



RESEARCH ARTICLE

Influence of sowing dates on productivity and profitability of sunflower (*Helianthus annuus* L.) hybrids in the north-western Himalayas of India

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Abstract

A field investigation was conducted at the Farming System Research Centre, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, during 2023 and 2024. The study aimed to assess the effect of sowing dates and varietal performance of sunflower on growth and productivity. The experiment was laid out in a factorial randomized block design with three replications, comprised of three sowing dates (10th and 20th February and 2nd March) as factor A and four sunflower varieties (PSH-2080, PSH-1962, DRSH-1 and KBSH-44) as factor B. Recommended doses of nutrients were applied and the soil was sandy clay loam, slightly alkaline and low in available nitrogen and organic carbon. Results revealed that sunflower sown on 10th February recorded significantly superior plant height, dry matter accumulation, leaf area index (at harvest), yield attributes and yield across both years. Among varieties, PSH-2080 performed significantly better as compared to other varieties in terms of productivity. However, DRSH-1 and KBSH-44 recorded higher growth attributes during both the years of investigation respectively. Overall, the sunflower variety PSH-2080 sown on 10th February proved to be the most productive and adaptable under irrigated north-western Himalayan regions.

Keywords: agrometeorological indices; productivity; sowing dates; varietal performance

Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops cultivated worldwide, contributing significantly to the global supply of edible oil. It accounts for nearly 8–10 % of the world's total oilseed production, with major production concentrated in the Russian Federation, Ukraine, the European Union, Argentina and China. Global sunflower production for the period 2024–25 is projected at approximately 55.4 million metric tonnes, highlighting its growing importance in the global oilseed market (1). Sunflower oil is highly valued for its quality as it is rich in polyunsaturated fatty acids, vitamin E and antioxidants, used extensively for both human consumption and industrial purposes. Despite being introduced comparatively later than other oilseeds, it has gained prominence due to its short growth duration, photo-insensitivity and ability to fit well into multiple cropping systems. During 2023–24, sunflower was cultivated on an area of 1.508 million ha, producing about 1.725 million tonnes with an average productivity of 1155 kg/ha at the national level (2). Although its share in the total oilseed acreage is relatively modest compared to soybean, groundnut and rapeseed-mustard, sunflower plays a crucial role in bridging the edible oil demand–supply gap in the

country. Despite being one of the world's major producers of oilseeds, India continues to face persistent challenges in meeting its growing domestic demand for edible oils. Although oilseed production has shown marginal gains in both area and output in recent years, these improvements have been insufficient to achieve self-sufficiency (3). National production has fluctuated considerably, rising to 41.36 million tonnes in 2022–23 before declining to 39.67 lakh tonnes in 2023–24 (4). Advance estimates for 2024–25 indicate a recovery to 42.61 million tonnes, achieved despite only minor increases in cultivated area, highlighting the limited scope for further area expansion due to competition from other profitable crops (5). These trends emphasize the need to enhance productivity through genetic improvement, adoption of improved production technologies and better crop management practices. Challenges such as low productivity levels, shifts in farmer crop preferences, inadequate dissemination of improved cultivars and vulnerability to climatic stresses further constrain growth in the sector. Although the government has set ambitious targets to increase oilseed output and reduce import dependence, rising consumption and population growth continue to intensify pressure on domestic supplies. This situation underscores the urgent need for productivity enhancement, varietal improvement

and optimized crop management strategies—particularly in crops like sunflower, which offer substantial potential under both irrigated and rain-fed conditions (6).

To address the challenges of increasing oilseed productivity and reducing import dependency, certain sunflower hybrids with promising traits were selected for evaluation in this study. The hybrids PSH-2080 and PSH-1962 are known for their early maturity and high yield potential, while DRS-1 is valued for its adaptability to varied agroclimatic conditions (7, 8). KBSH-44 is recognized for its disease tolerance and stable performance under irrigated conditions. Hence, this study was conducted to assess the influence of sowing dates on the productivity of sunflower hybrids in the north-western Himalayan region.

Sowing date is one of the most critical agronomic factors influencing sunflower productivity because it determines the crop's exposure to temperature, photoperiod and radiation during key phenological stages. Early or optimally timed sowing allows the crop to utilize favourable thermal and light conditions, resulting in better vegetative growth, timely flowering, enhanced seed set and improved seed filling. In contrast, delayed sowing often exposes the crop to terminal heat stress, reduced radiation intake and shortened growth duration, which collectively suppress yield formation. Therefore, identifying the most suitable sowing window is essential to maximize thermal use efficiency and ensure higher productivity under varying agro-climatic conditions.

Materials and Methods

A field study was conducted during the spring season of 2023–2024 at the Farming System Research Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, located at 32° 39'39.5" N latitude and 74°47'57.1" E longitude, with an elevation of 293 m above mean sea level in the subtropical foothills of Jammu, Jammu and Kashmir-UT. The experimental site was sandy clay loam and slightly alkaline pH (7.43). Initial soil analysis revealed an organic carbon content of 4.46 g/kg and the soil was low in available nitrogen (234.42 kg/ha) but medium in phosphorus (16.32 kg/ha), potassium (129.50 kg/ha) and sulphur (19.48 mg/kg). The study site is characterized by a subtropical climate with distinct seasonal variations.

The climate features hot and dry early summers followed by hot and humid monsoon seasons and cold winters. During the sunflower growing period, the total rainfall received was 280 mm in 2023 and 181 mm in 2024. Temperature during the crop growth period varied significantly, with maximum temperatures ranging from 37.66 °C and minimum temperatures reaching as low as 6.39 °C. Relative humidity also showed variation, with morning values ranging from 60.57 % to 94.36 % in 2023 and 45.70 % to 93.90 % in 2024, while evening relative humidity ranged from 22.70 % to 55.90 % in 2023 and 23.86 % to 57.00 % in 2024. These meteorological data reflecting the climatic conditions during crop growth in both years are illustrated in Fig. 1 & 2 respectively.

The experiment was laid out in a factorial randomized block design with three replications. Factor A comprised of three dates of sowing (10th and 20th February and 2nd March), while factor B consisted of four sunflower hybrids (PSH-2080, PSH-1962, DRS-1 and KBSH-44). The treatments were evaluated to study the effects of sowing dates and varietal performance on growth and productivity.

The sunflower crop was sown using line sowing with a uniform spacing of 60 cm between rows and 30 cm between plants within the row. Fertilizers were applied at the recommended dose of 60 kg nitrogen, 30 kg phosphorus (P₂O₅), 30 kg potassium (K₂O) and 20 kg sulphur per ha. Half of the nitrogen along with the full dose of phosphorus, potassium and sulphur were applied as basal at the time of sowing, while the remaining half of the nitrogen was top-dressed three weeks after sowing to support optimal crop growth.

Observations recorded

Yield attributes

The yield attributes recorded for sunflower included head diameter, total number of seeds per head, number of filled seeds per head, filling percentage and 100-seed weight. Head diameter was measured in centimetres (cm) on five randomly selected plants per plot and the average value was recorded. The total number of seeds per head was counted manually after harvesting and threshing the sunflower heads at physiological maturity.

Filled seeds were distinguished from unfilled or aborted seeds based on size, weight and visual appearance and their number per head was counted. Filling percentage was calculated as the ratio of filled seeds to the total number of seeds per head, expressed as a percentage (%). The 100-seed weight was determined by counting and weighing 100 fully developed seeds from each sampled plant after thorough drying.

Yield and harvest index

Seed yield was recorded by harvesting the central net plot area at maturity, followed by manual threshing, cleaning and weighing of seeds. The seed yield obtained was converted to kilograms per hectare (kg/ha) using standard conversion factors.

Stover yield comprised the dry biomass of stalks, leaves and empty heads remaining after threshing, which was weighed fresh and after sun-drying to a constant weight and expressed in kilograms per hectare (kg/ha). The harvest index was calculated as the ratio of economic yield (grain yield) to the total above-ground biological yield (sum of grain and stover yield), expressed as percentage, reflecting the efficiency of the crop in partitioning biomass to seed.

Economics

For economic analysis, gross returns (₹/ha) were calculated by multiplying the seed yield (kg/ha) of sunflower with the prevailing minimum support price during the respective years. Net returns (₹/ha) were obtained by deducting the cost of cultivation from the gross returns. The benefit–cost ratio (B:C ratio) was worked out by dividing the gross returns with the cost of cultivation, thereby indicating the profitability of different treatments.

Agrometeorological indices

Meteorological data on daily maximum and minimum temperature, bright sunshine hours and photoperiod were collected from the agrometeorological observatory located near the experimental site. These weather parameters were used to compute different agrometeorological indices at successive crop growth stages. Grain yield and associated yield attributes were recorded at physiological maturity.

Growing degree days (GDD) were calculated by summing the mean daily temperature above the base temperature (6 °C for sunflower) from sowing to maturity.

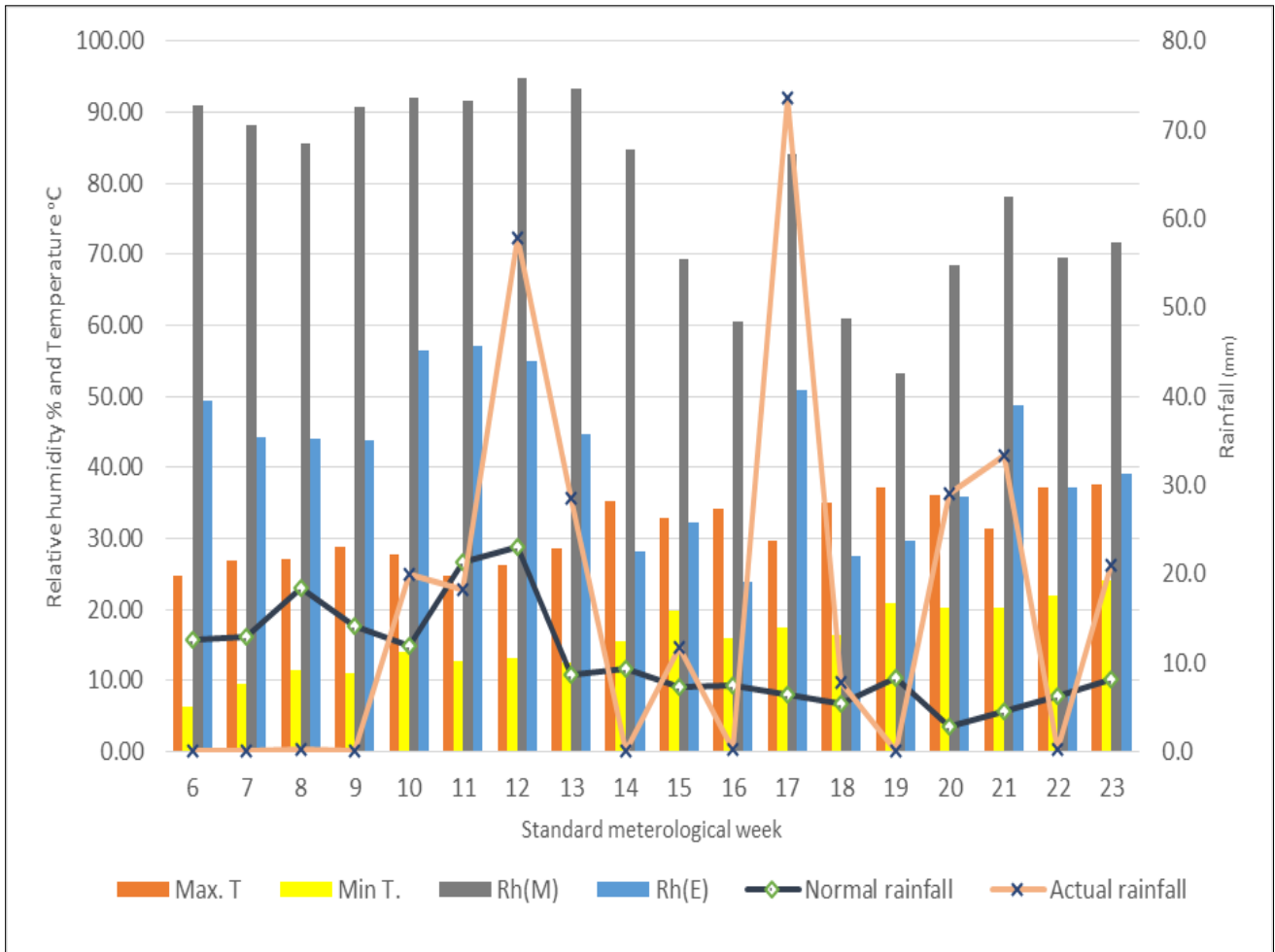


Fig. 1. Graphical representation of meteorological data of sunflower during 2023 [Agrometeorology section SKUAST-Jammu, Chatha].

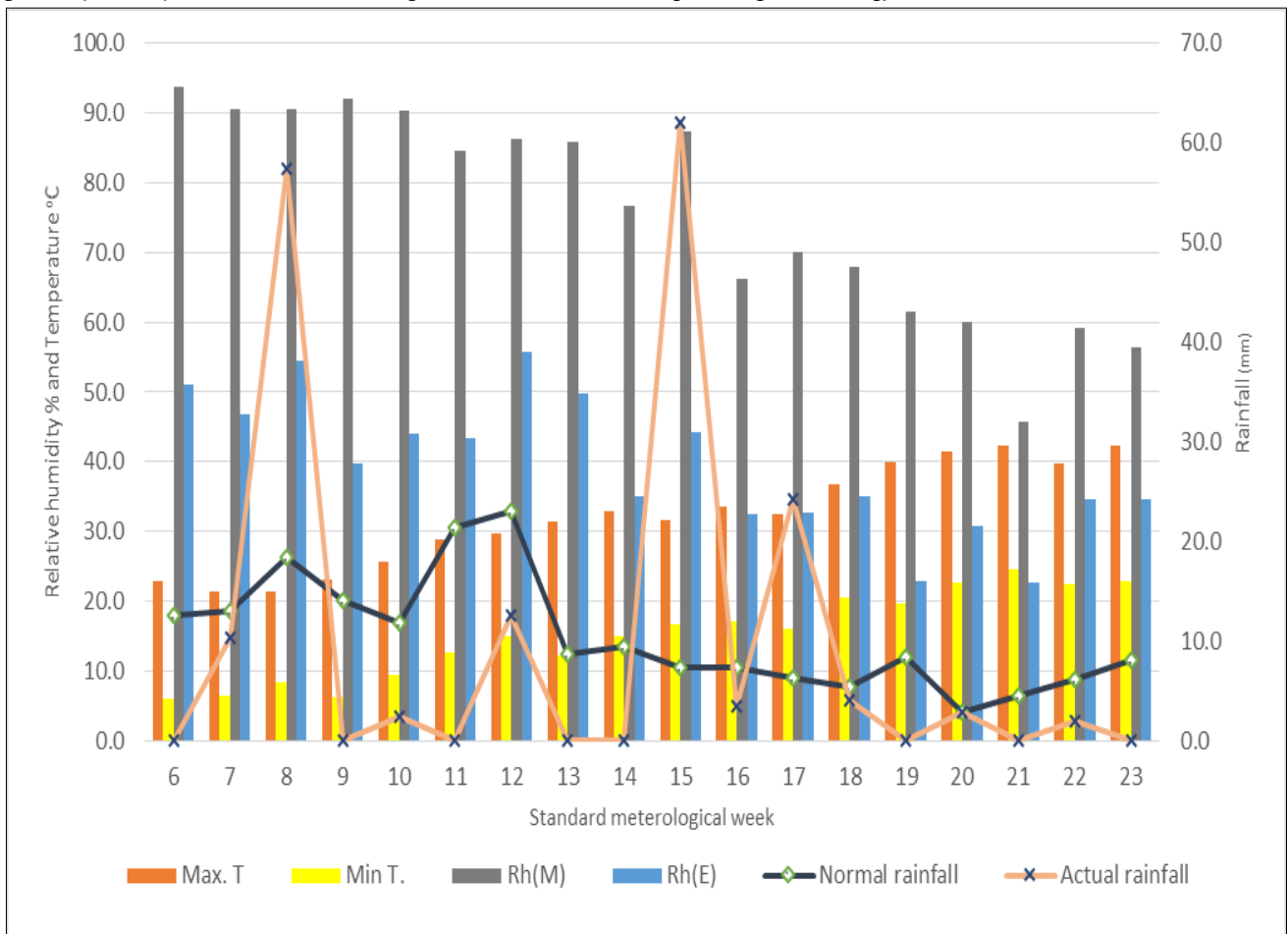


Fig. 2. Graphical representation of meteorological data of sunflower during 2024 [Agrometeorology section SKUAST-Jammu, Chatha].

$$\text{Growing degree days} = \sum_j^k \frac{(T_{\text{max}} + T_{\text{min}})}{2} - T_b$$

Where,

T_{max}: daily maximum temperature (°C)

T_{min}: daily minimum temperature (°C)

T_b: base temperature

j: starting date of phenophase of interest

k: Ending date of phenophase of interest

Σ: Accumulated from starting to ending date of particular phenophases

Photothermal units (PTU) were obtained by multiplying the accumulated GDD with the corresponding day length (hr).

$$\text{Photo thermal units (PTU)} = \sum_j^k (GDD \times N)$$

Where,

GDD: growing degree days (°C days)

N: day length (hrs)

Similarly, heliothermal units (HTU) were worked out by multiplying the accumulated GDD with actual bright sunshine hours of each day.

$$\text{Heliothermal units (HTU)} = \sum_i^k (GDD \times N)$$

Where,

GDD: growing degree days (°C days)

N: bright sunshine hours (hr)

The indices were computed stage-wise and on a seasonal basis to understand the influence of thermal and radiation regimes on crop growth and productivity. These values were further subjected to regression analysis to establish the relationship between agrometeorological indices and grain yield.

Statistical analysis

Growth attributes and nutrient use indices were subjected to ANOVA using a factorial randomized block design to assess the effects of different dates of sowing and hybrids. Significant differences were separated using the LSD test at a 0.05 probability level with SPSS software (version 17.0, SPSS Inc., Chicago, USA).

Results and Discussion

Yield attributes and yield

Among sowing dates, 10th February recorded significantly the highest yield attributes. In the first year, it achieved a head diameter of 19.64 cm, seeds/head of 1079.84 and 100-seed weight of 6.98 g, while in the second year, the corresponding values were 18.92 cm, 1034.67 seeds/head and 6.87 g respectively. Among sunflower hybrids, DRSH-1 maintained its superiority across years. In the first year, it recorded the highest head diameter of 18.74 cm, seeds/head of 987.42 and 100-seed weight of 6.85 g, whereas in the second year, the values were 18.12 cm, 956.38 seeds/head and 6.73 g respectively (Table 1).

With respect to yield performance, sowing on 10th February, increased seed yield by 25.83 % in the first year and 23.47 % in the second year and stover yield by 22.18 % and 20.36 % respectively, over the control. Similarly, the hybrid DRSH-1 exhibited an improved seed yield by 19.76 % in the first year and 18.92 % in the second year, while stover yield increased by 17.35 % and 16.84 % respectively, compared to the control (Table 2) (Fig. 3, 4 & 5).

Sowing sunflower on 10th February yielded significant gains in key yield attributes, viz, head diameter, seeds per head and 100-seed weight, in both experimental years, leading to marked enhancement of seed and stover yield compared to the control.

Table 1. Effect of different dates of sowing on yield attributes of sunflower hybrids

	Head Diameter (cm)		Total number of seeds/head		Number of filled seeds/head		Filling percentage (%)		100-seed weight	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Factor A (Dates of Sowing)										
10 th February	16.45	17.63	980.29	1000.89	804.80	832.10	82.10	83.13	6.91	6.96
20 th February	15.71	15.85	870.67	885.82	668.50	692.90	76.77	78.22	5.54	5.60
2 nd March	14.59	14.53	807.33	825.48	603.80	621.80	74.79	75.33	5.32	5.36
SEm (±)	0.27	0.30	15.65	14.91	12.69	12.73	0.27	0.25	0.06	0.05
CD (5%)	0.81	0.87	45.91	43.72	37.21	37.34	0.80	0.75	0.20	0.17
Factor B (Varieties)										
PSH-2080	17.01	17.48	1017.2	1037.0	812.60	834.40	79.88	80.46	6.31	6.40
PSH-1962	16.30	16.61	968.58	980.55	768.10	791.90	79.30	80.76	6.24	6.36
DRSH-01	14.90	15.85	829.64	839.67	635.80	659.50	76.63	78.55	5.63	5.65
KBSH-44	14.12	14.07	728.98	759.01	552.90	576.60	75.84	75.97	5.48	5.50
SEm (±)	0.32	0.34	18.07	17.21	14.65	14.70	0.43	0.53	0.04	0.02
CD (5%)	0.93	1.01	53.01	50.48	42.97	43.12	1.28	1.59	0.20	0.22

Table 2. Effect of different sowing dates on yield and economics of sunflower hybrids

Treatments	Seed yield (kg/ha)		Stover yield (kg/ha)		Harvest index (%)		Gross Return (₹/ha)		Net Return (₹/ha)		B:C Ratio	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Factor A (Dates of Sowing)												
10 th February	2123.92	2217.50	5129.34	5298.00	29.96	31.06	148309	163618	104690	118688	2.38	2.62
20 th February	1887.25	1920.15	4927.09	5025.09	28.74	29.77	133662	147802	89394	102222	2.01	2.23
2 nd March	1752.75	1812.48	4675.59	4863.59	28.38	29.20	118486	131459	74218	85879	1.67	1.87
SEm (±)	35.44	36.52	75.07	72.60	0.07	0.04	-	-	-	-	-	-
CD (5%)	103.94	107.12	220.18	212.92	0.21	0.13	-	-	-	-	-	-
Factor B (Varieties)												
PSH-2080	2108.11	2191.29	4860.67	5083.67	33.31	33.76	161662	177956	116204	131186	2.56	2.81
PSH-1962	2011.34	2074.28	4805.33	4962.56	32.48	33.27	153767	169454	108310	122685	2.39	2.63
DRSH-01	1782.23	1936.50	5002.89	5105.89	26.27	27.50	118000	130304	75292	86284	1.76	1.96
KBSH-44	1523.56	1695.94	4973.78	5096.78	23.45	24.97	100514	112791	57931	68897	1.36	1.57
SEm (±)	40.92	42.18	86.69	83.83	0.11	0.12	-	-	-	-	-	-
CD (5%)	120.02	123.70	254.25	245.85	0.33	0.34	-	-	-	-	-	-

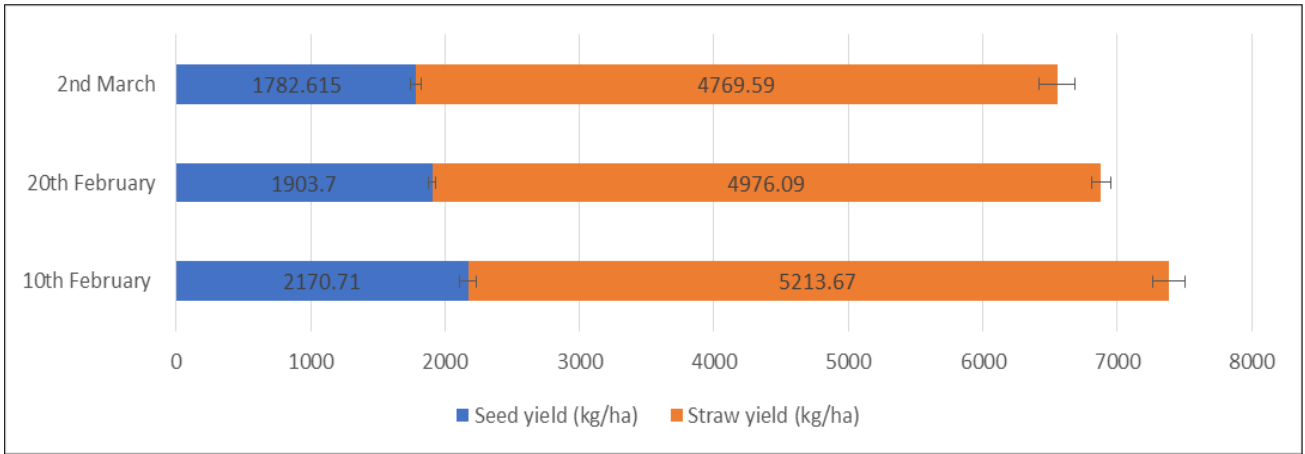


Fig. 3. Effect of dates of sowing on the grain and stover yield of sunflower (pooled data).

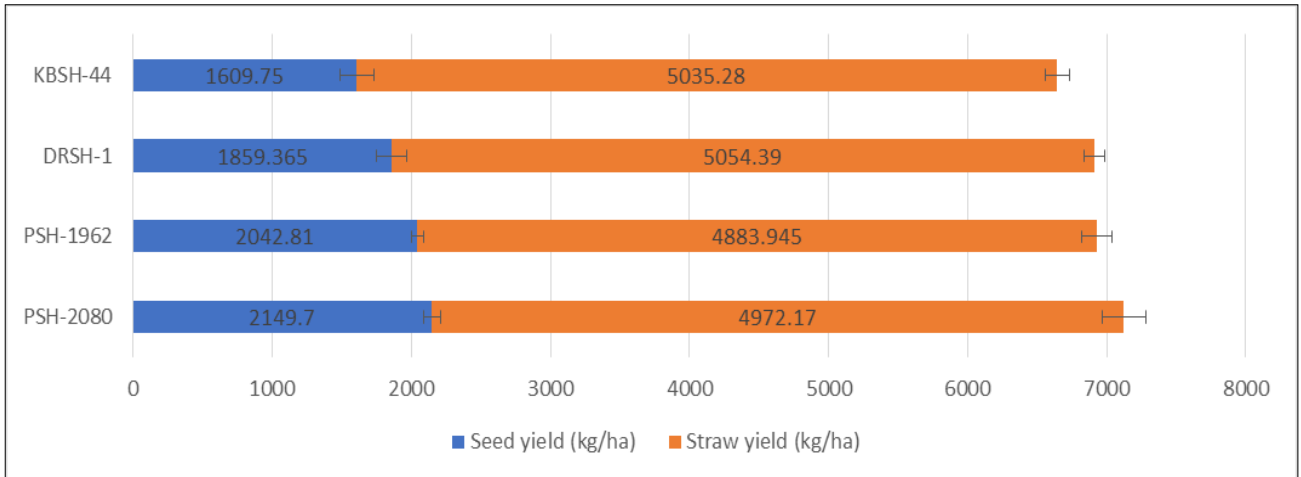


Fig. 4. Effect of hybrids on the grain and straw yield of sunflower (pooled data).



Fig. 5. Sunflower field Photographs.

These findings align with wider agronomic evidence showing that early sowing typically maximizes yield potential, likely by optimizing the crop's exposure to favourable temperature and light regimes and avoiding terminal stress (e.g. heat or moisture scarcity) at critical periods of reproductive development (9). Specifically, in semi-arid and steppe environments, early sowing coupled with proper crop management has been demonstrated to increase yield by 26–30 % over delayed sowing dates (9, 10).

Regarding hybrid performance, DRSH-1 consistently outperformed others in yield attributes across both years. This superiority reflects the genetic vigor and adaptation of DRSH-1 under variable agronomic and environmental conditions, as similar trends were reported in organic management trials where DRSH-1 exhibited seed yields on par with top-performing hybrids. Moreover, heterosis studies in sunflower further validate the benchmark status of DRSH-1; many newly developed hybrids surpassed DRSH-1 by 15–27 % in seed yield, confirming its high baseline productivity (11, 12).

The superior performance of sunflower sown on 10th February can be explained by the crop's physiological responses to temperature and radiation regimes during its critical growth stages. Sunflower is highly sensitive to environmental conditions during early vegetative development and reproductive phases, particularly anthesis and grain filling. Early sowing ensured that the crop experienced optimum temperatures (20–28 °C) and longer photoperiods during these stages, which enhanced leaf area development, photosynthetic rate and assimilate accumulation. This aligns with established findings that sunflower achieves maximum photosynthetic efficiency when the early vegetative phase coincides with moderate temperatures and adequate radiation.

Delayed sowing (20th February and 2nd March), on the other hand, exposed the crop to elevated temperatures during flowering and early seed filling. High temperatures (>32–35 °C) during these stages are known to impair fertilization, reduce pollen viability and accelerate leaf senescence, ultimately leading to smaller head diameter, fewer filled seeds and lower 100-seed weight. This corresponds with previous studies that reported substantial yield reductions when sunflowers encountered terminal heat or moisture stress under delayed sowing conditions in semi-arid and dry-steppe climates.

Agrometeorological indices

A perusal of data presented in Table 3 revealed that dates of sowing exerted a significant influence on the accumulation of agrometeorological indices in sunflower. Among the sowing dates, 10th February recorded the highest values of GDD (1141 and 1106 °C day hr at seed filling, 1731 and 20547 °C day hr at physiological maturity in 2023 and 2024 respectively), PTU (12554 and 12166 °C day hr at seed filling, 20773 and 20547 °C day hr at maturity) and HTU (9594 and 9312 °C day hr at seed filling, 10387 and 10273 °C day hr at maturity). Sowing on 20th February accumulated moderate values with GDD ranging between 1132–1097 °C day hr at seed filling and 1704–19722 °C day hr at maturity. The lowest values were observed with 2nd March sowing, where GDD was 1108–1073 °C day hr at seed filling and 1641–19652 °C day hr at maturity, along with correspondingly lower PTU and HTU. This clearly indicated that early sowing on 10th February enabled higher accumulation of thermal indices compared to later sowing dates.

Among sunflower hybrids, DRSH-1 recorded the highest values of agrometeorological indices with GDD (1190 and 1135 °C day hr at seed filling, 1816 and 1791 °C day hr at maturity during 2023 and 2024), PTU (13089 and 12482 °C day hr at seed filling, 19677 and 18676 °C day hr at maturity) and HTU (9950 and 9654 °C day hr at seed filling, 12752 and 12371 °C day hr at maturity). This was followed closely by KBSH-44, which also showed higher values of GDD (1169 and 1114 °C day hr at seed filling, 1785 and 1755 °C day hr at maturity) and comparable PTU and HTU values. Thus, DRSH-1 and KBSH-44 proved to be more efficient in utilizing thermal and radiation resources compared to other varieties.

The results clearly revealed that early sowing (10th February) of sunflower accumulated higher GDD, PTU and HTU compared to later sowing dates. This might be because early-sown crops are exposed to relatively favourable thermal and radiation regimes, which prolong the duration of vegetative and reproductive phases and allowed greater utilization of heat and light resources. Similar findings were reported that early sowing of sunflower enhanced heat unit accumulation and improved crop productivity. Likewise, delay in sowing reduced thermal time accumulation and adversely affected yield in oilseed crops due to shortened growth duration and exposure to terminal heat stress (10, 13).

Table 3. Effect of different dates of sowing on agrometeorological indices of sunflower hybrids

Treatments	Growing degree days (°C day hours)				Photothermal units (°C day hours)				Helio-thermal units (°C day hours)			
	Seed filling		Physiological maturity		Seed filling		Physiological maturity		Seed filling		Physiological maturity	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Factor A (Dates of Sowing)												
10 th February	1141	1106	1731	20547	12554	12166	20773	20547	9594	9312	10387	10273
20 th February	1132	1097	1704	19722	12454	12070	20446	19722	9575	9287	10223	10157
2 nd March	1108	1073	1641	19652	12193	11806	19691	19652	9407	9126	10117	9988
SEm (±)	7.04	6.47	7.39	6.39	7.04	6.47	7.39	6.39	5.36	6.77	6.69	8.26
CD (5%)	21.13	19.42	22.19	19.10	21.13	19.42	22.19	19.10	15.32	20.32	20.11	21.25
Factor B (Varieties)												
PSH-2080	1126	1091	1584	1558	12381	11996	17120	16115	9100	8830	10664	11326
PSH-1962	1125	1090	1573	1555	12375	11988	17120	16086	9143	8879	10793	11439
DRSH-01	1190	1135	1816	1791	13089	12482	19677	18676	9950	9654	12752	12371
KBSH-44	1169	1114	1785	1755	12855	12250	19332	18284	9949	9653	12751	12371
SEm (±)	3.99	4.19	3.84	4.15	7.53	6.17	7.42	6.41	4.76	7.44	6.37	6.67
CD (5%)	12.13	09.32	10.22	10.84	21.43	19.12	22.98	19.11	14.47	22.10	19.17	20.03

Among hybrids, DRSH-1 and KBSH-44 recorded higher GDD, PTU and HTU values as compared to PSH-2080 and PSH-1962. The higher accumulation of thermal and radiation indices in the former hybrids might be attributed to their relatively longer growth duration and better adaptability to prevailing agro-climatic conditions. These results are in agreement with studies that reported differences in sunflower genotypes with respect to agrometeorological indices and their influence on seed yield. Similarly, hybrids with longer maturity duration tend to accumulate higher heat and radiation units, thereby supporting better seed filling and yield realization. Thus, the variation in thermal use efficiency among hybrids indicates that the selection of a suitable hybrid plays an important role in optimizing yield under different sowing environments (14-16).

Correlation matrix

The correlation matrix between yield attributes and grain yield of sunflower, as shown in Table 4, reveals strong positive relationships among all studied variables. Seed yield demonstrated a near-perfect correlation with all other traits, including head diameter ($r = 0.98$), total number of seeds per head ($r = 1.00$), number of filled seeds per head ($r = 1.00$), filling percentage ($r = 1.00$) and 100-seed weight ($r = 0.98$). This suggests that improvements in any of these attributes are closely associated with an increase in seed yield. Head diameter also exhibited strong positive correlations with the total number of seeds per head ($r = 0.99$), number of filled seeds per head ($r = 0.98$), filling percentage ($r = 0.98$) and 100-seed weight ($r = 0.93$), indicating its significant role in influencing key yield components.

Further, the total number of seeds per head and the number of filled seeds per head were perfectly correlated with

each other and with filling percentage ($r = 1.00$) and strongly correlated with 100-seed weight ($r = 0.98$). This highlights that effective seed filling and a higher seed count are integral to achieving superior seed yields. Filling percentage itself showed perfect or near-perfect positive associations with all measured parameters, underscoring its critical importance in determining final yield outcomes. Although the 100-seed weight displayed slightly lower, yet still strong correlations with other characters, especially head diameter ($r = 0.93$), it remains a substantial contributor to overall yield (Fig. 6).

Linear regression

The linear regression between grain yield and meteorological indices as influenced by dates of sowing (Fig. 7) indicated a strong positive association. Grain yield increased linearly with increasing GDD ($R^2 = 0.96$), PTU ($R^2 = 0.98$) and HTU ($R^2 = 0.95$). Among these, PTU exhibited the highest coefficient of determination ($R^2 = 0.98$), suggesting that photothermal units explained the variation in grain yield more effectively than other indices. This implies that early sowing dates, which accumulated higher thermal and radiation units, were closely associated with higher grain yields in sunflower.

In contrast, regression analysis with hybrids (Fig. 8) showed a negative relationship between grain yield and agrometeorological indices. GDD, PTU and HTU all exhibited declining trends with increasing grain yield, as indicated by negative slopes (-0.44, -4.85 and -3.28 respectively). The strength of association varied, with HTU ($R^2 = 0.79$) showing a stronger relationship than GDD ($R^2 = 0.68$) and PTU ($R^2 = 0.69$). This suggests that higher yielding hybrids utilized thermal and radiation resources more efficiently, thereby requiring relatively lower accumulation of indices to achieve superior productivity.

Table 4. Correlation matrix between yield attributes and grain yield of sunflower as influenced by dates of sowing and varieties

	Seed yield	Head diameter	Total number of seeds/head	Number of filled seeds/head	Filling percentage	100-seed weight
Seed yield	1.00	0.98	1.00	1.00	1.00	0.98
Head diameter	0.98	1.00	0.99	0.98	0.98	0.93
Total number of seeds/head	1.00	0.99	1.00	1.00	1.00	0.98
Number of filled seeds/head	1.00	0.98	1.00	1.00	1.00	0.98
Filling percentage	1.00	0.98	1.00	1.00	1.00	0.98
100-seed weight	0.98	0.93	0.98	0.98	0.98	1.00

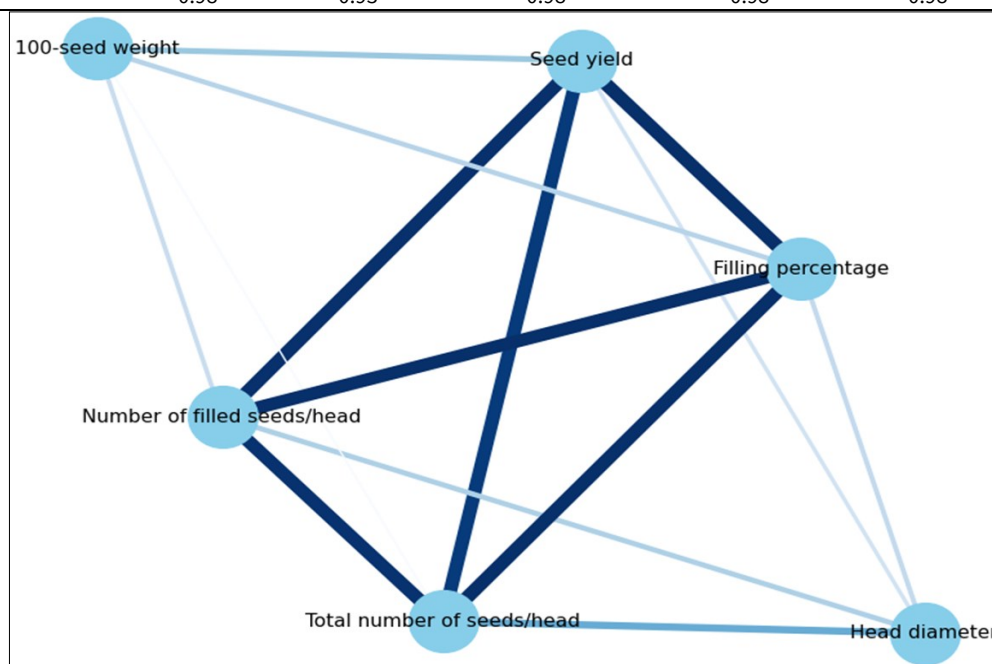


Fig. 6. Network Graph of correlation between grain yield and yield attributes of sunflower hybrids as influenced by dates of sowing.

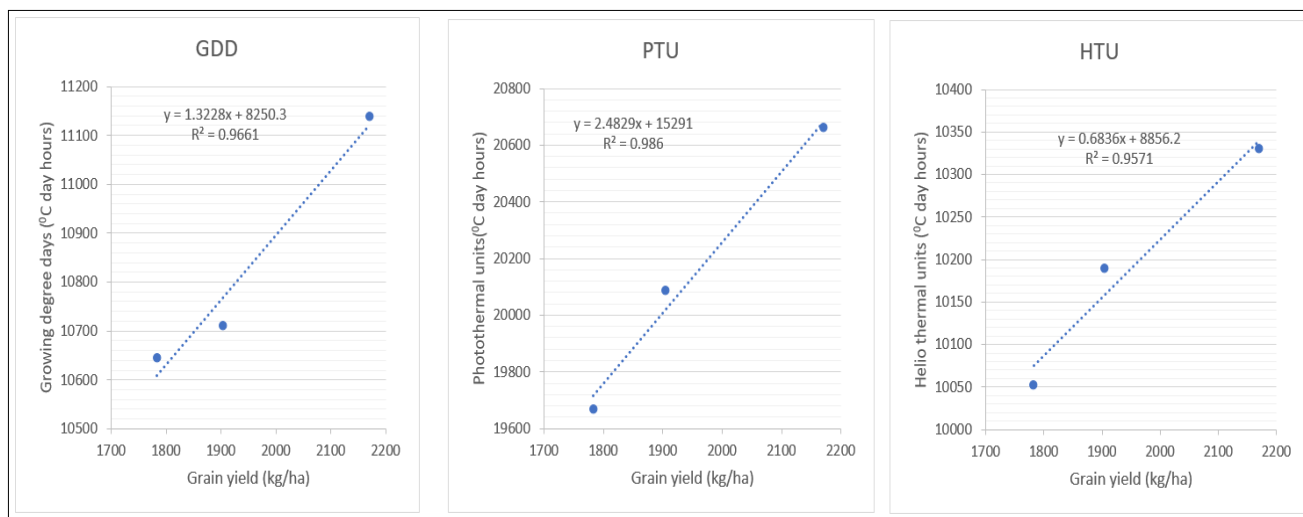


Fig. 7. Linear regression relationship between meteorological indices and grain yield as influenced by dates of sowing.

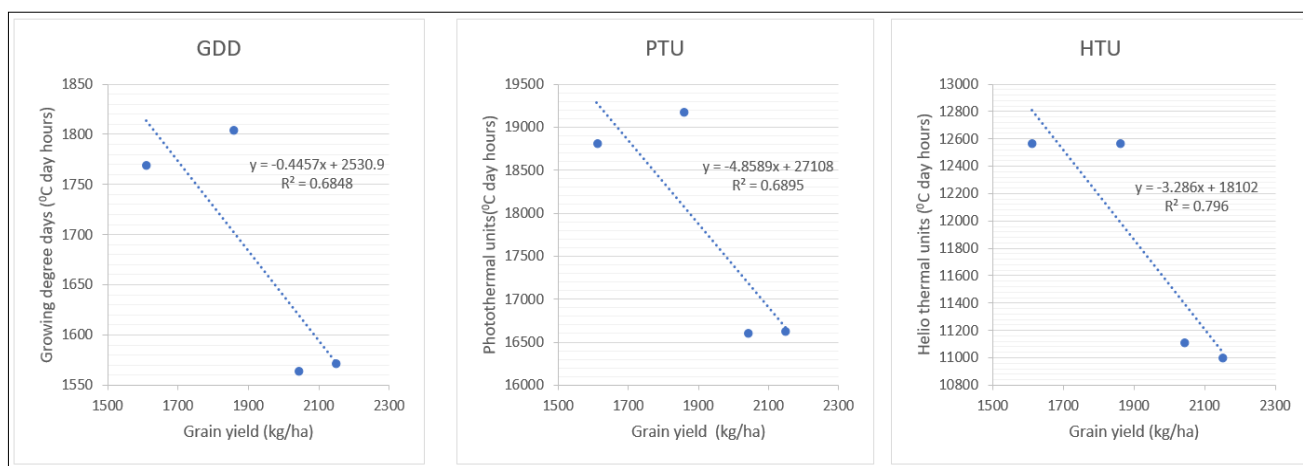


Fig. 8. Linear regression relationship between meteorological indices and grain yield as influenced by hybrids.

Economics

The highest gross return (₹148309 and ₹163618/ha in 2023 and 2024 respectively), net return (₹104690 and ₹118688/ha) and B:C ratio (2.38 and 2.62) were obtained when sunflower was sown on 10th February. This was followed by 20th February sowing which recorded intermediate values of gross return (₹133662 and ₹147802/ha), net return (₹89394 and ₹102222/ha) and B:C ratio (2.01 and 2.23).

With respect to hybrids, PSH-2080 recorded the highest gross returns (₹161662 and ₹177956/ha in 2023 and 2024 respectively), net returns (₹116204 and ₹131186/ha in 2023 and 2024 respectively) and B:C ratio (2.56 and 2.81 in 2023 and 2024 respectively), followed by PSH-1962, which also registered higher profitability with gross return of ₹153767 and ₹169454/ha, net return of ₹108310 and ₹122685/ha and B:C ratio of 2.39 and 2.63 in 2023 and 2024 respectively. On the contrary, the lowest economic returns were associated with hybrid KBSH-44, which recorded minimum gross return (₹100514 and ₹112791/ha in 2023 and 2024 respectively), net return (₹57931 and ₹68897/ha in 2023 and 2024 respectively) and B:C ratio (1.36 and 1.57 in 2023 and 2024 respectively).

Conclusion

This study shows that sowing date plays a decisive role in determining sunflower productivity in the north-western Himalayas. Early sowing on 10th February allowed the crop to utilize more

favourable temperature and radiation conditions, resulting in higher yield and better economic returns. Among the hybrids, PSH-2080 proved to be the most adaptable and productive across seasons. Overall, aligning sowing time with local agro-climatic conditions, along with choosing suitable hybrids, is essential for maximizing sunflower yield and improving regional oilseed production.

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Authors' contributions

CL carried out the research part of the paper. VK carried out the corrections. RB participated in the modification and corrections. RSS participated in the sequence alignment. JSM participated in the arrangement of tables. FF helped in the rearrangement of the subheadings and finishing. HS helped in arranging the subtopics. GK helped in searching for relevant information. 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.

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References

1. USDA Economic Research Service. Oil crops outlook. Washington (DC): United States Department of Agriculture; 2024.
2. Directorate of Oilseeds Development. Area, production and yield of oilseeds - sunflower (2023–24). Hyderabad: Ministry of Agriculture & Farmers Welfare, Government of India; 2024.
3. Mint. Cooking oil imports rise despite oilseed growth. Mint; 2025.
4. Directorate of Oilseeds Development. Oilseed production statistics for 2023–24. New Delhi: Ministry of Agriculture & Farmers Welfare, Government of India; 2025.
5. Ministry of Agriculture & Farmers Welfare. Third advance estimates of oilseeds production for 2024–25. New Delhi: Press Information Bureau, Government of India; 2025.
6. Department of Agriculture and Farmers Welfare. National mission on edible oils - oil palm and oilseeds. New Delhi: Ministry of Agriculture & Farmers Welfare, Government of India; 2023.
7. ICAR-Indian Institute of Oilseeds Research. Sunflower hybrid PSH-2080. Hyderabad: ICAR-IIOR; 2019.
8. ICAR-Indian Institute of Oilseeds Research. Sunflower hybrid DRSH-1. Hyderabad: ICAR-IIOR; 2007.
9. Hilwa DA, Marajan WA, Mohammed AB, Idris BEM. Influence of sowing date on growth and yield components of sunflower (*Helianthus annuus* L.) in semi-arid zone. J Agron Res. 2019;2:36–42. <https://doi.org/10.14302/issn.2639-3166.jar-19-2961>
10. Gordeyeva Y, Shelia V, Shestakova N, Amantayev B, Kipshakbayeva G, Shvidchenko V, et al. Sunflower (*Helianthus annuus* L.) yield and yield components for various agricultural practices for steppe and dry steppe growing conditions. Agronomy. 2024;14:36. <https://doi.org/10.3390/agronomy14010036>
11. ICAR-Indian Institute of Oilseeds Research. Sunflower cultivars. Hyderabad: ICAR-IIOR; 2025.
12. Lakshman SS, Godke MK, Kar J. Standard heterosis for seed and oil yield in sunflower (*Helianthus annuus* L.). Grassroots J Nat Resour. 2020;4:18–27. <https://doi.org/10.33002/nr2581.6853.03042>
13. Angeloni F, Furlan L, Rossi F, Conti F. Radiation and photothermal coefficient as major determinants of grain yield and oil content in sunflower under different sowing dates. Helia. 2024; 47:1–12.
14. Awadalla A. Performance of sunflower cv. Sakha-53 as influenced by accumulated heat units under different sowing dates and plant spacing at Aswan conditions. South J Agric Sci. 2022;48:1–10. <https://doi.org/10.21608/sjas.2022.107520.1170>
15. Ma'ali S. The impact of planting dates and hybrid selection on sunflower productivity in semi-arid environments. S Afr J Plant Soil. 2024;41:1–10. <https://doi.org/10.1080/02571862.2024.2352174>
16. Qadir G, Hassan FU, Malik MA. Growing degree days and yield relationship in sunflower (*Helianthus annuus* L.). Int J Agric Biol. 2007;9:564–68.

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