



## Evaluating productivity potential of spring planted sunflower (*Helianthus annuus*) hybrids in response to sowing time under changing climate scenario

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### ABSTRACT

A field experiments was conducted during the spring seasons of 2005–06 to 2007–08 at Ludhiana, Punjab, to assess the interaction between genotypic variability and modified environmental conditions in response to changing sowing time for sustainable crop production in sunflower (*Helianthus annuus* L.). Maximum harvestable yield was obtained when sunflower was sown in mid-January. Very early sowing (20 December) did not generate any advantage not only for the earliness but also for the yield components; however, later sowings (5 and 20 February) resulted in overall reduction in crop duration, poor seed setting, hastened maturity ultimately culminating in lesser sunflower yields. Cooler temperature prevailing during the initial crop establishment, particularly under the earlier sowing dates (20 December, and 5 January), imparted considerably longer seed emergence period. Sunflower hybrid 'PSH 569' recorded the highest seed yield (2.06 t/ha), excelling 'SH 3322' by 3.5% and 'PSFH 118' by 13.8%. Correlation studies indicated stronger association for yield components and yield with the weather variables during flowering and seed-filling period, therefore, reveals a decisive factor to optimize sunflower yield by adjusting sowing time under changing climatic scenario.

**Key words** : Crop production, Hybrids, Planting dates, Seed yield, Sunflower, Weather variables

The yield and its formation process depend on genetic, environmental and agronomic factors as well as the interaction between them. Understanding of the growth dynamics on its adaptability to various environments and identifying the yield-limiting factors, and appropriate management practices are decisive to amplify the crop's potential. Cultural management practices such as cultivars' selection, planting time and duration of cultivar's life cycle are the important key factors influencing the growth and yield. Matching the phenology of the crop to the duration of favourable environment by adjusting the appropriate sowing time is crucial for attaining maximum harvestable seed yield. Sowing date is an important non-monetary production input that can be manipulated to counter the adverse effects of environmental stresses during the critical stages of plant growth.

Weather variables, especially temperature, incident solar radiation and sunshine duration are the major attributes having significant influence on phenological (Seiler,

1983), physiological, morphological, quantitative and qualitative (Zheljazkov *et al.*, 2009) expressions of sunflower during the crop-growing season. The most common temperature index used to estimate plant development and crop display is growing degree-days (GDD), having strong influence on crop phenology, estimate harvest maturity and predict the duration between two developmental stages (Bonhomme, 2000). Incident solar radiation and sunshine duration are also equally effective that affect plant's developmental and physiomorphic adaptations of the sunflower. Andrade *et al.*, (2002) and Bange *et al.*, (1997) have hypothesized the significance of temperature association and incident radiation interception with growing period, flowering windows in relation to potential yield for sunflower crop.

To cope up environmental vulnerability with changes in climatic scenario as reported by International Panel on Climate Change (IPCC, 2007), there is dire need to re-investigate the effect of weather variables under varying planting windows and its consequent effect on crop yield. The relationship between climatic variables and management practices could be quite helpful in understanding their biophysical impact on sunflower growth and development ultimately predicting the harvestable yield. Taking into

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consideration, the present study was carried out with the hypothesis that genotypes behave differently under different environmental conditions due to change in planting time. Secondly, all physiological and morphological developments occurring within the plant are markedly influenced by related environmental factors having an impact on the growth and development processes, yield and yield components of spring sunflower.

## MATERIALS AND METHODS

For the evaluation of main (sowing dates, hybrids) and interaction effects, 3 hybrids of sunflower ('PSH 569', 'PSFH 118' and 'SH 3322') were grown under 5 sowing dates at 15 days interval (20 December, 5 January, 20 January, 5 February, 20 February) during 3 consecutive years (2005–06, 2006–07 and 2007–08) at the Oilseeds Research Farm (30°56' N, 75°52' E, 247 m above mean sea-level) of the Punjab Agricultural University, Ludhiana, India. The area has a subtropical, semi-arid continental monsoon climate. Annual precipitation is about 760 mm, about 80% of which occurs from June to September. Representative soil samples were taken from the experimental site prior to planting, and standard procedure were followed to determine the physico-chemical properties of the soil. The soil was loamy sand in texture (72.7±2.7% sand; 14.6±1.5% silt; 12.0±1.3% clay), slightly alkaline (pH 7.8±0.2), free from salts (0.20±0.1 dS/m), low in organic carbon (0.19±0.1%) and available N (134±5.5 kg/ha  $\text{KMnO}_4\text{-N}$ ) and medium in available phosphorus (12.8±0.44 kg/ha Olsen's P) and potassium (174±6.5 kg/ha  $\text{NH}_4\text{OAC-K}$ ). The experiment was laid out in a split-plot design with 3 replications having sowing dates as main plot treatments and sunflower hybrids as subplots.

Treatment-wise sunflower hybrids were sown by dibbling method putting 2–3 seeds/hill in 7 row subplots, 5.1 m long with spacing of 0.6 m between rows and 0.3 m between plants. The plots were thinned to one plant/hill when the plants were at the 4 to six-leaf stage. The crop was grown under irrigated conditions with standard cultural inputs applied in accordance with state recommendations. Phosphorus (P) through 30 kg  $\text{P}_2\text{O}_5$  and potassium (K) through 30 kg  $\text{K}_2\text{O}$ /ha were placed and incorporated following the soil analysis and state recommendations. Half dose of nitrogen (N) at sowing and remaining half as side-dressing was applied 30–35 days after sowing to provide a total of 60 kg N/ha over the growing season.

Agro-meteorological data were recorded daily by an automatic weather station located half-a-kilometer from the experimental field. Plants were monitored at 2–3 days interval to determine important phenological phases such as crop emergence, star bud, flowering and physiological maturity for each sowing date. Plots were considered to be

in a particular growth stage, when 50% of the plants had reached that developmental stage. Crop cycle was calculated as the time of period from emergence to physiological maturity. Thermal time for each phenological stage and growth duration was calculated for each sowing date treatment. Thermal time for each day was derived from the mean of minimum and maximum temperature minus base temperature of 8°C (Sadras and Hali, 1998). If mean of minimum and maximum temperatures was lower than base temperature, the thermal time was assumed as zero. Total incident solar radiation and total sunshine duration parameters for each treatment were computed using daily solar radiation values and daily sunshine hours respectively. Photothermal quotient (PQ) was calculated as the ratio of daily solar radiation to daily thermal as per the procedure described by Poggio *et al.* (2005). Then cumulative PQ and mean PQ for each phenological stage and growth duration were derived from daily PQ values. Since the response of test hybrids across sowing dates was more or less remained the same in the evaluating years, therefore, the data on respective parameters for phenological development durations were averaged together over the years.

The sunflower plants were hand harvested at the stage of physiological maturity when the back of the head turned from green to yellow and the bracts turned brown. At each harvest date, 5 plants from each sub-plot were selected for determining plant height, head diameter, stem girth and seed weight. At maturity, head samples for yield were harvested from the centre 5 rows of each net plot, dried and threshed manually to determine the seed yield which was then expressed in t/ha. The collected data for various parameters were statistically analysed using analysis of variance (ANOVA) technique and the treatments means were compared at 5% level of significance.

## RESULTS AND DISCUSSION

### *Growing seasons*

Significant differences for the days taken to appearance of different growth stages, thermal time and sunshine duration were observed in different years. On an average, the sunflower crop took almost 110 days to reach physiological maturity with the accumulation of around 1730 °Cd and 930 h, irrespective of sowing dates and diverse maturity hybrids sown in different growing seasons under irrigated semi-arid subtropical climatic conditions (Table 1). Overall, the cumulative thermal time and total sunshine duration had the higher values (1,824 °Cd and 981 h) in 2007–08 compared to previous years since the crop acquired around 8–10 days longer period for seed to seed maturity. The crop took almost 70–75 days for the completion of flowering in all the growing seasons though

**Table 1.** Calendar days, thermal time and total sunshine duration for different phenological stages of spring-planted sunflower hybrids in relation to sowing time

Treatment	Sowing to emergence (S1)			Emergence to star bud (S2)			Star bud to of flowering (S3)			Completion of flowering completion			Total crop cycle to physiological maturity (S4)			
	CD	THT	SUN	CD	THT	SUN	CD	THT	SUN	CD	THT	SUN	CD	THT	SUN	
<i>Year</i>																
2005-06	12	112	78	41	543	330	27	475	246	25	547	243	106	1678	897	
2006-07	13	105	92	50	583	380	21	404	206	24	593	242	108	1685	914	
2007-08	16	106	94	48	597	387	21	391	197	31	730	297	116	1824	981	
SEM±	0.1	1.5	0.8	0.3	6.5	3.4	0.6	8.9	7.3	0.4	9.4	6.0	0.3	8.5	3.0	
CD (P=0.05)	0.4	4.4	2.3	0.9	19.0	9.9	1.6	26.5	21.5	1.2	28.0	17.4	0.9	25.3	8.8	
<i>Sowing date</i>																
20 December	19	131	104	56	500	390	25	388	220	28	582	283	127	1601	997	
5 January	17	106	105	51	553	375	24	405	226	27	612	282	119	1696	980	
20 January	13	104	99	45	560	362	24	421	219	28	627	273	109	1732	939	
5 February	11	100	68	43	622	359	21	432	213	26	646	249	101	1758	887	
20 February	9	96	63	39	638	340	20	471	206	25	650	217	93	1859	851	
SEM±	0.2	1.3	1.2	0.3	4.1	2.5	0.3	5.4	2.8	0.4	8.3	3.5	0.3	7.2	2.5	
CD (P=0.05)	0.5	3.8	3.4	0.9	12.0	7.4	0.9	15.9	8.1	1.1	24.5	10.3	0.8	21.2	7.2	
<i>Hybrid</i>																
'PSH 569'	14	115	93	45	555	354	23	420	216	26	609	258	109	1699	921	
'PSFH 118'	15	114	92	44	537	345	22	401	206	25	558	250	105	1611	894	
'SH 3322'	12	94	78	51	632	397	24	449	228	29	703	274	115	1878	977	
SEM±	0.1	1.1	0.9	0.2	2.7	1.6	0.3	4.0	2.6	0.3	5.3	2.6	0.2	5.5	1.8	
CD (P=0.05)	0.3	3.0	2.7	0.6	7.9	4.8	0.7	11.9	7.6	0.7	15.6	7.5	0.6	16.1	5.4	

CD, Calendar days; THT, thermal time (°Cd); SUN, total sunshine duration (h).

the phenological development duration representing S4 stage (completion of flowering to physiological maturity) extended over a week time in 2007–08.

The sunflower crop took significantly higher number of days (additional 3–4 days) for seed germination in 2007–08 compared to preceding growing seasons (Table 1). The mean temperature was comparatively low in December and January which might have contributed towards delayed emergence under earlier sowings dates; however, reverse was the trend under delayed sowings where the crop germinated 1–3 days earlier for February sowings in 2005–06 and 2006–07. Sunflower sown in 2006–07 and 2007–08 acquired statistically similar indices values for all the phenological development durations except S4 stage (completion of flowering to physiological maturity) where the crop accumulated significantly higher cumulative thermal time (730 °Cd) and total sunshine duration (297 h) in 2007–08 (Table 2). In contrast, the sunflower sown during 2005–06 had the longest period between star bud to completion of flowering (S3 stage) and took significantly higher number of calendar days (27 days) and consequently accumulated more cumulative thermal time (475 °Cd) and total sunshine duration (246 h).

The sunflower yield and yield components were significantly ( $P < 0.05$ ) influenced by different growing seasons. Significantly higher seed yield (2.05 t/ha) was recorded in 2007–08 as against the 1.93 t/ha in 2006–07 and 1.89 t/ha in 2005–06, both in turn were statistically at par with each other (Table 3). The favourable weather conditions in 2007–08 resulted in prolonged duration of reproductive period representing S4 stage (completion of flowering to physiological maturity), thus significantly improving the 100-seed weight and other growth parameters (Table 3) which culminated in overall better yield performance in contrast to other growing seasons. Seasonal variability in terms of capture and utilization of environment-driven resources during the seed-filling period might have compensated towards better expressions of physio-morphic traits and ultimately yield components and yield during spring 2007–08. Flagella *et al.* (2002) and Kaleem *et al.* (2010) also reported effect of seasonal variations on yield and yield components. Sunflower sown in 2007–08 also showed its superiority in terms of both oil content and oil yield.

#### Sowing dates

Prevailing weather conditions during the crop-growing season have direct bearing upon appearance of different phenological events. Sowing dates markedly influenced the onset and duration of different phenophases. Significant and noticeable differences in thermal time and sunshine duration for different phenological durations were

observed during the study period (Table 1). The calendar days for sowing to emergence (S1), emergence to star bud (S2), star bud to completion of flowering (S3) and completion of flowering to physiological maturity (S4) decreased with each successive delay in sowing date (Table 1). Sunflower sown on 20 December required around 30 days longer growing period compared to its sowing on 20 February. The differences within number of days required to attain physiological maturity under different sowing dates could be attributed to extended vegetative period due to prevalence of comparatively cooler temperature under earlier sowing dates in comparison to later sown crop. The crop compensated for the maximum reduction in days taken to the total crop duration under each successive delay in planting date stands between emergence to star bud (S2), followed by sowing to emergence (S1). Irrespective of the sowing date, the sunflower crop germinated with the accumulation of around 100–105 °Cd except for the earliest sowing on 20 December, which needed 131 °Cd (Table 1).

With each successive fortnight delay in sowing, there was a consistent and significant increase in cumulative thermal time; however, reverse is the case for accumulation of total sunshine duration. Plants sown on 20 December accumulated least thermal time and highest total sunshine duration for respective phenological durations while 20 February sunflower sowing resulted in accumulation of highest thermal time and lowest total sunshine duration (Table 1). The cumulative photothermal quotient ( $PQ_{cum}$ ) obtained with sum up daily values significantly decreased with each successive delay in sowing date for all the phenological developmental durations (S1 to S4 stages). The data presented in Table 2 elucidated that cumulative solar radiation ( $SR_{cum}$ ) values followed the trend of  $PQ_{cum}$  for S1 stage; however, it progressively increased with later sowing dates up to 20 January, thereafter it started decreasing till last sowing (20 February). Mean solar radiation values increased with each successive delay in sowing time (Table 2). Plants were exposed to higher mean solar radiations under delayed planting conditions and the cooler temperature prevailed during initial crop establishment particularly under the earlier sowing dates (20 December and 5 January) imparted considerably longer emergence period and sub-optimal root and vegetative growth.

Variations in yield and yield components were witnessed due to change in sowing time of sunflower. There was a consistent reduction in head diameter, 100-seed weight and ultimately seed and oil yield with each fortnight delay in sowing time from 5 January onwards (Table 3). The present results indicated that very early sowing (20 December) during spring season did not generate any advantage not only for the earliness but also for the yield

**Table 2.** Treatment-wise derived climatic parameters for different phenological stages of spring planted sunflower hybrids in relation to sowing time

Treatment	Sowing to emergence (S1)			Emergence to star bud (S2)			Star bud to completion of flowering (S3)			Completion of flowering to physiological maturity (S4)					
	SRcum	SRmean	PQmean	SRcum	SRmean	PQcum	PQmean	SRcum	SRmean	PQcum	PQmean	SRcum	SRmean	PQcum	PQmean
<i>Year</i>															
2005-06	110	9.6	10.9	511	12.5	39.8	0.96	419	15.5	24.9	0.91	435	17.3	18.9	0.75
2006-07	121	9.4	11.9	621	12.7	52.7	1.05	347	16.8	18.4	0.89	425	17.7	17.5	0.73
2007-08	148	9.7	11.2	625	13.1	39.2	0.80	348	17.2	19.4	0.95	642	20.7	26.9	0.86
SEM±	1.4	0.05	0.1	5.4	0.03	0.4	0.004	13.3	0.2	0.5	0.011	12.0	0.17	0.4	0.07
CD (P=0.05)	4.1	0.14	0.2	15.9	0.07	1.0	0.011	39.6	0.5	1.5	0.030	35.7	0.49	1.2	0.021
<i>Sowing date</i>															
20 December	145	7.7	15.1	578	10.3	47.8	0.85	366	14.8	25.7	1.04	520	18.5	24.9	0.89
5 January	144	8.5	13.0	590	11.6	47.3	0.93	374	15.8	22.2	0.93	522	18.7	23.0	0.83
20 January	128	9.8	10.9	601	13.4	43.4	0.96	377	16.1	21.9	0.92	525	18.8	21.9	0.79
5 February	111	10.2	9.1	586	13.7	42.6	0.99	370	17.4	18.2	0.86	498	19.1	18.8	0.72
20 February	104	11.4	8.5	570	14.7	38.5	0.99	366	18.2	16.7	0.84	438	17.6	16.8	0.68
SEM±	1.7	0.09	0.2	4.0	0.03	0.3	0.003	8.2	0.2	0.3	0.009	7.9	0.12	0.3	0.006
CD (P=0.05)	4.9	0.26	0.5	11.5	0.07	0.8	0.007	NS	0.5	0.9	0.026	22.9	0.35	0.8	0.018
<i>Hybrids</i>															
PSH 569	135	9.7	12.1	567	12.7	42.6	0.95	364	16.1	20.8	0.91	502	18.5	21.1	0.79
PSFH 118	133	9.4	11.9	551	12.8	41.7	0.95	358	16.5	20.5	0.95	468	18.7	20.3	0.81
SH 3322	111	5.6	10.0	638	12.8	47.4	0.94	391	16.8	21.4	0.90	531	18.4	21.8	0.75
SEM±	1.3	0.04	0.1	2.7	0.02	0.2	0.002	5.3	0.2	0.2	0.009	5.1	0.09	0.2	0.006
CD (P=0.05)	3.9	0.11	0.4	7.9	NS	0.6	0.005	15.4	0.4	0.6	0.027	15.1	0.27	0.5	0.018

SRcum, cumulative solar radiation during growing period (MJ m<sup>-2</sup>); SRmean, mean solar radiation during growing period (MJ m<sup>-2</sup> day<sup>-1</sup>); PQcum, cumulative photothermal quotient (MJ/m2/°Cd); PQmean, Mean photothermal quotient (MJ/m<sup>2</sup>/°Cd); NS, non-significant

components and yield. The slower germination and growth problems at early sowing prolonged the vegetative period (S1/S2 stage) rather than reproductive phase (S3/S4 stage) without culminating any significant yield advantage when compared with later sowing dates on 5 and 20 January. Similar findings were also reported by Prasad *et al.* (2006). However, further delayed sowing of sunflower in the month of February, i.e. 5 and 20 February, resulted in overall reduction in crop duration being more prominent in reproductive phase due to rise in temperature resulting in poor seed setting, hastened maturity, lesser accumulation of photosynthates ultimately leading to lower crop yields and oil content compared to early sowings.

Highest seed yield of was recorded when the crop was sown on 5 January, though it was statistically at par with 20 January sowing date, which in turn resulted in similar seed yield obtained with 20 December sowing date (Table 3). Better expression of growth parameters (head diameter and stem girth) and yield attributes (100-seed weight) might have contributed towards comparatively higher seed yield under earlier planting dates. Favourable weather conditions during the reproductive phase might have compensated for better translocation of photosynthates (source to sink ratio), ultimately contributing towards improved yield components and yield. The crop sown on 5 January resulted in 5.6, 4.4, 17.4 and 34.3% higher mean seed yield and 8.4, 4.5, 19.7 and 40.3% higher mean oil yield than 20 December, 20 January, 5 February and 20 February sowings respectively. Irrespective of the sowing dates, sunflower sowing in January month (as planting window) ascertained 3.4 and 22.6% seed yield superiority and 6.1 and 26.4% oil yield improvement to its simultaneous sowing in December and February months, respectively. This could be ascribed to variable response of sunflower yield components with changes in environmental conditions during the seed-filling period. These findings corroborate with the earlier findings of Aguirrezabal *et al.* (2003). Oil concentration gradually de-

creased with delayed planting conditions (Table 3). The influence of sowing dates was discernible on oil yield and substantial reduction in yield was observed with each fortnight delay in sowing time from 5 January onwards. Though there was a significant variation in oil content but the statistically similar seed yield obtained with 20 December and 20 January planting dates might have compensated for overall comparable oil yield obtained under both these sowing dates. Mean yield reduction to the tune of 15.7 and 18.1% in seed yield and 16.0 and 20.9% in oil yield was recorded with delayed sowings February when compared with December and January sowings respectively.

### Hybrids performance

The response of any genotype depends on genetic potential and its reaction with environmental conditions of the domain, necessitating the identification of a suitable genotype. Among the test hybrids, consistent and marked differences were observed in maturity duration and accumulation of cumulative thermal time, total sunshine duration, cumulative solar radiation and photothermal quotient (Tables 1 and 2). Sunflower hybrid 'SH 3322' was the earliest one to emerge and accumulated minimum thermal time (94°Cd), total sunshine duration (78 h), cumulative solar radiation (111 MJ m<sup>-2</sup>) and photothermal quotient (10.0 MJ m<sup>-2</sup> °Cd), however, reverse was the case for

completion of other phenological developmental stages (S2 to S4) in contrast to other hybrids under study. Overall, 'SH 3322' took the maximum number of days (110 days) to mature as against 106 days for 'PSFH 118' and 108 days for 'PSH 569'.

Results reveal that hybrids under evaluation showed significant differences for yield and yield components under the influence of different sowing dates and growing seasons. Sunflower hybrid 'PSH 569' gave the highest seed yield (2.06 t/ha), significantly excelling 'SH 3322' by 3.5% and 'PSFH 118' by 13.8% (Table 4). Better expression of physiological growth parameters and yield components particularly seed weight (Table 3) as well as comparatively longer phenological developmental durations (Table 1) in comparison to 'PSFH 118' might have explicated the yield advantage in favour of both 'PSH 569' and 'SH 3322'. Hybrids exhibited statistically significant differences for oil yield. Zheljzakov *et al.* (2011) also reported genotypic differences for physio-morphic traits and potential yield components under varied planting time.

Oil yield is a complex character determined by interaction between genetic and environmental factors and has a direct dependence on seed yield and oil content. Non-conspicuous differences in oil yield though observed for sunflower hybrids 'PSH 569' and 'SH 3322' but both were significantly superior to 'PSFH 118'. Significantly lower oil content (34.5%) and seed yield (1,812 kg/ha) were

**Table 3.** Effect of sowing time on the yield and yield attributes of spring planted sunflower hybrids

Treatment	Plant height (cm)	Stem girth (cm)	Head diameter (cm)	100-seed weight (g)	Seed yield (t/ha)	Oil content (%)	Oil yield (t/ha)
<i>Year</i>							
2005-06	156.1	6.5	16.2	5.38	1.89	36.5	0.69
2006-07	140.0	6.5	16.4	5.42	1.93	36.8	0.71
2007-08	138.7	7.3	16.9	5.56	2.05	39.9	0.82
SEm±	0.9	0.10	0.11	0.04	0.04	0.33	0.02
CD (P=0.05)	2.5	0.29	0.31	0.11	0.11	0.98	0.05
<i>Sowing date</i>							
20 December	138.9	6.8	17.4	5.70	2.06	37.4	0.77
5 January	146.3	7.3	17.4	6.06	2.17	38.5	0.84
20 January	146.6	6.9	16.8	5.81	2.08	38.4	0.80
5 February	147.7	6.5	15.8	4.99	1.85	37.7	0.70
20 February	145.3	6.4	15.2	4.71	1.62	36.8	0.60
SEm±	1.6	0.07	0.14	0.04	0.03	0.32	0.01
CD (P=0.05)	4.6	0.20	0.40	0.12	0.08	0.90	0.03
<i>Hybrids</i>							
'PSH 569'	153.7	7.0	16.7	5.92	2.06	39.1	0.81
'PSFH 118'	133.1	6.0	15.9	4.98	1.81	34.5	0.63
'SH 3322'	148.1	7.3	16.9	5.47	1.99	39.6	0.79
SEm±	0.9	0.06	0.12	0.04	0.02	0.25	0.01
CD (P=0.05)	2.6	0.18	0.33	0.11	0.06	0.72	0.03

mainly responsible for lower oil yield in case of sunflower hybrid ‘PSFH 118’ (Table 3).

**Interaction**

The interactive effect of sowing dates and hybrids revealed that hybrids ‘SH 3322’ and ‘PSFH 118’ showed consistent improvement in seed yield up to 5 January, however, such an increase was extended up to 20 January; in case of ‘PSH 569’ (Table 4). Further delay in sowing time put forth consistent reduction in seed yield irrespective of the sunflower hybrid. Variable response of different maturity group hybrids under different planting dates has also been reported by Balalic *et al.* (2010). Maximum seed yield of 2.30 t/ha was obtained when sunflower hybrid ‘PSH 569’ was sown on 20 January, although it was found on a par with ‘SH 3322’ when sown on 5 and 20 January and ‘PSH 569’ on 5 January. Maximum yield reduction was noticed in February month planting window (5 to 20 February) for sunflower hybrids ‘PSH 569’ (14.5%) and ‘PSFH 118’ (16.8%). Highest yield reduction of 14.2% was noticed with ‘SH 3322’ coinciding fortnight delay in January month planting (5 to 20 January). Oil yield followed the similar trend as that of seed yield.

**Interrelationship between weather variables and yield components and yield**

Significant correlations between weather parameters and yield attributes and yield were noticed between different phenological developmental durations from sowing to maturity (Table 5). Thermal time was negatively correlated with seed yield and seed weight during flowering period (S3 stage); however, total sunshine durations and cumulative solar radiations had significant positive correlations during seed filling period (S4 Stage). Thermal time before or after flowering and total sunshine durations and cumulative solar radiations up to reproductive phase did not correlate with both seed yield and seed weight. Mean solar radiation negatively correlated with seed yield and seed weight from sowing to completion of flowering (S1 to S3 stage) while cumulative photothermal quotient showed significant positive correlation from emergence to maturity (S2 to S4 stage). Similarly, mean photothermal quotient had higher positive correlations during star bud to maturity (S3 to S4 stage). Poggio *et al.* (2005) also reported similar type of stronger association between mean PQ and seed yield and seed weight.

This study, in turn, provides valuable information re-

**Table 4.** Interaction effect of sowing time and hybrids on the evaluated traits of spring sunflower (mean of 3 years)

Hybrids	Sowing dates					CD (P=0.05)
	20 December	5 January	20 January	5 February	20 February	
<i>Plant height (cm)</i>						
‘PSH 569’	144.3	157.4	156.1	156.5	154.1	5.9
‘PSFH 118’	124.0	129.7	135.1	136.9	139.9	
‘SH 3322’	148.5	151.9	148.8	149.2	141.9	
<i>Stem girth (cm)</i>						
‘PSH 569’	7.0	7.6	7.3	6.7	6.4	0.3
‘PSFH 118’	5.9	6.0	6.4	5.8	5.9	
‘SH 3322’	7.5	8.2	7.1	6.9	6.9	
<i>Head diameter (cm)</i>						
‘PSH 569’	17.6	17.3	17.2	16.0	15.1	0.7
‘PSFH 118’	16.1	16.4	16.2	15.8	15.2	
‘SH 3322’	18.4	18.4	16.9	15.6	15.3	
<i>100-seed weight (g)</i>						
‘PSH 569’	6.01	6.60	6.38	5.37	5.23	0.26
‘PSFH 118’	5.12	5.56	5.47	4.49	4.27	
‘SH 3322’	5.99	6.02	5.58	5.12	4.64	
<i>Seed yield (t/ha)</i>						
‘PSH 569’	2.03	2.24	2.30	2.03	1.73	0.14
‘PSFH 118’	1.87	1.99	1.98	1.76	1.46	
‘SH 3322’	2.28	2.30	1.97	1.77	1.66	
<i>Oil content (%)</i>						
‘PSH 569’	38.9	39.6	40.0	39.2	37.8	1.1
‘PSFH 118’	33.8	35.9	34.1	34.4	34.5	
‘SH 3322’	39.4	40.0	41.0	39.5	38.1	
<i>Oil yield (t/ha)</i>						
‘PSH 569’	0.79	0.88	0.92	0.80	0.66	0.06
‘PSFH 118’	0.63	0.71	0.68	0.61	0.50	
‘SH 3322’	0.90	0.92	0.81	0.70	0.63	

**Table 5.** Correlation coefficient between seed yield and seed weight with weather parameters during different phenological durations in spring sunflower

Traits	Seed yield	100-seed weight
SW	0.458**	
THT (sowing to emergence; S1 Stage)	-0.280	-0.244
THT (emergence to star bud; S2 Stage)	-0.135	-0.171
THT (star bud to completion of flowering; S3 Stage)	-0.339**	-0.326**
THT (Completion of flowering to physiological maturity; S4 Stage)	0.191	0.169
SUN (sowing to emergence; S1 Stage)	0.275	0.299**
SUN (emergence to star bud; S2 Stage)	0.181	0.161
SUN (star bud to completion of flowering; S3 Stage)	0.065	0.052
SUN (completion of flowering to physiological maturity; S4 Stage)	0.482*	0.319**
SR <sub>cum</sub> (sowing to emergence; S1 Stage)	0.231	0.229
SR <sub>cum</sub> (emergence to star bud; S2 Stage)	-0.019	-0.059
SR <sub>cum</sub> (star bud to completion of flowering; S3 Stage)	-0.005	-0.067
SR <sub>cum</sub> (completion of flowering to physiological maturity; S4 Stage)	0.380*	0.332*
SR <sub>mean</sub> (sowing to emergence; S1 Stage)	-0.438*	-0.412*
SR <sub>mean</sub> (emergence to star bud; S2 Stage)	-0.609*	-0.572*
SR <sub>mean</sub> (star bud to completion of flowering; S3 Stage)	-0.319**	-0.439*
SR <sub>mean</sub> (completion of flowering to physiological maturity; S4 Stage)	-0.280	0.149
PQ <sub>cum</sub> (sowing to emergence; S1 Stage)	0.159	0.204
PQ <sub>cum</sub> (emergence to star bud; S2 Stage)	0.299**	0.307**
PQ <sub>cum</sub> (star bud to completion of flowering; S3 Stage)	0.404*	0.372**
PQ <sub>cum</sub> (completion of flowering to physiological maturity; S4 Stage)	0.483*	0.378**
PQ <sub>mean</sub> (sowing to emergence; S1 Stage)	-0.137	-0.069
PQ <sub>mean</sub> (emergence to star bud; S2 Stage)	-0.188	-0.092
PQ <sub>mean</sub> (star bud to completion of flowering; S3 Stage)	0.424*	0.304**
PQ <sub>mean</sub> (completion of flowering to physiological maturity; S4 Stage)	0.478*	0.442*

\*P < 0.05; \*\*P < 0.01; THT, thermal time (°Cd); SUN, total sunshine duration (h); SR<sub>cum</sub>, cumulative solar radiation during growing period (MJ/m<sup>2</sup>); SR<sub>mean</sub>, mean solar radiation during growing period (MJ/m<sup>2</sup>/day<sup>1</sup>); PQ<sub>cum</sub>, cumulative photothermal quotient (MJ/m<sup>2</sup>/Cd<sup>1</sup>); PQ<sub>mean</sub>, mean photothermal quotient (MJ/m<sup>2</sup>/°Cd)

garding choice of suitable hybrids and optimum sowing time for desired yield potential in sunflower on sustainable basis while taking into consideration the prevailing weather conditions. Based on the study, it can be suggested that the most appropriate sowing time for spring-planted sunflower in northern India is mid-January, as the plants were exposed to suitable temperature regime and receive more solar radiation and sunshine duration during the seed-filling period. Correlation indicated stronger association between yield components and yield with the weather variables during reproductive period. Significantly higher seed yield was recorded with sunflower hybrid 'PSH 569' in comparison to 'SH 3322' and 'PSFH 118'.

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