016). With extra sugars available, the plants could afford to grow more foliage, which in turn fuels stronger stems and new branches (Smith et al. 2018, Smith 2000). This pattern fits exactly with Lambers et al. (2008) who showed that when temperatures approach the optimal range for leaf-level carbon gain, canopy expansion and branching take off. The differences in leaf number among varieties, such as the high leaf production in Khumal Seto-1 compared to the lower counts in Desiree, may be linked to genetic traits and susceptibility to pests, as noted by Adhikari (1970). Such varietal variation aligns with findings that genotypes normally differ in growth pattern, stem height, and leaf number per plant as similarly reported by Banjade et al. (2019). Specific genes responsible for branch development play a critical role in determining the branching potential of each variety (Pasare et al. 2013). The variation in the number of stems per plant among potato varieties is influenced by both genetic differences and environmental factors (Banjade et al. 2019). Genotypic controls over tillering habit and apical dominance set a baseline for stem number (Tessema et al. 2020) but factors like tuber seed size, physiological age, and sprout duration further adjust how many stems actually emerge (Eaton et al. 2017).

The interaction between planting date and varieties of potatoes had a significant impact on growth parameters. In field evaluations, Khumal Seto-1 exhibited a notably erect, vigorous growth habit, reaching approximately 69.39 cm in height and producing about 105 leaves per plant, a profile that aligns perfectly with Singh et al. (2019)'s observation that taller potato plants develop more foliage, which in turn enhances overall plant health and productivity. Low temperatures (at around 10 °C) on 10th February resulted in slow vegetative growth, reducing crop duration, branch count, and leaves per plant (Begum et al. 2015, Bhatia et al. 1992), as presented in Figure 1. When growing circumstances are ideal, better sprouting and taller plants, such as Khumal Seto-1, tend to produce more branches (28.58). Variation in branches is affected by variety, planting materials, and environmental conditions (Banjade et al. 2019). The difference in stem number per plant is most likely caused by genetics, planting material (age and quality), and climate (Paudel et al. 2023).

A finding by Haverkort and Verhagen (2008) was in line with our observation that planting dates significantly affected tuber formation. Early planting (10th February) exposed plants to cold temperatures, hindering growth and tuber formation, while planting in late (March 1st) provided more favorable conditions for tuberization, resulting in increased tuber numbers per plant. Genetic variation among cultivars likewise governs tuber size distribution and total hill weight, with some genotypes forming fewer but larger tubers, thus higher per-plant weight while others set many smaller tubers resulting in lower aggregate yield (Haile et al. 2015). Tuber-bulking phenology differs by maturity class; Early-maturing potatoes (Desiree and Cardinal) typically reach physiological maturity (vine senescence and harvest readiness) in about 85–90 days after emergence, mid-season types (MS-42.3 and Khumal Seto-1) in roughly 90–120 days, and late-maturing cultivars often require 120 days or more, so early-maturing types complete bulking sooner to yield larger average tubers but lower total mass, whereas mid or, late-maturing types extend bulking for higher yields at the expense of average tuber size (Yayeh et al. 2025).

The highest tuber yield was observed on 20th February (34.56 t/ha), followed by 10th February (31.31 t/ha), and the lowest yield on 1st March (29.29 t/ha) may be attributed to temperature stress, as warmer temperatures can accelerate haulm growth and redirect assimilates to above-ground parts, delaying tuber formation (Lamsal et al. 2022). Although late planted (1st March) potatoes produced more branches, leaves, and tubers per hill, their final yield was lowest (29.29 t ha^{-1}), a discrepancy best explained by temperature stress: by early March in Nepal's mid-hills, temperatures commonly exceed 22 °C, above the optimal (15–20 °C) range for tuber initiation, thereby prolonging vegetative growth and diverting photo-assimilates into vigorous haulm development at the expense of stolon-to-tuber transition (Lamsal et al. 2022). Conversely, earlier planting (10th February) had low temperatures which resulted in the reduction of aerial growth, such as plant height, number of leaves, branches, and canopy development, leading to a decrease in total yield. These findings are supported by Haile et al. (2015), who highlight the significant role temperature stress plays in affecting yield. Genetic differences among potato genotypes play a significant role in determining tuber size, which in turn affects the number of marketable and unmarketable tubers. Varieties like MS-42.3 and Khumal Seto-1 have a genetic advantage, allowing them to grow taller plants with more leaves and branches, which contribute to the production of a higher number of marketable tubers. Banjade et al. (2019) noted that these varieties have a genetic predisposition to form desirable-sized and shaped tubers, leading to higher marketable yield. Moreover, Khumal Seto-1's relative drought tolerance, demonstrated in mid-hill and Western Terai trials, underpins its stability in both hill and lowland environments despite moisture stress (Bhattarai and Chaudhary 2024).

Interaction effects between planting date and cultivar significantly shape both vegetative growth and yield components. For example; MS-42.3 and Khumal Seto-1 consistently leverage their genetic vigor to produce taller plants with more leaves and branches and thus more marketable tubers, when sown at optimal dates (Keleta et al. 2018). Early planting exposed plants to milder temperatures, while delayed planting exposed them to higher temperatures, which caused heat stress in plants that impacted tuber formation of early and delayed planting (Momčilović 2019). In contrast, early-bulking varieties such as Cardinal and Desiree are notably prone to *Phytophthora infestans* (late blight) and *Alternaria solani* (early blight), with farmers reporting moderate to high disease susceptibility that predisposes them to misshapen or poorly developed tubers under slight early-March heat stress (Li et al. 2011). Even a modest 2–3 °C rise above the (15–20 °C) optimal range for tuber initiation, as occurs by 1st March in Nepal's mid-hills can shift assimilate partitioning toward vigorous haulm growth and away from stolon-to-tuber transition, exacerbating the number of malformed tubers in these susceptible cultivars (Rykaczewska and Rykaczewska 2013). Finally, combined drought and heat stress can reduce yields by over 50% in susceptible varieties, whereas Khumal Seto-1 loses only about 25%, further highlighting its genetic resilience under multiple abiotic stresses (Haverkort and Verhagen 2008). Together, these insights emphasize that synchronizing sowing dates with each variety's thermal and physiological requirements is essential to optimize canopy development and maximize final tuber yield.

Conclusion

This study evaluated the growth and yield performance of potato varieties at different planting dates at Dadeldhura. Khumal Seto-1 performed best when planted in late February, yielding 46.32 t/ha, while MS-42.3 was well-suited to early March planting. These results highlighted the importance of adjusting sowing dates to local temperature shifts for stable yields under climate change. As the findings are site-specific, further multi-season trials with temperature monitoring are needed to refine planting schedules for broader adaptation.

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Author contributions

Aakriti Kawar: Developed the original draft, contributed to methodology, resource collection, investigation, formal analysis, data curation, and conceptualization, and was actively involved in writing, reviewing, and editing the manuscript.
Raksha Sharma: Supervised the research, reviewing and editing the manuscript.
Bhishma Raj Regmi: Supervised the research and provided valuable input during the review process.
Nabin Ghimire: Contributed to reviewing, and editing the manuscript.

Conflict of interest declaration

The authors declare that there is no conflict of interest in publishing this work.

Data availability statement

The authors have stated that the data supporting the study's findings are included in the article. Additionally, the raw data underlying these findings can be obtained from the corresponding author upon reasonable request.

Declaration on the use of generative AI tools

Generative AI tools (such as ChatGPT by OpenAI) were used solely to improve the grammar and formatting of the manuscript. The content was critically reviewed and edited by the authors to ensure academic accuracy and integrity.

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