Growth and yield responses of castor bean (*Ricinus communis* L.) to two enhanced CO_2 levels

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ABSTRACT

Growth and yield responses of castor bean (*Ricinus communis* L.) to two elevated CO_2 levels (550 and 700 ppm) were evaluated up to the maturity of first order spikes in open top chambers (OTCs). The growth characteristics – root and shoot lengths, root volume, root:shoot ratios, leaf area, dry weights of different plant parts, leaf area duration and crop growth rate increased with 550 and 700 ppm of CO_2 levels compared with ambient control. The spike length, pod and seed yield of first order spikes increased under enhanced CO_2 levels over ambient control. Elevated CO_2 levels significantly increased the total biomass and yield of castor bean, however enhanced CO_2 levels *per se* did not changed the content and quality of the castor oil. A positive response of castor bean to increased CO_2 concentrations is a good indication for its future existence in potentially changed climatic conditions.

Keywords: castor bean; elevated carbon dioxide; total biomass; yield; quality

The atmospheric concentration of carbon dioxide, the most important anthropogenic greenhouse gas, has been increasing at alarming rates (1.9 ppm per year) in recent years compared to the natural growth rate. Since the beginning of the industrial revolution, human activity has the potential to alter biogeochemical cycling and climate patterns through an increase in CO_2 and other greenhouse gases in the atmosphere (IPCC 2007). A major goal of current research is to understand how terrestrial ecosystem will respond to this changing environment.

Castor bean (*Ricinus communis* L.) is an indeterminate, non-edible oil seed crop grown in low rainfall regions of semi-arid tropics and sub-tropics. Castor bean is almost entirely grown under dryland conditions. India ranks first in castor bean production in the world; it is grown in the area of 75 000 ha with production of 730 000 MT and productivity of 1210 kg/ha. Very little work has been done on this non-edible cash crop concerning its growth and yield response to increased CO_2. Understanding physiological responses of castor bean to the environmental factors, such as elevated CO_2 levels, will be useful in assessing its ability to survive in changed climatic situation and to improve the crop to fit into the predicted new environment.

MATERIAL AND METHODS

The seeds of castor bean (*Ricinus communis* L.) cv. DCS-9 were sown in open top chambers (OTCs) of 3 m × 3 m × 3 m diameter lined with transparent PVC sheet to study the effect of elevated CO_2 levels (550 ppm and 700 ppm) on its growth and yield. The seeds were sown directly in the soil (Alfisol) and crop was raised under rainfed conditions with all recommended agronomic management practices. The crop was raised up to the maturity of first order spikes (primaries) as the crop canopy was huge and there was mutual shading. Two OTCs each were maintained at 700 ppm, 550 ppm and at ambient CO_2 level (365 ppm) as chamber control (Ch-control). The CO_2 concentrations within OTCs were maintained and continuously monitored during experimental period as described by Vanaja et al. (2006a). The experimental site was sandy loam in texture, neutral in pH (6.8), low in

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available nitrogen 225 kg/ha, phosphorus 10 kg/ha and medium to high in available potassium 300 kg K_2O/ha. The crop received 572.65 mm rainfall during the crop growth period with optimal distribution and without any long dry spells.

The observations on shoot length, root length, leaf area and total biomass were recorded at different time intervals (10, 20, 30, 45, 60, 75, 90 and 105 DAS). The observations were recorded up to the maturation of first order spikes (primaries), as the canopy of castor bean plants was very huge and hard to continue further in OTC structures due to mutual shading. For each treatment, three plants were sampled in two replications from each chamber. Plants were uprooted carefully, roots were made free from soil particles by washing with water, and plant parts were separated. Root and shoot lengths of each plant were recorded and leaf area was measured by using leaf area meter (LI-3100, LI-COR) and expressed as cm^2/plant. Dry weights were recorded after obtaining constant weights by keeping the plant parts in hot air oven at 80°C. Total biomass (g/plant), root:shoot ratio, and specific leaf weight (mg/dm^2) were derived from basic data.

Yield measurements of first order spikes were made after harvesting the plants at 105 DAS. Number of capsules, spike length (cm/plant), spike dry weight (g/plant), capsule dry weight (g/plant), seed weight (g/plant) and 100 seed weight were recorded. Total oil content was determined by using Soxhlet apparatus and fatty acid analysis was done by using HPLC. All the data were statistically analyzed using two-way analysis of variance (ANOVA) to determine the significant differences.

RESULTS AND DISCUSSION

Castor bean cv. DCS-9 showed significant response under elevated CO_2 levels (700 and 550 ppm) in terms of growth, biomass and yield when compared with ambient level of chamber control (Ch-control). The results were presented as the response of different growth and yield parameters to different levels of CO_2, i.e. 700 ppm, 550 ppm and ambient level at different time intervals and their response to CO_2 increasing from 550 ppm to 700 ppm. The percentage increment/improvement of each parameter due to increased CO_2 at different growth stages was calculated over ambient level values and the maximum responsive growth stage to different levels of CO_2 was identified. Yield and yield components were presented for the final harvest at 105 DAS.

The ANOVA results for various growth characteristics viz., root and shoot lengths, root:shoot ratios, leaf area, root, stem, and leaf dry weights and specific leaf area were found to be significant at 550 and 700 ppm CO_2. The conditions, time

Table 1. ANOVA for various growth characteristics of castor bean and their significant response to elevated CO_2 levels (550 and 700 ppm) over ambient chamber control (365 ppm)

Source	*df*	Mean sum of squares								
		total dry weight	root dry weight	stem dry weight	leaf dry weight	root/shoot ratio	leaf area	specific leaf weight	shoot length	root length
Replication	2	124.59**	0.19	7.25	0.965**	0.00	10880.0	656	1.68	53.76**
Conditions	2	1835.46**	60.53**	31.85**	114.35**	0.001**	38897670**	150464**	9979.93**	102.98**
Time intervals	6	223313.0**	5477.39**	5220660.9**	19234.26**	0.019**	647948600**	237369.3**	151780.70**	1521.94**
Condition × time intervals	12	498.70**	19.51**	953.83**	31.92**	0.000**	8395605**	14254.6**	2059.32	17.73*
Error	40	13.67	0.29	3.88	0.17	0.000	270380	1633.8	283.10	6.70

**significant at $P < 0.01$, *significant at $P < 0.05$; *df* – degrees of freedom intervals and their interactions were significant for all growth characteristics (Table 1); except for shoot length the interactions between conditions and time intervals were non significant.

Root characteristics

Root length increased throughout the crop growth period, i.e. from 10 to 105 DAS and the highest root length was recorded at 105 DAS in all the treatments. The root length under elevated CO_2 was higher at all stages when compared with ambient Ch-control (Figure 1). Among the elevated CO_2 levels, 700 ppm showed a better response than 550 ppm. At different growth stages the increment in root length varied from 3.86 to 48.22% with 700 ppm, from –18.38 to 24% with 550 ppm when compared with Ch-control, and the maximum response was recorded at 20 DAS for 700 ppm and at 30 DAS for 550 ppm. The increased response of root length due to CO_2 level enhanced from 550 ppm to 700 ppm ranged from 0.61 to 32.03% over the Ch-control, and the maximum response was recorded at 20 DAS.

Root dry weight followed the same trend as root length and it increased from 10 to 105 DAS. Initially, root dry weight increased slowly but from 60 to 90 DAS it showed the maximum increase (Figure 1). The highest root dry weight was recorded at 105 DAS in all the treatments. The percentage increase over Ch-control in root dry weight was about 3.4 to 43.1% under 550 ppm and 12.4 to 87% with 700 ppm of CO_2 level at different growth stages and the maximum response was at 20 DAS. The increment in root dry weight due to CO_2 level enhanced from 550 to 700 ppm showed a different trend and the response was highest at 30 DAS (39.9%).

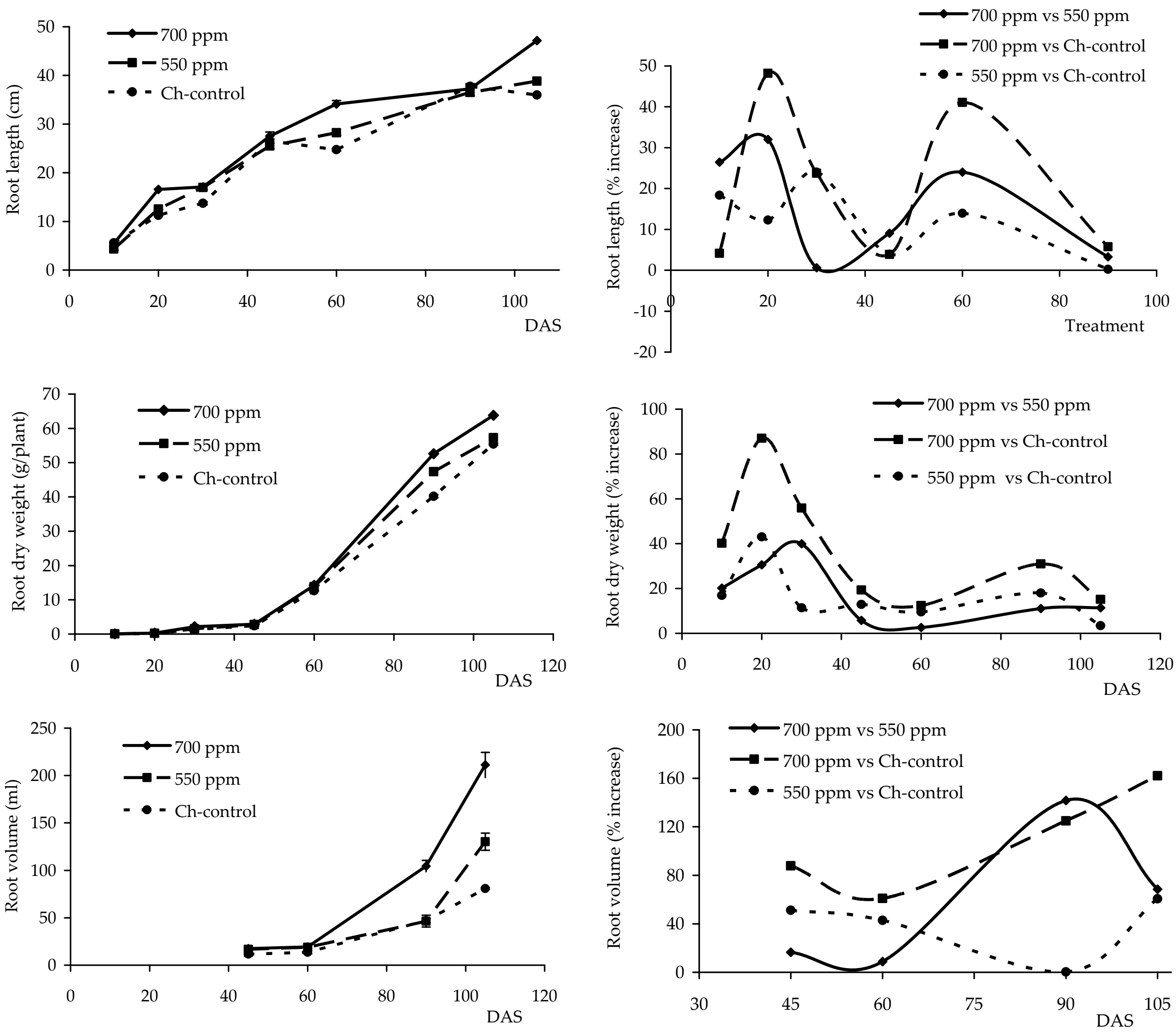

Figure 1. Root characteristics of castor bean (cv. DCS-9) under elevated CO_2 levels and chamber control conditions

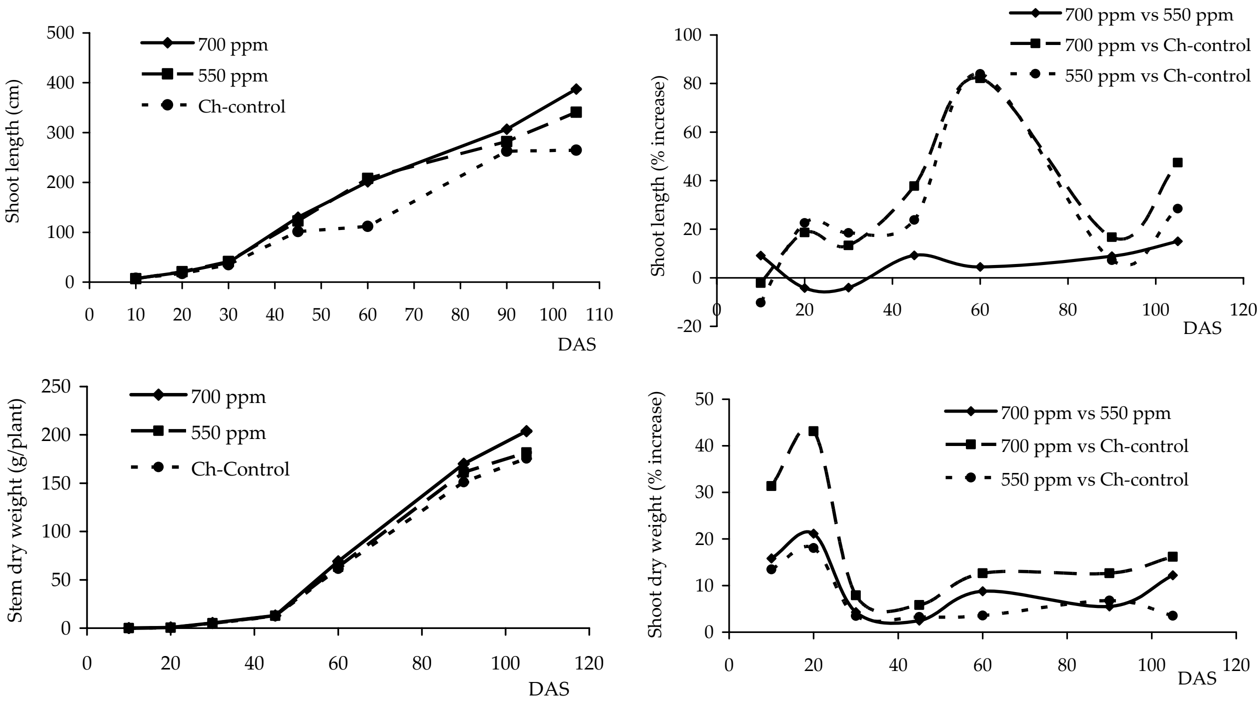

Figure 2. Shoot characteristics of castor bean (cv. DCS-9) under elevated CO_2 levels and chamber control conditions

Root volume was recorded from 45 to 105 DAS. Root volume followed the same trend as root dry weight. It showed maximum increase from 60 to 90 DAS in all the treatments. Compared to Ch-control, the increment in root volume was higher when compared to increment in root length under elevated CO_2. The percentage increase in root length was 48.2% with 700 ppm whereas for root volume it was 124.9% over Ch-control. This was mainly due to the formation of more lateral roots and root hair formation under elevated CO_2 levels. The root volume was 61 to 124.9% higher under 700 ppm than Ch-control and the maximum response was observed at 90 DAS whereas with 550 ppm it ranged between 0.3 and 60.6% and a higher response was observed at 105 DAS than Ch-control. With the increase in CO_2 from 550 to 700 ppm the root volume varied from 8.9 to 141.7%, maximum being at 90 DAS (Figure 1).

Shoot characteristics

Shoot length also increased from 10 to 105 DAS in all the treatments. Under 700 ppm, shoot length was higher than under 550 ppm and Ch-control at all stages of crop growth (Figure 2). The percentage increase in shoot length at 700 ppm ranged from –2.2 to 82.1% and –10.2 to 84% at 550 ppm over Ch-control. The maximum response was observed at 60 DAS for both CO_2 levels. The percentage of increase in shoot length at 700 ppm over 550 ppm ranged from –4.2 to 15% and the maximum response was recorded at 105 DAS.

Stem dry weight increased throughout the crop growth period in all the treatments. Elevated CO_2 significantly enhanced the stem dry weight. At 105 DAS, the mean stem dry weight was 203.83, 181.67 and 175.5 g/plant for 700 ppm, 550 ppm and Ch-control respectively (Figure 2). The stem dry weight increased from 3.2% to 18% under 550 ppm and 5.8% to 43.1% with 700 ppm of CO_2 level over the Ch-control. The percentage increment in stem dry weight varied from 2.5% to 21.1% when CO_2 levels increased from 550 to 700 ppm and the maximum was recorded at 20 DAS.

Leaf characteristics

Leaf area increased from 10 to 105 DAS in all the treatments and 700 ppm showed the maximum leaf area compared to 550 ppm and Ch-control (Figure 3). The percentage increase in leaf area ranged from 9.79 to 41.77% over Ch-control with 550 ppm whereas it was 19.91 to 90.58% with 700 ppm at different growth stages. The response of leaf area to increase in CO_2 from 550 to 700 ppm ranged from 10.47 to 38.1% with the maximum response for CO_2 at 45 DAS.

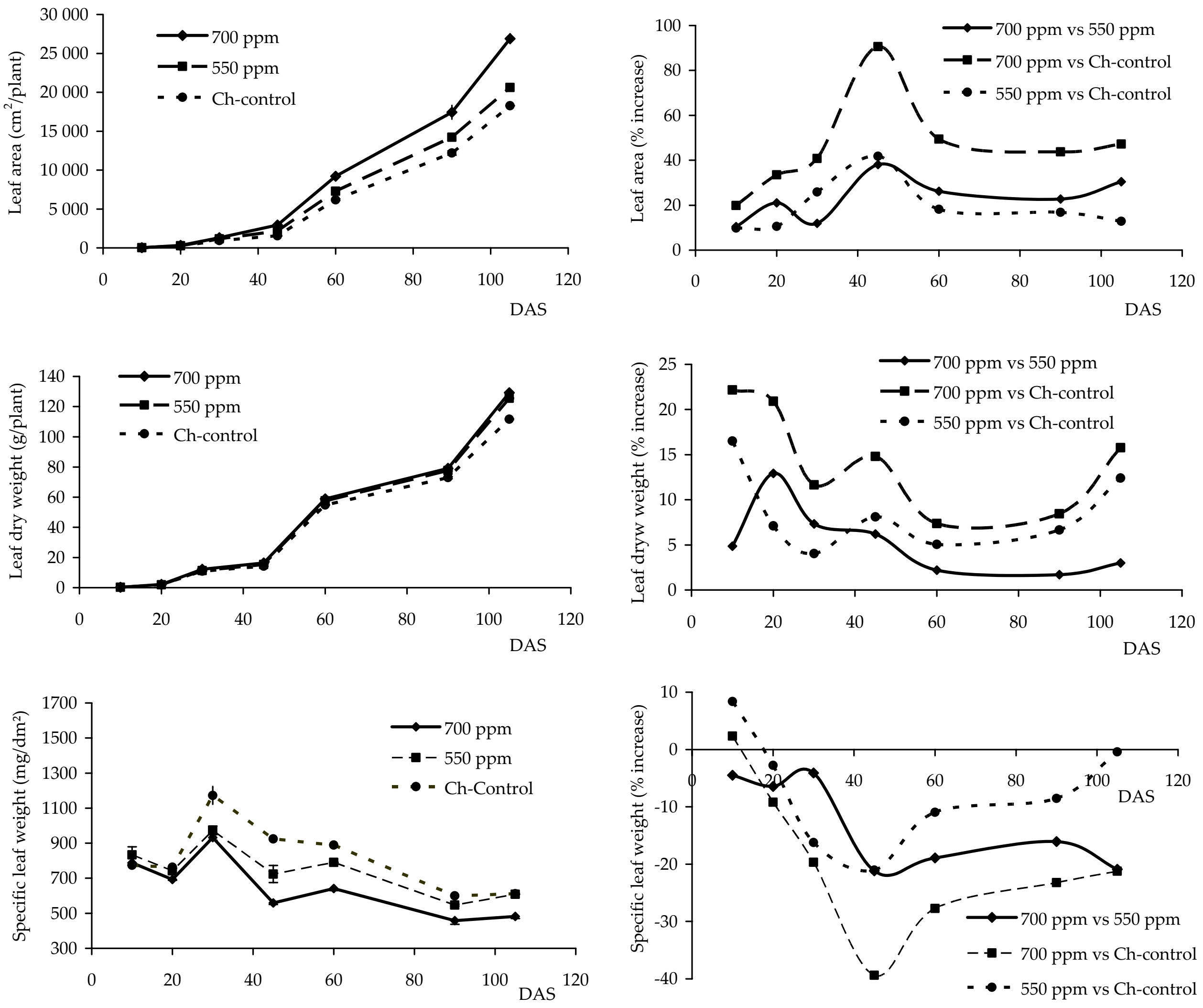

Figure 3. Leaf characteristics of castor bean (cv. DCS-9) under elevated CO_2 levels and chamber control conditions

Leaf dry weight increased throughout the crop growth period from 10 to 105 DAS. Initially, the leaf dry weight was low but from 45 DAS, it showed the maximum response. The leaf dry weight was highest with 700 ppm CO_2, followed by 550 ppm CO_2 and ambient Ch-control (Figure 3). The maximum percentage of increase in leaf dry weight was 16.51% with 550 ppm and 22.18% with 700 ppm over Ch-control at 10 DAS and it was 12.92% at 20 DAS for 700 ppm over 550 ppm.

The values recorded for the specific leaf weight were lower under both elevated levels of CO_2 (550 and 700 ppm) when compared with Ch-control at all stages of growth. There was a clear negative response observed for SLW with increased CO_2 levels (Figure 3). This indicates that with increased CO_2 the relative rate of leaf expansion in castor bean was higher than the increase in leaf weight.

Total biomass

Elevated CO_2 levels enhanced the total biomass at all growth stages and the maximum total biomass was observed under 700 ppm followed by 550 ppm and Ch-control. The percentage increment in total biomass varied from 4.47 and 15.89% at 550 ppm and from 11.33 to 28.61% at 700 ppm over Ch-control. The response of total biomass to levels of CO_2 increased from 550 ppm to 700 ppm ranged from 4.62 to 15.79%, the maximum being at 20 DAS (Figure 4).

Root:shoot ratio

Root:shoot ratio was high under both elevated CO_2, i.e. 700 and 550 ppm. Elevated CO_2 increased the crop growth rate in castor bean at all growth

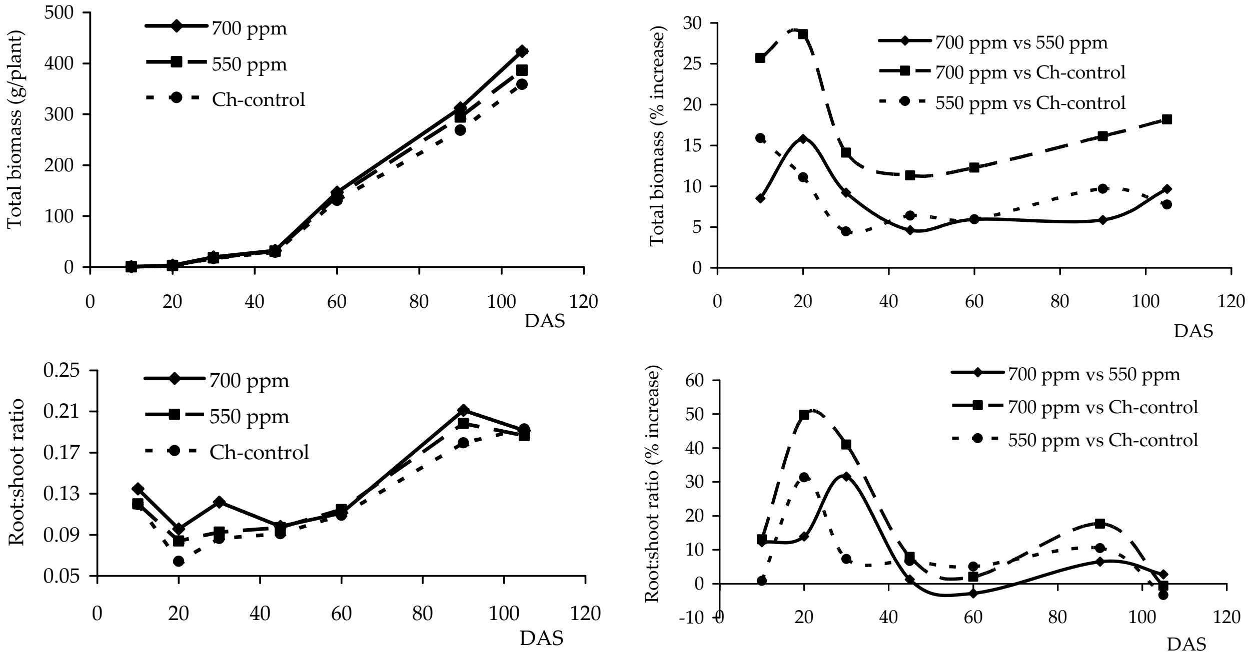

Figure 4. Total biomass and root/shoot ratio of castor bean (cv. DCS-9) under elevated CO_2 levels and chamber control conditions

stages; at 90 DAS it showed the maximum value in all the treatments (Figure 4). Elevated CO_2 levels maintained better root:shoot ratio than ambient Ch-control and it could be due to the stronger response of roots to enhanced levels of CO_2 compared to shoots.

Yield and yield components

The yield parameters – spike length, spike dry weight, number of capsules, capsule dry weight, seed weight and 100 seed weight were recorded per three plants for each treatment (Table 2). Total biomass and yield of primaries were enhanced under both elevated CO_2 levels i.e. 700 and 550 ppm and the increment in seed yield of primaries was higher under 550 ppm when compared to 700 ppm. The yield parameters like spike length, number of capsules, spike dry weight, capsule dry weight and seed weight were higher under 550 ppm followed by 700 ppm and ambient control.

The maximum spike length was also observed under 550 ppm followed by 700 ppm and Ch-con-

Table 2. Yield parameters of castor bean (per plant) under 550 and 700 ppm CO_2 levels and percentage increase over the ambient chamber control (365 ppm)

	Treatments			Percentage increase over the chamber control	
	700 ppm	550 ppm	chamber control	700 ppm	550 ppm
Spike length (cm)	26.0	27.21	23.8	9.37	14.48
Effective spike length (cm)	24.4	23.7	21.2	15.0	11.49
Number of capsules	31.2	37.4	18.9	64.98	97.75
Spike dry weight (g)	35.7	35.6	24.4	46.28	45.82
Capsule dry weight (g)	26.8	25.4	17.4	53.99	45.75
Rachis dry weight (g)	8.7	8.5	5.8	49.42	47.63
Seed weight (g)	17.9	17.1	6.7	165.4	154.3
Husk weight (g)	8.9	8.2	10.7	–16.43	–22.82
100 seed weight (g)	23.5	23.3	22.0	6.82	5.91
Total biomass	423.8	386.6	358.7	18.13	7.77
Harvest index	4.2	4.4	1.9	124.7	135.9

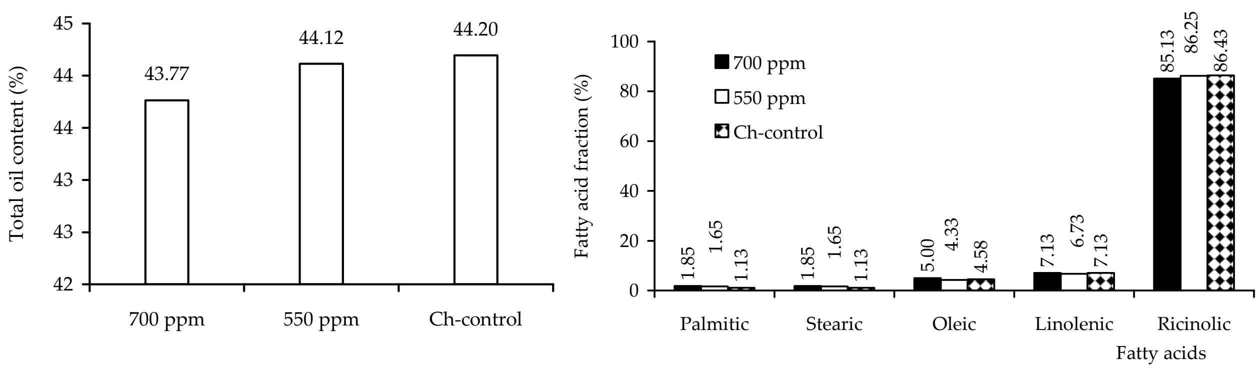

Figure 5. Oil content and fatty acid composition in castor bean (cv. DCS-9) under elevated CO_2 levels and chamber control conditions

trol. The number of capsules showed a different response by recording higher values at 550 ppm when compared with 700 ppm; hence, the response to the CO_2 concentration increased from 550 ppm to 700 ppm was not so remarkable. The spike length, number of capsules, spike dry weight, capsules dry weight and seed weight increased more under elevated CO_2 levels (550 ppm and 700 ppm) than at Ch-control. However, the above-mentioned parameters showed a different response when the CO_2 levels increased from 550 ppm to 700 ppm. A decrease was recorded in spike length and number of capsules in the case of CO_2 increasing from 550 ppm to 700 ppm; a non-significant difference was observed for spike dry weight, capsules dry weight and seed weight. The percentage increase of reproductive biomass was by 18.1% (700 ppm) and 35.3% (550 ppm) higher than ambient Ch-control. The increment in reproductive biomass from 550 ppm to 700 ppm was negative (–8.48%), hence the harvest index (HI) was the highest under 550 ppm followed by 700 ppm and Ch-control.

The oil content and quality was not changed significantly with increased CO_2 levels (Figure 5). In the case of the ambient level, slightly higher values were recorded for percentage of oil followed by 550 ppm and 700 ppm. The variation in individual fatty acids composition was marginal; at 700 ppm, CO_2 decreased the ricinoleic acid content by 1.5% when compared with ambient chamber control. The fraction of palmitic and stearic acid contents were found to be slightly higher under 700 ppm and 550 ppm, whereas oleic and linolenic acid contents were higher at 700 ppm compared to the chamber control.

Castor bean showed a positive response to elevated CO_2 levels in terms of biomass and seed yield. Data on different growth characteristics, such as root length, shoot length, leaf area, root volume, root:shoot ratio, and dry matter partitioning into different plant parts – leaf, stem, root, reproductive structures, crop growth rate etc., were increased under elevated CO_2 levels at all growth stages. At 700 ppm CO_2 level, all the growth characteristics showed a maximum response followed by 550 ppm and ambient Ch-control. Castor bean has a high rate of photosynthetic capacity (Dai et al. 1992); due to this feature it could fix extra CO_2 available under enhanced CO_2 conditions and it ultimately was reflected in increased growth and biomass production.

Root length, volume and dry weight were significantly increased under 700 ppm followed by 550 ppm and Ch-control. Salsman et al. (1999) reported root growth increased nearly by 60% in *Phaseolus acutifolius* under 700 ppm over 550 ppm, which is considered as ambient. In semi-natural grassland the root production increased up to 25% in the first year and around 80% in the next two years at 700 ppm CO_2 over ambient level (Sindhoj et al. 2004). The shoot length of castor bean increased with enhanced levels of CO_2 more at the higher concentration. Higher shoot growth and stem dry weight were reported in *Phaseolus acutifolius* under 700 ppm than at ambient CO_2 level (Salsman et al. 1999). At 90 DAS, the maximum root:shoot ratio values were observed for castor bean with enhanced levels of CO_2 in the present study; however, in other oil seeds, like sunflower and groundnut, the effect of elevated CO_2 (600 ppm) on root:shoot ratio at vegetative stage was non-significant (Vanaja et al. 2006b).

At elevated CO_2 levels, the leaf area and leaf weight increased more during the crop growth period than at ambient level. A decrease in specific leaf weight at increased levels of CO_2 resulted thinner leaves. Elevated CO_2 (700 ppm) stimulated the leaf growth and area 1.7 folds compared to ambient CO_2 in *Ricinus communis* (Grimmer et al. 1999).

The increased CO_2 level in the atmosphere not only improved the shoot and root biomass in castor bean but also yield and its components. Capsule number, seed yield and seed weight of soybean increased with CO_2 enrichment, as reported by Heinemann et al. (2006). Similarly, the improvement in spike length, spike weight, capsule number, capsule weight and seed size was observed with CO_2 enrichment in the present study. It is interesting to note that increased capsule number and seeds per capsule contributed to the increased seed yield at 550 ppm CO_2, whereas at 700 ppm this increase was caused by capsule number and seed size. Rogers and Dahlman (1993) compiled a synopsis of dry matter production and yield increase of ten most important crop species in response to elevated CO_2. Their work shows that in some species, there was an increase in total biomass and in others, it was economic yield that was greater. The results obtained in the present study showed an increase in the dry matter production as well as economic yield at both 550 and 700 ppm. The seed yield improved by 17.3% with increase in CO_2 from 550 to 700 ppm, whereas the harvest index (HI) reduced. This shows that the CO_2 levels above 550 ppm clearly improved biomass more than economic yield of castor bean. Our studies were restricted by the maturity of the first order spikes, as the canopy was too huge for OTCs. The contribution of first order spike yield to total bean yield in castor bean ranges between 40 to 60%. A much higher yield increment can be thus expected in castor bean crop under CO_2 enrichment than the values we obtained in the present investigation.

Several studies were conducted to document the changes in seed composition caused by climate change, e.g. elevated CO_2 concentration (Thomas et al. 2003). Dry weight of soybean seed comprises 20 and 40% oil and protein, respectively (Hyrrowitz et al. 1972). Thomas et al. (2003) and Heagle et al. (1998) reported that oleic and linolenic acid contents were increased in soybean under elevated CO_2. The oil content and quality of castor bean has not changed significantly under elevated CO_2 levels compared to the ambient level. The content of major fatty acid, i.e. ricinoleic acid, in castor bean oil was reduced to 1.5% with 700 ppm CO_2 concentration; the fraction of palmitic, stearic, oleic and linolenic acids however increased with enhanced levels of CO_2. Hence, it may be concluded that castor bean responds positively to increasing CO_2, not only in terms of biomass but also with respect to its economic yield.

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