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SUNFLOWER TRAITS RESPONSE TO ELEVATED CO_2 LEVELS UNDER COOL AND WARM SEASON CONDITIONS

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SUMMARY

A study was conducted in the Open Top Chambers (OTCs) to assess the influence of cool and warm season conditions on the response of sunflower (KBSH-1) to two elevated CO_2 levels (550 and 700 ppm) and compare them with the response to an ambient level (390 ppm). The effect of elevated CO_2 levels on biomass accumulation, seed yield and yield components were quantified in two seasons. Apart from the main effects of CO_2 and different seasons, a significant interaction effect between CO_2 levels and seasons was also observed. The CO_2 levels differed significantly in influencing biomass accumulation, seed yield and number of seeds. Four Principal Components (PC) based on PC analysis explained about 85% of the variability in the response of traits influenced by CO_2 levels in winter and summer seasons. In order to predict total dry weight, seed yield and harvest index obtained in winter and summer seasons, regression models of these variables were also calibrated and used through PC scores of different components. The analysis indicated that significant predictions could be made at ambient level with 550 ppm, compared to 700 ppm of CO_2 level. The plant traits with a significantly higher loading of more than ± 0.70 on PCs were identified and have been recommended for future research in genetic improvement of sunflower, taking into account the change of climate due to elevated CO_2 and temperature levels.

Key words: elevated CO_2, correlation, principal components, regression, prediction, climate change

INTRODUCTION

The climate change is expected to result in hotter and drier environments in many parts of the world due to rising CO_2 and temperature. Global concentration of CO_2 in the atmosphere has been rising continuously and at present it is about 35%

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higher than before the industrial revolution. The present mean CO_2 level of 390 ppm is expected to reach the levels of 650 to 970 ppm by the end of the 21st century (IPCC, 2007). The mean global temperature increased by 0.6°C in the 20th century (Folland *et al.*, 2001) and is expected to increase between 1.7°C and 4.9°C by 2100 (Cubasch *et al.*, 2001). Changes in the CO_2 concentration and associated changes in the global temperature would cause significant changes in the crop production. The increasing temperature is expected to have a significant effect on the yield of annual crops (Alexandrov and Hoogenboom, 2000).

Sunflower is one of four most important oil seed crop and globally it is cultivated in the area of 25,225 thousand ha with the annual production of 35,568 MT and productivity of 1.41 MT ha^{-1} (www.sunflowernsa.com) in 2012-13. In India, sunflower is grown in the area of 1.88 million ha with the production of 620 MT and productivity of 694 kg ha^{-1}. The optimum growth temperature for sunflower is 20 to 35°C. Tubiello and Ewert (2002) reported that increasing CO_2 levels in atmosphere would raise the optimum growth temperature of the crop significantly.

The important objective of any plant scientist is to identify an optimum number of plant traits which are sufficient to explain the maximum variability in the crop growth, from sowing to harvest. Based on the principal component analysis, we can identify important plant traits for explaining the maximum variability in the crop growth (Dunteman *et al.*, 1989). McMurtrie *et al.* (1992) examined forest growth models and explored mathematical models to assess the response of tree stands to the elevated CO_2 levels and increased temperature. Similarly, the impact of climate change on wheat yields was modeled by Ozdogon (2011). The changes in sunflower crop growth were modeled based on the observations recorded on plant traits using regression models (Maruthi Sankar *et al.*, 1999) and principal component models (Maruthi Sankar *et al.*, 2003 and 2004). The elevated CO_2 and temperature would interact to impact plant growth and productivity, which is the vital issue for any crop to fit into the changing climatic conditions. The present study was carried out to (i) assess the growth and yield of sunflower at elevated CO_2 levels in winter and summer season; and (ii) identify suitable plant traits for explaining the maximum variability in crop responses.

MATERIALS AND METHODS

Experiments were conducted in the Open Top Chambers (OTCs) at two elevated CO_2 levels of 550 and 700 ppm to assess the response of sunflower (*Helianthus annuus* L.) hybrid KBSH-1 during winter and summer seasons, having the temperature difference of 5-6°C at anthesis and grain filling stages and compared with the ambient (390 ppm) chamber control conditions. The maximum temperature of the winter crop was below 35°C, whereas the summer crop experienced more than 40°C at anthesis and grain filling stages (Figure 1). Sunflower plants were raised in plastic pots filled with 18 kg of red loamy soil (Alfisol) in OTCs from October to

January (winter) and January to May (summer). Recommended fertilizer dose of 60 kg of N, 90 kg P_2O_5, and 30 kg K_2O/ha was applied to the crop.

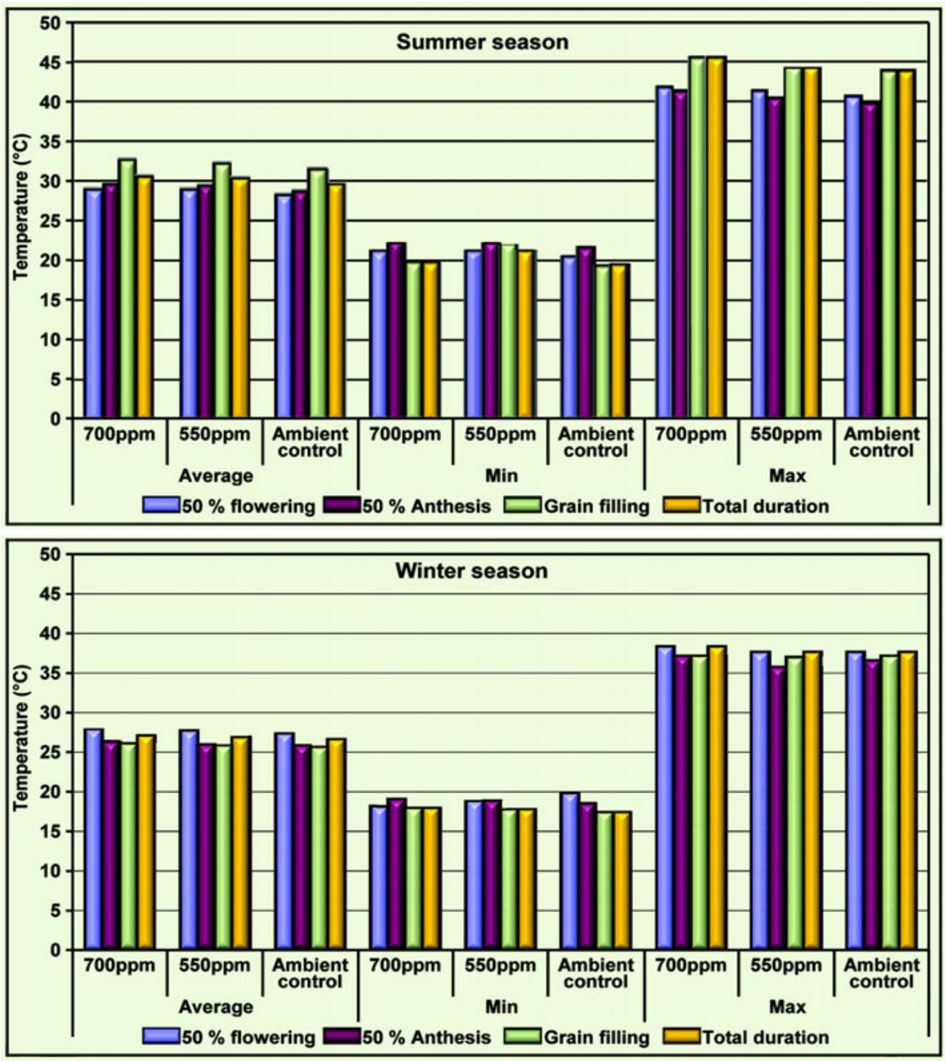

Figure 1: The average, minimum and maximum temperatures at different pheno-phases during warm (summer) and cool (winter) season of sunflower crop raised at three CO_2 levels (700 ppm, 550 ppm & 390 ppm)

The CO_2 levels of ambient, 550 and 700 ppm, were maintained throughout the study period as described by Vanaja *et al.* (2006). Two elevated CO_2 levels of 550 and 700 ppm were maintained in two OTCs, while the third OTC without any additional CO_2 supply served as ambient control. Twelve plants were maintained in each

OTC (one plant per pot). At the time of the harvest, representative samples of 6 replicates were randomly chosen to determine the biomass and yield characters. During harvest, plants were separated into roots, stem, leaves and capitulum. The heads (capitula) were dried in the sun light and seeds were separated. The harvested plant parts *viz*., leaves, stems, roots and de-seeded heads were dried in tray drier at 60°C till constant weights were attained to determine the dry weights. Observations were recorded on 12 plant traits *viz*., (i) leaf dry weight (LDW, g pl^{-1}); (ii) stem dry weight (SDW, g pl^{-1}); (iii) root dry weight (RDW, g pl^{-1}); (iv) head dry weight (HDW, g pl^{-1}); (v) fodder dry weight (FDW, g pl^{-1}); (vi) total dry weight (biomass) (TDW, g pl^{-1}); (vii) harvest index (HI, %); (viii) head diameter (HD, cm); (ix) seed yield (SY, g pl^{-1}); (x) total seed number (TSN); (xi) filled seed number (FSN); and (xii) unfilled seed number (UFSN, g pl^{-1}) at the level of CO_2 in winter and summer seasons. The total dry weight (TDW) was calculated as the sum of stem, leaf, root and head biomass; fodder dry weight (FDW) by subtracting the seed weight from total biomass and harvest index (HI, %), while the % of seed weight was obtained from total biomass produced.

The main effects of CO_2 levels and seasons, and their interaction were tested based on the Analysis of Variance (ANOVA) procedure. Based on the Least Significant Difference (LSD) criteria, the main effects of CO_2 levels and seasons and their interaction effects were compared in order to identify a superior level of CO_2 at which significantly higher response of traits has occurred in a given season. An assessment of correlation between plant traits at different CO_2 levels in summer and winter seasons could be made in order to develop suitable regression models for predicting total biomass, seed yield and harvest index. We can identify significant plant traits contributing to total biomass, seed yield and harvest index in winter and summer seasons based on the principal component (PC) analysis (Jolliffe, 1986; Dunteman, 1994). The significant PCs which have the value of more than “one” are identified and the variance (%) captured by each PC could be determined. The loadings of plant traits on leading principal components could be determined and important plant traits could be identified based on the standard computational procedure. The plant traits with loadings of more than ±0.70 on PCs could be identified. A principal component regression model of total biomass, seed yield and harvest index could be developed through PC scores of different components to assess the effects of CO_2 on the response of plant traits, apart from predicting total biomass, seed yield and harvest index in winter and summer seasons.

The principal component regression models calibrated at different levels of CO_2 in winter and summer seasons could be evaluated for superiority based on the coefficient of determination (R^2) and prediction error statistics and used for prediction of seed yield, total biomass and harvest index that could be attained in winter or summer season.

RESULTS AND DISCUSSION

The mean value and coefficient of variation of plant traits at ambient, 550 and 700 ppm levels in summer and winter seasons are given in Table 1.

Table 1: Mean and coefficient of variation of plant traits of sunflower at different levels of CO_2 in winter and summer seasons

Seasons	Winter						Summer					
CO_2 (ppm)	Ambient		550		700		Ambient		550		700	
Traits	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
LDW	9.3	9.8	9.9	9.2	11.5	14.3	16.9	15.7	14.8	14.2	15.5	14.8
SDW	22	7.4	27.4	13.1	31.2	7.1	23.4	7.7	21.7	21.5	24.6	19.3
RDW	5.1	21.3	6.6	18.3	8.5	33	12.8	47.4	10.1	69.2	7	27.2
HDW	33.1	7.4	38.5	10.7	47.4	7.6	37.3	5.4	42.1	9.2	40.3	10
SY	23.3	7.8	28.2	11.4	34	6.6	23.8	10.8	25.9	3.2	24.6	18.5
TDW	69.6	8	82.6	11	101	10	90.3	6.9	88.7	13.3	87.4	9.1
FDW	46.3	9.7	54.4	11.2	67	12.6	126.5	9.7	120.6	17.6	113	17
HD	98.2	3.1	106.6	5.7	117.5	5.4	90.5	6.4	93.8	8	100	7.1
TSN	733	16	701	17.2	872	14.3	478	11.3	514	10.2	540	3.4
FSN	561	21.9	568	11.5	709	11	414	14.7	439	9.3	443	13.6
UFSN	172	28	133	62.4	163	41.2	64	89.5	75	35.7	97	47.1
HI	33.5	6.2	34.2	3	34	5.4	26.4	12.3	29.6	13.9	28.1	16

Table 2: Improvement (%) of sunflower plant traits at 550 and 700 ppm levels of CO_2 over ambient control in winter and summer and decrease (%) due to increased temperature during summer sunflower

Plant trait	Increase (%) over ambient -winter		Increase (%) over ambient -summer		Decrease (%) with increased summer temperature		
CO_2 (ppm)	700	550	700	550	700	550	Ambient
LDW	22.9	6.2	-8.4	-12.2	-25.9	-33.2	-44.8
SDW	42.0	24.9	5.2	-7.1	26.9	26.4	-6.0
RDW	110.7	29.9	-44.8	-20.7	56.1	-33.0	-59.1
HDW	43.3	16.3	7.9	12.8	17.6	-8.7	-11.5
SY	46.1	20.9	3.2	8.7	38.6	8.8	-2.1
TDW	45.2	18.7	-3.3	-1.8	15.6	-7.0	-23.0
FDW	44.7	17.6	-10.6	-4.7	-40.8	-54.9	-63.4
HD	9.8	5.3	10.5	3.7	12.0	14.5	12.7
TSN	19.0	-4.3	12.9	7.5	61.5	36.4	53.2
FSN	26.5	1.4	7.0	6.1	60.1	29.4	35.4
UFSN	-5.3	-22.9	51.4	16.6	67.6	77.3	168.1
HI	1.9	2.1	6.4	12.0	21.3	15.6	26.7

In winter season, all traits except HI and unfilled seed number had the maximum value at 700 ppm; while HI had its maximum at 550 ppm and the unfilled seed number had the maximum at ambient conditions. In summer season, stem biomass, head diameter, total, filled and unfilled seed number had their maximum at 700 ppm; while head weight, HI and seed yield had the maximum at 550 ppm; and leaf, root, fodder and total biomass had the maximum at the ambient level. Fritsch *et al.* (1999) reported a response of total biomass production in forage crops due to interaction of CO_2 and temperature.

At 700 ppm level of CO_2, the increase in plant traits in winter in comparison to the ambient conditions ranged from 1.9% (HI) to 110.7% (RDW); 1.4% (FSN) to 29.9% (RDW) at 550 ppm (Table 2). In summer, the increase (%) in plant traits over ambient conditions ranged from 3.2% (SY) to 51.4% (UFSN) at 700 ppm and 3.7% (HD) to 16.6% (UFSN) at 550 ppm. Based on the comparison of the mean response of plant traits during winter and summer seasons and with the increased temperature in summer, the decrease was in the range of 12.0% (HD) to 67.6% (UFSN) at 700 ppm; 8.8% (SY) to 77.3% (UFSN) at 550 ppm; 12.7% (HD) to 168.1% (UFSN) at ambient conditions.

Table 3: Analysis of the variance of plant traits observed at different CO_2 levels in winter and summer sunflower

CO_2/ Season	LDW	SDW	RDW	HDW	SY	TDW	FDW	HD	TSN	FSN	UFSN	HI
700 ppm	13.5	27.9	7.8	43.4	29.3	109.7	90.0	109	706	576	130	31.1
550 ppm	12.4	24.6	8.3	39.1	27.0	100.6	87.5	100	607	504	104	31.9
Ambient	13.1	22.7	8.9	34.8	23.6	75.7	86.4	94	606	488	118	29.9
Winter	10.2	26.9	6.7	38.8	28.5	101.8	55.9	107	769	613	156	34.0
Summer	15.7	23.2	10.0	39.4	24.7	88.8	120.0	95	511	432	79	28.1
Mean	13.0	25.0	8.3	39.1	26.6	95.3	88.0	101	640	523	117	31.0
CV (%)	14.8	13.6	50.9	7.5	9.9	14.1	16.4	6.3	13.5	14.6	48.6	10.2
LSD ($p<0.05$)												
CO_2	NS	2.9	NS	2.5	2.2	11.3	NS	5.4	72	64	NS	NS
Seasons (S)	1.3	2.3	2.9	NS	1.8	9.2	9.9	4.4	59	52	39	2.2
$CO_2 \times S$	NS	4.0	5.1	3.5	3.1	16.0	17.1	NS	NS	NS	NS	NS

The analysis of variance of plant traits at 3 levels of CO_2 levels in winter and summer sunflower indicated that the CO_2 levels differed significantly ($p<0.05$) in influencing the biomass of stem, head, total biomass, head diameter, seed yield, total and filled seed number (Table 3). The seasonal differences were significant ($p<0.05$) for leaf, stem, root, total and fodder biomass, HI, head diameter, seed yield, total, filled and unfilled seed number. Significant interaction of CO_2 levels and seasons was observed on the stem, root, head, total and fodder biomass and seed yield at $p<0.05$ level. Based on the least significant difference (LSD) criteria, stem, head and total biomass, head diameter, seed yield, total, filled seed number were significantly higher at 700 ppm compared to 550 ppm and ambient control in winter; while head and total biomass, head diameter and seed yield were significantly higher at 550 ppm compared to ambient control in summer season.

The CO_2 levels did not influence the leaf, root and fodder biomass, HI, and unfilled seed number in both seasons. In winter season, significantly higher stem and total biomass, HI, head diameter, seed yield, total, filled and unfilled seed number were observed compared to summer, while in the summer season significantly higher leaf, root and fodder biomass were observed compared to winter. The biomass of head did not differ between the two seasons. Cowling and Sage (1998) observed an enhanced plant biomass of barley and wheat with 200 ppm increase in atmospheric CO_2 concentration and higher temperatures. With the increase of temperature by 3°C and 700 ppm CO_2 the spring wheat biomass was improved by 23% compared to ambient conditions (Hakala, 1998). Wurr *et al.* (2000) observed the increase of 50% in yield of French bean to elevated CO_2 and 4°C increase in temperature compared to no response at ambient temperature. Studies with rhizoma peanut (Fritschi *et al.*, 1999) revealed that the elevated CO_2 did not significantly interact with an increase in the ambient temperature (4.5°C) to impact the growth. The interactive effect of elevated CO_2 and temperature was observed to be specific to the crop and the range of temperature. In our study, a better performance of sunflower was observed under cooler temperature in winter compared to warmer temperature in summer as indicated by the superiority of 8 traits in winter compared to 3 traits in summer.

Relationship between different traits

The total biomass was correlated significantly and positively with fodder biomass during both winter and summer seasons and with only head weight in winter season at all three levels of CO_2 (Table 4).

Table 4: Estimates of correlation between total biomass, seed yield and HI and other traits of sunflower during winter and summer at three levels of CO_2

	Winter season			Summer season		
	Ambient	550 ppm	700 ppm	Ambient	550 ppm	700 ppm
Total biomass						
LDW	0.871*	-	-	-	-	-
SDW	0.909*	0.928**	-	-	-	0.896*
RDW	0.853*	-	-	0.868*	-	-
HDW	0.918**	0.974**	0.912**	-	-	-
SY	-	0.953**	-	-	-	-
FDW	0.957**	0.987**	0.987**	0.947**	0.978**	0.822*
TSN	-	0.906*	-	-	-	-
FSN	-	0.861*	-	-	-	-
HI	-	-	-	-	-0.974**	-
Seed yield						
HDW	0.866*	0.990**	0.954**	-	-	0.850*
TDW	-	0.953**	-	-	-	-
FDW	-	0.894*	-	-	-	-
FSN	-	0.927**	0.906*	-	-	-
HI	-	-	-	0.834*	-	0.880*
HI						
SY	-	-	-	0.834*		0.880*
TDW	-	-	-	-	-0.974**	-
FDW	-	-	-0.879*	-	-0.935**	-
FSN	-	-	-	-	-	0.840*
UFSN	-0.821*	-0.842*	-	-	-	-

Stem biomass, seed yield, filled and total seed number also registered significant and positive correlation with total biomass in winter and negative correlation of HI during summer at 550 ppm only. It is interesting to record that during summer total biomass significantly correlated with root biomass at ambient and stem biomass at 700 ppm level and none of the yield components registered any significant correlation with total biomass.

Seed yield correlated positively and significantly with head weight at all three levels of CO_2 during winter and only at 700 ppm during summer season. At 550 ppm, total biomass, fodder biomass, filled seed number registered significant and positive correlation with seed yield in winter, while none of the traits recorded a significant correlation in summer.

Significant and positive correlation of HI with seed yield was observed at 700 ppm and ambient CO_2 level during summer season. Fodder biomass was negatively and significantly correlated with HI at 700 ppm during winter and 550 ppm during summer season. HI correlated negatively and significantly with unfilled seed number (UFSN) at 550 ppm and ambient conditions during winter, whereas it correlated positively and significantly with filled seed number (FSN) at 700 ppm during summer season. These results clearly indicate the seasonal variation in response of different traits to enhanced CO_2 levels and their contribution to the improvement of biomass and seed yield as well as partitioning of biomass. With the increased temperature during summer the majority of traits lost their importance.

Principal component analysis

Based on the correlation coefficients between different plant traits, principal components (PCs) were determined to (i) explain maximum variability of the plant traits and (ii) identify significant plant traits which contributed to sunflower growth at different CO_2 levels maintained in winter and summer seasons. The eigenvalues and the variance explained by PCs are given in the Table 5.

Table 5: Eigenvalues and percent of variance explained by principal components of plant traits at different levels of CO_2 in winter and summer sunflower

Principal component	Winter season			Summer season		
	Ambient	550 ppm	700 ppm	Ambient	550 ppm	700 ppm
Eigenvalues						
P_1	4.59	6.31	5.91	2.83	4.43	5.42
P_2	1.91	1.09	1.17	2.19	2.21	2.06
P_3	1.43		1.03	1.99	1.41	
P_4				1.32		
Variance (%)						
P_1	51.1	70.2	65.7	31.5	49.2	60.3
P_2	21.2	12.2	13.0	24.4	24.6	22.9
P_3	15.9		11.5	22.2	15.7	
P_4				14.7		
Total variance	88.2	82.4	90.2	92.8	89.5	83.2

The eigenvalues of PCs were higher at 700 ppm, followed by 550 ppm and the ambient control indicating the superiority of elevated CO_2 for attaining a higher response in the growth of plant traits. Taking the winter sunflower into account, 3 PCs explained the maximum variance of 90.9% in the plant traits recorded at 700 ppm. Using this variance, the 1^{st} PC P_1 explained 66.1%, while the 2^{nd} and 3^{rd} PCs P_2 and P_3 explained variance of 14.3 and 10.5%, respectively. In summer, 4 PCs explained the maximum variance of 97.9% at 700 ppm, out of which P_1 explained 50.4%, while P_2 explained 27.4%. At 550 ppm, 3 PCs explained 92.9% of the variance in winter, out of which 66% was explained by P_1; 15.5% by P_2 and 11.4% by P_3 components, whereas in summer, 4 PCs explained 97.8% of the variance at 550 ppm, out of which 48.5% was explained by P_1, compared to 19.9, 19.3 and 10.1% variance by P_2, P_3 and P_4 components, respectively. At ambient conditions, 3 PCs explained 91.2% of the variance in winter, out of which P_1 explained 51.2%, while P_2 and P_3 explained 24.6 and 15.4% of variance, respectively. In summer 4 PCs explained the variance of 93.4% at ambient conditions, this comprised of 36.8% by P1; 26.8% by P2; 16.8% by P3 and 12.9% by P4. Thus variance in traits was better explained by less number of PCs in winter compared to more number of PCs in summer season.

The variance explained by PCs was almost the same at all levels of CO_2 in winter, while it was relatively higher at 700 and 550 ppm compared to ambient control in summer. There was a better performance of sunflower in winter compared to summer season which is evident based on the variance explained by the 1^{st} PC at all levels of CO_2. In fact, 700 ppm was superior to 550 ppm and ambient levels based on the first two PCs.

The importance of plant traits was assessed based on the magnitudes of loadings on PCs determined at different CO_2 levels in winter and summer seasons (Table 6). In winter sunflower, all traits except HI (SDW) and unfilled seed number were significantly loaded on P_1 at 700 ppm, while no trait was loaded on P_2. At 550 ppm, all traits except root biomass, head diameter and HI had a significant loading on P_1, while only HI had a significant loading on P_2. The biomass of leaf, stem, root, head, fodder and total biomass had a significant loading on P_1; while HI, seed yield and unfilled seed number had a significant loading on P_2 at ambient conditions for explaining the variance in plant traits.

In summer sunflower, traits such as leaf and fodder biomass, head diameter, filled, unfilled and total seed number had a significant loading on P_1; while only head biomass, seed yield and total seed number had a significant loading on P_2 at 700 ppm (Table 6). At 550 ppm, all traits except leaf, root and head biomass, head diameter, seed yield and filled seed number had a significant loading on P_1, while only head diameter and filled seed number had a significant loading on P_2. At the ambient level, root and head biomass, HI and seed yield had a significant loading on P_1; while leaf and total biomass had a significant loading on P_2.

Root biomass had a significantly higher loading on P_1 at ambient control in summer indicating that the traits lost their importance under elevated CO_2 levels. The unfilled seed number was important at both 550 and 700 ppm since it had a higher loading on P_1 compared to the ambient. This indicated that though the seed set was maintained at 550 ppm, seed filling did not happen due to high temperature, as indicated by the significance of unfilled seed number under elevated CO_2 condition. Our findings are in conformity with those of Havelka *et al.* (1984) and Idso *et al.* (1987).

Table 6: Loadings of plant traits on PCs at different levels of CO_2 in winter and summer sunflower

Trait	Ambient				550 ppm			700 ppm		
	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_1	P_2	P_3
Winter										
LDW	0.966*	-0.001	0.043		0.668	-0.552		0.969*	-0.110	0.139
SDW	0.952*	0.141	0.175		0.973*	0.138		0.678	-0.618	-0.397
RDW	0.809*	0.450	-0.328		0.730*	0.336		0.733*	-0.629	0.205
HDW	0.861*	-0.078	-0.335		0.907*	-0.305		0.784*	0.485	-0.378
FDW	0.935*	0.328	0.022		0.987*	-0.054		0.804*	0.177	-0.380
HD	-0.014	0.151	0.593		0.634	0.183		0.811*	-0.018	-0.207
TSN	0.518	-0.742*	0.410		0.970*	0.143		0.912*	0.212	0.343
FSN	0.451	-0.888*	0.075		0.816*	-0.443		0.864*	0.244	0.028
UFSN	0.110	0.461	0.806*		0.764*	0.558		0.690	0.110	0.605
Summer										
LDW	-0.607	-0.621	0.363	-0.189	0.585	0.536	-0.531	0.831*	0.299	
SDW	0.582	0.713*	0.201	0.303	0.891*	-0.437	0.012	0.682	-0.341	
RDW	0.700*	-0.477	0.461	0.225	0.681	0.348	0.079	-0.514	-0.779*	
HDW	-0.865*	0.305	0.255	0.128	0.042	-0.117	-0.981*	0.553	0.649	
FDW	0.590	-0.346	0.637	0.292	0.908*	0.069	-0.176	0.870*	0.385	
HD	-0.158	0.424	-0.357	0.700*	-0.416	0.890*	-0.027	0.873*	-0.398	
TSN	0.471	0.500	0.033	-0.622	0.886*	0.234	0.242	-0.702*	0.677	
FSN	-0.088	0.626	0.706*	-0.317	0.603	0.664	0.259	-0.915*	0.252	
UFSN	0.537	-0.191	-0.716*	-0.251	0.823*	-0.555	0.080	0.921*	-0.062	

*Traits with significant loadings on PCs (loadings of more than ±0.7)

Regression model of total dry weight, harvest index and seed weight through PC scores of components

Based on the PC model, principal component scores of each component were derived at each level of CO_2 in winter and summer seasons and regression models of total biomass, seed yield and HI were derived for each season. The estimates of regression coefficients, coefficient of determination (R^2) and prediction error are given in Table 7. The regression models through principal components indicated that total biomass had maximum predictability at 550 ppm, followed by ambient and 700 ppm in summer season; while the prediction reached its maximum at ambient control, followed by 550 and 700 ppm in winter season. Seed yield had its maximum predictability at ambient control, followed by 550 and 700 ppm in summer season, while in winter season it was at ambient control and 700 ppm, followed by 550 ppm. HI had its maximum predictability at 550 ppm, followed by ambient and 700 ppm in summer season, while at ambient it happened in winter season, followed by 550 and 700 ppm.

Table 7: Regression model of total dry weight, seed weight and harvest index through PC scores of plant traits in winter and summer sunflower

	CO_2	Winter season		
		Regression model	R^2	PE
Total biomass	Ambient	$TDW=16.709 + 0.537^{**} P_1 + 0.251^{**} P_2 - 0.225^{**} P_3$	0.98**	1.03
	550 ppm	$TDW=14.629 + 0.045^{**} P_1 - 0.052 P_2$	0.91*	3.52
	700 ppm	$TDW=3.618 + 0.173 P_1 - 0.385 P_2 - 0.167 P_3$	0.66	9.38
Seed yield	Ambient	$SY=15.221 + 0.107 P_1 + 0.042 P_2 - 0.063 P_3$	0.90*	0.92
	550 ppm	$SY=1.532 + 0.017^{*} P_1 - 0.037 P_2$	0.89*	1.39
	700 ppm	$SY=13.860 - 0.003 P_1 + 0.091 P_2 - 0.027 P_3$	0.90*	1.13
HI	Ambient	$HI=47.327^{**} - 0.105 P_1 - 0.060 P_2 + 0.017 P_3$	0.96*	0.87
	550 ppm	$HI=32.043^{**} + 0.001 P_1 - 0.019^{*} P_2$	0.88*	0.47
	700 ppm	$HI=48.780 - 0.067 P_1 + 0.238 P_2 + 0.035 P_3$	0.49	2.07

	CO_2	Summer season		
		Regression model	R^2	PE
Total biomass	Ambient	$TDW=68.497+0.182 P_1-0.143 P_2+0.184 P_3 +0.053 P_4$	0.89*	4.63
	550 ppm	$TDW=-19.027+0.218^{**} P_1+0.137^{*} P_2- 0.863^{**} P_3$	0.99**	1.93
	700 ppm	$TDW=55.028 + 0.066 P_1 + 0.127 P_2$	0.54	6.91
Seed yield	Ambient	$SY=40.186^{*} - 0.101^{*} P_1 - 0.124 P_2 + 0.044 P_3 - 0.169 P_4$	0.99**	0.42
	550 ppm	$SY=27.163^{*} - 0.002 P_1 - 0.019 P_2 + 0.054 P_3$	0.80	0.79
	700 ppm	$SY=-65.533 + 0.037 P_1 + 0.218 P_2$	0.69	3.26
HI	Ambient	$HI=50.690 - 0.163 P_1 - 0.097 P_2 - 0.003 P_3 - 0.203 P_4$	0.94*	1.82
	550 ppm	$HI=68.063^{**} - 0.078^{*} P_1 - 0.070 P_2 + 0.365^{*} P_3$	0.97*	1.18
	700 ppm	$HI=-59.644 + 0.021 P_1 + 0.198 P_2$	0.77	2.78

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level, respectively
R^2: Coefficient of determination
PE: Prediction error

From the above analysis it was observed that in summer season the biomass of leaf, root, fodder and total biomass were important at ambient control and did not respond to elevated CO_2 levels. This implied that at elevated CO_2 levels, these traits lost the importance in summer compared to winter season. Flower head weight, seed yield and HI were higher at 700 ppm, while head diameter and filled seed number were higher at 550 ppm.

In summer season, stem and fodder biomass, filled, unfilled and total seed number were important at 700 ppm since they had a significantly higher response compared to ambient control. At 700 ppm, biomass of leaf, stem, fodder and total biomass head diameter and filled seed number were significant contributors to a better response in both seasons. Though filled seed number was positive in winter and negative in summer, indicating that the improved seed yield occurred due to increased number of seeds in cool season, whereas this trait negatively responded during warm season. Similarly, unfilled seed number was significant in summer, while it did not happen in winter.

In winter HI was significantly higher at 550 ppm and ambient control and in summer at 700 ppm with positive loading while it was with significant negative loading at 550 ppm and ambient. This indicates that 550 ppm or less could be optimum in cool environments for maximum HI, whereas in warm environments, 700 ppm was beneficial. Similar results were reported by Wheeler *et al.* (1996).

CONCLUSIONS

The study revealed that the elevated CO_2 condition and seasons differed significantly in influencing different traits of sunflower. A significant interaction of CO_2 levels and seasons was also observed.

In both winter and summer seasons, total biomass was significantly higher at 700 ppm. In summer, root biomass was significant at ambient indicating that the traits lost importance at elevated CO_2 levels. During warm season though the seed set was better at 550 ppm, seed filling was affected and unfilled seed number was high at both 550 and 700 ppm as compared to ambient. HI was important at 550 ppm and ambient in winter and 700 ppm in summer. With significant positive loading of HI in summer at 700 ppm and negative at 550 ppm and ambient condition, indicating that 550 ppm or less could be beneficial in winter for maximum HI, whereas in summer it will be negative. Thus sunflower responded better to elevated CO_2 levels in winter compared to summer season with significantly higher response of traits at elevated CO_2 compared to ambient control. The identified superior traits contributed to sunflower growth in both seasons and are important for further genetic improvements under enhanced CO_2 and temperature conditions.

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