Indian Journal of Agricultural Sciences **85** (3): 321–30, March 2015/Article
https://doi.org/10.56093/ijas.v85i3.47078

Research Articles

Genotypic variation for growth and yield response at two elevated levels of CO_2 and three seasons in blackgram (*Vigna mungo*)

M VANAJA[1], G R MARUTHI SANKAR[2], M MAHESWARI[3], N JYOTHI LAKSHMI[4], S K YADAV[5], P VAGHEERA[6], S K ABDUL RAZAK[7], BABU ABRAHAM[8], G VIJAY KUMAR[9] and B VENKATESWARLU[10]

Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Andhra Pradesh 500 059

Received: 2 January 2014; Revised accepted: 17 September 2014

ABSTRACT

Eighteen blackgram [*Vigna mungo* (L) Hepper] genotypes were evaluated at three levels of CO_2 (390, 550 and 700 ppm) under Open Top Chamber (OTC) condition during summer, rainy and winter seasons to assess the interactive effect of seasons and CO_2 levels on the performance of morphological, biomass and yield traits to identify efficient genotype(s). The analysis of variance indicated significant differences among genotypes, CO_2 levels and seasons. The interaction of genotypes × CO_2 levels, genotypes × seasons and seasons × CO_2 levels were also observed significant. The study indicated that performance of the majority of traits improved with both elevated CO_2 levels of 550 ppm and 700 ppm in all three seasons; however the magnitude of response of individual traits differed with seasons. Elevated CO_2 improved the seed yield of blackgram genotypes by improving pods/plant, seed number and test weight. The improvement of the traits was significantly high in summer and rainy season as compared with winter season. Among the 18 blackgram genotypes evaluated majority of the traits including total biomass and seed yield of LBG 20 check variety and IC398971 performed best in summer over all three CO_2 levels; IC436665 in rainy season and IC398971 and IC519805 in winter. At ambient level (390 ppm) the genotype IC343947, at 550 ppm the genotype IC587751 and at 700 ppm the genotype IC436665 recorded superior performance for the majority of the traits over the seasons. The variability in response of blackgram genotypes for CO_2 levels and seasons provide a basis to identify suitable traits in developing stable performing varieties for changing climatic conditions.

Key words: Analysis of variance, Dry matter traits, Interactive effect, Morphological traits, Yield traits

Increasing atmospheric CO_2 concentration impact the growth of the crop plants, however in crop plants, a distinction has to be made between the response of biomass and economic yield. The review on the dry mass production and yield increase in response to elevated CO_2 of ten most important crop species in the world revealed that in some species, the increase in total biomass was higher, while in others, economic yield was higher (Rogers and Dahlmann 1993). The Open Top Chambers (OTCs) study with blackgram [*Vigna mungo* (L) Hepper] indicated that under increased CO_2 levels, proportioning of assimilate was greater to the roots than to the shoots in a moisture stress condition (Vanaja *et al*. 2006b).

It is well known that the elevated CO_2 would enhance crop photosynthesis. C_3 crop plants are the most responsive to elevated CO_2 levels since it would increase photosynthesis, growth and yield, but with large differences among species (Kimball *et al.* 2002). Significant intra-specific variation in response to elevated CO_2 was found in several non-crop species (Ward and Kelly 2004) and intra-specific variation in yield response to elevated CO_2 was reported in rice (Ziska *et al*. 1996, Shimono *et al*. 2009), cowpea (Ahmed *et al*. 1993), wheat (Ziska *et al*. 2004), soybean (Ziska *et al*. 2001), *Phaseolus vulgaris* (Bunce 2008) and blackgram (Jyothi Lakshmi *et al*. 2013).

Identifying a suitable blackgram genotype which would perform efficiently under different seasons and respond to elevated CO_2 condition is crucial for recommending for future changed climatic conditions. An optimum number of plant traits need to be identified which can explain maximum variability in the crop performance under different growth conditions. Since the information on these aspects is limited, we conducted experiments to assess (i) the effect of enhanced levels of CO_2 on the performance of different blackgram genotypes for morphological, dry weight and yield traits; (ii) the performance of selected traits in different seasons;

[1]Principal Scientist (Plant physiology) (e mail: mvanaja@crida.in), [2]Principal Scientist (Agricultural Statistics) (e mail: gmsankar @crida.in), [3]Head, Division of Crop Sciences (e mail: mmaheswari@crida.in), [4]Senior Scientist (Plant Physiology) (e mail: njyothi@crida.in), [5]Principal Scientist (Biochemistry) (e mail: skyadav@crida.in), [6]Research Associate (e mail: pvagheerap@yahoo.com), [7]Senior Research Fellow (e mail: razzaq.cs@gmail.com), [8]Chief Technical Officer (e mail: ubabham@gmail.com), National Bureau of Plant Genetic Resources, Regional Station, Hyderabad 500 030, [9]Senior Research Fellow (e mail: vijay.genetics@gmail.com), [10]Director (CRIDA) (vbandi_1953@yahoo.com)

and (iii) identify superior genotypes for different CO_2 levels and seasons.

MATERIALS AND METHODS

Experiments were conducted with 18 genotypes of blackgram with different biomass and yield potential (Babu Abraham *et al*. 2013) in OTCs at 3 CO_2 levels (390, 550 and 700 ppm). The performance of genotypes was assessed for different morphological, dry matter and yield traits in summer, rainy and winter seasons. The germplasm was obtained from the National Bureau of Plant Genetic Resources, Hyderabad, Regional Station. The blackgram plants were raised from seeds in plastic pots filled with 8 kg of red loamy Alfisol in OTCs from (i) 31 January to 9 May 2010 in summer season; (ii) 23 June to 16 August 2010 in rainy season; and (iii) 8 October to 15 December 2010 in winter season. The seeds were treated with rhizobium culture before sowing. Fertilizer N @ 15 kg/ha and P @ 40 kg/ha was applied as basal dose. The genotypes tested in the study were Acc. No. IC587753, IC436720, IC436519, IC343947, IC519805, IC343952, IC587752, IC587751, IC282009, IC436753, IC436610, IC436665, IC398971, IC281987, IC436652 and three checks PU 19, LBG 20 and T 9.

Six OTCs were used to maintain three concentrations of CO_2 (390, 550 and 700 ppm) and monitored continuously throughout the study as illustrated by Vanaja *et al.* (2006a). Each concentration of CO_2 was maintained in two OTCs, and the OTCs with 390 ppm CO_2 served as ambient chamber control. Three plants of each genotype were maintained in each OTC (one plant/pot) with total six plants for each genotype for each CO_2 concentration. The study was conducted in summer, rainy and winter seasons in a randomized block design with 6 replications in each season. The minimum and maximum temperatures during flowering and pod filling phenophases were 19.3°C and 36.0°C during winter season, 24.9°C and 35.36°C during rainy season, 23.2°C and 38.6°C during summer season, respectively (Table 1).

The plants were harvested at maturity and representative plant samples of 3 replicates of each treatment were randomly chosen for each genotype to determine observations on the morphological, dry matter and yield characters. The roots were separated and washed carefully to remove the soil adhere to them. Plants were separated into stem, leaves and pods. The harvested matured and dry pods were separated into seeds and husk. The harvested plant parts, viz. roots, stem, leaves and husk were dried at 60° C till constant weights were attained to determine the respective components biomass. Observations were recorded at harvest on 5 morphological traits, viz. (i) root length (RL, cm); (ii) root volume (RV, ml); (iii) shoot length (SL, cm); (iv) number of branches (NOB) and (v) number of pods (PN); 6 dry weight traits, viz. (vi) root dry weight (RDW, g/plant); (vii) stem dry weight (SDW, g/plant); (viii) leaf dry weight (LDW, g/plant); (ix) pod weight (PW, g/plant); (x) fodder dry weight (FDW, g/plant); (xi) total biomass (TBM, g/plant); and 8 yield traits, viz. (xii) filled seed number (FSN); (xiii) total seed number (TSN); (xiv) filled seed weight (FSW, g/plant); (xv) seed yield (SY, g/plant); (xvi) test weight (TW, g/plant); (xvii) husk weight (HW, g/plant); (xviii) percentage of shelling (SH, %); and (xix) harvest index (HI, %) under each CO_2 level. The total dry weight (TBM, g/plant), fodder dry weight (FDW, g/plant), harvest index (HI, %) and percentage of shelling (SH, %) were derived from the recorded observations.

Table 1 Minimum, maximum and average temperatures (°C) during different phenophases of blackgram in summer, rainy and winter seasons

Stage of the crop	Flower initiation	50% flowering	Pod initiation	Total crop duration
Rainy season				
Minimum	23.52	24.02	25.44	23.52
Maximum	39.78	34.36	33.84	39.78
Average	29.49	29.38	28.69	29.19
Winter season				
Minimum	12.15	12.15	12.15	12.15
Maximum	34.87	34.87	34.87	34.87
Average	24.87	24.87	24.92	24.64
Summer season				
Minimum	15.78	21.64	23.20	15.78
Maximum	34.50	38.57	41.05	41.05
Average	28.70	30.10	31.48	30.33

The analysis of variance (ANOVA) of different effects in each season and pooled over 3 seasons was carried out (Gomez and Gomez 1984). The pair-wise differences between seasons, CO_2 levels and genotypes were compared based on the Least Significant Difference (LSD) criteria at $P < 0.05$ and $P<0.01$ levels for each plant trait in order to identify superior genotype(s) which had a significantly better performance at different levels of CO_2 in each season and also pooled over seasons.

RESULTS AND DISCUSSION

Performance of morphological traits

Based on ANOVA, it was observed that there was a significant difference in the effects of CO_2 levels, seasons, genotypes for all the 5 morphological traits, viz. root length and volume, shoot length, number of branches and pod number at $P < 0.01$ level (Table 2). Significant interaction of CO_2 levels × seasons, and CO_2 levels × seasons × genotypes was observed for all morphological traits. However, significant difference in the effects of CO_2 levels × genotypes was recorded for root volume, shoot length, and pod number only.

The root length of genotypes was significant for CO_2 levels, genotypes and CO_2 × genotypes in winter season only. The response of root volume was significant for CO_2 levels, genotypes and CO_2 × genotypes in summer and winter season, whereas in rainy season significant for CO_2 levels only. Shoot length response varied with seasons whereas CO_2 levels was significant in summer and winter seasons, genotypes was significant in rainy and winter

Table 2 Analysis of variance of effect of CO_2 levels on the blackgram genotypes morphological traits performance in three seasons

	Root length (cm)				Root volume (ml)				Shoot length (cm)				Number of branches				Pod number/pl			
CO_2 (ppm) →	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C
Summer																				
Min	30.3	30.0	22.3	30.9	2.0	4.0	2.0	4.4	27.5	32.3	39.3	37.6	3.0	2.0	2.3	2.9	41.3	44.3	67.0	58.7
Max	42.3	51.2	42.3	40.4	6.0	11.0	11.3	8.1	49.7	56.7	60.3	48.7	7.0	3.7	3.7	4.2	76.7	84.3	103.0	77.1
μ_G	35.3	38.6	30.2	34.7	4.1	7.5	5.9	5.8	38.0	44.6	46.3	43.0	4.7	2.8	3.0	3.5	57.7	65.5	81.2	68.1
CV (%)	8.5	11.9	16.4	7.3	32.0	27.1	37.7	18.7	14.2	14.0	10.8	6.5	23.5	20.1	9.8	12.8	17.8	15.1	13.0	7.8
LSD (CO_2)	2.5				0.8				2.6				0.4				4.3			
LSD (G)	NS				1.9				NS				0.9				10.5			
LSD ($CO_2 \times G$)	NS				3.3				11.0				1.5				18.1			
Rainy																				
Min	24.8	24.7	20.5	26.5	3.3	2.9	3.7	4.2	43.3	35.2	46.1	42.0	2.7	2.3	2.0	2.6	37.7	43.7	39.2	41.0
Max	36.1	43.7	38.2	37.3	7.0	6.3	7.7	6.7	96.3	122.6	112.8	103.5	4.0	3.8	4.0	3.6	59.6	66.0	71.7	64.2
μ_G	30.5	32.6	30.2	31.1	4.8	4.5	5.4	4.9	64.4	67.5	65.6	65.8	3.3	3.0	3.0	3.1	47.2	52.8	52.4	50.8
CV (%)	10.7	15.4	16.9	8.6	21.6	19.1	21.4	12.2	20.1	27.4	23.3	22.3	12.0	13.2	18.9	9.2	12.7	13.5	18.7	11.3
LSD (CO_2)	NS				0.6				NS				0.2				3.7			
LSD (G)	NS				NS				9.6				0.5				9.0			
LSD ($CO_2 \times G$)	NS				NS				NS				0.9				NS			
Winter																				
Min	25.0	16.0	13.0	19.3	1.0	2.0	1.0	2.3	29.0	28.0	32.0	29.7	2.0	2.0	2.0	2.0	19.0	30.0	29.0	34.3
Max	35.0	44.0	44.0	41.0	6.0	12.0	11.0	8.0	82.0	96.0	104.0	94.0	4.0	4.0	5.0	4.3	51.0	54.0	59.0	50.7
μ_G	31.1	31.7	27.6	30.1	3.3	5.0	4.4	4.2	58.4	67.9	64.4	63.6	2.8	2.7	3.3	2.9	39.8	40.9	46.7	42.5
CV (%)	10.7	23.8	24.7	15.5	38.9	45.0	57.9	36.5	28.2	22.7	25.0	23.7	25.0	25.7	34.1	24.3	18.5	16.5	17.5	11.7
LSD (CO_2)	2.5				0.8				3.8				0.3				2.7			
LSD (G)	6.2				1.8				9.4				0.7				6.5			
LSD ($CO_2 \times G$)	10.7				3.1				NS				1.2				11.3			

seasons, and CO_2 × genotypes was significant in summer season only. Number of branches was significant for CO_2 levels, genotypes and CO_2 × genotypes in three seasons. Pods/plant were significant for CO_2 levels, genotypes and CO_2 × genotypes in summer and winter seasons and during rainy season it was significant for CO_2 levels and genotypes only.

Maximum values for root length was recorded in summer season at 390 ppm (42.3 cm) and 550 ppm (51.2cm) and in winter season at 700 ppm (44.0cm). The response of root length was positive with elevated CO_2 of 550 ppm during all three seasons (Table 2). Maximum values for root volume was recorded in rainy season at 390ppm (6.3 ml), in winter season at 550ppm (12.0 ml) and in summer season at 700ppm (11.3 ml). The response of root volume was positive and highly significant at both elevated CO_2 levels of 550ppm and 700ppm during winter season. The response of shoot length was maximum during rainy season at all three CO_2 levels- 390ppm (123 cm), 550ppm (113 cm) and 700ppm (104 cm). The elevated CO_2 condition either decreased or maintained the number of branches of blackgram genotypes in summer and rainy seasons and improved with 700ppm in winter season. Pods/plant is one of the important yield contributing traits and a linear increase in pod number in majority of the genotypes was observed with increase in CO_2 concentration from 390ppm to 700ppm in all the seasons and in summer season maximum values for number of pods were recorded at all CO_2 levels.

Performance of dry weight traits

Based on ANOVA, it was observed that there was a significant difference in the effects of CO_2 levels, seasons and genotypes for all the six biomass traits studied- dry biomass of root, stem, leaf, pod, fodder and total biomass at $P < 0.01$ level (Table 3). Significant interaction of CO_2 levels × seasons, seasons × genotypes and CO_2 levels × seasons × genotypes was observed for all biomass traits. However, significant interaction of CO_2 levels × genotypes was recorded for all dry weight traits except leaf dry biomass.

The root mass of genotypes was significant for CO_2 levels, and genotypes in all three seasons and the interaction of CO_2 × genotypes was significant in summer season only (Table 3). The response of stem dry biomass was significant for CO_2 levels, genotypes and CO_2 × genotypes in all three seasons, whereas leaf, pod, fodder and total biomass was significant for CO_2 levels, and genotypes in all three seasons and the interaction of CO_2 × genotypes was significant only in summer and winter seasons.

Pod weight, fodder weight and total biomass recorded a linear increase with increase in CO_2 concentration from 390ppm to 700ppm in all three seasons. The maximum values were recorded in rainy season for fodder weight and total biomass whereas pod weight in both summer and rainy seasons. It is interesting to observe that all the biomass traits recorded lowest values in winter season at all CO_2 levels. Plants grown at higher concentration of CO_2 were reported to partition more carbon to supporting structures such as stems, petioles and roots (Allen *et al*. 1991). This mechanism could be for balancing the supply and demand for carbohydrates needed by the whole plant for balanced growth (Acock and Allen 1985). Increased partitioning of biomass to roots, increased root length and volume at elevated CO_2 condition was reported in soybean (Prasad *et al*. 2005) and cotton (Reddy *et al*. 1999).

Performance of yield traits

Based on ANOVA, it was observed that there was a significant difference in the effects of CO_2 levels for the yield traits studied- filled seed number and weight, total seed number, seed yield, test weight, husk weight, and shelling % at $P < 0.01$ level (Table 4). Significant difference of seasons effects was observed for all the yield traits, whereas genotypes for all the yield traits except filled seed weight and seed yield. Significant interaction of CO_2 levels × seasons, CO_2 levels × genotypes, seasons × genotypes and CO_2 levels × seasons × genotypes was observed for all yield traits (Table 4 and 5) except shelling % which is significant for only seasons × genotypes. Several reports showed that increases in CO_2 concentration increased seed yields in soybean (Allen *et al*. 1991), dry bean (Prasad *et al*. 2002), peanut (Clifford *et al*. 1993), and cowpea (Ahmed *et al*. 1993). Higher seed yields due to elevated CO_2 have been observed in other studies (Ainsworth *et al*. 2002, Rogers *et al*. 2009) and it was mainly attributed to increases in number of pods and seeds from improved branching and greater number of pods on branches.

Among the five morphological characters, six dry weight and eight yield traits assessed for CO_2 levels, genotypes and CO_2 levels × genotypes except shoot length all other traits are non-significant for CO_2 levels × genotypes during rainy season, though number of branches, pod number per plant, all the dry weight traits, filled seed weight, seed yield/plant, test weight, and husk weight are significant individually for CO_2 levels and genotypes (Table 2, 3, 4 and 5). This could be due to the magnitude of the response of genotypes was similar and the differences were not significant during rainy season where the growth conditions are at optimum level. The values are significant during summer and winter revealing that under unfavorable condition the influence of CO_2 on the response of individual genotype is varying and significant.

Genotype differences

There was a significant difference between seasons for different plant traits, observed in genotypes (Table 6 and 7). In rainy season, there was a significantly higher stem, leaf, fodder and total biomass and shoot length at all CO_2 levels. Based on overall performance at three CO_2 levels, LBG-20 was superior for 8 traits in summer season, which include total biomass, number of branches, pod number and seed yield, while IC398971 was also superior for 8 traits which include root volume and weight, total and filled seed number and seed yield (Table 8). In rainy season, IC436665 was superior for 13 traits which include total biomass, pod

Table 3 Analysis of variance of effect of CO_2 levels on the blackgram genotypes dry weight traits performance in three seasons

	Root dry weight (g/pl)				Stem dry weight (g/pl)				Leaf dry weight (g/pl)				Pod weight (g/pl)				Fodder weight (g/pl)				Total biomass (g/pl)			
CO_2 (ppm)→	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C
Summer																								
Min	0.9	1.1	1.1	1.2	3.7	3.7	5.5	4.8	3.1	3.0	4.6	4.5	14.1	14.1	22.6	18.8	14.6	14.4	19.3	16.8	24.8	24.5	35.8	31.3
Max	2.0	2.5	2.7	2.1	6.5	7.3	9.0	7.1	8.4	9.0	9.6	7.5	27.2	28.6	31.7	25.8	24.3	26.8	29.6	24.3	44.1	47.3	52.2	42.3
μ_G	1.3	1.7	1.7	1.6	4.6	5.8	6.6	5.7	4.7	5.3	6.5	5.5	20.6	21.7	26.6	23.0	17.1	18.9	22.7	19.6	31.2	34.4	41.4	35.7
CV (%)	22.1	20.3	24.4	14.8	15.4	20.7	15.6	10.1	26.6	31.3	20.7	17.2	16.3	13.7	11.0	7.7	13.5	18.9	13.7	9.2	13.3	15.3	11.7	7.9
LSD (CO_2)	0.1				0.4				0.6				1.3				1.3				1.8			
LSD (G)	0.4				1.1				1.5				3.1				3.1				4.4			
LSD (CO_2×G)	0.6				1.9				2.6				5.4				5.3				7.6			
Rainy																								
Min	0.9	0.9	0.9	1.0	5.0	5.5	6.2	5.7	2.9	4.5	3.9	4.0	16.4	18.4	17.0	18.4	15.0	17.8	18.8	17.3	28.6	31.6	32.5	32.1
Max	1.6	1.7	1.7	1.6	9.5	13.4	14.5	11.8	9.2	13.0	13.6	11.4	24.8	26.9	30.5	26.2	25.1	35.4	37.2	32.6	41.9	52.5	58.5	51.0
μ_G	1.2	1.3	1.3	1.3	7.7	8.6	9.3	8.5	6.3	7.4	7.8	7.1	19.5	21.8	22.2	21.2	20.7	23.5	24.9	23.0	34.6	39.1	40.6	38.1
CV (%)	14.3	15.3	15.8	11.8	15.2	22.1	23.3	17.4	24.2	29.6	32.2	25.6	11.8	11.3	17.0	9.5	12.5	18.2	20.1	15.2	10.3	13.4	16.4	11.5
LSD (CO_2)	0.1				0.7				0.8				1.6				1.7				2.5			
LSD (G)	0.3				1.6				2.0				3.9				4.1				6.1			
LSD (CO_2×G)	NS				2.8				NS				NS				NS				NS			
Winter																								
Min	0.5	0.6	0.3	0.5	3.2	3.2	3.6	3.6	1.4	2.3	2.2	2.0	5.1	7.2	7.7	9.6	8.1	10.6	11.0	10.8	11.5	14.7	17.9	18.5
Max	1.5	1.6	1.4	1.3	8.5	7.7	7.0	7.5	6.0	6.8	5.7	5.8	16.0	17.7	20.1	16.9	20.0	21.5	17.8	18.3	27.2	30.9	30.7	28.4
μ_G	0.7	1.0	0.8	0.8	4.4	5.0	5.2	4.9	4.4	4.2	3.9	4.2	12.7	13.9	15.8	14.2	14.0	14.7	15.2	14.6	22.3	24.1	25.7	24.0
CV (%)	31.4	32.3	35.7	24.3	26.2	24.7	17.2	19.5	22.1	29.0	19.5	18.7	21.6	20.1	19.9	14.8	16.7	18.5	13.2	11.9	16.7	15.8	13.8	10.5
LSD (CO_2)	0.1				0.4				0.3				0.8				0.8				1.0			
LSD (G)	0.3				0.9				0.8				1.9				1.9				2.4			
LSD (CO_2×G)	NS				1.5				1.4				3.2				3.3				4.2			

Table 4 Analysis of variance of effect of CO_2 levels on the blackgram genotypes for yield traits performance in three seasons

	Total seed number				Filled seed number				Seed yield (g/pl)				Filled seed wt. (g/pl)			
CO_2 (ppm) →	390	550	700	µC	390	550	700	µC	390	550	700	µC	390	550	700	µC
Summer																
Min	200	174	372	281	175	166	305	252	9.4	10.1	15.6	12.8	8.9	9.9	14.4	12.1
Max	442	457	514	409	442	450	511	403	19.8	20.6	22.5	18.7	19.8	20.4	22.4	18.6
µG	296	334	427	352	287	326	405	340	14.0	15.5	18.7	16.1	13.8	15.3	18.2	15.8
CV (%)	21	18	11	9	23	19	15	11	18.5	14.3	11.8	9.4	19.5	15.0	13.9	10.3
LSD (CO_2)	21				22				0.95				1.01			
LSD (G)	52				55				2.33				2.48			
LSD (CO_2 ×)G	91				95				4.04				4.30			
Rainy																
Min	234	266	247	264	234	254	247	256	11.8	13.2	12.4	13.4	11.7	13.1	12.4	13.3
Max	381	426	451	383	377	421	451	371	17.3	19.1	21.3	18.4	17.2	19.1	21.1	17.9
µG	298	327	321	316	294	319	319	311	13.9	15.6	15.7	15.1	13.8	15.5	15.7	15.0
CV (%)	15	13	18	12	14	13	18	12	11.2	10.7	16.3	9.0	11.3	10.6	16.2	8.7
LSD (CO_2)	NS				NS				1.1				1.1			
LSD (G)	62				61				2.7				2.7			
LSD (CO_2 ×)G	NS				NS				NS				NS			
Winter																
Min	91	108	103	123	67	76	103	111	3.4	4.2	5.2	6.6	3.2	3.5	5.2	6.3
Max	232	270	271	248	206	243	247	223	11.0	12.4	13.3	11.6	10.5	12.2	13.2	11.5
µG	187	200	217	201	156	179	204	180	8.3	9.4	10.5	9.4	7.9	9.1	10.4	9.1
CV (%)	23	23	20	19	23	26	19	19	24.4	21.5	20.0	16.1	25.2	23.0	20.1	16.5
LSD (CO_2)	14				13				0.56				0.58			
LSD (G)	35				32				1.39				1.44			
LSD (CO_2 ×)G	61				55				2.41				2.49			

Table 5 Analysis of variance of effect of CO_2 levels on the blackgram genotypes for yield traits performance in three seasons

	Test wt. (g)				Husk wt. (g/pl)				Shelling (%)				HI (%)			
CO_2 (ppm) →	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C	390	550	700	μ_C
Summer																
Min	4.0	4.1	4.0	4.2	4.7	4.1	6.8	5.9	55.0	67.0	66.6	65.3	33.8	39.6	38.2	39.8
Max	5.7	6.4	4.7	5.0	10.4	8.0	9.6	7.6	72.8	74.2	72.5	72.6	51.2	50.4	48.7	48.4
μ_G	4.8	4.7	4.4	4.6	6.5	6.2	7.9	6.9	68.1	71.4	70.2	69.9	45.0	45.4	45.2	45.2
CV (%)	7.5	10.8	4.8	4.2	19.4	14.5	10.6	6.7	5.9	2.6	2.0	2.6	10.5	8.4	5.8	5.4
LSD (CO_2)	0.2				0.46				1.3				NS			
LSD (G)	NS				NS				3.2				4.8			
LSD (CO_2 × G)	0.8				1.97				5.6				NS			
Rainy																
Min	4.0	4.2	4.5	4.3	4.5	5.0	4.7	5.0	68.2	69.5	68.4	68.9	34.1	32.9	31.4	34.4
Max	5.4	6.1	6.0	5.4	7.5	7.8	9.3	7.8	73.2	74.5	75.2	73.0	47.9	46.1	47.0	46.9
μ_G	4.7	4.9	5.0	4.9	5.6	6.2	6.5	6.1	71.4	71.7	71.2	71.4	40.3	40.4	39.2	40.0
CV (%)	8.7	9.0	7.3	5.5	14.6	13.7	20.4	11.6	2.0	1.8	2.2	1.6	7.7	9.4	10.9	7.8
LSD (CO_2)	0.2				0.5				NS				NS			
LSD (G)	0.5				1.3				1.9				3.7			
LSD (CO_2 × G)	NS				NS				NS				NS			
Winter																
Min	3.5	4.0	3.9	3.9	1.7	2.2	2.5	3.1	55.7	58.3	56.4	59.4	26.4	28.8	26.5	28.0
Max	5.6	6.5	6.0	5.7	5.4	5.5	6.8	5.6	68.7	77.1	75.7	70.2	42.8	46.9	45.2	43.7
μ_G	4.5	4.8	4.9	4.7	4.4	4.5	5.3	4.8	64.8	67.5	66.3	66.2	36.8	39.1	40.5	38.8
CV (%)	11.4	15.1	12.4	10.4	18.9	20.0	23.2	14.0	5.8	5.6	5.8	3.6	14.0	14.7	12.2	11.3
LSD (CO_2)	0.3				0.53				NS				2.1			
LSD (G)	0.7				1.29				NS				5.1			
LSD (CO_2 × G)	NS				2.24				NS				NS			

Table 6 LSD comparison of effect CO_2 levels on plant traits in different seasons

Seasons	Summer			Rainy			Winter		
CO_2 (ppm) →	390	550	700	390	550	700	390	550	700
Morphological traits									
RL	35.3 b	38.6 a	30.2 c	30.5 a	32.6 a	30.2 a	31.1 a	31.7 a	27.6 b
RV	4.1 c	7.5 a	5.9 b	4.8 b	4.5 b	5.4 a	3.3 b	5.0 a	4.4 a
SL	38.0 b	44.6 a	46.3 a	64.4 a	67.5 a	65.6 a	58.4 b	67.9 a	64.4 a
NOB	4.7 a	2.8 b	3.0 b	3.3 a	3.0 b	3.0 b	2.8 b	2.7 b	3.3 a
PN	57.7 c	65.5 b	81.2 a	47.2 a	52.8 a	52.4 a	39.8 b	40.9 b	46.7 a
Dry weight traits									
RDW	1.3 b	1.7 a	1.7 a	1.2 b	1.3 a	1.3 a	0.7 b	1.0 a	0.8 b
SDW	4.6 c	5.8 b	6.6 a	7.7 b	8.6 a	9.3 a	4.4 b	5.0 a	5.2 a
LDW	4.7 c	5.3 b	6.5 a	6.3 b	7.4 a	7.8 a	4.4 a	4.2 ab	3.9 b
PW	20.6 b	21.7 b	26.6 a	19.5 b	21.8 a	22.2 a	12.7 c	13.9 b	15.8 a
FDW	17.1 c	18.9 b	22.7 a	20.7 b	23.5 a	24.9 a	14.0 b	14.7 ab	15.2 a
TBM	31.2 c	34.4 b	41.4 a	34.6 b	39.1 a	40.6 a	22.3 c	24.1 b	25.7 a
Yield traits									
TSN	296.3 c	334.4 b	426.7 a	297.9 a	327.3 a	321.5 a	187.1b	200.1b	216.5 a
FSN	287.5 c	326.1 b	405.1 a	293.7 b	319.5 a	319.0 a	155.7c	179.3b	203.5 a
SY	14.0 c	15.5 b	18.7 a	13.9 b	15.6 a	15.7 a	8.2 c	9.4 b	10.5 a
FSW	13.8 b	15.3 b	18.2 a	13.8 b	15.5 a	15.7 a	7.8 c	9.1 b	10.4 a
TW	4.8 a	4.7 a	4.4 b	4.7 a	4.9 a	5.0 a	4.5 b	4.8 a	4.9 a
HW	6.5 b	6.2 b	7.9 a	5.6 b	6.2 a	6.5 a	4.4 b	4.5 b	5.3 a
SH	68.1 b	71.4 a	70.2 a	71.4 a	71.7 a	71.2 a	64.8 a	67.5 a	66.3 a
HI	44.9 a	45.4 a	45.2 a	40.3 a	40.4 a	39.2 a	36.8 b	39.1 a	40.5 a

Note: Within a season, traits with same letter (a, b or c) are at par with each other between CO_2 levels

Table 7 LSD comparison of effects of seasons on plant traits at different CO_2 levels

CO_2 (ppm) →	390			550			700		
Season	Summer	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter
Morphological traits									
RL	35.3 a	30.5 b	31.1 b	38.6 a	32.6 b	31.7 b	30.2 a	30.2 a	27.6 b
RV	4.1 a	4.8 a	3.3 b	7.5 a	4.5 b	5.0 b	5.9 a	5.4 a	4.4 b
SL	38.0 c	64.4 a	58.4 b	44.6 b	67.5 a	67.9 a	46.3 b	65.6 a	64.4 a
NOB	4.7 a	3.3 b	2.8 c	2.8 a	3.0 a	2.7 a	3.0 a	3.0 a	3.3 a
PN	57.7 a	47.2 b	39.8 c	65.5 a	52.8b	40.9 c	81.2 a	52.4b	46.7c
Dry weight traits									
RDW	1.3a	1.2a	0.7 b	1.7 a	1.3 b	1.0 c	1.7 a	1.3 b	0.8 c
SDW	4.6b	7.7a	4.4b	5.8 b	8.6 a	5.0 c	6.6 b	9.3 a	5.2 c
LDW	4.7b	6.3 a	4.4 b	5.3 b	7.4 a	4.2 c	6.5 b	7.8 a	3.9 c
PW	20.6a	19.5a	12.7 b	21.7 a	21.8a	13.9b	26.6 a	22.2b	15.8c
FDW	17.1b	20.7a	14.0 c	18.9b	23.5a	14.7c	22.7 b	24.9a	15.2c
TBM	31.2b	34.6a	22.3 c	34.4 b	39.1 a	24.1 c	41.4 a	40.6 a	25.7 b
Yield traits									
TSN	296a	298a	187b	334a	327a	200b	427a	322b	217c
FSN	288a	294a	156b	326 a	320 a	179b	405 a	319 b	204 c
SY	14.0a	13.9a	8.2 b	15.5 a	15.6 a	9.4 b	18.7 a	15.7 b	10.5 c
FSW	13.8a	13.8a	7.8 b	15.3a	15.5a	9.1 b	18.2a	15.7 b	10.4c
TW	4.8 a	4.7 ab	4.5 b	4.7 a	4.9 a	4.8 a	4.4 b	5.0 a	4.9 a
HW	6.5 a	5.6 a	4.4 c	6.2 a	6.2 a	4.5 b	7.9 a	6.5 b	5.3 c
SH	68.1a	71.4a	64.8 a	71.4 a	71.7 a	67.5 a	70.2 a	71.2 a	66.3 a
HI	44.9a	40.3b	36.8 c	45.4 a	40.4 b	39.1 c	45.2 a	39.2 b	40.5 b

Note: Within a CO_2 level, traits with same letter (a, b or c) are at par with each other between seasons

Table 8 Blackgram genotypes with superior performance in each season and CO_2 levels for the morphological, dry weight and yield traits

Seasons	Summer				Rainy				Winter				Over seasons		
CO_2 (ppm) →	390	550	700	Over	390	550	700	Over	390	550	700	Over	390	550	700
Morphological traits															
Root length (cm/pl.)	IC398971	IC343952	PU-19	PU-19	IC436610	T-9	IC436720	IC587751	IC519805, T-9	T-9	T-9	T-9	IC398971	T-9	T-9
Root volume (ml)	IC398971	IC436519	IC398971	IC398971	IC398971	IC436665	IC282009	IC398971	T-9	LBG-20	IC398971	IC398971, LBG-20	IC398971	LBG-20	IC398971
Shoot length (cm/pl.)	IC398971	IC587751	IC398971	IC398971	IC436665	IC436665	IC398971	IC436665	IC398971	IC398971	IC398971	IC398971	IC398971	IC436665	IC398971
Number of branches	T-9	IC436753	IC436652	LBG-20	IC436753	PU-19	IC436652	IC436753	IC398971, LBG-20, T-9	LBG-20, T-9	IC343952, LBG-20, T-9	LBG-20, T-9	T-9	LBG-20	IC343952
Pod number	IC398971	LBG-20	IC587753	LBG-20	IC436665	IC587751	IC436665	IC436665	IC436610	T-9	IC343952	IC436610	IC436610	T-9	IC587753
Dry weight traits															
Root dry weight (g/pl)	IC398971	LBG-20	IC398971	IC398971	IC436665	IC436665	LBG-20	IC436665	IC587752	IC282009	LBG-20	IC398971	IC398971	LBG-20	IC398971
Stem dry weight (g/pl)	IC398971	LBG-20	IC398971	LBG-20	IC436610	IC436665	IC398971	IC436665	IC398971	IC282009	LBG-20	IC398971	IC398971	PU-19	IC398971
Leaf dry weight (g/pl)	IC398971	LBG-20	IC398971	LBG-20	IC398971	IC436665	IC436665	IC436665	IC398971	IC282009	IC519805	IC282009	IC398971	LBG-20	IC398971
Pod dry weight (g/pl)	IC398971	LBG-20	LBG-20	IC398971	IC519805	IC587751	IC436665	IC436665	IC436519	IC519805	IC436720	IC519805	IC519805	IC587752	IC436665
Fodder dry weight (g/pl)	IC398971	LBG-20	LBG-20	LBG-20	IC436665	IC436665	IC436665	IC436665	IC398971	IC282009	LBG-20	IC282009	IC398971	LBG-20	IC398971
Total biomass (g/pl)	IC398971	LBG-20	LBG-20	LBG-20	IC436665	IC436665	IC436665	IC436665	IC398971	IC282009	IC282009	IC282009	IC398971	LBG-20	IC436665
Yield traits															
Total seed number	IC398971	LBG-20	IC587753	IC398971	IC436665	IC587751	IC282009	IC436665	IC343947	IC587752	IC343952	IC587752	IC343947	T-9	IC282009
Filled seed number	IC398971	LBG-20	IC587753	IC398971	IC436665	IC587751	IC282009	IC436665	IC343952	IC587752	IC343952	IC587752	IC343947	T-9	IC436610
Seed yield (g/pl)	IC398971	LBG-20	LBG-20	IC398971	IC519805	IC587751	IC436665	IC436665	IC436519	IC519805	IC436720	IC519805	IC519805	IC587752	IC436665
Filled seed weight (g/pl)	IC398971	LBG-20	LBG-20	IC398971	IC519805	IC587751	IC436665	IC436665	IC436652	IC519805	IC436720	IC519805	IC519805	IC587751	IC436665
Test weight (g/pl)	PU-19	IC436720	IC519805	IC436720	IC436652	LBG-20	IC436652	IC436652	IC519805	IC398971	IC519805	IC519805	IC436519	IC398971	IC519805
Husk weight (g/pl)	IC436720	LBG-20	IC587753	LBG-20	IC519805	IC587751	IC282009	IC436665	IC587752	IC282009	IC436720	IC587752	IC343952	IC587752	IC282009
Shelling (%)	IC398971	IC343952	IC398971	IC398971	IC436720	IC436519	IC436610	IC436519	IC436519	IC398971	IC587751	IC587751	IC5877534	IC398971	IC587751
Harvest Index (%)	IC436610	IC436665	IC343952	IC343952	T-9	IC587753	T-9	T-9	IC343947	IC519805	IC587753	IC436720	IC343947	T-9	IC343947
Over-all				LBG-20, IC398971				IC436665				IC398971, IC519805	IC343947	IC587751	IC436665

number and weight, total and filled seed number and seed yield; while IC398971 was superior for 2 root traits of root biomass and volume. In winter season, IC398971 was superior based on overall performance at three CO_2 levels while IC519805 was superior for yield traits.

During summer season genotypes showed variability among different parameters with CO_2 concentrations. At 390ppm, genotype IC398971 showed superiority for 15 traits out of 19 traits studied which include all dry weight traits, all morphological traits except number of branches and yield traits of filled and total seed number, seed yield and shelling (%); elevated CO_2 concentration (550ppm) leads to variability in the level of different plant parameters among genotypes. Genotype LBG 20 showed better performance at 550ppm for 13 traits includes all dry weight traits, pod number and yield traits of filled and total seed number, filled seed weight and seed yield. The CO_2 concentration of 700ppm led to highest value for pod, fodder and total biomass, filled seed weight and seed yield in LBG 20. The experiments with cotton at ambient and elevated CO_2 (720 ppm) and their interaction with temperature ranging 2°C below and 7°C above ambient air temperature revealed that the number of bolls in cotton increased by 40% with elevated CO_2 irrespective of temperatures (Reddy *et al*. 1999).

In rainy season, IC436665 showed superiority at 390 ppm for 7 traits include root, fodder and total biomass, pod number, total and filled seed number; IC519805 for pod weight, filled seed weight, husk weight and seed yield. At 550ppm, IC436665 recorded highest values for both morphological traits such as root volume and shoot length; all dry weight traits except pod weight but none of the yield traits. IC587751 showed improved performance for majority of the yield traits such as pod number and weight, total and filled seed number, filled seed weight, husk weight and seed yield. The CO_2 concentration of 700ppm led to highest value for majority of morphological and dry weight traits of IC436665 along with seed yield and filled seed weight. Based on overall performance at three CO_2 levels in rainy season, IC436665 was superior for 13 traits which include all dry weight traits, pod number and majority of the yield traits including seed yield. Cultivars within the same crop species are reported to differ in their responses to enhanced CO_2 concentration and temperature and their interactions. Ziska *et al*. (2001) tested nine soybean cultivars differing in determinacy, maturity group and morphology in response to elevated CO_2. They reported that Mandarin, an ancestral indeterminate cultivar, showed a greater relative response of seed yield to elevated CO_2 due to a greater pod weight per plant and seed weight from branches.

In winter season, at 390ppm genotype IC398971 showed superiority for shoot length, leaf, stem, fodder and total biomass and IC436519 for pod weight and seed yield. At elevated CO_2 concentration (550ppm) the genotype IC282009 showed better performance for majority of the dry weight traits, IC519805 for pod weight, filled seed weight, seed yield and HI. The CO_2 concentration of 700ppm led to highest value for root, stem, fodder biomass and number of branches in LBG-20 and pod weight, filled seed weight and seed yield in IC436720, IC398971 was superior based on overall performance at three CO_2 levels in winter season, while IC519805 was superior for yield traits.

CONCLUSION

Based on the overall performance across the seasons, the genotype IC343947 at 390ppm, IC587751 at 550ppm and IC436665 at 700ppm had higher values for majority of the traits. Similarly when assessed across the CO_2 levels LBG 20 check variety and IC398971 in summer, IC436665 in rainy and IC398971 and IC519805 in winter showed best performance for majority of the traits. The response of root traits such as root volume and root mass to elevated CO_2 was significantly high with the genotype IC398971 in all seasons. The response change in total biomass and seed yield of high yielding and stable genotype IC519805 at elevated CO_2 levels was very small and it maintained comparable values at all the CO_2 levels.

Majority of the traits of the selected blackgram genotypes recorded significant improved performance at elevated CO_2 levels. Elevated CO_2 significantly improved the total biomass, seed yield of the blackgram genotypes in all the seasons as compared with ambient condition. The seasons influenced the response to elevated CO_2 levels and the lowest performance was recorded in winter season. The improvement in seed yield of blackgram genotypes due to elevated CO_2 was contributed by improvement in pod number, seed number and test weight. The source limited low yielding genotypes recorded better response to elevated CO_2.

ACKNOWLEDGEMENT

The present work was carried out under ICAR Network project on Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change and we acknowledge the funding.

REFERENCES

Acock B and Allen L H Jr. 1985. Crop responses to elevated carbon dioxide concentration. (In) *Direct Effects of Increasing Carbon Dioxide on Vegetation*, pp 53-97. Strain B R and Cure J D (Eds). DOE/ER-0238, U S Department of Energy, Carbon Dioxide Research Division, Washington, DC.

Ahmed F E, Hall A E and Madore M A. 1993. Interactive effects of high temperature and elevated carbon dioxide concentration on cowpea (*Vigna unguiculata* (L.) Walp.). *Plant Cell and Environment* **16**: 835–42.

Ainsworth E A, Davey P A, Bernacchi C J, Dermody O C, Heaton E A, Moore D J, Morgan P B, Naidu S L, Yoo Ra H, Zhu X, Curtis P S and Long S P. 2002. A meta-analysis of elevated [CO_2] effects on soybean (*Glycine max*) physiology, growth and yield. *Global Change Biology* **8**: 695–709.

Allen L H Jr, Bisbal E C, Boote K J and Jones P H. 1991. Soybean dry matter allocation under subambient and superambient levels of carbon dioxide. *Agronomy Journal* **83**: 875–83.

Babu Abraham, Vanaja M, Raghu Ram Reddy P, Sivaraj N, Sunil N, Kamala V and Varaprasad K S. 2013. Identification of stable and high yielding genotypes in blackgram (*Vigna mungo* (L.) Hepper) germplasm. *Indian Journal of Genetics and Plant Breeding* **73**(3): 264–9.

Bunce J A. 2008. Contrasting responses of seed yield to elevated carbon dioxide under field conditions within *Phaseolus vulgaris*. *Agriculture Ecosystems and Environment* **128**: 219–24.

Clifford S C, Stronach I M, Mohamed A D, Azamali S N and Crout N M J. 1993. The effects of elevated atmospheric carbon dioxide and water stress on light interception, dry matter production and yield in stands of groundnut (*Arachis hypogaea* L.). *Journal of Experimental Botany* **44**:1 763–70.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. John Wiley Inc., New York.

Jyothi Lakshmi N, Vanaja M, Yadav S K, Maheswari M, Vagheera P and Venkateswarlu B. 2013. Genotypic variation in growth and yield of blackgram (*Vigna mungo*) genotypes in response to increased carbon dioxide concentration. *Indian Journal of Agricultural Sciences* **83** (2): 184–8.

Kimball B A, Kobayashi K and Bindi M. 2002. Responses of agricultural crops to free air CO_2 enrichment. *Advances in Agronomy* **77**: 293–368.

Mishra R. C. (1986): Genetic divergence in greengram *(Vigna radiata* (L.) Wilczek). *Gujarat Agricultural University of Research Journal* **12**: 56–8.

Prasad P V V, Allen Jr. L H and Boote K J. 2005. Crop responses to elevated carbon dioxide and interaction with temperature: Grain legumes. *Journal of Crop Improvement* **13**(1):113–55.

Prasad P V V, Boote K J, Allen L H and Thomas J M G. 2002. Effects of elevated temperature and carbon dioxide on seed-set and yield of kidney bean (*Phaseolus vulgaris* L.). *Global Change Biology* **8**: 710–21.

Reddy K K, Davidonis G H, Johnson A S and Vinyard B T. 1999. Temperature regime and carbon dioxide enrichment alter cotton boll development and fiber properties. *Agronomy Journal* **91**: 851–8.

Rogers A, Ainsworth E A and Leakey A D B. 2009. Will elevated carbon dioxide concentration amplify the benefits of nitrogen fixation in legumes? *Plant Physiology* **151**: 1 009–16.

Rogers H H and Dahlamann R C. 1993. Crop responses to CO_2 enrichment. (In): *CO_2 and Biosphere* pp 117–32. Rozema J, Lambers H, Van De Geiji S C and Cambridge M L. (Eds). Kluwer Acad. Publ., Dortrecht, Netherlands.

Shimono H, Okada M, Yamakawa Y, Nakamura H, Kobayashi K and Hasegawa T. 2009. Genotypic variation in rice yield enhancement by elevated CO_2 relates to growth before heading, and not to maturity group. *Journal of Experimental Botany* **60** (2): 523–32.

Vanaja M, Maheswari M, Ratna Kumar P and Ramakrishna Y S. 2006a. Monitoring and controlling of CO_2 concentration in open top chambers for better understanding of plants response to elevated CO_2 levels. *Indian Journal of Radio and Space Physics* **35**: 193–7.

Vanaja M, Ratna Kumar P, Vagheera P, Jyothi M, Raghuram Reddy P, Jyothi Lakshmi N, Maheshwari M and Yadav S K. 2006b. Initial growth responses of blackgram (*Vigna mungo* L. Hepper) under elevated CO_2 and moisture stress. *Plant Soil and Environment* **52** (11): 499–504.

Ward J K and Kelly J K. 2004. Scaling up evolutionary responses to elevated CO_2: lessons from *Arabidopsis*. *Ecology Letters* **7**: 427–40.

Ziska L H, Bunce J A and Caulfield F A. 2001. Rising atmospheric carbon dioxide and seed yield of soybean genotypes. *Crop Science* **41**: 385–91.

Ziska L H, Manalo P A and Ordonez R A. 1996. Intraspecific variation in the response of rice (*Oryza sativa* L) to increased CO_2 and temperature: growth and yield response of 17 cultivars. *Journal of Experimental Botany* **47**: 1 353–9.

Ziska L H, Morris C F and Goins E W. 2004. Quantitative and qualitative evaluation of selected wheat varieties released since 1903 to increasing atmospheric carbon dioxide: can yield sensitivity to carbon dioxide be a factor in wheat performance. *Global Change Biology* **10**: 1 810–8.