Response of seed yield and its components of red gram (*Cajanus cajan* L. Millsp.) to elevated CO_2

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ABSTRACT

Pigeon pea (*Cajanus cajan* L. Millsp.) is an important grain legume crop of the semi arid tropics and is a major dietary protein source. The extra short duration cultivar of pigeon pea ICPL 88039 was evaluated at ambient (370 μmol/mol) and twice the ambient (700 μmol/mol) concentrations of CO_2 in open top chambers (OTCs). The results showed that the crop recorded a significant positive enhanced response for total biomass, fodder yield, grain yield, number of pods and seeds per plant, test weight and HI at elevated CO_2. The ANOVA revealed significant differences in response of the characteristics to CO_2 concentrations. Under elevated CO_2 the total biomass recorded an improvement of 91.3%, grain yield 150.1%, fodder yield 67.1%. The major contributing components for improved grain yield under elevated CO_2 were number of pods, number of seeds and test weight which recorded an increase of 97.9%, 119.5% and 7.2%, respectively. The crop maintained a significant positive increase of harvest index (HI) at elevated CO_2 with an increment of 30.7% over ambient values. This increase in HI was due to its improved pod set and seed yield under enhanced CO_2 concentration thereby emphasizes this crop for sustained food with nutritional security under climate change scenario.

Keywords: pigeon pea; total biomass; yield; pod set; harvest index; elevated CO_2

Food grain requirements of India (both human and cattle) are estimated at 300 Mt in 2020 (Sinha et al. 1998). With the alarming increase in Greenhouse gases (GHG) concentration and its expected impact on climate, the issue emerging would be to achieve the targeted production. To address the above issue from the agricultural point of view, it is desirable to select the crops and their cultivars thereof, that can better utilize the increased concentration of CO_2 for both biomass and grain yield. Unlike other non-leguminous C3 plants, only legumes have the potential to maximize the benefit of elevated CO_2 by matching stimulated photosynthesis with increased N_2 fixation (Rogers et al. 2009). In case of food legumes where grain is harvested for human consumption, the translation of increased biomass more towards grain or improved harvest index need to be achieved for breaking the yield barriers of these very important C3 grain legumes predominantly grown in the marginalized rainfed areas. India is the largest producer and consumer of pulses in the world. India grows pulses in about 22.5 million hectare and 80 per cent is in dry areas. However, pulses production has been stagnant between 11 and 14 million tonnes over the last two decades. Per capita pulses consumption over the years lowered from 61 g/day in 1951 to 30 g/day in 2008 (Amarender Reddy 2009). Elevated CO_2 condition appears to improve the overall growth of plants in general and may result in changes in partitioning of photosynthetic assimilates to various plant organs over time.

Pigeon pea is an indeterminate pulse crop mainly grown during monsoon season for food, feed and soil fertility. An attempt was made in this paper to quantify the response of pigeon pea- major rainfed grain legume crop to increased atmospheric CO_2 concentration in terms of yield and its components to know the response of not only the grain yield but also to find out the most important yield contributing characteristics. The outcome of this study is useful to the crop improvement

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programs, which enable the overall productivity increase of this important grain legume for nutritional security of the vast majority of semi arid rainfed ecosystem of the drought prone areas of the world including Afro-Asian underdeveloped and developing nations.

MATERIALS AND METHODS

The seeds of the extra short duration grain legume pigeon pea cv. ICPL 88039 were sown in open top chambers (OTCs) of 3 × 3 m diameter lined with transparent PVC (polyvinyl chloride) sheet, which had 90% transmittance of light. The study was conducted during monsoon season (June to September) of 2008 and 2009 at the Central Research Institute for Dryland Agriculture, Hyderabad, India. The seeds were sown directly in the soil (alfisol) within the OTC's. The crop was evaluated at two CO_2 concentrations, i.e. 370 μmol/mol (aCO_2) and 700 μmol/mol (eCO_2) and two OTCs were maintained for each CO_2 concentration. Two OTCs were at aCO_2 without any external CO_2 supply and served as ambient control. The elevated concentration of CO_2 (eCO_2) were maintained throughout the 24 h a day from sowing to final harvesting. To maintain the eCO_2 in OTCs, i.e. 700 μmol/mol at crop canopy level, continuous injecting of 100% CO_2 from a compressed CO_2 cylinder into plenum of OTCs was done where it was mixed with air from air compressor before entering into the chamber. The air sample from each chamber was drawn from the center point of OTCs at three-minute interval into non-dispersive infrared (NDIR) CO_2 analyzer (California Analytical) and the set CO_2 concentration was maintained with an automatic switching solenoid, rotameters, Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) software (Vanaja et al. 2006a).

The experimental site was sandy loam in texture, neutral in pH (6.8), low in available nitrogen (225 kg/ha), phosphorus (10 kg/ha) and medium to high in available potassium (300 kg/ha). For the two years of study with pigeon pea cv. ICPL 88039, seeds were obtained from the ICRISAT, Patancheru, Hyderabad and every year fresh seeds were sown. The crop was raised in OTCs following recommended agronomy practices and crop was maintained free from moisture stress, pests and diseases. The crop received 828.6 mm and 566.4 mm rainfall during the years 2008 and 2009, respectively, distributed in 30 rainy days (A day is 'rainy' with more than 2.5 mm rainfall). The temperature and humidity within the OTCs with aCO_2 and eCO_2 were presented in Table 1.

The pigeon pea crop was harvested at 120 days. Five replications with fifteen plants for each replication in each CO_2 concentration were harvested and used for recording biomass, fodder yield, grain yield and its components viz., pod number, seed number and 100 seed weight. HI was calculated as (grain yield)/(total above ground dry mass).

The data were statistically analyzed using a two-way analysis of variance (ANOVA) to test the significance of variability between the characteristics, CO_2 concentrations and their interactions.

RESULTS AND DISCUSSION

The response of pigeon pea to two concentrations of CO_2 namely 370 μmol/mol (ambient) and 700 μmol/mol (elevated) were studied in terms of total biomass, grain yield, fodder yield and the harvest index (HI). The ANOVA revealed signifi-

Table 1. Chamber temperature and relative humidity of [eCO_2] and [aCO_2] for the crop during 2008 and 2009

Parameters	2008		2009	
	eCO_2	aCO_2	eCO_2	aCO_2
Temperature (°C)				
Minimum	19.0	17.9	16.6	16.5
Maximum	38.8	38.4	40.2	38.0
Average	27.55	26.1	28.3	25.8
Relative humidity (%)				
Minimum	18.0	25.27	16.6	29.6
Maximum	91.7	93.54	87.8	87.7
Average	61.9	67.2	61.1	66.3

Table 2. ANOVA for various characters at [aCO_2] and [eCO_2] in pigeon pea

Source	*df*	Mean sum of squares
Replications	4	43625**
Characteristics	7	125406**
CO_2 concentrations	1	76724*
Characteristics × CO_2 concentrations	7	18529
Error		11671
SE ±		
Characteristics		34.16
CO_2 concentrations		17.08
Characteristics × CO_2 concentrations		48.31

*significant at 5% level; **significant at 1% level

cant differences for the characteristics and CO_2 concentrations (Table 2). From this analysis it is also evident that the magnitude of response of different characters was different with increased CO_2 concentration.

Total biomass (grams per plant). In pigeon pea, the total biomass improved from 61.1 g/pl at ambient to 116.9 g/pl under elevated CO_2 (Figure 1), thereby showing an improvement of 91.3% (Figure 2). In mung bean, Das et al. (2002) reported that the biomass response to elevated CO_2 condition at initial growth stages was higher (55%) as compared with later growth stages (8%). At elevated CO_2 condition, the increased photosynthesis in all C3 plants result in increased plant biomass and the response of nitrogen fixing legumes is higher compared with other non leguminous C3 crops (Vanaja et al. 2006b, Rogers et al. 2009). This could be due to the unaffected leaf N levels of majority of legumes under elevated CO_2 condition (Winkler and Herbst 2004).

The capacity for legumes to coordinate enhanced assimilation of C and N at elevated [CO_2] to avoid down-regulation of photosynthetic capacity and ultimately maximize gains in productivity has been demonstrated across a range of species, environmental conditions, and ecological settings (Ainsworth and Rogers 2007, Leakey et al. 2009).

Fodder yield (grams per plant). The fodder yield improved from 43.3 g/pl. at aCO_2 to 72.3 g/pl. by eCO_2 (Figure 1), showing an increment of 67.1% with eCO_2 (Figure 2). Legumes are so responsive to atmospheric CO_2 enrichment that they actually increase in abundance within mixed communities. Campbell et al. (2000) determined that the legume content of grass-legume swards increased by about 10% in response to a doubling of the air CO_2 content, which would ultimately make more nitrogen available to the ecosystem's non-leguminous plants.

Grain yield (grams per plant). The grain yield improved from 17.8 g/pl at ambient to 44.6 g/pl at 700 μmol/mol (Figure 1), thereby showing an increment of 150.1% with eCO_2 (Figure 2). At twice-ambient concentrations of atmospheric CO_2, Palta and Ludwig (2000) recorded 52% and 55% increases in dry matter and seed yield, respectively, in narrow-leafed lupin. In mung bean

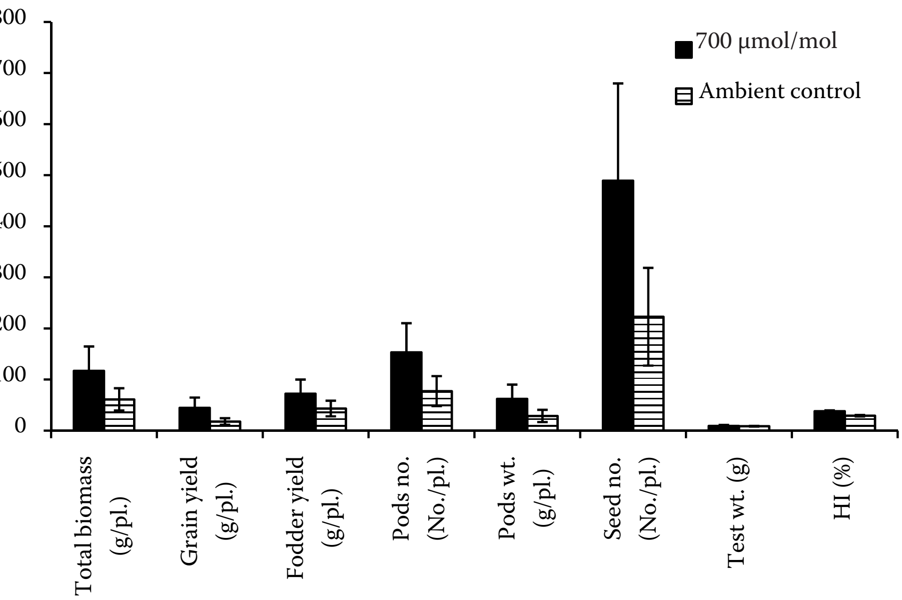

Figure 1. Per se values of total biomass, fodder yield, grain yield, its components and HI for pigeon pea at [aCO_2] and [eCO_2]

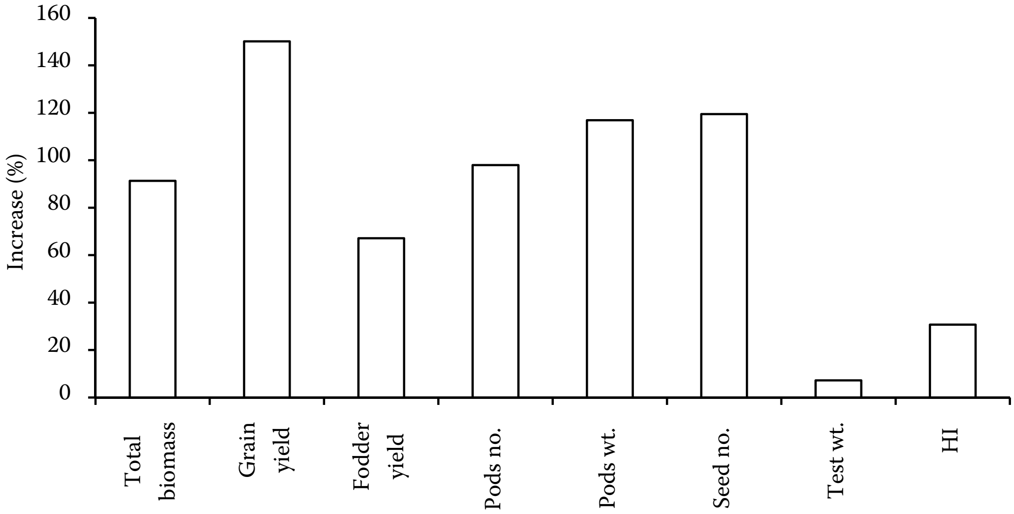

Figure 2. % increase of total biomass, fodder yield, grain yield, its components and HI for pigeon pea with [eCO_2]

a significant increases in pod number, pod weight and total seed weight were reported at elevated CO_2 concentration (Ziska and Blowsky 2007).

Number of pod per plant. The pod number per plant showed an increase of 97.9% over ambient chamber control i.e. a two fold value as that obtained at aCO_2 showing it to be an important yield contributing component with eCO_2. The flower to pod conversion and retention of flower as well as pods in pulses is sensitive to abiotic stresses like moisture, temperature and nutritional stresses there by reduction in sink size result in reduced grain yield. In the present study it was clearly evident the enhanced concentrations of CO_2 significantly improving the number of pods and seeds translating into higher grain yield.

Number of seed per plant. A very high response of 119.5% increase in number of seed over ambient control was observed at eCO_2, showing more than two fold increase in the value. This indicates the character importance in yield increase as well as its response to eCO_2, thereby impetuous, on yield contributing character that is to be laid in the crop improvement program. The enhancement of seed production was strongly correlated with the enhancement of seed nitrogen per plant under elevated CO_2 which was caused by increased N acquisition during the reproductive period. Legume species tend to acquire more N and produce more seeds at elevated CO_2 than non-nitrogen fixing species (Miyagi et al. 2007).

Test weight (g). The test weight recorded an increase of 7.2% over the ambient control implying that the response under eCO_2 was relatively low for this character as compared to number of pods and number of seeds. The increment in test weight with eCO_2 could be due to more filled seed rather than increment in weight of filled seed. Developing seeds can represent a large carbon sink for the plant and elevated CO_2 can also lead to heavier seeds (Darbah et al. 2008). Increased carbon allocation to seeds can be matched by complementary nutrient allocation, resulting in no change in the seed nutrient content, as is often the case in legumes (Miyagi et al. 2007).

Harvest index (%). The crop maintained a significant positive increase of HI at eCO_2 i.e. from 29.2% HI at aCO_2 to 38.2% (Figure 1), thus showing an increment of 30.7% over ambient values (Figure 2). This was the resultant of a proportionate equal increment in total biomass and also grain yield under eCO_2. Therefore this crop may be worth emphasizing for food sustenance with nutritional security under climate change scenario. Moreover, the results which are in tune with previously reported findings by Vanaja et al. (2007) revealed a significant increase in the HI due to their improved partitioning efficiency under eCO_2 condition. Enriched CO_2 reduced to zero the number of pods that had small seeds (≥ 30–80 mg) and reduced the number of pods with unfilled seeds from 16 to 1 pod/plant in narrow-leafed source-limited lupin (Palta and Ludwig 2000). This increased seed yield per plant by 44–66%, but did not affect the harvest index.

An increase of 97.9% for number of pods/plant by eCO_2 over ambient control and 119.5% for number of seeds/plant, while for test weight it was 7.2%. The above results indicate that the increase in grain yield (115.1%) with eCO_2 was primarily due to the increases in the yield components viz., number of pods and number of seeds.

The grain legumes are one of the mainstay of the drylands as these crops provide much needed nutritional security in the form of proteins to the large junk of predominant vegetarian populations of India and also the world. The present results indicate that their importance under climate change scenario could also sustain as all the yield components as well as the HI have shown significant increase under elevated CO_2. Apart from improving the soil through their root nodulation effect (soil health sustenance) they are also known to improve the nutrition of animals (fodder) and humans (protein) (Kretschmer and Pitman 2001). The replenishment of nutrients, especially the N to the soil through grain legumes can be a boon as the rainfed/drylands are not only thirsty but are also hungry. Crop rotation is one of the agronomic principles in agriculture. Grain legumes could be a very important component of crop rotation for their ability in soil building process with emphasis on soil fertility, apart from being food and nutrition resource.

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