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Research Article

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Vegetative, Flowering, and Yield-Attributing Parameters as Affected by the Planting Dates and Cultivars of Banana in the Western Terai Region of Nepal

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Abstract

A field experiment was conducted from 2021 to 2023 at the Directorate of Agricultural Research, Khajura, Banke, to assess the effect of cultivars and planting dates on vegetative growth, crop duration, and yield attributes of Cavendish banana cultivars 'Grand Naine', 'Williams', and 'Indonesian'. The experiment was laid out in a split-plot design, with three banana cultivars as the main plot factor and six planting dates as the sub-plot factor, replicated three times. The first planting was carried out on 15th May 2021, and subsequent plantings were done at two-month intervals over one year. Results indicated that planting dates significantly influenced vegetative growth, crop duration, and yield attributes, while variety had little effect. Among the planting dates, the 15th July planting recorded the highest values across key parameters: base circumference (70.77 cm), leaf area (12.11 m^2), cumulative leaves (42.56), bunch length (110.11 cm), distance between the first and final hand (53.44 cm), and yield attributes such as number of hands (9.67), number of fingers per bunch (169.10), finger length (21.26 cm), finger girth (13.03 cm), finger weight (141.00 g), and bunch weight (20.85 kg). Although, early planting on 15th March or 15th May shorten the harvest duration, the yield potential was lower (45.38 t ha^{-1} for the 15th March planting and 53.26 t ha^{-1} for the 15th May planting) compared to the 15th July planting (64.37 t ha^{-1}). This study suggests that the 15th July planting is optimal for maximizing banana growth and yield in the Western Terai region of Nepal.

Keywords: Cavendish banana, Leaf area, Bunch weight, Hand weight, Bunch yield

Introduction:

Bananas (*Musa* spp.) are an important fruit crop ranking as the fourth most important crop after rice, wheat, and maize in the world cultivated on 5,336,862 ha of land, producing 124,978,578 t of bananas, with a productivity of 23.42 t ha^{-1} (FAO, 2022). In Nepal, bananas are mostly cultivated as a tropical fruit crop; however, some plantains are found to be grown in the mid-hill region of the country. Bananas are cultivated on 21,413 ha, with a total production of 339,435 t and a productivity of 15.85 t ha^{-1} in Nepal (MoALD, 2023). The productivity of bananas in Nepal is far lower than the global (23.42 t ha^{-1}) and India's average (34.53 t ha^{-1}) (FAO, 2022). The lower productivity of banana is related with several biotic and abiotic factors (Ghimire et al., 2023). Selection of suboptimal planting date, inadequate orchard management including disease and insect pest, lack of quality planting materials, and natural calamities are the major problems associated with poor productivity of banana.

Being a tropical fruit crop, banana requires a warmer climate to produce a good yield. Due to the longer crop duration of about 13-18 months, every banana plantation faces summer and winter seasons. Therefore, planting

All the authors declares that there is no any conflict of interest.

has to be selected rationally for producing a higher yield. Temperature, sunshine intensity and duration, and relative humidity are the major factors considered during the selection of planting time. The optimum mean temperature for banana production is 26°C (Salau et al., 2016). The lower temperature during the critical nutrient requiring period influence the nutrient uptake by the root system resulting the poor quality fruit as well as lower yield (Turner & Lahav, 1985). Solar intensity of 2,000-10,000 lux is favorable for banana, beyond 10,000 and below 1000 lux hampers the growth and development of banana (Borges et al., 2000). Similarly, sunshine duration also affects the duration of flowering and harvesting of banana. Significant positive correlations have been observed between sunshine hours and the duration of flowering and harvesting, while finger girth and bunch weight showed negative correlations with sunshine hours (Badgujar, 2016). Additionally, higher soil water availability, and temperatures increase the content of Ca, Zn, Cu, and B in leaves, leading to higher growth during the summer rainy season (Guimaraes & Lima de Deus, 2021). Therefore, this study was designed with an objective to assess the effect of cultivars and planting dates on vegetative growth and yield attributing parameters in the Western Terai region of Nepal.

Materials and Methods:

Experimental site

The experimental site, Directorate of Agricultural Research, Khajura, is located in the Banke district of Lumbini Province, Nepal, at an altitude of 133.00 meter above mean sea level, extending from 28.11° N latitude to 81.59° E longitude. The climate of the site is humid tropical type. The soil physicochemical properties and weather data are presented in Table 1 and Figure 1 respectively.

Table 1. The physicochemical properties of soil at DoAR, Khajura, Banke, Nepal

Parameters	0-16 cm depth	16-56 cm depth	Mean
Sand (%)	15.40	13.40	14.40
Silt (%)	56.00	60.00	58.00
Clay (%)	28.60	26.60	27.60
Soil pH	6.98	6.63	6.81
Soil organic matter (%)	2.50	1.42	1.96
Total nitrogen (%)	0.16	0.10	0.13
Available P_2O_5 (mg kg^{-1})	12.01	6.98	9.49
Exchangeable K_2O (mg kg^{-1})	110.40	125.50	117.95
Extractable Ca (mg kg^{-1})	2028.00	2168.00	2098.00
Extractable Mg (mg kg^{-1})	315.00	410.40	362.70
Available S (mg kg^{-1})	1.35	5.43	3.39
Available B (mg kg^{-1})	0.32	-	0.32

Source: DoAR (2020)

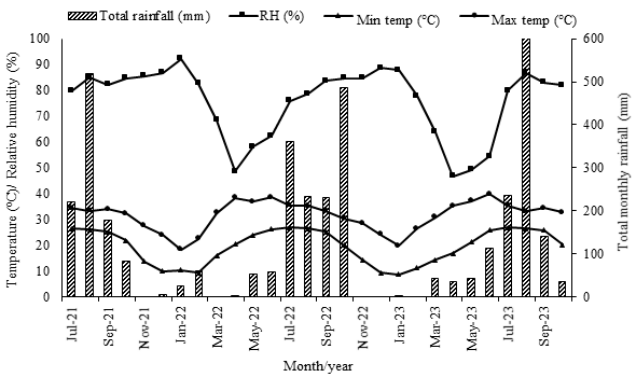

Figure 1. Monthly weather data during the cropping period (2021-2023) at Khajura, Banke, Nepal

Selection of the genotypes and planting materials

'Grand Naine' banana plant is medium-tall, allowing for easy cultural operations, and is moderately tolerant to wind, which was registered in Nepal in 2019. 'Williams' banana is taller than 'Grand Naine' and was also registered in Nepal in the same year. 'Indonesian' banana has a dwarf stature compared to 'Williams' and 'Grand Naine.' It was introduced from Indonesia but remains unregistered in Nepal (SQCC, 2023). Well-acclimatized tissue culture banana plants were used as planting materials in the study to ensure uniformity and disease-free conditions among the experimental plants.

Field layout, experimental design, and treatments

The field was laid out in a split plot design, with three cultivars as the main plot factor (Factor A) and six planting dates as the sub-plot factor (Factor B). The treatments were replicated three times. Planting was done at a spacing of 1.8 m × 1.8 m in 3.6 m × 3.6 m experimental plots, with four plants per plot. A total of 54 experimental plots were included in the study. A 30 cm wide and deep trench was created between plots to separate the experimental units within each replication, and a 60 cm wide trench separated the replications. Detailed information about the treatment is provided in Table 3.

Land preparation, pit digging, filling, and manuring

The land used in the trial was a cultivated field, so only ploughing and levelling activities were carried out. A 60 cm deep trench was dug along the boundary of the experimental area to provide drainage. Pit digging was completed one month before planting. Each pit, approximately 40 cm deep and 40 cm wide, was dug with a spade. Five kilograms of FYM, 25 g of Sudo 0.5% WP (*Pseudomonas fluorescens),* and 40 g of Cartap hydrochloride 3G were mixed with the soil obtained from digging, and the pit was filled with this mixture up to the ground level. The pits were filled 15 days prior to planting.

Transplanting

Hardened tissue culture plants of three banana cultivars were transplanted into the previously filled pits. The plants were 60 days old at the time of transplanting, having been grown for one month in primary nursery and another month in secondary nursery. Plants with similar appearance were selected for planting in the experimental units.

Manure and chemical fertilizer application

Manure and chemical fertilizers were applied @ 20 kg and 250:250:350 g N, P_2O_5, and K_2O per clump per crop cycle at 30, 75, 110, 150, 180 days after transplanting, and at the time of shooting, in six installments. During shooting, muriate of potash was applied @ 100 g per clump. Micronutrients, including $ZnSO_4$ (0.5%), $FeSO_4$ (0.2%), $CuSO_4$ (0.2%), and Borax (0.1%) were applied at 3rd, 5th, and 7th month after transplanting through foliar spray.

Observation and measurement

Observations on vegetative growth, floral initiation, flowering, and yield parameters were taken from two sample plants located at opposite corners of each plot.

Pseudostem base circumference and plant height

The base circumference was measured at the base of the pseudostem, just above the corm. The plant height was measured from the base to the point where the final two leaves intersect at shooting stage.

Leaf area

The leaf area of a plant was calculated using the number of effective leaves, and the length and width of the third leaf lamina, according to the formula provided by Nyombi et al. (2009) at shooting stage.

$$\text{Leaf area } (m^2) = \frac{\text{Number of effective leaves} \times \text{leaf length (cm)} \times \text{Leaf width (cm)} \times 0.75}{100 \times 100}$$

Note: 0.75 is the leaf area factor

Cumulative leaves per plant

The total leaves produced by the plant was calculated by summing the leaves from nursery stage to shooting stage.

Days required for shooting

The number of days from planting to floral initiation or shooting was recorded for the sample plants and averaged to obtain the mean value.

Days required for flowering

The number of days from planting to the opening of the flower of the second hand enclosed in the spathe of the floral bud was recorded for sample plants and averaged to obtain the mean value.

Days required for harvesting

The number of days from planting to harvest was recorded and averaged to determine the number of days required for bunch harvesting.

Bunch length and length between the first and final hand

Bunch length was measured from the base to the tip of the bunch. The measurement covered the distance between the first and final hand, excluding the section from the base to the first hand and the tip of the bunch beyond the final hand.

Number of hands per bunch

The number of marketable hands per bunch was counted from the bunch of sample plant and averaged to obtain the mean number of hands.

Number of fingers per bunch

The total number of fingers per bunch was calculated by summing the fingers in each hand and averaged from two sample plants.

Weight of second hand

The weight of the second hand was recorded from a sample plant in kilogram. The second hand was separated from the rachis and weighed. The average weight was calculated from two bunches of the sample plant. Second hand is the representative hand of a bunch (INIBAP, 1996).

Finger length

The length of each finger, measured in centimeters, was obtained from 10 fingers selected from the upper row of the hand. Finger length was measured from the convex side of the fruit.

Finger girth

The circumference of each finger was measured in centimeter using a measuring tape. Measurements were taken from 10 fingers of the first row of the second hand.

Bunch weight

The average bunch weight per plant was obtained from four plants in each experimental plot. The bunch weight included a 30 cm long rachis from the first hand of the bunch.

Bunch yield

The yield from all four plants was summed to obtain the yield per plot and expressed in t ha^{-1}.

Table 2. Treatment details of the experiment conducted at DoAR, Khajura, Banke, Nepal

S.N.	Treatments	Cultivar	Date of planting	Combination
1	T_1	Grand Naine (C_1)	15-May (D_1)	$C_1 \times D_1$
2	T_2		15-July (D_2)	$C_1 \times D_2$
3	T_3		15-September (D_3)	$C_1 \times D_3$
4	T_4		15-November (D_4)	$C_1 \times D_4$
5	T_5		15-January (D_5)	$C_1 \times D_5$
6	T_6		15-March (D_6)	$C_1 \times D_6$
7	T_7	Williams (C_2)	15-May (D_1)	$C_2 \times D_1$
8	T_8		15-July (D_2)	$C_2 \times D_2$
9	T_9		15-September (D_3)	$C_2 \times D_3$
10	T_{10}		15-November (D_4)	$C_2 \times D_4$
11	T_{11}		15-January (D_5)	$C_2 \times D_5$
12	T_{12}		15-March (D_6)	$C_2 \times D_6$
13	T_{13}	Indonesian (C_3)	15-May (D_1)	$C_3 \times D_1$
14	T_{14}		15-July (D_2)	$C_3 \times D_2$
15	T_{15}		15-September (D_3)	$C_3 \times D_3$
16	T_{16}		15-November (D_4)	$C_3 \times D_4$
17	T_{17}		15-January (D_5)	$C_3 \times D_5$
18	T_{18}		15-March (D_6)	$C_3 \times D_6$

Note: T = treatment, D = date of planting, C = cultivar

Statistical analysis

Data collected from sample plants in each experimental unit were organized and averaged using Microsoft Office Excel. Statistical analysis was done using Genstat 18th Edition (VSNI, 2016), with treatments assessed for significance through analysis of variance (ANOVA) as described by Gomez and Gomez (1984). Duncan's Multiple Range Test (DMRT) was employed to separate means at the 0.05 and 0.01 level of significance as defined by Steel et al. (1997).

Results:

Vegetative growth parameters

Pseudostem base circumference, plant height, leaf area, and cumulative leaves per plant

Pseudostem base circumference, leaf area, and cumulative leaf number were non-significant among the three cultivars, whereas plant height was significant and recorded the highest in 'Williams' (201.70 cm). The effect of planting dates on all the vegetative growth parameters was highly significant. The base circumference (70.77 cm), leaf area (12.11 m^2), and cumulative leaves per plant (42.56) were the highest with the 15th July planting; however, the pseudostem was the tallest with the 15th May planting (211.00 cm). The interaction effect was significant for pseudostem base circumference, while it was non-significant for the remaining vegetative parameters (Table 3).

Reproductive or phenological parameters

Shooting, flowering, and harvest duration

The number of days required for shooting, flowering, and harvesting among the three cultivars of banana was significant. The duration was the longest in 'Williams' (334.30, 344.70 and 473.90 days, respectively), followed by 'Indonesian' while, the shortest in 'Grand Naine' (307.00, 317.00 and 434.80 days, respectively). The effect of planting dates on the number of days required for shooting, flowering, and harvesting was also significant, with the shortest duration observed in the 15th May planting, followed by the 15th March planting, and the longest in the 15th November planting (Table 4). The interaction effect was also highly significant for these phenological events (Appendix 1).

Yield attributing parameters

Bunch length, length between first and final hand, number of hands and fingers per bunch

The effect of planting dates was highly significant on bunch length, distance between the first hand to final hand, number of hands, and number of fingers per bunch, whereas the effect of cultivar and interaction between cultivar and planting date were non-significant. The longest bunch (110.11 cm), the greatest distance between the first and final hand (53.44 cm), the highest number of hands per bunch (9.67), and the highest number of fingers per bunch (169.10) were observed with the 15th July planting (Table 5).

Finger length, girth, and weight

The finger length and weight were non-significant, whereas finger girth was significantly the highest in 'Grand Naine' (12.62 cm). The effect of planting dates on finger length, girth, and weight was significant. The greatest finger length (21.26 cm), maximum girth (13.03 cm), and the highest finger weight (141.00 g) were recorded in the 15th July planting. The interaction effect on finger length, girth and weight was non-significant (Table 6).

Table 3. Effect of planting dates on pseudostem base circumference, plant height, leaf area and cumulative leaves of different banana cultivars at shooting during 2021-2023 at Khajura, Banke, Nepal

Treatments	Base circumference (cm)	Plant height (cm)	Leaf area (m^2)	Cumulative leaves
Cultivars				
Grand Naine	60.10	195.60^{a}	11.25	40.74
Williams	60.60	201.70^{a}	10.80	39.86
Indonesian	61.12	168.90^{b}	8.96	39.44
SEm±	0.54	5.50	0.86	0.43
LSD (p<0.05)	-	15.26	-	-
F-test	1.80^{NS}	20.15**	3.94^{NS}	4.82^{NS}
Date of planting				
15-May	62.97^{b}	211.00^{a}	11.80^{a}	40.17^{b}
15-July	70.77^{a}	196.60^{b}	12.11^{a}	42.56^{a}
15-Sep	62.91^{b}	175.10^{d}	10.32^{ab}	38.78^{b}
15-Nov	55.28^{c}	173.40^{d}	11.50^{a}	39.79^{b}
15-Jan	51.90^{c}	183.40^{cd}	8.12^{b}	38.50^{b}
15-Mar	59.82^{b}	192.80^{bc}	8.16^{b}	40.30^{b}
Grand mean	60.61	188.70	10.33	40.01
SEm±	1.88	6.04	1.13	0.81
LSD (p<0.05)	3.83	12.33	2.31	1.65
F-test	24.90***	11.20***	5.07**	6.38***
Cultivars × Date of planting				
SEm±	3.01	11.01	1.99	1.35
LSD (p<0.05)	6.14	-	-	-
F-test	2.24*	0.73^{NS}	0.34^{NS}	1.48^{NS}
CV (%)	6.60	6.80	23.20	4.30

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, NS= Non-significant, * = Significant at 5%, **= Significant at 1%, *** = Significant at less than 0.1% level

Table 4. Effect of planting dates on number of days required for shooting, flowering, and harvesting of different banana cultivars from planting during 2021-2023 at Khajura, Banke, Nepal

Treatments	Number of days required for		
	Shooting	Flowering	Harvesting
Cultivars			
Grand Naine	307.00[b]	317.00[b]	434.80[b]
Williams	334.30[a]	344.70[a]	473.90[a]
Indonesian	329.70[a]	339.80[a]	467.60[a]
SEm±	2.87	2.98	3.14
LSD (p<0.05)	7.96	8.28	8.70
F-test	52.05**	49.05**	89.87***
CV (%)	0.40	4.20	0.30
Date of planting			
15-May	310.80[e]	317.90[d]	428.40[e]
15-July	316.70[d]	324.30[c]	440.40[d]
15-Sep	330.60[b]	338.50[b]	477.30[b]
15-Nov	348.80[a]	360.10[a]	506.00[a]
15-Jan	325.40[c]	340.10[b]	465.30[c]
15-Mar	309.90[e]	322.00[cd]	435.00[d]
Grand mean	323.69	333.84	458.76
SEm±	2.48	2.47	3.14
LSD (p<0.05)	5.07	5.05	6.41
F-test	70.42***	80.89***	180.13***
Cultivars × Date of planting			
SEm±	4.86	4.92	5.87
LSD (p<0.05)	10.07	10.22	12.05
F-test	8.34***	8.29***	5.60***
CV (%)	1.60	1.60	1.50

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, NS= Non-significant, **= Significant at 1%, *** = Significant at less than 0.1% level

Weight and number of fingers in the second hand and bunch yield

The weight and number of fingers in the second hand were non-significant among the different banana cultivars, whereas the individual bunch weight (16.68 kg) and bunch yield (51.49 t ha^{-1}) were significantly the highest in 'Grand Naine'. The effect of planting date was highly significant. The highest hand weight (2.69 kg), the greatest number of fingers in the second hand (19.44), the highest individual bunch weight (20.85 kg), and the highest bunch yield (64.37 t ha^{-1}) were recorded in the 15th July planting. The interaction effect on the weight and number of fingers in the second hand was non-significant, while the effect on bunch weight and yield were highly significant. The highest bunch weight (22.87 kg) and yield (70.59 t ha^{-1}) were recorded in 'Williams' banana planted on 15th July (22.87 kg), whereas the lowest bunch weight (8.58 kg) and yield (26.49 t ha^{-1}) were observed in 'Indonesian' banana planted on 15th January (Table 7 and Annex 1).

Discussion:

Vegetative growth parameters

Planting bananas at a favorable time helps with early establishment and growth momentum. In this study, bananas planted on 15th May and 15th July showed good vegetative growth, likely due to optimal environmental and soil moisture conditions. In contrast, planting in winter (November to January) resulted in reduced vegetative growth, characterized by smaller base circumference, shorter plant height, fewer effective and cumulative leaves, lower plant spread, smaller leaf size, and ultimately lower leaf area. This reduced growth in winter is due to unfavorable temperatures for normal physiological activities and impaired nutrient absorption from the soil (Turner & Lahav, 1985).

The present results are supported by several research findings. Sora and Guji (2023) reported that 'Williams Hybrid' banana had a plant height of 197.97 cm,

pseudostem girth of 70.81 cm, 9.96 leaves, leaf length of 167.55 cm, and leaf width of 60.54 cm. Another study done by Dagnew et al. (2021) reported a plant height of 315.00 cm, pseudostem girth of 88.13 cm, and 12 leaves in 'Williams' banana from a comparative study of different banana cultivars. Ara et al. (2011) in Bangladesh found that pseudostem height was the highest in February-March plantings (262.78 cm and 260.22 cm), the number of green leaves was highest in October-November plantings (14.56 and 13.89), and base girth was highest in March-April plantings (65.22 cm and 63.56 cm). El-Khawaga (2013) reported that 15th March was the best time for planting 'Williams' banana in Egypt, as vegetative growth parameters like plant height, base circumference, number of green leaves, and leaf area were the highest. Kumar et al. (2021) found the highest base circumference (61.90 cm), functional leaves (12.00), leaf area (9.76 m^2), and leaf area index (3.61) with 15th July plantings in Lucknow, India. Variations in results may be due to differences in the climates of the study locations. In Nepal, the 4th March planted sucker had the lowest cumulative leaves (36.54), while the 4th July planted sucker had the highest cumulative leaves (41.86) during shooting in 'Jhapali Malbhog' banana (Gautam & Gautam, 2002).

Reproductive or phenological parameters

The number of days required for shooting, flowering,

Table 5. Effect of planting dates on bunch length, distance between the first and final hand, number of hands, and finger number per bunch of different banana cultivars during 2021-2023 at Khajura, Banke, Nepal

Treatments	Bunch length (cm)	Distance between first hand to final hand (cm)	Number of hands per bunch	Number of fingers per bunch
Cultivars				
Grand Naine	100.25	49.19	7.86	127.80
Williams	93.56	43.61	7.47	115.20
Indonesian	97.73	44.75	7.39	114.80
SEm±	2.41	2.54	0.34	7.35
LSD (p<0.05)	-	-	-	-
F-test	3.95^{NS}	2.69^{NS}	1.09^{NS}	2.02^{NS}
Date of planting				
15-May	102.33^{b}	47.78^{ab}	7.83^{bc}	133.60^{b}
15-July	110.11^{a}	53.44^{a}	9.67^{a}	169.10^{a}
15-Sep	98.56^{b}	37.78^{c}	7.22^{c}	120.30^{b}
15-Nov	89.58^{c}	46.33^{b}	6.50^{d}	88.30^{c}
15-Jan	82.89^{c}	40.44^{c}	6.00^{d}	78.80^{c}
15-Mar	99.61^{b}	49.33^{ab}	8.22^{b}	125.30^{b}
Grand mean	97.18	45.85	7.57	119.2
SEm±	3.37	2.69	0.35	7.39
LSD (p<0.05)	6.89	5.49	0.72	15.10
F-test	16.30***	9.31***	27.66***	38.94***
Cultivars × Date of planting				
SEm±	5.85	4.95	0.66	13.81
LSD (p<0.05)	-	-	-	-
F-test	2.02^{NS}	1.88^{NS}	0.83^{NS}	1.13^{NS}
CV (%)	7.40	12.40	9.90	13.20

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, NS= Non-significant, *** = Significant at less than 0.1% level

Table 6. Effect of planting dates on mean fingers length, girth, and weight of different banana cultivars during 2021-2023 at Khajura, Banke, Nepal

Treatments	Finger length (cm)	Finger girth (cm)	Finger weight (g)
Cultivars			
Grand Naine	19.67	12.62^{a}	119.90
Williams	19.50	12.18^{ab}	120.70
Indonesian	19.67	11.81^{b}	109.40
SEm±	0.42	0.18	6.32
LSD (p<0.05)	-	0.50	-
F-test	0.11^{NS}	10.13*	1.98^{NS}
Date of planting			
15-May	19.75^{b}	11.85^{bc}	121.90^{b}
15-Jul	21.26^{a}	13.03^{a}	141.00^{a}
15-Sep	19.09^{bc}	12.43^{abc}	122.90^{b}
15-Nov	18.55^{c}	11.73^{bc}	96.10^{c}
15-Jan	18.23^{c}	11.63^{c}	88.70^{c}
15-Mar	20.79^{a}	12.56^{ab}	129.40^{b}
Grand mean	19.61	12.20	116.70
SEm±	0.46	0.37	4.90
LSD (p<0.05)	0.94	0.76	10.01
F-test	14.19***	4.42**	33.71***
Cultivars × Date of planting			
SEm±	0.84	0.62	10.00
LSD (p<0.05)	-	-	-
F-test	1.48^{NS}	0.72^{NS}	2.02^{NS}
CV (%)	5.00	6.50	8.9

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, NS= Non-significant, * = Significant at 5%, **= Significant at 1%, *** = Significant at less than 0.1% level

and harvesting was significant among different cultivars, planting dates, and their interaction (Table 4 and Appendix 1). 'Williams' required the longest duration for all the phenological stages followed by 'Indonesian' while 'Grand Naine matures earliest, indicating genotypic differences in the growth and maturity. The longer cycle in 'Williams' and 'Indonesian' may be due to their vigorous vegetative growth and delayed floral initiation, whereas 'Grand Naine' showed early maturity. Similar variations were reported by Singh et al. (2012) and Kumar et al. (2018).

The effect of planting date on these phenological parameters was also highly significant. Plants transplanted on 15th November required the longest time to reach shooting (348.80 days), flowering (360.10 days), and harvesting (506.00 days), whereas those planted on 15th May and 15th March reached these stages the earliest (310.80, 317.90, and 428.40 days; and 309.90, 322.00, and 435.00 days, respectively) (Table 4). The prolonged duration in the November planting may be attributed to suboptimal temperature, humidity, and light intensity, promoting faster growth and early growth, resulting in delayed physiological activity and slower pseudostem development. Conversely, May and March Plantings coincides with favorable temperature, humidity, and light intensity, promoting faster growth and earlier initiation of reproductive phase. These findings are consistent with the observations of Hazarika et al. (2015), Salau et al. (2016), and Arwatchananukul et al. (2022), who reported that warm and humid conditions favor rapid development and shorten the banana growth cycle. Similarly, in Bangladesh, Ara et al. (2011) found that plantings in February-March had the shortest time to harvest, ranging from 328.68 to 341.67 days supporting the present results.

The significant interaction between cultivar and planting date further indicates differential responses to planting date. 'Grand Naine' planted on 15th May showed the shortest crop duration (403.00 days), whereas 'Williams' planted on 15th November took the longest duration

(521.00 days) for bunch harvest (Appendix 1). These results highlight the importance of matching cultivars with suitable planting dates for optimum crop duration and synchronized harvesting.

Yield and yield attributing parameters

The yield and its attributing parameters such as bunch length, length between first and final hand, number of hands per bunch, number of fingers per bunch, weight of the second hand, number of fingers in the second hand, and bunch weight were significantly influenced by the date of planting rather than the cultivar or the interaction between planting date and cultivar. The highest values were observed for the 15th July planting date: bunch length (110.11 cm), length between first and final hand (53.44 cm), number of hands (9.67), number of fingers per bunch (169.10), weight (2.69 kg) and number of fingers in the second hand (19.44), and bunch weight (20.85 kg). The yield and yield contributing parameters were closely related to the vegetative growth of the plant. Plants with optimal growth characterized by larger base circumference, a higher number of effective leaves, greater leaf length and width, and more cumulative leaves per plant produced higher yields compared to those with stunted growth. Optimal growth is dependent on favorable weather conditions, proper application of manure and chemical fertilizers, and timely irrigation.

Banana planted during the winter season experience low temperatures during their early vegetative and flowering stages, which significantly hampers their growth and development. The reduced growth rate is primarily attributed to the adverse effects of low temperatures on the physiological processes and nutrient uptake mechanisms essential for normal plant development. Specifically, bananas planted between November and January align their bunch development phase with the coldest part of the year, resulting in suboptimal growth conditions (Robinson & Sauco, 2010). In the Terai region of Nepal, winter weather conditions are not

Table 7. Effect of planting dates on weight and number of fingers in the second hand and bunch yield of different banana cultivars during 2021-2023 at Khajura, Banke, Nepal

Treatments	Hand weight (kg)	Number of fingers per hand	Bunch weight (kg)	Bunch yield (t ha^{-1})
Cultivars				
Grand Naine	2.22	18.22	16.68^{a}	51.49^{a}
Williams	1.91	15.06	15.66^{a}	48.33^{a}
Indonesian	1.92	17.22	13.31^{b}	41.07^{b}
SEm±	0.16	0.97	0.70	2.16
LSD (p<0.05)	-	-	1.95	6.01
F-test	2.65^{NS}	5.62^{NS}	12.19*	12.19*
Date of planting				
15-May	2.26b	18.00^{ab}	17.26^{b}	53.26^{b}
15-July	2.69^{a}	19.44^{a}	20.85^{a}	64.37^{a}
15-Sep	1.96^{b}	15.56^{b}	15.52^{c}	47.91^{c}
15-Nov	1.58^{c}	16.44^{b}	11.94^{d}	36.87^{d}
15-Jan	1.46^{c}	15.67^{b}	11.01^{d}	34.00^{d}
15-Mar	2.16^{b}	15.89^{b}	14.70^{c}	45.38^{c}
Grand mean	2.017	16.83	15.22	46.96
SEm±	0.15	1.23	0.74	2.29
LSD (p<0.05)	0.31	2.52	1.51	4.67
F-test	17.99***	3.21*	47.07***	47.06***
Cultivars × Date of planting				
SEm±	0.29	2.18	1.37	4.22
LSD (p<0.05)	-	-	2.79	8.63
F-test	1.98^{NS}	1.42^{NS}	2.79*	2.79*
CV (%)	16.00	15.60	10.30	10.30

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, NS= Non-significant, * = Significant at 5%, 1%, *** = Significant at less than 0.1% level

conducive to optimal bunch development. During this period, ambient temperatures often fall below 13°C, a threshold at which banana growth ceases (Turner & Lahav, 1983). Additionally, persistent fog and further drops in temperature, sometimes reaching as low as 4°C, can lead to leaf firing. The loss or reduction of functional leaves during or after bunch emergence compromises the plant's photosynthetic capacity, delaying bunch development and reducing fruit quality. Furthermore, plants shooted during this period may fail to complete the process due to unfavorable weather conditions, ultimately impacting both the timing and quality of the harvest. Yield and yield-attributing traits are closely linked with the vegetative vigor of the plant. Banana exhibiting robust vegetative growth in warmer season, larger base circumference, more number of effective leaves, and higher leaf area tend to produce significantly higher yield compared to stunted plants under winter stress condition.

The present findings are supported by a number of researchers. Kumar et al. (2021) reported the highest bunch weight (20.20 kg), number of hands per bunch (11.00), number of fingers (120.00), second hand weight (2.02 kg), and number of fingers in the second hand (16.00) for banana cv. 'Grand Naine' planted on 15th July. El-Khawaga (2013) found the highest bunch weight (15.50 kg), hand weight (2.15 kg), and finger weight (104.00 g) in bananas planted on 15th March in Egypt. Bauri et al. (2002) observed the highest bunch weight (15.02 kg) and number of fingers per bunch (116.60) in February planted bananas, while June planting produced the lowest bunch weight (13.23 kg) and number of fingers per bunch (89.60). However, finger weight was the highest in June planting (137.60 g). Liu et al. (1999) observed that monoculture of banana cv. 'Grand Naine' planted in November yielded the highest bunch (44.65 t ha^{-1}) compared to other planting dates: January (40.53 t ha^{-1}), March (30.40 t ha^{-1}), and May (33.65 t ha^{-1}). The difference in yield and its attributing parameters might be due to locational variations of the study site.

Conclusion:

The present study revealed that banana planting between 15th March and 15th September ensures good crop performance. Among the combinations, planting on 15th July produced the highest yields in all cultivars, Williams' (70.59 t ha^{-1}), 'Grand Naine' (67.23 t ha^{-1}), and 'Indonesian' (55.28 t ha^{-1}), indicating this time as the optimum planting date for the Western Terai of Nepal. Early planting of 15th March and 15th May shortened the production cycle, facilitating earlier harvests and better market regulation.

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Declaration of conflict of interest and ethical approval:

BC served as the lead researcher, managing the field experiments, data collection, literature review, and manuscript preparation. AKS, AS, and KMT contributed to the experimental design, supervision, and overall guidance throughout the research. All authors carefully reviewed the manuscript before submitting to *Nepalese Horticulture* and declare that there are no competing interests regarding the current manuscript.

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Appendix 1. Interaction effect of cultivars and planting dates on base circumference, number of days required for shooting, flowering, and harvesting from transplanting, and bunch weight and yield during 2021-2023 at Khajura, Banke, Nepal

Treatments	Base circumference (cm)	Number of days required for			Bunch weight (kg)	Yield (t ha^{-1})
		Shooting	Flowering	Harvesting		
$Cv_1 \times D_1$	60.50^{b-d}	295.00^{gh}	301.70^{h}	403.00^{h}	16.03^{cd}	49.47^{cd}
$Cv_1 \times D_2$	69.21^{ab}	301.70^{f-h}	309.20^{gh}	416.30^{gh}	21.78^{ab}	67.23^{ab}
$Cv_1 \times D_3$	63.10^{a-c}	315.30^{ef}	323.20^{e-g}	456.30^{d-f}	17.34^{a-d}	53.52^{a-d}
$Cv_1 \times D_4$	57.67^{b-d}	336.70^{b-d}	348.70^{b-d}	487.00^{bc}	13.50^{c-f}	41.67^{c-f}
$Cv_1 \times D_5$	49.80^{d}	303.00^{f-h}	317.70^{f-h}	438.00^{fg}	14.10^{c-f}	43.51^{c-f}
$Cv_1 \times D_6$	60.33^{b-d}	290.30^{h}	301.80^{h}	408.00^{h}	17.34^{a-d}	53.53^{a-d}
$Cv_2 \times D_1$	67.07^{a-c}	324.30^{de}	331.50^{d-f}	448.00^{ef}	18.82^{a-c}	58.08^{a-c}
$Cv_2 \times D_2$	74.17^{a}	330.30^{c-e}	337.70^{d-f}	457.00^{d-f}	22.87^{a}	70.59^{a}
$Cv_2 \times D_3$	64.17^{a-c}	349.70^{ab}	357.60^{a-c}	501.70^{ab}	15.01^{c-e}	46.33^{c-e}
$Cv_2 \times D_4$	49.67^{d}	359.00^{a}	371.00^{a}	521.00^{a}	11.96^{d-f}	36.92^{d-f}
$Cv_2 \times D_5$	49.93^{d}	324.70^{de}	339.80^{c-e}	467.00^{c-e}	10.36^{ef}	31.99^{ef}
$Cv_2 \times D_6$	58.60^{b-d}	318.00^{d-f}	330.50^{d-f}	449.00^{ef}	14.93^{c-e}	46.09^{c-e}
$Cv_3 \times D_1$	61.33^{b-d}	313.00^{e-g}	320.70^{e-h}	434.30^{fg}	16.92^{b-d}	52.23^{b-d}
$Cv_3 \times D_2$	68.94^{a-c}	318.00^{d-f}	326.00^{e-g}	448.00^{ef}	17.91^{a-c}	55.28^{a-c}
$Cv_3 \times D_3$	61.45^{b-d}	326.70^{de}	334.80^{d-f}	474.00^{cd}	14.22^{c-e}	43.90^{c-e}
$Cv_3 \times D_4$	58.50^{b-d}	350.70^{ab}	360.70^{ab}	510.00^{ab}	10.37^{ef}	32.01^{ef}
$Cv_3 \times D_5$	55.97^{cd}	348.70^{a-c}	363.00^{ab}	491.00^{bc}	8.58^{f}	26.49 ^{f}
$Cv_3 \times D_6$	60.53^{b-d}	321.30^{d-f}	333.70^{d-f}	448.00^{ef}	11.83^{d-f}	36.52^{d-f}
Grand mean	60.61	323.69	333.84	458.76	15.22	46.96
SEm±	3.01	4.86	4.92	5.87	1.37	4.21
LSD (p<0.05)	6.14	10.07	10.22	12.05	2.79	8.63
F-test	2.24*	8.34***	8.29***	5.60***	2.79*	2.79*
CV (%)	6.60	1.60	1.60	1.50	10.30	10.30

Note: SEm± = Standard error of mean difference, LSD (<0.05) = Least significant difference at probability value 0.05, CV = Coefficient of variation, Treatment means followed by common letter (s) within a column are not significantly different at 5% by DMRT, * = Significant at 5% level, *** = Significant at less than 0.1% level, Cv = Cultivar