International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(10): 785-791
www.biochemjournal.com
Received: 05-07-2025
Accepted: 07-08-2025

K Kishore
Department of Seed Science and Technology, Seed Research and Technology Centre (SRTC), PJTAU, Rajendranagar, Hyderabad, Telangana, India

K Prabhavati
Department of Genetics and Plant Breeding, Seed Research and Technology Centre (SRTC), PJTAU, Rajendranagar, Hyderabad, Telangana, India

Manimurugan C
Department of Seed Science and Technology, Crop Improvement Section, ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad, Telangana, India

P Jagan Mohan Rao
Department of Genetics and Plant Breeding, College of Agriculture, PJTAU, Rajendranagar, Hyderabad, Telangana, India

Corresponding Author:
K Kishore
Department of Seed Science and Technology, Seed Research and Technology Centre (SRTC), PJTAU, Rajendranagar, Hyderabad, Telangana, India

Influence of sowing dates and pollen sources on seed yield and quality parameters of sunflower (*Helianthus annuus* L.)

K Kishore, K Prabhavati, Manimurugan C and P Jagan Mohan Rao

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i10Sj.5924

Abstract
The present study was aimed at evaluating the effect of sowing dates and pollen sources on yield and seed quality in sunflower and to find out the optimum planting window and pollen sources for large-scale multiplication of sunflower hybrid seed. Four sowing dates and five pollen sources were tested in the Tilhan Tec-SUNH-1 sunflower hybrid to study their impact on seed yield and seed quality. Out of which the sowing dates(S4)- sowing during second fortnight of November is found to be best to obtain maximum seed yield 713 Kg/ha, followed by S3- the second fortnight of October with 691 Kg/ha seed yield. Among the different pollen sources tested, pollination with fresh pollen recorded highest yield (713 Kg/ha) followed by pollen stored at -80 °C (694 Kg/ha). The pollen viability of frozen pollen (-80 °C) is found to be 15 days. The seed quality parameters are observed to be best in Sowing-3 and Sowing-4 with pollen source P1, P3 and P4.

Keywords: Sunflower, sowing dates, pollen sources, yield, and quality

Introduction
Sunflower (*Helianthus annuus* L.) belongs to the family Asteraceae, and it is native to Central America. Seemingly, it is Peruvian or Mexican in origin (Demir *et al*., 2006 and Salman *et al*., 2012) [5, 20]. The oil content of sunflower is about 38 - 42% and is considered good for human consumption because of its anti-cholesterol properties (Singh *et al.*, 2009) [22]. Its oil contains 20-25% essential vitamins like A, D, E, and K (Satyabrat *et al*, 1988) [21]. Sunflower has gained popularity across diverse agro-climatic regions of the country due to its broad adaptability, high seed yield potential, shorter duration, responsiveness to intensive farming practices, and greater economic returns. In India, the crop is cultivated in an area of 0.23 mha with production of 0.21 m tonnes and productivity of 931kg ha^{-1}(Directorate of Economics and Statistics, 2021) [6]. Sunflower cultivation is concentrated in the southern parts, mostly in five states, *viz*., Karnataka, Maharashtra, Andhra Pradesh, Telangana, and Tamil Nadu (Meena *et al*., 2022) [13]. In Telangana, sunflower is grown in an area of 0.01 m ha with the production of 0.02 m tonnes and productivity of 2231 kg ha^{-1} (Directorate of Economics and Statistics, 2021) [6]. Out of the total edible oil imports in India, sunflower oil constitutes 16% of the share during 2020-21.

Sunflower productivity in terms of seed yield and oil production varies significantly depending on technological and environmental factors, such as temperature elevation (Kaleem *et al*., 2009, 2011; Paraschivu *et al*., 2021a) [8, 16], uneven distribution of precipitation (Lawal *et al*., 2011; Olowe *et al*., 2013) [12, 15], technological links such as sowing time (Lawal *et al*., 2011; Anjum *et al*., 2012) [12, 4], plant density and nitrogen nutrition (Ali *et al*., 2012) [3], varied planting pattern (Yasin *et al*., 2013) [25] and sowing of genetically enhanced hybrids (Ali *et al*., 2011; Paraschivu *et al*., 2021b) [2, 17]. Reduction in production area due to non-availability of good quality seed. The limitation in production could be attributed to the low yield potential of commonly cultivated varieties, the impact of various biotic and abiotic stresses (temperature and rainfall), and the inadequate adoption of recommended sunflower cultivation practices. Challenges in sunflower seed production are required greater isolation distance, maintenance of A, B, R lines, a longer anthesis time, stigma is receptive only for 3-5 days, and sometimes unexpected rainfall leads to a shortage of pollen.

The major challenge among them is that stigma is receptive for only 3-5 days, and a shortage of pollen due to unexpected rainfall, which greatly influences seed set and yield. To increase the pollen availability, we have stored the pollen in three different storage conditions (stored pollen at 5°C, pollen preserved under deep-freeze at -20 °C, pollen preserved under deep-freeze at -80 °C). To maximise the pollen usage, pollen is mixed with filler material in a 1:1 ratio. Identifying different pollen sources and pollination practices to maximise seed set and yield. Therefore, to improve yield and quality, it is necessary to identify the optimum sowing time and pollen sources to supply superior quality seed to the farming community. So, keeping this in view, "A field study was carried out to evaluate the effect of four sowing dates and various pollen sources on improving seed set and enhancing the yield potential of sunflower."

Materials and Methods

The present experiment was conducted during Kharif 2024 and Rabi 2024-25 at ICAR-IIOR, Rajendranagar, and evaluated for seed yield. The parental lines (A X R) of the sunflower hybrid (Tilhan Tec-SUNH-1) collected from ICAR- Indian Institute of Oilseeds Research, Rajendranagar, were sown at 4 different sowing times. (plot size: 4×2.5 $m^{2)}$. The field experiment was laid out in a Factorial Randomized Block Design (FRBD).

Factor 1: Sowing time

S1) First fortnight of August

S2) First fortnight of September

S3) Second fortnight of October

S3) Second fortnight of November

Factor 2: Pollen sources

P1) Fresh / Normal pollen

P2) Stored pollen @ 50°C

P3) Deep freeze at -20ºC

P4) Deep freeze at -80°C

P5) Pollen mixing with filler material (saw dust)

The weather parameters like Temperature, Rainfall, and Relative Humidity are also considered during the experimental period. Plant protection methods are followed to control leaf hopper, *Helicoverpa armigera* and Alternaria. The combined effects of these treatments were assessed to determine the most effective combinations for enhancing seed production and overall yield.

Results and Discussion

The experimental results revealed significant differences among different dates of sowing and different pollen sources for yield and quality parameters in sunflower.

Yield per ha

The data presented in Table 2 reveal that seed yield of sunflower was significantly influenced by different sowing dates and pollen sources. Among the sowing dates, the highest mean seed yield was recorded at S4 (677.33 kg/ha), followed by S3 (663.47 kg/ha) and S2 (625.53 kg/ha), whereas the lowest seed yield was observed at S1 (599.67 kg/ha) this may be due to heavy rains during seed set. This indicates that delayed sowing up to S4 enhanced seed yield, probably due to favourable agro-climatic conditions during the reproductive phase, which supported better seed set and filling.

With respect to pollen sources, the maximum mean seed yield was obtained with P1 (675.00 kg/ha), which was statistically on par with P4 (668.75 kg/ha). The lowest yield was noted in P5 (613.42 kg/ha), followed by P2 (619.92 kg/ha). This variation among pollen sources might be attributed to differences in genetic potential and compatibility for efficient pollination and fertilization.

These results are in accordance with Krsticc *et al*. (2023) [10] who reported that the seed yield was significantly affected by the sowing date, the genotype and their interaction Similarly, these results are also supported by El-Mohsen A. A. (2013) [7] who reported that different sowing dates significantly affect seed yield in sunflower. Similarly, Partal (2022) [18] who reported that the seed yield and quality of the sunflower were significantly influenced by the climatic conditions of the agricultural year, the sowing date and used hybrids, as well as the interaction between these factors.

100 Seed weight

The results presented in Table 2 clearly indicate that sowing dates and pollen sources exerted a significant influence on 100-seed weight in sunflower. Among the sowing dates, the highest mean 100-seed weight was recorded under S4 (5.89 g), which was closely followed by S3 (5.88 g), whereas the lowest seed weight was observed in S2 (5.43 g). This suggests that timely and favourable sowing enhances seed filling and contributes to heavier seeds, while delayed sowing adversely affects seed development.

Similar findings were reported by Ahmed *et al*. (2015) [1], who observed that early November sowing produced significantly higher 100-seed weights compared to late December sowings. Similarly, Kiyothong *et al*. (2005) [9] reported 100 seed weight and germination percentage were unaffected by planting date, ranging from 3.769 to 3.829 g and 98.7 to 99.2%, respectively in S. guianensis. In the present study, pollen source also played a considerable role, with P4 recording the maximum mean seed weight (5.98 g) and P5 the minimum (5.61 g). The superior performance of P4 may be attributed to better pollen viability and effective fertilization, which is in line with the observations of Plant Genetic Resources (2023), where pollen quantity rather than grain size was found to be critical in ensuring successful seed set in sunflower.

The interaction effect further highlighted that the combination S4 × P4 produced the heaviest seeds (6.25 g), while S2 × P3 resulted in the lowest value (5.04 g). This demonstrates that both environmental conditions at sowing and the efficiency of pollen sources interactively determine seed development and final seed weight. The relatively higher SEd value for the interaction (0.483) compared to main effects (0.216-0.241) further substantiates the importance of combined effects of sowing season and pollen source on this trait.

Germination percentage

The data pertaining to the effect of different sowing seasons (Factor S) and pollen sources (Factor B) on the germination are presented in Table 2. The analysis of variance revealed that both sowing seasons and pollen sources exerted significant influence on the germination, whereas the interaction effect (S × P) was found to be non-significant.

The mean germination due to different sowing seasons (A) ranged from 84.10 to 90.10. The lowest mean germination was observed in S1 (84.10), followed by S2 (85.15), while the highest mean germination was recorded in S4 (90.10). The treatment S3 (89.05) also showed a higher mean value, being at par with S4 but significantly superior to S1 and S2, as the differences exceeded the critical difference (C.D =2.235). This indicates that later sowing seasons (S3 and S4) resulted in significantly better performance of the germination under study when compared to early sowings (S1 and S2).

The mean germination values for pollen sources (B) varied between 85.31 (P5) and 89.38 (P1). The highest mean germination was obtained in P1 (89.38), which was significantly superior over P2 (85.69) and P5 (85.31) as the differences were higher than the C.D. value of 2.498. The treatment P4 (88.50) was statistically on par with P1, whereas P3 (86.63) occupied an intermediate position. This clearly indicates that the choice of pollen source influenced the germination considerably, with P1 and P4 showing superiority over other pollen sources.

The interaction effect between sowing seasons and pollen sources (S × P) was found to be non-significant. For instance, the highest mean germination was recorded under the combination S4 × P1 (92.50), followed closely by S3 × P1 (91.00) and S4 × P3 (90.00). In contrast, the lowest mean values were observed under S1 × P5 (81.75) and S1 × P3 (83.00). These results suggest that the beneficial effect of superior sowing seasons (S3 and S4) could be further enhanced when combined with efficient pollen sources such as P1 or P4.

It may be concluded that both sowing seasons and pollen sources significantly influenced the germination under investigation. Among the sowing seasons, S4 consistently outperformed all other seasons, while among pollen sources, fresh pollen (P1) was found to be the most effective. The interaction effects further indicated that S4 × P1 combination was the best, recording the maximum mean value, while early sowing (S1) with inferior pollen sources (P5 and P3) resulted in the least values.

Similar findings were reported by Rivera *et al*. (2023), who observed that maternal environmental conditions strongly influenced sunflower seed dormancy and germination.

Seedling length (cm)

The data pertaining to the effect of different sowing dates (Factor S) and pollen sources (Factor P) on seedling length in sunflower are presented in Table 2. The analysis of variance revealed that the differences due to sowing dates, pollen sources, and their interactions (S × P) were non-significant. However, certain numerical variations among treatments were observed.

The mean seedling length across sowing dates ranged from 25.002 cm (S3) to 25.626 cm (S1). The longest seedlings were obtained in S1 (25.626 cm), followed by S2 (25.212 cm) and S4 (25.278 cm), while the shortest seedlings were recorded under S3 (25.002 cm). The mean values for different pollen sources varied between 24.869 cm (P2) and 25.846 cm (P1). The highest mean seedling length was recorded in P1 (25.846 cm), followed by P4 (25.659 cm) and P5 (25.083 cm). The lowest seedling length was observed in P2 (24.869 cm), which was closely followed by P3 (24.939 cm).

The interaction between sowing dates and pollen sources showed some variability, though it remained non-significant (SE(d) = 0.834; SE(m) = 0.590). Among the combinations, the maximum seedling length was recorded in S1 × P1 (25.958 cm), followed closely by S4 × P1 (25.983 cm) and S2 × P1 (25.915 cm). The lowest values were observed in S3 × P5 (24.408 cm) and S4 × P3 (24.470 cm).

It may be inferred that although the effects of sowing dates and pollen sources on seedling length were not statistically significant, numerically higher values were consistently associated with early sowing (S1) and pollen source P1. The interaction effect also indicated that the combinations involving S1 or S4 with P1 tended to produce longer seedlings compared to other treatment combinations.

Navya *et al*. (2022) [14] The study evaluated the effect of sowing dates (15th December and 15th January) and soybean varieties (AISb-50, Basara, JS-335) on seed quality during the off-season. Significant differences were observed in seedling length due to sowing dates and varieties.

Seedling Dry Weight

The data pertaining to the effect of different sowing dates (Factor A) and pollen sources (Factor B) on seedling dry weight in sunflower are presented in Table 2. The analysis of variance indicated that both sowing dates and pollen sources exerted a significant influence on seedling dry weight, whereas the interaction effect (A × B) was non-significant.

The mean seedling dry weight across sowing dates ranged from 19.60 g (S1) to 23.22 g (S4). The lowest dry weight was observed in S1 (19.60 g), while the highest was recorded under S4 (23.22 g). Intermediate values were obtained in S2 (20.87 g) and S3 (22.24 g). The differences between the treatments were significant as they exceeded the critical difference (C.D. = 0.677). Thus, seedling dry weight increased progressively with later sowing dates, with S3 and S4 producing significantly higher values compared to S1 and S2.

The mean seedling dry weight across pollen sources varied from 19.18 g (P5) to 24.09 g (P1). The highest mean value was observed in P1 (24.09 g), which was significantly superior to P2 (20.20 g), P3 (21.29 g), and P5 (19.18 g), as the differences were greater than the C.D. (0.757). The treatment P4 (22.65 g) was also significantly better than P2 and P5 but at par with P1. The lowest mean was recorded in P5 (19.18 g).

The interaction effect between sowing dates and pollen sources (A × B) was not significant (SE(d) = 0.755, SE(m) = 0.534). However, variations among treatment combinations were evident. The maximum seedling dry weight was recorded under S4 × P1 (25.51 g), followed by S3 × P1 (24.92 g) and S4 × P4 (24.28 g). On the other hand, the lowest dry weights were observed in S1 × P2 (17.71 g) and S1 × P5 (17.78 g).

It can be concluded that both sowing dates and pollen sources had a significant influence on seedling dry weight. Among sowing dates, S4 (23.22 g) produced the highest mean dry weight, whereas S1 (19.60 g) recorded the lowest. Similarly, among pollen sources, P1 (24.09 g) consistently outperformed all other pollen sources, while P5 (19.18 g) remained the least effective. The interaction effect revealed that the combination S4 × P1 was the most beneficial in enhancing seedling dry weight. These results are in accordance with Sulthana *et al*. (2017) [23] who reported that the sowing date significantly affected the seedling dry weight.

Seedling Vigour Index-I

The data on the effect of different sowing dates (Factor A) and pollen sources (Factor B) on seedling vigour index I in sunflower are presented in Table 2. Analysis of variance revealed that both sowing dates and pollen sources had a significant effect, while their interaction (A × B) was non-significant.

The mean seedling vigour index ranged from 1,652.10 (S1) to 2,094.65 (S4). The lowest vigour index was observed in S1 (1,652.10), whereas the highest was recorded in S4 (2,094.65). Intermediate values were recorded in S2 (1,779.45) and S3 (1,983.65). The differences were statistically significant (C.D. = 77.953). These results indicate that seedling vigour index increased progressively with later sowings, with S3 and S4 performing significantly better than early sowings S1 and S2.

The mean vigour index across pollen sources ranged from 1,640.06 (P5) to 2,156.00 (P1). The maximum mean was recorded in P1 (2,156.00), which was significantly superior to P2 (1,734.19), P3 (1,849.13), and P5 (1,640.06) as per the C.D. (87.154). P4 (2,007.94) was at par with P1, while P5 recorded the lowest vigour index (1,640.06). Pollen sources with better viability and compatibility tend to produce seeds with higher reserves, which translate into more vigorous seedlings.

Though the interaction effect was statistically non-significant (SE(d) = 86.924; SE(m) = 61.460), numerical differences were recorded. The maximum vigour index was obtained with S4 × P1 (2,357.25), followed by S3 × P1 (2,268.00) and S4 × P4 (2,221.75). Conversely, the lowest values were observed in S1 × P5 (1,453.50) and S1 × P2 (1,473.75). These results indicate that superior pollen sources such as P1 and P4 enhanced seedling vigour particularly when combined with favourable sowing dates (S3 and S4).

It can be concluded that both sowing dates and pollen sources had a significant influence on seedling vigour index I. Among sowing dates, S4 (2,094.65) produced the highest mean value, whereas S1 (1,652.10) recorded the lowest. Among pollen sources, P1 (2,156.00) was the most effective, followed by P4 (2,007.94), while P5 (1,640.06) was least effective. The interaction revealed that the combination S4 × P1 was the most beneficial in enhancing seedling vigour index, whereas S1 × P5 was the least effective.

These results are in accordance with Kundu *et al*. (2016) [11] who reported that the sowing dates significantly influenced the vigour of seed. Similar to present investigation Veeresha *et al*. (2018) [24] concluded that Fresh pollen performed better than one- or two-day-old pollen, giving higher fruit set (39.87%), seed yield (43.25 g), germination (83.64%) and vigour index (1244).

Seedling Vigour Index-II

The data on the effect of different sowing dates (Factor A) and pollen sources (Factor B) on seedling vigour index II in sunflower are presented in Table 2. Analysis of variance indicated that both sowing dates and pollen sources significantly influenced seedling vigour index II, whereas their interaction (A × B) was found to be nonsignificant.

The mean seedling vigour index II ranged from 2,147.55 (S2) to 2,278.10 (S4). The lowest value was observed in S2 (2,147.55), while the highest was recorded in S4 (2,278.10), followed by S3 (2,224.40) and S1 (2,154.70). Statistical differences were significant as per the critical difference (C.D. = 73.983). These results suggest that later sowings (S3 and S4) enhanced seedling vigour index II compared to early sowings (S1 and S2). The mean seedling vigour index II across pollen sources varied from 2,130.00 (P2) to 2,305.63 (P1). Among pollen sources, the highest value was recorded in P1 (2,305.63), followed by P4 (2,271.25), while the lowest was recorded in P2 (2,130.00) and P5 (2,140.13). The differences among pollen sources were significant (C.D. = 82.716).

Although the interaction effect of sowing dates and pollen sources was nonsignificant (SE(d) = 82.498; SE(m) = 58.335), numerical differences were evident. The maximum vigour index II was observed in S4 × P1 (2,401.75), closely followed by S3 × P1 (2,309.50) and S4 × P4 (2,372.75). The lowest vigour index was noted in S2 × P2 (2,078.75) and S1 × P2 (2,089.00). This indicates that superior pollen sources (P1 and P4) enhanced seedling vigour when combined with favourable sowing dates (S3 and S4).

It can be concluded that both sowing dates and pollen sources significantly influenced seedling vigour index II. Among sowing dates, S4 (2,278.10) produced the highest mean value, whereas S2 (2,147.55) recorded the lowest. Among pollen sources, P1 (2,305.63) was the most effective, followed by P4 (2,271.25), while P2 (2,130.00) was least effective. Though the interaction was statistically non-significant, the combination S4 × P1 (2,401.75) proved superior, whereas S2 × P2 (2,078.75) was least effective in enhancing seedling vigour index II. These results are in accordance with Kundu *et al*. (2016) [11] and Navya *et al*. (2022) [14] who reported that the sowing dates significantly influenced the vigour of seed.

Weather parameters

In the first sowing (first fortnight of August) and second sowing (first fortnight of, the seed set/yield and quality are least due to the rainfall (Figure 1). So, there is a shortage of pollen availability during rainfall and low seed yield is recorded. In the third and fourth sowing, there are no unfavourable weather conditions. So, suitable weather conditions resulted in higher seed yield and quality.

Table 1: Effect of sowing dates and pollen source on seed yield, 100 seed weight, germination (%), seedling length(cm), seedling dry weight, SVR-I and SVR-II during 2024-25 (Mean table)

Sowing dates	Treatments	Yield	100 seed weight	Germination (%)	Seedling length(cm)	Seedling dry wt.	Seedling vigour index-I	Seedling vigour index-II
1st sowing	S1P1	646.33	5.75	86.50	25.958	22.24	1,925.50	2,245.50
	S1P2	542.00	5.69	83.25	25.108	17.71	1,473.75	2,089.00
	S1P3	590.33	5.62	83.00	25.760	19.25	1,597.50	2,137.50
	S1P4	623.67	6.06	86.00	25.750	21.03	1,810.25	2,212.50
	S1P5	596.00	5.40	81.75	25.553	17.78	1,453.50	2,089.00
2nd sowing	S2P1	649.67	5.56	87.50	25.915	23.72	2,073.25	2,265.75
	S2P2	588.67	5.48	84.00	24.758	20.02	1,681.25	2,078.75
	S2P3	619.00	5.04	84.50	24.825	19.80	1,671.50	2,099.00

	S2P4	669.00	6.03	86.00	25.153	22.13	1,902.50	2,163.25
	S2P5	601.33	5.06	83.75	25.410	18.71	1,568.75	2,131.00
3rd sowing	S3P1	691.00	5.90	91.00	25.530	24.92	2,268.00	2,309.50
	S3P2	670.00	5.99	86.50	24.558	20.66	1,786.25	2,123.00
	S3P3	648.00	5.87	89.00	24.703	22.62	2,014.75	2,198.00
	S3P4	688.00	5.59	90.50	25.810	23.17	2,097.25	2,336.50
	S3P5	620.33	6.04	88.25	24.408	19.84	1,752.00	2,155.00
4th sowing	S4P1	713.00	5.77	92.50	25.983	25.51	2,357.25	2,401.75
	S4P2	679.00	5.55	89.00	25.053	22.44	1,995.50	2,229.25
	S4P3	664.33	5.93	90.00	24.470	23.48	2,112.75	2,201.25
	S4P4	694.33	6.25	91.50	25.925	24.28	2,221.75	2,372.75
	S4P5	636.00	5.94	87.50	24.960	20.39	1,786.00	2,185.50

Table 2: Mean values of seed yield and different quality parameters in sunflower

Treatments	Yield (kgha^{-1})	100 seed weight	Germination (%)	Seedling length (cm)	Seedling dry weight	Seedling Vigour Index-I	Seedling Vigour Index-II
Sowing dates (04)							
S1: First fortnight of August	599.67	5.7	84.1	25.626	19.60	1,652.10	2,154.70
S2: First fortnight of September	625.53	5.43	85.15	25.212	20.87	1,779.45	2,147.55
S4: Second fortnight of October	663.47	5.88	89.05	25.002	22.24	1,983.65	2,224.40
S5: Second fortnight of November	677.33	5.89	90.1	25.278	23.22	2,094.65	2,278.10
SE(d)	10.241	0.216	1.114	0.373	0.338	38.874	36.894
SE(m)	7.241	0.153	0.788	0.264	0.239	27.488	26.088
CD(P=0.05)	20.811	N/A	2.235	N/A	0.677	77.953	73.983
Pollen sources (05)							
P1: Fresh /Normal pollen	675	5.74	89.38	25.846	24.09	2,156.00	2,305.63
P2: Stored pollen at 50ºC	619.92	5.68	85.69	24.869	20.20	1,734.19	2,130.00
P3: Deep freeze at -20ºC	630.42	5.62	86.63	24.939	21.29	1,849.13	2,158.94
P4: Deep freeze at -80º C	668.75	5.98	88.5	25.659	22.65	2,007.94	2,271.25
P5: pollen mixed with filler material	613.42	5.61	85.31	25.083	19.18	1,640.06	2,140.13
SE(d)	11.449	0.241	1.246	0.417	0.378	43.462	41.249
SE(m)	8.096	0.171	0.881	0.295	0.267	30.732	29.167
CD(P=0.05)	23.268	N/A	2.498	N/A	0.757	87.154	82.498
Interaction (S×P)							
SE(d)	22.899	0.483	2.492	0.834	0.755	86.924	82.498
SE(m)	16.19	0.341	1.762	0.59	0.534	61.465	58.335
CD(P=0.05)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CV%	4.3	10.1	4.87	4.66	6.5	6.54	5.3
S/NS	NS	NS	NS	NS	NS	NS	NS

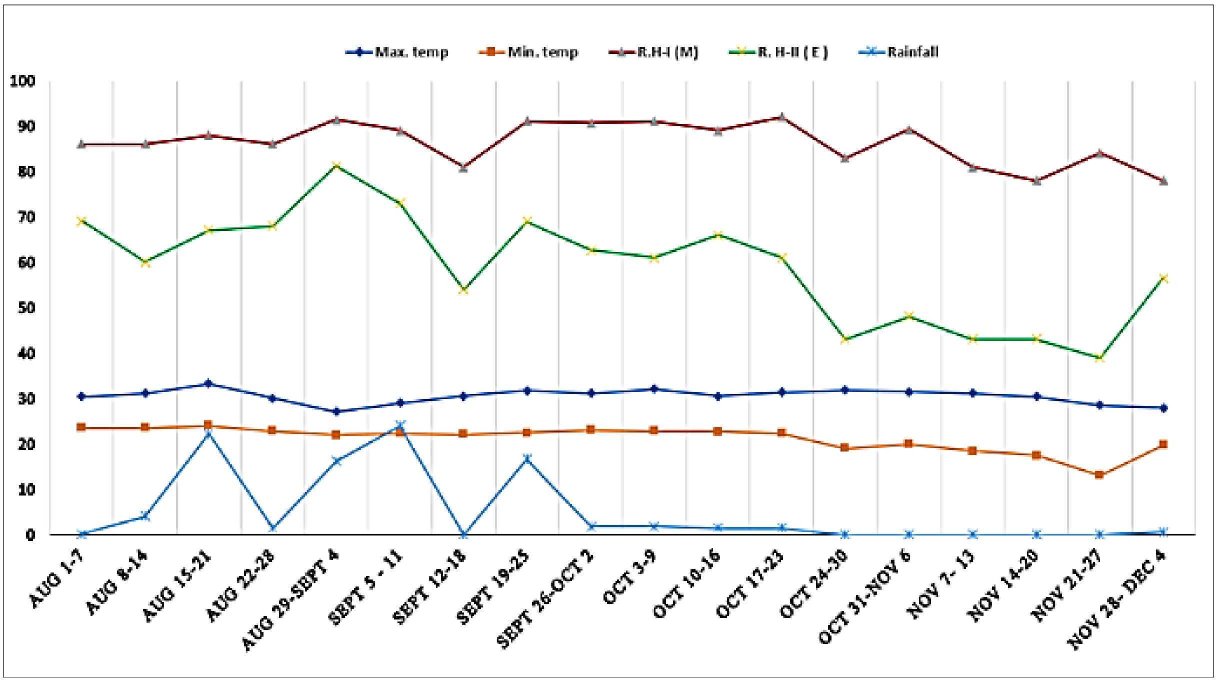

Fig 1: Graphical representation metereological data during the experimental period

Fig 2: View of field experiment of different sowings

Fig 3: Collection of Fresh pollen and storage of pollen at different freeze conditions (5 °C, -20 °C, -80 °C)

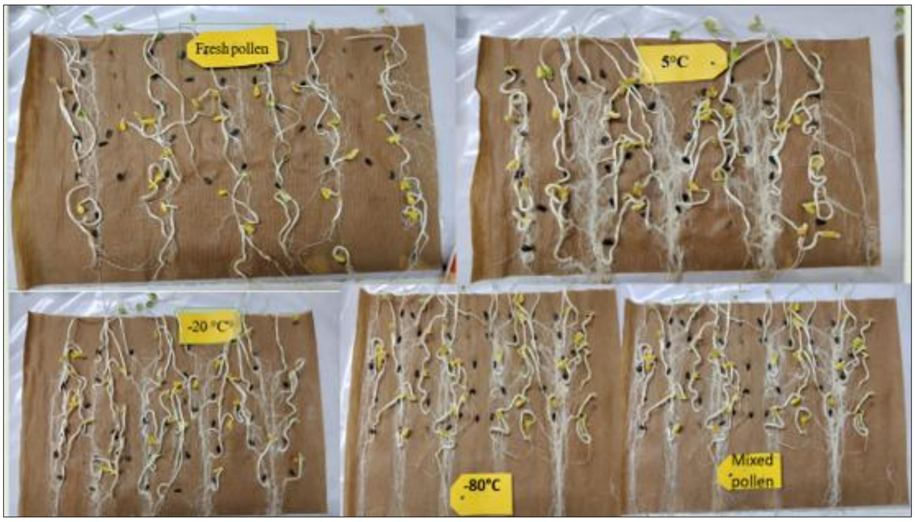

Fig 4: Germination percentage of seeds of different treatments

Conclusion

The study revealed that sowing dates and pollen sources significantly influenced seed yield and quality parameters in sunflower. Later sowings (S3-October and S4-November) consistently produced higher seed yield, 100-seed weight, germination, seedling dry weight, and vigour indices compared to early sowings (S1-August and S2-September), due to favourable weather conditions during the reproductive stage. Among pollen sources, P1 (Fresh pollen) and P4 (Deep freeze at -80°C) showed superiority in enhancing seed yield, seed weight, germination, and seedling vigour, while P5 (Pollen mixing with filler material (saw dust)) remained least effective. Interaction effects were mostly non-significant but numerically supported S4 × P1 as the best combination.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that no generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used by them during writing or editing manuscripts.

Acknowledgements

Authors are grateful to the ICAR- Indian Institute of Oilseeds Research, Rajendranagar, and the Department of Seed Science and Technology, Professor Jayashankar Telangana Agricultural University, Hyderabad- 500030.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Ahmed B, Sultana M, Zaman J, Paul SK, Rahman MM, Islam MR, *et al*. Effect of sowing dates on the yield of

sunflower. Bangladesh Agron J. 2015;18(1):1-5.
2. Ali A, Afzal M, Rasool I, Hussain S, Ahmad M. Sunflower (*Helianthus annuus* L.) hybrids performance at different plant spacing under agro-ecological conditions of Sargodha, Pakistan. Int Conf Food Eng Biotechnol. 2011;9:317-322.
3. Ali A, Ahmad A, Khaliq T, Akhatar J. Planting density and nitrogen rates optimization for growth and yield of sunflower (*Helianthus annuus* L.) hybrids. J Anim Plant Sci. 2012;22:1070-1075.
4. Anjum AS, Muhammad S, Imran M, Arshadullah M. Performance of early and late sown sunflower hybrids under organic farming system in rainfed area. Sci Technol Dev. 2012;31:26-28.
5. Demir AO, Goksoy AT, Buyukcangaz H, Turan ZM, Koksal ES. Deficit irrigation of sunflower (L.) in a sub-humid climate. Irrig Sci. 2006;24:279-289.
6. Directorate of Economics and Statistics. 2021.
7. El-Mohsen AAEA. Analysing and modelling the relationship between yield and yield components in sunflower under different planting dates. 2012.
8. Kaleem S, Hassan FU, Saleem A. Influence of environmental variations on physiological attributes of sunflower. Afr J Biotechnol. 2009;8:3531-3539.
9. Kiyothong K, Satjipanon C, Pholsen P. Effect of planting dates on seed yield and seed quality of *Stylosanthes guianensis* CIAT 184. Songklanakarin J Sci Technol. 2005;27(6):1163-1169.
10. Krstic M, Mladenov V, Banjac B, Babec B, Dunderski D, Cuk N, *et al*. Can modification of sowing date and genotype selection reduce the impact of climate change on sunflower seed production. Agriculture. 2023;13(11):2149.
11. Kundu PK, Roy TS, Khan SH, Parvin K, Mazed HEMK. Effect of sowing date on yield and seed quality of soybean. J Agric Ecol Res Int. 2016;9(4):1-7.
12. Lawal BA, Obigbesan GO, Akanbi WB, Kolawole GO. Effect of planting time on sunflower (*Helianthus annuus* L.) productivity in Ibadan, Nigeria. Afr J Agric Res. 2011;6:3049-3054.
13. Meena HP, Sujatha M, Dudhe MY, Yadav P, Srinivas PS, Madhuri P, *et al*. TilhanTec-SUNH-1 (IIOSH-15-20): A new high seed and oil yielding and downy mildew resistant sunflower hybrid suitable for rainfed condition of India. J Environ Biol. 2023;44(6):855-862.
14. Navya K, Parimala K, Reddy MR, Padmasri A. Effect of planting dates and varieties on seed quality parameters of off-season soybean (*Glycine max* L.). Biol Forum Int J. 2022;14(3):143-146.
15. Olowe VI, Folarin OM, Adeniregun O, Atayese MO, Adekunle YA. Seed yield, head characteristics and oil content in sunflower varieties as influenced by seeds from single and multiple headed plants under humid tropical conditions. Ann Appl Biol. 2013;163:394-402.
16. Paraschivu M, Cotuna O, Sarațeanu V, Durau CC, Paunescu RA. Microgreens - current status, global market trends and forward statements. Sci Pap Ser Manag Econ Eng Agric Rural Dev. 2021;21(3):633-639.
17. Paraschivu M, Matei Gh, Cotuna O, Paraschivu M, Draghici R. Reaction of rye cultivars to leaf rust (*P. recondita* f. sp. *secalis*) in the context of climate change in dry area in southern Romania. Sci Pap Ser A Agron. 2021;64(1):500-507.
18. Partal E. Sunflower yield and quality under the influence of sowing date, plant population and the hybrid. Rom Agric Res. 2022;39:463-470.
19. Riveira Rubin M, Arata GJ, Lopez ED, Rodriguez MV, Batlla D. Dormancy attributes in sunflower achenes (*Helianthus annuus* L.): II. Sowing date effects. Crop Sci. 2021;61(6):4309-4324.
20. Salman A, Muhammad NI, Ihteramuarhan A, Waheed MD, Khilwat A. Plant Breeding and Genetics Division, Nuclear Institute of Agriculture, TandoJam. Khyber Pakhtunkhwa Agric Univ, Peshawar, Pakistan. 2012.
21. Satyabrat M, Hedge MR, Chattapadhyay. Hand book of annual oilseed crops. Oxford and IBH Publ Co (Pvt) Ltd, New Delhi; 1988. p.176.
22. Singh C, Singh P, Singh R. Modern techniques of raising field crops. 2nd ed. Oxford and IBH Publ Co (Pvt) Ltd, New Delhi; 2009. p.376-386.
23. Sulthana I, Sujatha P, Rani KJ, Rani MS, Keshavulu K. Physiological quality of soybean (*Glycine max* L.) as affected by sowing date. J Pharmacogn Phytochem. 2017;6(5):1246-1249.
24. Veeresha SM, Shantappa T, Dileep Kumar M, Jagadeesha R, Harshavardhan G. Effect of time of pollination and period of pollen storage on seed yield and quality of brinjal hybrid (*Solanum melongena* L.). Int J Curr Microbiol Appl Sci. 2018;7(7):1783-1791.
25. Yasin M, Mahmood A, Ali A, Aziz M, Javaid MM, Iqbal Z, *et al*. Impact of varying planting patterns and fertiliser application strategies on autumn-planted sunflower hybrid. Cercet Agron Moldova. 2013;56:39-51.