



RESEARCH ARTICLE

Assessing agro-meteorological indices and yield performance of groundnut genotypes under varying sowing windows

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Abstract

Groundnut (*Arachis hypogaea* L.) productivity is highly sensitive to climatic variability. The agro-meteorological assessment is important for getting improvement in yield. The present study was conducted to evaluate the performance of 3 groundnut genotypes namely KCG-6, KL-1812 and K-6 raised under 2 sowing windows (late June and early July) during the *Kharif* seasons of 2023 and 2024 in field conditions. The results showed that early July sowing led to significantly high pod yield and resource-use efficiency, which is likely due to better thermal and radiation conditions. Among the 3 genotypes, KL-1812 consistently outperformed others, showing superior canopy development, biomass accumulation and pod yield potential. The interaction between genotype and sowing window showed that KL-1812 produced the highest pod yield when sown in late June, indicating that this genotype performed optimally under the environmental conditions associated with this sowing window. Agro-meteorological indices such as growing degree days (GDD), photo-thermal units (PTU) and radiation use efficiency (RUE) were high during July sowing, contributing to better yield performance. In conclusion, the study emphasizes that aligning sowing time and cultivar selection with prevailing weather conditions can significantly enhance groundnut productivity. These findings support the development of climate-smart agricultural strategies and highlight the need for multi-location validation to refine region-specific recommendations.

Keywords: agro-meteorological indices; genotype performance; groundnut productivity; heat unit efficiency; sowing window

Introduction

Groundnut (*Arachis hypogaea* L.) is an oilseed crop growing in semi-arid regions. This crop plays a crucial role in meeting the rising demand for edible oils and fats in a sustainable manner. It is an integral part of the Indian diet. The kernels contain 48-50 % of edible oil, 25 % protein 20 % carbohydrates and vitamins and minerals (1). Groundnut productivity is largely determined by prevailing weather conditions during the growing season and the time of sowing. Every crop has sowing time and that gives optimal growth and favourable climate (2). Studies have shown that groundnut sown at the onset of the monsoon experiences a yield reduction of 19-31 %, while a 15-day delay in sowing can lead to a 21-38 % decline in yield due to unfavorable weather changes (3). Temperature is a key determinant of crop phenology, as it regulates plant growth and development through the accumulation of heat units required to progress from one growth stage to the next. Each growth stage requires a specific temperature regardless of the sowing date, crop, or variety. Previous studies have explored the influence of sowing time and genotypic variation on groundnut yield. The studies focused either on a single season, few environmental conditions

and lacked integration of agro-meteorological indices such as GDD, PTU, helio thermal units (HeTU) and RUE. Only few studies examined the combined effect of sowing window and genotype interaction using a factorial approach under South Indian monsoonal agro-climatic conditions. There is also limited literature linking observed yield outcomes to physiological traits such as leaf area (LA), leaf area index (LAI) and growth rates, particularly in the context of resource-use efficiency under variable weather patterns.

This present study was conducted with an aim to evaluate performance of three genotypes across 2 sowing windows in a factorial design over 2 consecutive monsoon seasons providing detailed agro metrological indices obtained after assessment of resource-use dynamics.

The link between canopy and growth traits, with yield performance and environmental responses was also evaluated.

By addressing these gaps, the study provides a more integrated, climate-aware framework for guiding sowing strategies and cultivar recommendations under changing climatic conditions.

Materials and Methods

A field experiment was conducted at AICRP on Agro meteorology field unit, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, during *Khari* 2023 and 2024. The experimental site is characterized by moderately acidic sandy loam soil with a pH of 5.10. The experiment was designed in factorial randomized complete block design (RCBD) with 2 dates of sowing viz., 2nd fortnight of June (D₁) and 1st fortnight of July (D₂) and 3 groundnut genotypes viz., KCG-6 (V₁), KL-1812 (V₂) and K-6 (V₃). The layout consisted of 3 replications and all treatment combinations were randomly allocated within each replication following standard RCBD randomization procedures to ensure unbiased treatment distribution. The gross plot size was 5.1 m × 5.2 m. The seedlings were planted with inter row spacing of 30 cm and intra-row spacing of 10 cm. A uniform recommended dose of 25:50:25 kg of N₂, P₂O₅ and K₂O fertilizers were applied at the time of sowing. Other management practices, including weed control, nutrient management and plant protection measures, were followed across all treatments. Biotic and abiotic stress factors were minimized through timely pest and disease management and maintenance of optimal field conditions. Interaction effects between sowing window and genotype were assessed using factorial Analysis of Variance (ANOVA) and significance was determined at $p = 0.05$ to understand combined influence of both factors on growth and yield parameters.

Measurements

Plant growth parameters such as height (cm) and number of branches per plant were recorded at harvest. LA was measured from 5 sampled plants per treatment using a leaf area meter (LICOR 3100, LI-COR, Inc.) and LAI was calculated as:

$$LAI = \frac{\text{leaf area}}{\text{land area (spacing)}}$$

Sampled plants were dried at 80 °C to record dry weight, which was further used to compute growth indices:

Absolute growth rate (AGR):

$$AGR \text{ (g day}^{-1}\text{)} = \frac{W_2 - W_1}{t_2 - t_1} \quad (4)$$

Where, W_1 and W_2 are dry weight of plants at time t_1 and t_2 , respectively.

Relative growth rate (RGR):

$$RGR \text{ (g g}^{-1}\text{ day}^{-1}\text{)} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \quad (4)$$

where W_1 and W_2 are dry weight of plants at time t_1 and t_2 , respectively \log_e , natural logarithm.

Dry matter accumulation was recorded in leaf, stem and pod. Pod yield (kg ha⁻¹) was estimated from net plot and haulm yield (kg ha⁻¹) from dried plants. Harvest index (HI) was computed as:

$$HI = \frac{\text{Pod yield (kg ha}^{-1}\text{)}}{(\text{Pod yield} + \text{Haulm yield}) \text{ (kg ha}^{-1}\text{)}} \quad (5)$$

Daily weather data (T_{\max} , T_{\min} , sunshine, day length, RH, rainfall) during 2023–24 were used to derive agro-meteorological indices and resource efficiencies viz., GDD, PTU, HeTU, hydro

thermal units (HyTU), heat use efficiency (HUE), photo thermal use efficiency (PTUE), helio thermal use efficiency (HeTUE), hydro thermal use efficiency (HyTUE) and RUE for the corresponding cropping period from sowing to harvest.

Growing degree days (GDD):

$$GDD \text{ (}^\circ\text{days)} = \sum \frac{T_{\max} + T_{\min}}{2} - T_b \quad (6)$$

Where, T_{\max} and T_{\min} = Maximum and minimum temperature, respectively. T_b = Base temperature and it is 10 °C for groundnut (7).

Photo-thermal units (PTU):

$$PTU \text{ (}^\circ\text{days hours)} = GDD \times \text{Day length (8).}$$

Helio-thermal units (HeTU):

$$\text{HeTU (}^\circ\text{days hours)} = GDD \times \text{Sunshine hour (Bright SSH) (9).}$$

Hydro-thermal units (HyTU):

$$\text{HyTU (}^\circ\text{days)} = \sum [GDD \times \text{Average relative humidity (\%)}] \text{ (9).}$$

Accumulated value of these indices was used from sowing to harvest of the crop.

Heat use efficiency (HUE):

$$\text{HUE (kg }^\circ\text{days}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Accumulated growing degree days (}^\circ\text{day)}}$$

Photo-thermal use efficiency (PTUE):

$$\text{PTUE (kg }^\circ\text{days hour}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{PTU (}^\circ\text{days hours)}}$$

Helio-thermal use efficiency (HeTUE):

$$\text{HeTUE (kg }^\circ\text{days hour}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{HeTU (}^\circ\text{days hours)}}$$

Hydro-thermal use efficiency (HyTUE):

$$\text{HyTUE (kg }^\circ\text{days}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{HyTU (}^\circ\text{days)}}$$

Radiation use efficiency (RUE):

$$\text{RUE (kg MJ}^{-1}\text{)} = \frac{\text{Grain yield (kg)}}{\text{Solar radiation (MJ)}}$$

The meteorological data used in this study meteorological data were obtained from the A-type observatory, GKVK, Bengaluru.

Statistical analysis and the interpretation of data

Data were analyzed using ANOVA under a factorial randomized block design (RBD). Significance was tested at $p = 0.05$ and critical differences (CD) were calculated wherever the F-test was significant. ANOVA was performed using R software (version 4.3.2) and treatment means were compared using Duncan's multiple range test (DMRT) at $p < 0.05$. Correlation analysis among key traits was conducted and visualized as a heat map in R Studio.

Results and Discussion

Weather prevailed during the cropping seasons

The variation in weather parameters was observed during the cropping seasons and it directly influenced the crop phenology.

Weather data during the cropping season for 2023 and 2024 season from June to November is presented Table 1. In 2024, precipitation significantly increased as compared to 2023, particularly in October, while temperature trends remained relatively stable. The rise in rainfall corresponds with a noticeable decline in total solar radiation in 2024, suggesting increased cloud cover and reduced sunlight exposure.

Yield and yield attributes

Among the 3 genotypes, KL-1812 recorded higher pod yield (3603 kg ha⁻¹), haulm yield (15077 kg ha⁻¹), number of pods per plant (36.88), pod weight per plant (41.28 g) and total dry matter (TDM) accumulation (92.38 g), followed by KCG-6 (2181 kg ha⁻¹, 8207 kg ha⁻¹, 23.75, 27.42 g and 73.23 g) and K-6 (2080 kg ha⁻¹, 6975 kg ha⁻¹, 13.69, 23.38 g and 64.78 g). This indicated that V₂ had superior genetic potential for vegetative and reproductive growth. The variety produced more haulm biomass whereas V₃ was more efficient in partitioning assimilates leading to pod development. The high haulm yield in V₂ also indicated better plant vigour and height, contributing to increased biomass accumulation.

Delayed sowing (D₂) resulted in a higher pod yield (2799 kg ha⁻¹) harvest index (0.30), pods per plant (27.96) and pod weight per plant (35.81 g), whereas early sowing (D₁) had lower values (2443 kg ha⁻¹, 0.19, 21.58 and 25.58 g, respectively), indicating that delayed sowing (D₂) aligned the crop's reproductive phases with more favorable environmental conditions such as optimal

temperature, sufficient soil moisture and higher relative humidity. This resulted in improved pod setting, grain filling and ultimately higher yields. These conditions reduced stress during critical growth stages and enhanced resource use efficiency (10). In contrast, early sowing (D₁) promoted excessive vegetative growth under relatively cooler conditions, which diverted assimilates away from reproductive development, leading to lower pod yield and harvest index. Conversely, early sowing (D₁) led to higher haulm yield (11709 kg ha⁻¹) and TDM (79.80 g) as compared to delayed sowing (D₂: 8463 kg ha⁻¹, 73.80 g), suggesting that early sowing led to prolonged vegetative growth resulting in greater biomass accumulation at the expense of reproductive output (11).

Interaction effects were mostly non-significant for all the parameters tested except for haulm yield. Treatment V₂D₁ recorded the highest (17368 kg ha⁻¹) haulm yield, while V₃D₂ had the lowest (5633 kg ha⁻¹) (Table 2 and Supplementary Table 1). This indicates that vegetative growth was more influenced by environmental factors, whereas pod yield was largely determined by genetic makeup. The source-sink relationship played a crucial role in regulating the vegetative and reproductive yield in plants (11). The delayed sowing enhanced assimilate translocation towards pod development, leading to improved yield components (12).

Table 1. Changes in the environmental variables such as temperature, total precipitation and total solar radiation noted in 2023-2024 during groundnut growing season at GKV, Bengaluru station

Year	Month	Solar radiation (MJ/m ²)	Precipitation (mm)	Temperature (°C)
2023	June	362.7	67.0	25.9
2023	July	328.2	115.2	24.0
2023	August	375.0	25.8	25.4
2023	September	338.9	194.0	24.6
2023	October	344.4	67.6	24.8
2023	November	290.9	154.2	24.0
2024	June	339.7	170.4	23.2
2024	July	320.3	84.4	23.9
2024	August	343.4	261.2	24.5
2024	September	334.0	33.6	23.9
2024	October	308.2	585.4	23.6
2024	November	277.0	48.0	25.9

Table 2. Effect of sowing windows and genotypes on yield, related yield traits of groundnut (Pooled data)

Treatments	Pod yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)	Harvest index	No. of pods per plant	Pod weight per plant (g)	TDM(g)
Genotypes						
V ₁ (KCG-6)	2181 ^b	8207 ^b	0.24 ^{ab}	23.75 ^b	27.42 ^b	73.23 ^b
V ₂ (K-1812)	3603 ^a	15077 ^a	0.22 ^b	36.88 ^a	41.28 ^a	92.38 ^a
V ₃ (K-6)	2080 ^b	6975 ^c	0.27 ^a	13.69 ^c	23.38 ^b	64.78 ^c
F test	**	*	**	**	**	**
S. Em. ±	91.0	243.6	0.01	1.89	2.52	1.68
CD @ 5 %	274.3	734.4	0.03	5.71	7.60	5.08
Date of sowing						
D ₁ (June 2 nd fortnight)	2443 ^b	11709 ^a	0.19 ^b	21.58 ^b	25.58 ^b	79.80 ^a
D ₂ (July 1 st fortnight)	2799 ^a	8463 ^b	0.30 ^a	27.96 ^a	35.81 ^a	73.80 ^b
F test	**	NS	**	*	**	**
S. Em. ±	74.31	198.9	0.009	1.54	2.06	1.37
CD @ 5 %	224.0	599.6	0.027	4.66	6.21	4.15
Interaction						
D ₁ V ₁	1921 ^c	9444 ^c	0.18 ^c	19.63 ^c	21.21 ^{cd}	76.26 ^b
D ₂ V ₁	2441 ^b	6969 ^c	0.29 ^b	27.88 ^b	33.63 ^{ab}	70.20 ^b
D ₁ V ₂	3510 ^a	17368 ^a	0.18 ^c	35.63 ^{ab}	39.41 ^{ab}	92.97 ^a
D ₂ V ₂	3696 ^a	12786 ^b	0.27 ^b	38.13 ^a	43.15 ^a	91.80 ^a
D ₁ V ₃	1899 ^c	8316 ^d	0.20 ^c	9.50 ^d	16.11 ^d	70.16 ^b
D ₂ V ₃	2261 ^{bc}	5633 ^f	0.34 ^a	17.88 ^{cd}	30.65 ^{bc}	59.39 ^c
F test	NS	**	**	NS	NS	NS
S. Em. ±	128.7	344.5	0.02	2.68	3.57	2.38
CD @ 5 %	NS	1038.5	NS	NS	NS	NS
CV (%)	13.09	11.29	9.80	14.8	12.29	8.22

*Values followed by the same letter(s) within a column indicate no significant difference according to Duncan's multiple range test ($p < 0.05$)

Growth and growth attributes

Among the 3 genotypes, V₁ recorded the higher plant height (54.20 cm) and lower number of branches per plant (8.90), leaf area (85.85 cm²) and LAI: 0.29, indicating its tendency toward greater vertical growth with limited lateral expansion. In contrast, V₂ exhibited the lower plant height (40.66 cm) and higher number of branches per plant (11.53), leaf area (287.9 cm²) and LAI (0.96), suggesting its superior canopy development and efficient light interception. V₂ also showed the higher AGR (1.08 g plant⁻¹ day⁻¹) and RGR (0.00709 g g⁻¹ day⁻¹), indicating its better biomass accumulation efficiency compared to V₁ (AGR: 0.83, RGR: 0.00674) and V₃ (AGR: 0.66, RGR: 0.00587). The superior performance of KL-1812 across multiple growth and yield parameters suggests underlying physiological traits that confer an advantage under both sowing windows. Its high LA and LAI indicate a more expansive and efficient canopy, enabling greater light interception and photosynthetic activity throughout the crop cycle. In contrast, KCG-6 though showed greater plant height but lagged in pod yield and canopy efficiency, suggesting a growth form skewed toward structural elongation rather than reproductive development. Similarly, K-6 (V₃), with the smallest canopy and lowest total biomass most likely suffered from limited photosynthetic potential and a smaller source pool, even though it displayed the highest HI due to efficient but limited partitioning (13).

Regarding sowing dates, delayed sowing (D₂) resulted in a higher plant height (49.35 cm) and more branches per plant (10.30) compared to early sowing (D₁: 44.41 cm and 9.99, respectively), suggesting that later planting favored vertical growth and branching. However, leaf area (D₂: 161.15 cm², D₁: 207.85 cm²) and LAI (D₂: 0.54, D₁: 0.69) was higher in early sowing, indicating that early-planted crops had better leaf expansion and canopy development. Indices such as AGR (D₁: 0.90, D₂: 0.82) and RGR (D₁: 0.00661, D₂: 0.00652) were slightly higher in early sowing, reflecting more efficient biomass accumulation due to longer exposure to favourable growth conditions. This suggests that

early sowing enhanced vegetative growth parameters, whereas delayed sowing promoted plant height and branching, likely as a compensatory mechanism to optimize light capture in a shorter growth duration (Table 3 and Supplementary Table 2) (14). Interaction effects were non-significant across all parameters.

Correlation

The correlation heatmap reveals strong positive associations between pod yield and important yield-determining traits such as the number of pods per plant (0.76), pod weight per plant (0.86), total dry matter production (0.74), number of branches per plant (0.92), LA (0.58) and LAI (0.75), indicating that canopy development, biomass accumulation and reproductive potential strongly influence yield performance. Haulm yield shows moderate correlation with pod yield (0.33) but exhibits very strong positive correlations with AGR (0.94) and total dry matter production (0.86), confirming that greater vegetative growth supports higher biomass production. HI displays a moderate positive correlation with pod yield (0.33), but a strong negative correlation with haulm yield (-0.68), suggesting that increased vegetative biomass may reduce assimilate partitioning efficiency toward pods. Plant height shows negative correlations with pod yield (-0.64), haulm yield (-0.54), LA (-0.61), LAI (-0.91) and number of branches (-0.84), indicating that excessive vertical growth likely limits canopy expansion and reduces total biomass allocation, thereby lowering yield efficiency. AGR exhibited strong positive correlation with total dry matter production (0.96), haulm yield (0.94) and substantial association with LA (0.9), highlighting its role in determining biomass accumulation and reproductive success. RGR, although weakly correlated with pod yield (0.20), showed moderate correlation with pod weight per plant (0.42) and pods per plant (0.33), suggesting its influence on early biomass allocation patterns. Overall, these correlations emphasize that biomass production, canopy traits and reproductive sink strength collectively drive yield formation in groundnut (Fig. 1).

Table 3. Effect of sowing windows and genotypes on growth attributes of groundnut (Pooled data)

Treatments	Plant height (cm)	No. of branches per plant	LA (cm ²)	LAI	AGR (g plant ⁻¹ day ⁻¹)	RGR (g g ⁻¹ day ⁻¹)
Genotypes						
V ₁ (KCG-6)	54.20 ^a	8.90 ^b	85.85 ^c	0.29 ^c	0.83 ^b	0.00674 ^a
V ₂ (K-1812)	40.66 ^c	11.53 ^a	287.94 ^a	0.96 ^a	1.08 ^a	0.00709 ^a
V ₃ (K-6)	45.77 ^b	10.00 ^{ab}	179.70 ^b	0.60 ^b	0.66 ^c	0.00587 ^b
F test	**	*	**	**	**	**
S. Em. ±	1.16	0.54	14.12	0.05	0.04	0.00033
CD @ 5 %	3.49	1.64	42.56	0.14	0.12	NS
Date of sowing						
D ₁ (June 2 nd fortnight)	44.41 ^b	9.99 ^a	207.85 ^a	0.69 ^a	0.90 ^a	0.00661 ^a
D ₂ (July 1 st fortnight)	49.35 ^a	10.30 ^a	161.15 ^b	0.54 ^b	0.82 ^a	0.00652 ^a
F test	**	NS	*	*	NS	NS
S. Em. ±	0.95	0.45	11.5	0.04	0.04	0.00019
CD @ 5 %	2.86	NS	34.7	0.12	NS	NS
Interaction						
D ₁ V ₁	50.46 ^b	8.63 ^b	90.70 ^c	0.30 ^c	0.86 ^b	0.00661 ^{abc}
D ₂ V ₁	57.94 ^a	9.18 ^{ab}	81.00 ^c	0.27 ^c	0.80 ^b	0.00687 ^{ab}
D ₁ V ₂	38.90 ^d	11.59 ^a	303.40 ^a	1.01 ^a	1.12 ^a	0.00723 ^a
D ₂ V ₂	42.43 ^d	11.46 ^a	272.48 ^{ab}	0.91 ^{ab}	1.05 ^a	0.00694 ^{ab}
D ₁ V ₃	43.86 ^{cd}	9.75 ^{ab}	229.44 ^b	0.76 ^b	0.72 ^{bc}	0.00600 ^{bc}
D ₂ V ₃	47.68 ^{bc}	10.25 ^{ab}	129.96 ^c	0.43 ^c	0.60 ^c	0.00574 ^c
F test	NS	NS	NS	NS	NS	NS
S. Em. ±	1.64	0.77	19.97	0.07	0.06	0.00033
CD @ 5 %	NS	NS	NS	NS	NS	NS
CV (%)	9.40	11.26	11.25	13.21	11.23	12.94

*Values followed by the same letter(s) within a column indicate no significant difference according to Duncan's multiple range test ($p < 0.05$)

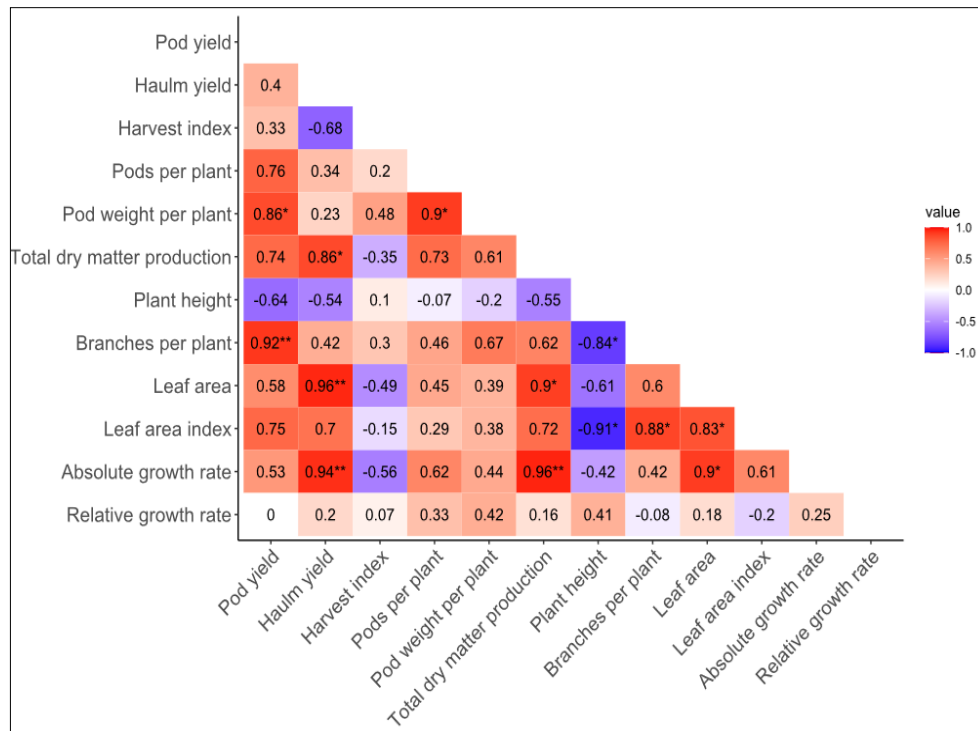


Fig. 1. Heat map on person's correlation coefficient between the growth and yield parameters of the groundnut as influenced by the date of sowing and genotypes.

Note: * indicates significance at $p < 0.05$ and ** indicates significance at $p < 0.01$.

Agro-meteorological indices

The impact of different sowing windows on crop yield and agro-meteorological indices was compared. The results revealed that sowing done in 1st fortnight of July resulted in a higher yield (2799 kg ha⁻¹) compared to 2nd fortnight (2443 kg ha⁻¹) of June (Table 4 and Supplementary Table 3). This enhancement was associated with increase in parameters such as GDD (1.74 vs. 1.60 °days), PTU (21.25 vs. 19.83 °days hours), HETU (9.19 vs. 7.85 °days hours) and HYTU (127.4 vs. 116.2 kg °days⁻¹), indicating improved thermal and radiation resource utilization. Additionally, the higher values of efficiency indices such as HUE (1.59 vs. 1.51 kg °days⁻¹), PTUE (0.131 vs. 0.122 kg °days⁻¹ hour⁻¹), HyTUE (0.022 vs. 0.020 kg °days⁻¹) and RUE (1.732 vs. 1.653 kg MJ⁻¹) in July sowing suggested that better environmental factors supported more biomass production and grain yield.

The results indicate that the July sowing window provided more favourable temperature and radiation conditions, leading to enhanced crop development and productivity. The findings highlight that July 1st fortnight sowing is more efficient and beneficial for maximizing yield, although further studies considering soil moisture, rainfall and management practices could help optimize sowing time recommendations (11).

The trends in 2023 and 2024 for different thermal and energy utilization indices (GDD, PTU, HeTU and HyTU) across growth stages reveal significant variations between the first and second sowing dates. Across both years, GDD remained relatively

stable, indicating similar temperature accumulation, while PTU showed slightly higher values in the first sowing compared to the second, suggesting better utilization of thermal energy in earlier sowing. The HeTU and HyTU values exhibited noticeable peaks at flower initiation, pod initiation and harvest stages, with the second sowing consistently showing higher values than the first, indicating greater heat and hydrothermal utilization efficiency in delayed sowing conditions. The spikes in HyTU at harvest suggest that late-sown crops experienced more accumulated thermal stress towards maturity, which could influence final yield outcomes (15). Overall, the differences in energy utilization patterns highlight the impact of sowing time on crop growth, with early sowing favoring better thermal accumulation and partitioning, while delayed sowing resulted in increased stress towards reproductive stage (Fig. 2).

Conclusion

This study highlights the critical role of sowing time and genotype selection in optimizing groundnut productivity under varying climatic conditions. Among the tested sowing windows, early July (1st fortnight) sowing consistently resulted in higher pod yield, HI and pod weight, suggesting its suitability for maximizing reproductive output. In contrast, late June (2nd fortnight) sowing favored vegetative growth and biomass accumulation, indicating its potential for fodder-oriented cultivation.

Table 4. Effect of sowing windows on accumulated agro meteorological indices and resource use efficiencies of groundnut (Pooled data)

Sowing window	Yield (kg ha ⁻¹)	GDD* (days)	PTU* (days hours)	HETU* (days)	HYTU* (kg days ⁻¹)	HUE* (kg days ⁻¹)	PTUE* (kg ° days hour ⁻¹)	HeTUE* (kg days hour ⁻¹)	HyTUE* (kg days ⁻¹)	RUE* (kg MJ ⁻¹)
June 2 nd fortnight	2443	1.60	19.83	7.85	116.2	1.51	0.122	0.317	0.020	1.653
July 1 st fortnight	2799	1.74	21.25	9.19	127.4	1.59	0.131	0.314	0.022	1.732

*Values for the given indices and efficiencies are in multiples of 1000.

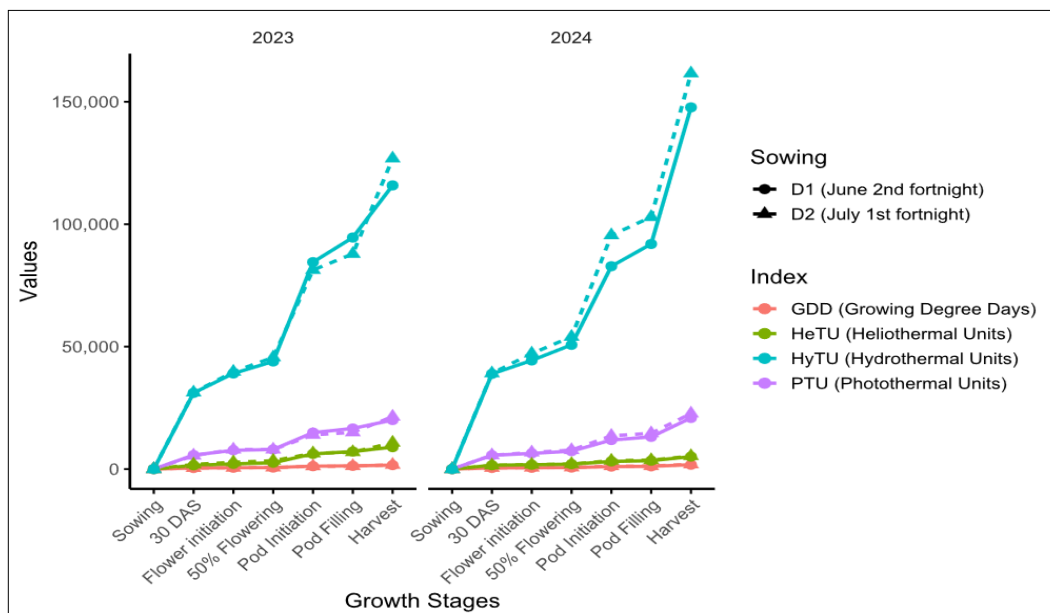


Fig. 2. Trends of GDD, PTU, HeTU and HyTU over different growth stages of groundnut during 2023-2024.

Among genotypes, KL-1812 demonstrated superior performance, with the highest pod yield, haulm yield, LA and growth rates, making it a strong candidate for cultivation across both sowing windows. Notably, the interaction of KL-1812 with late June sowing produced the highest pod yield, suggesting that cultivar-specific recommendations can further refine sowing strategies.

Future line of work

Future studies should incorporate soil moisture dynamics, long-term rainfall variability and multi-location trials to validate genotype environment interactions under diverse climatic conditions.

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Authors' contributions

Conceptualization was done by PMR, MNT, MHM and M. PMR, MHM, M, MNT, MBR and RJ planned and supervised the work. Conduction of field experiment was done by PMR, MNT, MHM, M, PRS and AV. Data analysis was performed by PMR, LH, DVS, PRS and AV. PMR prepared the draft and the manuscript was reviewed by MNT, MHM and M. Editing was done by PMR, LH, DVS, PRS and AV. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

AI Declaration : The authors used ChatGPT (OpenAI, GPT-5 version) for language polishing and grammatical corrections only. The intellectual content, interpretation of results and conclusions were entirely developed by the authors.

References

- Bonku R, Yu J. Health aspects of peanuts as an outcome of its chemical composition. *Food Sci Hum Wellness*. 2020;9(1):21-30. <https://doi.org/10.1016/j.fshw.2019.12.005>
- Ashok Kumar K, Malleswari SN, Sudheer KV, Bal SK, Manikandan N, Subba Rao AV, et al. Optimizing groundnut sowing for minimizing dry spell risks over Rayalaseema, a rainfed region of India. *Agron J*. 2025 Jan;117(1):e70020. <https://doi.org/10.1002/agj2.70020>
- Patel HR, Lunagaria MM, Karande BI, Pandey Vyas YS, Shah AV, Rao VU, et al. Impact of projected climate change on groundnut in Gujarat. *Journal of Agro meteorology*. 2013;15(special issue-I):41-4.
- Radford PJ. Growth analysis formulae, their use and abuse. *Crop Sci*. 1967;7:171-5. <https://doi.org/10.2135/cropsci1967.0011183X000700030001x>
- Donald CM. In search of yield. *J Aust Inst Agric Sci*. 1962;32(1-2):92-3.
- Monteith JC. Consistency and convenience in the choice of units for agricultural science. *Exp Agric*. 1984;20:115-7. <https://doi.org/10.1017/S0014479700000946>
- Nihalani AL. Assessment of yield of pigeonpea in relation to heat units [MSc thesis]. Anand: Gujarat Agricultural University; 1989.
- Wilsie CP. *Crop adaptation and distribution*. London: W H Freeman and Co; 1962. p. 52-9.
- Ram H, Singh G, Mavi GS, Sohu VS. Accumulated heat requirement and yield of irrigated wheat (*Triticum aestivum* L.) varieties under different crop growing environment in central Punjab. *J Agrometeorol*. 2012;14:147-53. <https://doi.org/10.54386/jam.v14i2.1414>
- Liu C, Xu Y, Zhao J, Nie J, Jiang Y, Shang M, et al. Optimizing sowing date and plant density improve peanut yield by mitigating heat and chilling stress. *Agron J*. 2023 Sep;115(5):2521-32. <https://doi.org/10.1002/agj2.21307>
- Honnaiah PA, Sridhara S, Gopakkali P, Ramesh N, Mahmoud EA, Abdelmohsen SA, et al. Influence of sowing windows and genotypes on growth, radiation interception, conversion efficiency and yield of guar. *Saudi J Biol Sci*. 2021 Jun 1;28(6):3453-60. <https://doi.org/10.1016/j.sjbs.2021.03.010>
- Sannagoudar MS, Patil RH, Rajanna GA, Ghosh A, Singh AK, Halli HM, et al. Rising temperature coupled with reduced rainfall will adversely affect yield of kharif sorghum genotypes. *Curr. Sci*. 2023 Apr 25;124:921. <https://doi.org/10.18520/cs/v124/i8/921-927>
- Liu J, He Q, Zhou G, Song Y, Guan Y, Xiao X, et al. Effects of sowing date variation on winter wheat yield: conclusions for suitable sowing dates for high and stable yield. *Agron J*. 2023;13(4):991. <https://doi.org/10.1002/agj2.21307>

doi.org/10.3390/agronomy13040991

14. Thimmegowda MN, Manjunatha MH, Sathisha GS, Huggi L. Weather based yield prediction of pigeonpea crop with the resource use efficiency under varied sowing windows. *Legum Res.* 2024;1:8. <https://doi.org/10.18805/LR-5308>
15. Huggi L, Shivaramu HS, Manjunatha MH, Soumya DV, Kumar PV, Lunagaria MM. Agro-climatic onset of cropping season: a tool for determining optimum date of sowing in dry zones of southern Karnataka. *J Agrometeorol.* 2020;22(3):240-9. <https://doi.org/10.54386/jam.v22i3.185>

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