



Genotypic variation in growth and yield of blackgram (*Vigna mungo*) genotypes in response to increased carbon dioxide concentration

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ABSTRACT

A study was conducted with 13 genotypes of blackgram (*Vigna mungo* L. Hepper) under two levels of CO₂, viz elevated (550 ppm) and ambient (370 ppm) in open top chambers (OTCs) to assess the variability in crop yield responses to elevated CO₂. The results revealed an increase in plant height, number of branches, leaf area, total dry weight, pod number, pod weight and seed yield under enhanced CO₂ conditions as compared to ambient CO₂ condition. Total dry weight and pod weight per plant were the most important yield contributing attributes in both conditions. There was a significant variety × CO₂ interaction for seed yield, ranging from 7.95% to 65.4% higher than at ambient CO₂. The percentage increase in seed yield with elevated CO₂ conditions was highest in T 9 (65.4%) followed by WBG 26 (60.3%), which are early varieties. The high-yielding variety LBG 645 (4.35g/plant) at ambient CO₂ also responded to elevated CO₂ (5.35 g/plant), with an increase of only 23%. Though the early variety (T 9) showed low yield as compared to long duration varieties as recorded in the ambient CO₂ conditions, it is very pertinent as well as interesting here to note that these early varieties have recorded higher percentage of increase over control as compared to long duration varieties. This shows that the adaptability for change in climatic conditions especially with reference to higher CO₂ levels was highest in the short duration variety as compared to late varieties indicating that a case to case study is essential for identifying the adaptable varieties to changing environment depending upon the candidature crop.

Key words: Blackgram, Elevated carbon dioxide, Genotypes, Open-top chambers, Yield

The atmospheric CO₂ concentration has been rising due to human activities since the Industrial Revolution, and is projected to double before the end of this century (IPCC, 2007). The increase in CO₂ was about 64 ppm (Krull *et al.* 2005) during the last fifty years (1953 to 2003). Current models suggest that CO₂ will increase to 550 ppm by year 2050 and exceed 700 ppm by 2100 from the present ambient levels of 350 ppm (Krull *et al.* 2005). The rising concentration of CO₂ in the atmosphere represents an increase in a growth limiting resource for C₃ crop species. Increase in atmospheric CO₂ increases the quantum of yield produced photosynthetically, net photosynthesis, biomass production and ultimate output. Elevated CO₂ increases photosynthesis, growth and yield of C₃ crop plants, but with large differences among species in the magnitude of the yield stimulation

(Kimball *et al.* 2002). With impending global change and the need to secure food supplies for the future, several CO₂ enrichment experiments have concentrated on agricultural crops, with yield serving as an important economic parameter.

The pulse crops showed better response to elevated CO₂ levels compared to cereals and oil seeds (Vanaja *et al.* 2006 b). The positive response of pulse crops like cowpea (Mbikayi *et al.* 1983) and mung bean (Srivastava *et al.* 2001) urd bean, (Vanaja *et al.* 2007) to elevated CO₂ condition was reported in terms of biomass, leaf area and seed yield. Intraspecific variation in yield response to elevated CO₂ has been found in rice (Ziska *et al.* 1996, Moya *et al.* 1998, and Baker, 2003), wheat (Manderscheid and Weigel, 1997 and Ziska *et al.* 2004) and soybean (Ziska and Bunce 2000 and Ziska *et al.* 2001). Identification of lines or the characteristics of lines which have superior yield at elevated CO₂ in the field could aid in adaptation of crops to this global change by facilitating the development of varieties better able to exploit the increase in atmospheric CO₂. Since blackgram (*Vigna mungo* L. Hepper) is an important short duration pulse crop, an attempt was made to assess the variability in 13 genotypes of

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blackgram for seed yield to elevated CO₂ (550 ppm) in field plots of open top chambers (OTCs).

MATERIALS AND METHODS

Seeds from thirteen genotypes of black gram with different maturity groups were sown in open top chambers (OTCs) of 3 m × 3 m × 3 m diameter lined with transparent PVC sheet. The duration of crop was 70-75 days for T 9, WBG 26, and LBG 20, 75-80 days for LBG 623, LBG 708, LBG 709 and LBG 752, 80-85 days for LBG 17, LBG 645 and LBG 685 and 90-95 days for LBG 611, LBG 402, LBG 648.

The seeds were sown directly in the soil (alfisol) to study the effect of elevated CO₂ level (550 ppm) on growth, biomass and yield. Each genotype was grown in one row of 1.2-meter lengths with plant-to-plant and row-to-row spacing of 10 and 30cm. Each chamber had two 1.2 m × 3 m plots with 8 rows of crop and 12 plants in each row were maintained. Two border rows were planted on both the sides in each plot. The seed material was obtained from Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh. Recommended dose of fertilizer was used and standard agronomic practices were adopted. None of the varieties had disease or pest problem. The crop was sown in the first week of October 2008 and each variety was harvested depending on the duration.

Two OTCs were maintained at 550 ppm to have the elevated levels of CO₂ at crop canopy level by continuously injecting 100% CO₂ into plenum where it was mixed with ambient air from compressor before entering into the chamber. Other two OTCs were maintained at ambient CO₂ level (370 ppm) without any external CO₂ supply and served as control chamber. The air sample from each chamber was drawn from the center point of OTC at 3 minutes interval into non-dispersive infrared (NDIR) CO₂ analyzer (California Analytical) and the set ppm of CO₂ conc. (550 ± 25 ppm) was maintained with the help of solenoid valves, roto meters, PCs, program Logic Control (PLC) and supervisory control and Data Acquisition (SCADA) software. Throughout the experiment period, continuous measurement of relative humidity and temperature of all the OTC were possible with the sensors fitted inside the chambers (Vanaja *et al.* 2006 a). The temperature of chambers with elevated levels of CO₂ remained nearly the same as in the control chambers that were maintained at ambient CO₂ levels. The light intensity in chambers was 80-95 % of the outside field. The elevated levels of CO₂ was maintained 24 hr a day from sowing to final harvest.

Leaf area was recorded at 45 DAS. For each genotype two plants were sampled from each chamber. Leaf area was measured by using leaf area meter (LI-3100, LI-COR) and expressed as cm²/plant. At maturity, five plants of each genotype (from each chamber) grown under ambient and elevated CO₂ were used to determine above ground dry

matter accumulation and seed yield. Dry weights were recorded after keeping the plant parts at 80° C for 48 hours in hot air oven. Plant height and number of branches were recorded. Number of pods counted, pod weight and seed weight were recorded and expressed as g/plant. Harvest index was computed as the proportion of seed yield to total above ground dry weight.

RESULTS AND DISCUSSION

Elevated CO₂ significantly increased the leaf area and number of branches/plant of all the varieties at flowering (45 DAS). At this stage the leaf area was highest in the long duration cultivar LBG 648 recording a leaf area of 764.7 cm²/plant under ambient conditions and 1 019 cm²/plant under elevated CO₂ conditions followed by LBG 645 with 722 and 991.0 cm²/plant conditions respectively (Table 1). The percentage increases in leaf area over ambient varied from 10% (LBG 752) to 79% (T 9) in different cultivars. Similar reports with *Vigna radiata* L. (Srivastava *et al.* 2001) and *Vigna mungo* L. (Vanaja *et al.* 2007) also showed an increase in leaf area and total biomass under elevated CO₂ conditions.

The number of branches/plant was increased by elevated CO₂ for all cultivars by 4-52.8% (Table 1). The magnitude differed between cultivars. Highest increase with CO₂ enrichment was in LBG 611 with 11.6 branches (73%) followed by LBG 709 (52.8%).

At maturity, elevated CO₂ significantly increased biomass (by 5.64 to 39.21%), and there was a significant CO₂ × variety interaction (Table 2). The magnitude of the biomass difference caused by elevated CO₂ was greater for the early cultivars T 9 (39.21 %) followed by WBG 26 (30.69%). Though the highest dry matter was produced by long duration varieties LBG 648 (18.30 g/plant) and LBG 645 (17.5 g/plant) under elevated CO₂, the percent increase was 32.09 for LBG 648 and 16.6% for LBG 645 when compared with ambient grown plants.

The yield parameters, viz number of pods, pod weight, seed weight/plant were significantly greater under elevated CO₂ and the major contributor to the increased grain yield (Table 2). The hundred seed weight differed among the varieties and elevated CO₂ significantly increased the mass per seed. The results are in accordance with Ziska and Bunce (2000) who reported that increase in pod number at elevated CO₂ was also the primary cause of increased seed yield in soybean. Bunce (2008) reported significant variation in the response of seed yield to elevated CO₂ does exist among four varieties of *Phaseolus vulgaris* and that variation in the response of pod and seed number may be more important than variation in photosynthetic response.

Seed yield was significantly increased by elevated CO₂ but the percentage of increase varied among the 13 genotypes (Table 2). The CO₂ × variety interaction was significant. LBG 645 (4.35g/plant), LBG 623 (3.9 g/plant) and LBG 402

Table 1 Leaf area, number of branches, plant height and pod number in blackgram genotypes grown under ambient and elevated CO₂ conditions

Genotypes	Duration of crop (days)	Leaf area at 45 DAS (cm ² /plant)			No. of branches /plant			Plant height at harvest			Pods/plant		
		Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control
T 9	70-75	395	707	79.0	7.3	9	23.3	34.2	50.7	48.2	14.8	19.0	28.6
WBG 26		493	816	65.4	7.3	9.6	31.5	34.0	51.7	52.1	18.3	23.0	25.3
LBG 20		486	733	50.7	5.3	7.3	37.7	27.3	54.0	97.8	20.5	22.1	7.9
LBG 623	75-80	559	646	15.5	6.8	9.6	41.2	42.7	58.7	37.5	23.4	24.1	3.3
LBG 708		716	890	24.3	8.0	10.0	25.0	63.3	111.0	74.9	23.2	26.7	15.3
LBG 709		613	855	39.5	7.0	10.7	52.8	47.7	79.3	66.2	25.0	27.7	10.6
LBG 752		631	694	10.0	7.6	8.6	13.2	63.5	80.0	26.0	20.4	22.2	8.8
LBG 17	80-85	470	769	63.6	7.3	7.6	4.1	33.0	48.0	25.4	18.5	21.1	14.5
LBG 645		722	991	37.2	7.0	9.3	32.8	83.3	97.0	16.4	24.4	28.1	15.2
LBG 685		696	855	22.9	8.6	9.0	4.6	79.0	108.0	36.3	23.4	25.1	7.4
LBG 611	90	569	984	72.9	6.7	11.6	73.1	58.0	98.3	69.5	25.0	27.7	10.8
LBG 402	90-95	523	867	65.7	5.7	8	40.3	62.2	73.0	17.4	23.9	25.0	4.8
LBG 648	90-95	765	1019	33.2	8.6	11	27.9	95.0	110.0	15.8	28.0	34.0	26.4
Average		587.5	833		7.2	9.33		55.6	78.4		22.2	25.0	
CD (0.05)													
CO ₂		14.28			0.438			2.41			1.305		
Varieties		36.41			1.116			6.146			3.328		
CO ₂ × Var		51.49			1.579			8.69			NS		

(3.95 g/plant) yielded the highest at ambient CO₂, but at elevated CO₂, LBG 645 (5.35g/plant) yielded the highest followed by LBG 648 (5.03 g/plant), WBG 26 (4.73 g/plant), LBG 709 (4.7 g/plant), and LBG 20 (4.52 g/plant). The percentage increase in seed yield with elevated CO₂ conditions was highest in T 9 (65.4%) followed by WBG 26 (60.3%), which are early cultivars, and the lowest increase was in LBG 611 (11.0%) with crop duration of 90 days. Though LBG 645 with duration of 80-85 days yielded the highest under ambient and elevated CO₂ conditions, the % increase with elevated CO₂ was 23.0%. On an average the % increase in seed yield with elevated CO₂ was 23.75% compared to ambient conditions. Elevated CO₂ generally increases photosynthesis, growth and yield of C₃ crop plants, but with large differences among species in the magnitude of the yield stimulation (Kimball *et al.* 2002).

Harvest index was significantly increased by elevated CO₂ in early varieties. The percentage of increase was highest in WBG 26 (22.7%) followed by T 9 (18.8%) in early varieties (70-75 days duration). Similar reports in *Vigna mungo* L. (Vanaja *et al.* 2007) also showed an increase in harvest index under elevated CO₂ conditions.

The long duration blackgram varieties LBG 611 and LBG 402 produced higher dry matter under elevated CO₂ conditions but had a lower HI than ambient grown conditions. This may be because some of the CO₂-enriched plants do not have an adequate sink (inadequate growth capacity), or lack

capacity to load phloem and translocate soluble carbohydrates. Allen *et al.* (1991) and Baker *et al.* (1989) reported lower harvest index under elevated CO₂ conditions which may also be evidence of the lack of capacity to utilize completely the more abundant photoassimilate.

LBG 623 and LBG 752 cultivars had little change in leaf area, total dry weight, pod number and seed yield under elevated CO₂ and ambient conditions. Improvement of photoassimilate utilization should be one goal of designing cultivars for the future (Hall and Allen 1993). Selection of plants that can better utilize carbohydrates which are produced when plants are grown at elevated CO₂ is important

A significant correlation was observed for total dry weight and pod weight in both conditions with yield indicating them to be most important yield contributing attributes. However in ambient control, leaf area and pod number were also significantly correlated with yield, which were not correlated with yield under elevated CO₂ conditions (Table 3). The over all results of correlation studies indicated a total of 10 correlations, which were significant under ambient conditions while under elevated CO₂ the significant correlations reduced to 6, thereby implying a change in the significance among correlations between ambient and elevated CO₂ conditions. Under climate change with elevated CO₂ there is a change in the significance of correlations among yield components.

In the present study of blackgram, the highest yielding

Table 2 Pod weight, total dry weight, seed yield, harvest index and hundred seed weight in blackgram genotypes grown under ambient and elevated CO₂ conditions

Genotypes	Duration of crop (days)	Pod wt. (g/plant)			Total dry weight (g/plant)			Seed yield (g/plant)			Harvest Index			100 seed weight (g)		
		Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control	Ch-control	550 ppm	% inc. over control
T 9	70-75	3.62	5.88	62.6	7.2	10.0	39.21	2.17	3.59	65.44	30.10	35.77	18.8	3.15	3.35	6.35
WBG 26		4.84	7.75	60.24	9.5	12.4	30.69	2.95	4.73	60.34	31.12	38.18	22.7	3.40	3.55	4.41
LBG 20		5.67	7.17	26.61	11.3	13.7	21.68	3.4	4.52	32.94	30.08	32.87	9.25	3.49	3.57	2.29
LBG 623	75-80	6.40	7.23	13.08	12.5	14.0	11.39	3.9	4.40	12.82	31.10	31.50	1.29	3.60	3.80	5.55
LBG 708		6.81	7.50	10.05	12.3	14.4	17.58	3.68	4.50	22.28	30.00	31.20	4.0	3.32	3.50	5.42
LBG 709		6.58	7.46	13.44	12.8	14.7	14.96	3.88	4.70	21.13	30.37	32.00	5.4	3.23	3.40	5.26
LBG 752		5.00	5.73	14.6	10.5	11.05	5.64	3.15	3.61	14.60	30.11	32.67	8.5	3.24	3.40	4.94
LBG 17	80-85	5.06	6.53	29.03	10.9	12.7	16.17	3.24	4.05	25.00	29.61	31.86	7.6	3.71	4.02	8.35
LBG 645		7.37	8.77	18.96	15.0	17.5	16.57	4.35	5.35	23.00	29.01	30.61	5.5	3.72	3.95	6.18
LBG 685		5.97	6.35	6.41	12.4	13.2	5.93	3.58	4.00	11.73	28.82	30.40	5.5	3.20	3.32	3.75
LBG 611	90	4.10	4.53	10.6	9.7	11.2	15.36	2.37	2.63	11.00	24.43	23.50	-3.8	2.92	3.15	7.87
LBG 402	90-95	6.48	7.10	9.6	14.4	16.9	17.18	3.95	4.40	11.39	27.35	26.00	-4.9	3.45	3.66	6.08
LBG 648	90-95	7.08	8.67	22.39	13.8	18.3	32.09	3.90	5.03	28.97	28.30	27.50	-2.8	2.90	3.05	5.17
Average		5.77	6.98		11.7	13.6		3.42	4.21		29.26	31.08		3.33	3.52	
CD (0.05)																
CO ₂		0.153			0.629			0.166			0.975			0.168		
Varieties		0.389			1.604			0.423			2.485			0.429		
CO ₂ x Var		0.551			NS			0.598			NS			NS		

Table 3 Correlation between plant traits at ambient (370 ppm) and elevated CO₂ (550 ppm) in blackgram genotypes

Variable 1	Variable 2	370 ppm	550 ppm
Leaf area	Pod weight	0.724**	0.435
Leaf area	Total dry weight	0.665*	0.590*
Leaf area	Pod number	0.780**	0.804**
Leaf area	Seed yield	0.619*	0.382
Leaf area	Harvest Index	-0.159	-0.392
Pod weight	Total dry weight	0.941**	0.814**
Pod weight	Pod number	0.718**	0.471
Pod weight	Seed yield	0.870**	0.986**
Pod weight	Harvest Index	0.129	0.192
Total dry weight	Pod number	0.771**	0.728**
Total dry weight	Seed yield	0.954**	0.780**
Total dry weight	Harvest Index	-0.108	-0.391
Pod number	Seed yield	0.638*	0.374
Pod number	Harvest Index	-0.456	-0.691
Seed yield	Harvest Index	0.192	0.262

* and ** indicate significance at P <0.05 and P < 0.01 level respectively.

variety (LBG 645) at ambient CO₂ (4.35 g/plant) also produced the highest at elevated CO₂ (5.35 g/plant), which was a medium duration variety. The percentage increase in seed yield with elevated CO₂ was highest in T-9 (65.4%) followed by WBG 26 (60.3%), which are early cultivars. These results clearly indicate the variability in the ability of the genotypes to adapt to the increasing CO₂ levels vary. Hence a case-to-case study in each crop is necessary to identify the genotypes irrespective of duration of crop for identifying the levels of adaptability to increased CO₂ levels.

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