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Growth and Yield Behaviour of Pigeon pea (Cajanus cajan L.) and Black gram (Vigna mungo L.) Under Different Levels of Elevated CO_2

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Abstract

An open top chamber (OTC) of 4.77 m^2 experiment was conducted to study the impact of different elevated atmospheric carbon dioxide levels (500, 450 and ambient 400 ppm) on the growth and yield of pigeon pea and black gram. The study was conducted on two pulse crops i.e. pigeon pea and black gram in open top chambers (OTC) to study the impact of elevated CO_2 levels on its growth performance in comparison to natural climatic conditions. There was positive impact of different elevated CO_2 levels on plant growth and yield parameter. The results indicate that under varying levels of increased CO_2 had a progressive increase in plant height, number of branches per plant, number of pods per plant, pod length, pod weight and number of grains per pod. Maximum values were found under 500ppm CO_2 level followed by 450 ppm which was significantly higher over ambient 400 ppm and natural conditions. Similarly higher yield attributes were found in pigeon pea and black gram under 500 ppm CO_2 level followed by 450ppm CO_2, natural conditions & ambient. Highest grain yield (120g $plant^{-1}$) & straw yield was under 500ppm CO_2 followed by 450ppm level, natural condition & ambient (400ppm) in both pigeon pea and black gram. The yield attributes also differed significantly. Thus the findings focussed that increasing the CO_2 level up to 500 ppm may be beneficial in terms of increasing the productivity of these pulses in semi-arid regions of Gwalior district of Madhya Pradesh.

Keyword: *elevated carbon dioxide, black gram, pigeon pea, growth & yield, Open top chamber, Climate Change,*

1. Introduction

Agriculture is facing the dual challenges of increasing crop production and climate change. Rising temperature, drought, salinity, floods, desertification and weather extreme are adversely affecting agriculture especially in developing world (IPCC, 2007). Most of the predicted population growth to 2030 will be in developing countries and more than half of the work force engaged in agriculture in the third world countries is prone to more damage by climate change. Thus, there is need to improve crop productivity under changed climate, abiotic stresses and to meet the needs of increasing world populations. Of various abiotic stresses, high temperature, salt stress and drought alone or in combination are major threats to crop productivity. Rising temperatures may lead to altered geographical distribution and growing season of agricultural crops by allowing the threshold temperature for the start of the season and earlier crop maturity (Porter, 2005). An extreme temperature shortens the growing period and adversely effects all phases of growth such as tillering, flowering

and grain filling in late sown wheat. A series of morphological, physiological, biochemical and molecular changes may reduce expression of full yield potential of crop plants under these climatic stress conditions. Pigeon pea [*Cajanus cajan* (L.)] is one of the major pulse crops of the tropics and sub tropics including America, India, Australia, Hawaii, Uganda, Italy, East and West Indies and South-East Africa.

It is estimated that about 300 million tonnes of food grain requirement of India (including cattle) in 2020 (Sinha et al 1998), with the alarming increase in 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 there of, that can better utilize the increased concentration of CO_2 for growth and grain yield. Carbon dioxide (CO_2) concentration in the atmosphere has increased by nearly 37%, since the dawn of industrial revolution (Whorf & Keeling 1998) , and is likely to increase up to 570 ppm by the middle of the current century with a consequence of 2.0 to 4.5^o C warmer earth surface (IPCC, 2007). Since CO_2 is the substrate for photosynthesis, any change in its atmospheric concentration leads to enhanced carboxylation and reduced oxygenation; thereby altering portioning efficiency i.e. carbon allocation in various plant organs (Liu et al. 2005)

It is a kharif season crop and is commonly known as Red gram or *Arhar*. It is the second important pulse crop after the gram and a major kharif crop in the country. India ranks Ist in area and production in the world with 80% and67% of world's acreage and production respectively. Highest production of Pigeon pea is from Maharashtra which is around 30% of National Production. It contains about 26% protein. Black gram (*Vigna mungo* L.), is also one of the important pulses crop, grown throughout the country. Madhya Pradesh, Uttar Pradesh and Andhra Pradesh are major black gram growing states area-wise.

The effects of atmospheric CO_2 enrichment have been studied for more than a century in greenhouses, control environment chambers, OTC's and other elevated structures to confine the CO_2 gas around the experimental plants. The accuracy on maintenance of CO_2 inside the chamber installed around the crops did not succeed in many other studies because of technical constraints.

2. Material and methods

The experiment was conducted at semi-arid sub-tropical climate of Gwalior, Gird region of Madhya Pradesh, at the latitude of 26□.13' N and longitude 76□.14' E with an altitude of 211.52 meters from mean sea level. The region experienced with extreme weather condition having hot and dry summer and cold winter. Generally, monsoon sets in during the last week of June. Annual rainfall ranges from 700 to 800 mm, most of which falls during last June to the middle of September. The maximum temperature goes up to 45^{o}C during summer and minimum as low at 3.8^{o}C during winter. The soil of the experimental field was alluvial, sandy clay loam in texture. Representative soil samples of surface (0-15 cm depth) were collected from each OTC plot before sowing and after harvest of crop with the help of soil auger for determination of physico-chemical properties of soil.

The experiment was conducted in the three circular Open Top Chambers (OTCs). The pigeon pea and black gram crops were grown in the chambers as well as in the natural conditions. First open top chamber was maintained with elevation of 500 ppm CO_2 level, second chamber with elevated 450 ppm CO_2 and the third chamber was ambient (400 ppm CO_2 level) which was the control treatment for the present study. Carbon dioxide gas was supplied to the chambers and maintained the required levels of CO_2 by gas regulators, pressure pipelines, solenoid valves, samplers, CO_2 analyzer and SCADA. The CO_2 was maintained from 10 am to 5 pm everyday till the end of the experiment. A natural condition was also used as per diameters of OTC. The inorganic fertilizers in the form of urea, SSP and MOP were applied in individual treatment as basal dose during seed bed preparation. Remaining dose of urea again split into two doses and one was applied on month after sowing and another dose at the time of flowering by following recommended package of practices pulses. The crop was harvested at maturity stage, when the foliage was shaded off and the pods turned yellowish brown to brown colour. The Three tagged plants, for recording the post-harvest observations, were harvested separately from the net experimental plots. Plants height, number of branches per plant recorded after 30, 60 DAS & at the time of harvesting. Number of pods per plant, number of seeds per pods, pods length and weight were observed at the time of maturity.

Data sets were first analyzed for normal distribution and homogeneity of variance using the Shapiro Wilk and the modified Levene test and then subjected to ANOVA followed by the Tukey's test ($\alpha = 0.05$). All the collected data were analyzed using analysis of variance (ANOVA) two factor analysis with statistical software SPSS 11.5. For a significant F-value, the means were separated with least significant difference (LSD) with $p < 0.05$.

3 Results

The results in context to effect of elevated CO_2 levels on growth and yield parameters are depicted below

Plant height

Plant height was recorded at 30, 60 &harvest stage. The mean data on plant height in Table (1) indicates that different CO_2 levels under pigeon pea &black gram crop was significantly influenced under different CO_2 levels at all the growth stages. Under pigeon pea crop, different elevated CO_2 levels produced taller plant as compared to ambient and natural condition which was at par from each other. Maximum height (53.67cm, 145.00cm & 173.33 cm) at all crop growth stages was recorded with 500 ppm level which was significantly higher to rest of the treatments. However, a natural condition of CO_2 was also recorded more plant height as compared to ambient condition under OTC but not reach the level of significance. Similarly, in black gram crop, different elevated CO_2 levels produced taller plant as compared to ambient and natural condition which was at par from each other. Maximum height (31.20cm, 49.33 cm &59.00cm) at all growth stages was recorded with 500 ppm level which was significantly higher to rest of the treatments. However, a natural condition of CO_2 was also recorded more plant height as compared to ambient condition under OTC.

Number of Branches

Number of branches per plant is an important growth character, which has direct bearing on yield. Number of branches per plant were recorded at 30 das,60 das & at harvest stage (table 1) which clearly indicated that under two groups of crop, pigeon pea produced more number of branches per plant as compared to black gram. In pigeon pea group, different elevated CO_2 levels produced significantly higher number of branches per plant as compared to ambient and maximum being under 500 ppm which was significantly higher to ambient and 450 ppm levels. However, a natural condition of CO_2 was also produced significantly higher number of branches per plant as compared to ambient conditions under OTC. In the case of black gram, different elevated CO_2 levels maximum number of branches (15.33 g plant^{-1}) was recorded with 500 ppm which was significantly higher to ambient conditions under OTC and natural condition but was at par with 450 ppm levels. However, a natural condition of CO_2 was statistically at par with ambient conditions of CO_2 in respect of number of branches per plant at harvest stage.

Number of pods per plant:

Number of pods per plant is an important yield attributing character, which has direct bearing on yield. Number of pods per plant recorded at maturity stage. The data on number of pods per plant is given in Table 1. It is evident under different group of crops; pigeon pea produced more number of pods per plant as compared to black gram. In pigeon pea group, different elevated CO_2 levels produced significantly higher number of pods per plant as compared to ambient and maximum being under 500 ppm which was significantly higher to ambient and 450 ppm levels. However, a natural condition of CO_2 was also produced significantly higher number of pods per plant as compared to ambient. While in black gram, different elevated CO_2 levels maximum number of pods per plant was recorded with 500 ppm which was significantly higher to ambient and 450 ppm levels. However, a natural condition of CO_2 was statistically at par with ambient conditions of CO_2.

The higher pod weight found with elevated CO_2 level of 500ppm may be due to higher photosynthetic rate under more CO_2 available which resulted formation of more carbohydrate & proteins.

Number of grains per pod:

Number of grains per pod counted at maturity stage and mean data are presented in Table 2 which is clearly indicated that different group of crops; black gram produced more number of grains per pod as compared to pigeon pea. In pigeon pea group, different CO_2 levels produced significantly higher number of grains per pod as compared to ambient and maximum number of grains (6.33 pod^{-1}) was found with 500 ppm CO_2level which was significantly higher to rest of the CO_2 levels. Lower elevated CO_2 levels (450 ppm) also produced significantly higher number of grains per pod as compared to ambient. However, a natural condition of CO_2 was also produced more number of grains per pod as compared to ambient which was comparable with each other.

In black gram, maximum number of grains (7.00 pod^{-1}) was recorded with 500 ppm CO_2 level followed by 450 ppm CO_2 level with 6.67 grains $pod^{-1}$and both were significantly higher to ambient and natural conditions treatments. However, a natural condition of CO_2 was also recorded more number of grains per pod as compared to ambient but not cross the level of significance.

In the present investigation highest number of pods per plant in pigeon pea and blackgram was under 500 ppm CO_2 level over rest of the treatments. This may be due to the fact that more photosynthesis rate is there when CO_2 is high. So if more photosynthesis will happen then more proteins, carbohydrates amino acids will be there & these compounds are the building blocks of the main structural component of the plant which ultimately affect the yield by increased number of pods per plant.

Pod length (cm) at harvest

Analysis of data revealed that higher pod length (7cm) was recorded in pigeon pea grown under 500ppm CO_2 which was statistically significant with pod length (6cm) at 450ppm CO_2 level, natural conditions 5.67cm and ambient (5.33cm) Table 2

Similarly higher pod length (5.33cm) was in black gram grown under 500ppm CO_2 and was statistically significant with pod length (5cm) as 450 ppm CO_2 level, natural conditions (4.83 cm) and ambient (4.33 cm).

Pod weight at harvest

The results shown in Table 2 that pod weight (180 g/plant) was recorded significantly higher under 500ppm CO_2 level, followed by pod weight (122 g/plant) under 450ppm CO_2 level. The other two treatment combinations were at par with least pod weight (113.33 g $plant^{-1}$) in ambient. Likewise the pod weight (38.17 g/plant) in black gram was observed highest under 500ppm CO_2 with significantly different pod weight at 450ppm CO_2(25.53g $plant^{-1}$) and other levels**.**

Grain & straw yields of pigeon pea and black gram

Under different crops, pigeon pea produced higher grain and straw yield as compared to black gram. Table 3. In pigeon pea crop, different elevated CO_2 levels produced significantly higher grain and straw yield as compared to ambient and maximum yield was found at 500 ppm which was significantly higher to ambient and 450 ppm levels. However, a natural condition of CO_2 also produced significantly higher number of pods per plant as compared to ambient. While in black gram, different elevated CO_2 levels maximum grain and straw yield was recorded at 500ppm CO_2 which was significantly higher to ambient and 450 ppm CO_2 levels. However, a natural condition of CO_2 was statistically at par with ambient conditions of CO_2.

4. Discussion

The higher pod weight found with elevated CO2 level of 500ppm may be due to higher photosynthetic rate under more CO2 available which resulted formation of more carbohydrate & proteins. The present results are in level with the finding of Starciel et. al. (2000) who reported that pod weight of peanut was significantly higher at 1200 mmol/mol CO2 than ambient reflecting both an increase in pod number as well as assimilate partitioning to the pods.

The maximum plant height recorded under CO2 500ppm followed by 480ppm compared to ambient and natural conditions may be due to increased cell division and high vegetative growth which may be due to increased CO2 level. These findings are supported by Pilumwony et. al. (2007) who reported that CO2 resulted greater plant height in mung bean at different growth stages. These results are also cited by Meena Kumar et.al (2019) in pea crop at elevated CO2 and temperature.

As longest harvest duration was recorded under natural conditions which may be due to long duration of crop growth while duration got reduced under 500 ppm CO2 and 400 ppm CO2 which may be due to .early maturity under the influence of higher CO2. Wheeler et al (1996) reported increase in temperature reduced the duration of crop growth. Similar findings were given by Meena Kumari et.al (2019) in regard to pea crop in which they found the reduction in harvest duration at elevated CO2 and temperature.

The results in present investigation revealed that the fresh weight of pigeon pea and black gram was significantly higher under elevated CO2 levels of 500 ppm CO2 and 400 ppm. Similarly the dry weight was recorded more in both the crops when grown under 500 ppm CO2 and 400 ppmCO2 compared to natural and ambient. These results may be due to effect of higher CO2 levels which stimulate good vegetative growth of crops and consequently increase the fresh and dry weight or biomass accumulation under high CO2 level there finding are supported by the finding of Meena kumari et. al. (1997)

In the present investigation highest number of pods per plant in pigeon pea and black gram was under 500 ppm CO2 level over rest of the treatments. This may be due to the fact that more photosynthesis rate is there when CO2 is high. So if more photosynthesis will happen then more proteins, carbohydrates amino acids will be there & these compounds are the building blocks of the main structural component of the plant which ultimately affect the yield by increased number of pods per plant. This results can be supported by the results of Ackerson et. al. (1984) who reported that more number of pods and seeds per plant are produced under CO2 enrichment which attributed the high seed yield. Also similar findings were made by Meena Kumari et. al. (2019) in pea crop.

In present findings increase in pod yield at elevated CO2 levels of 500ppm and 480ppm were mainly attributed to increase in number of pods and grains form improved branching and greater number of pods on branches the present results are in agreement with the finding of Ainsworth et.al. (2002) who reported that yield of soybean increased by 24 per cent due to effects of doubled CO2 over ambient CO2 .The findings of Meena Kumari et.al. (2019) also suppose these results by adding that the pod yield and grain yield increased as elevated CO2 & temperature.

Grain yield at elevated CO_2 levels of 500ppm and 480ppm were mainly attributed to increase in number of pods and grains form improved branching and greater number of pods on branches the present results are in agreement with the finding of Ainsworth *et.al.,* (2002) who reported that yield of soybean increased by 24 per cent due to effects of doubled CO_2 over ambient CO_2 . The findings of Kumari *et.al.*, (2019) also support these results by adding that the pod yield and grain yield increased as elevated CO_2& temperature. Chowdhury *et al.*, (2005) also concluded that elevated CO_2 enhanced greatly the mung bean productivity. The better performance of mung bean plant due to high level of CO_2 was supported by the faster rate of photosynthesis, especially at flowering stage. Vanaja *et. al.,* (2015) found that three pigeon pea (*Cajanus cajan* L. Millsp.) genotypes – ICPL-88039, GT-1, and AKP-1 – with varying crop duration, growth habit and flowering pattern were grown at ambient (390 ppm) and elevated (550 ppm) CO_2 levels in Open Top Chambers (OTCs) to assess the variability in their responses for phenology, physiology, biomass and seed yield parameters.

5. Conclusion

The observed data indicated a significantly positive effect of CO_2 and temperature, individually as well as in combination, on the studied growth characteristics, viz. plant height, leaf area and aboveground biomass. Elevated CO_2, either alone or in combination with elevated temperature.

The increment in grain yield over the ambient was however higher in treatments with CO_2 elevation than temperature elevation. About 24% increase in grain yield was reported in rice under elevated CO_2 in OTCs. The significantly higher number of pods and seeds per plant as observed in the present experiment might be responsible for higher grain yield under elevated CO_2 and/or temperature conditions. The increase in sink capacity is also because of a significantly higher seed index under elevated CO_2 and/or temperature compared to ambient. Our observations are in agreement with several other reports. Similar to our findings, Pereira-Flores *et al.*[19] reported 11% increase in 1000 grain weight in soybean under elevated temperature (2.7^{0}C above ambient) and by 13.5% under the combined effect of elevated CO_2 (750ppmv) and elevated temperature. The results showed that both the crops pigeon pea and black gram recorded significant positive enhanced response for total biomass, grain yield and fodder yield.

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Table 1 **Effect of elevated CO_2 levels on plant height (cm) & number of branches plant^{-1} of pigeon pea and black gram**

Treatment combination	**Treatments**	**Plant height (cm)**			**Number of branches plant^{-1}**		
		30 das	**60 das**	**Harvest**	**30 das**	**60 das**	**Harvest**
Group-1 Pigeon pea (P)	**Mean**	**44.33**	**107**	134.75	**4.75**	**30.91**	**19.33**
PC_1	C_1: CO_2- ambient (400 ppm)	36.00	90.33	117.33	2.33	21.33	12.67
PC_2	C_2: CO_2-450 ppm	51.00	101.67	128.33	6.00	33.33	19.00
PC_3	C_3: CO_2- 500 ppm	53.67	145.00	173.33	7.67	36.00	29.00
PC_4	C_4 :CO_2- Natural	36.67	91.00	120.00	3.00	33.00	16.67
S.E m.±		**0.45**	**1.97**	**4.48**	**0.32**	**1.07**	**0.43**
C.D. (5%)		**1.35**	**5.99**	**13.59**	**0.96**	**3.26**	**1.32**
Group-2Blackgram (B)	**Mean**	**27.62**	**45.75**	49.25	**4.58**	**11.67**	**14.33**
BC_1	C_1: CO_2- ambient (400 ppm)	24.00	42.33	39.33	3.33	8.00	13.00
BC_2	C_2: CO_2-450 ppm	30.27	46.00	53.00	5.00	12.00	15.00
BC_3	C_3: CO_2- 500 ppm	31.20	49.33	59.00	5.33	15.67	15.33
BC_4	C_4 :CO_2- Natural	25.00	45.33	45.67	4.67	11.00	14.00
S.E m.±		**0.45**	**1.97**	**4.48**	**0.32**	**1.07**	**0.43**
C.D. (5%)		**1.35**	**5.99**	**13.59**		**0.96**	**3.26**

Table 2 : **Effect of elevated CO_2 levels on number of pods plant^{-1}, number of grains pod^{-1} , pod length (cm) & pod weight (g plant^{-1}) of pigeon pea and black gram**

Treatment combination	**Treatments**	**Number of pods plant^{-1}**	**Number of grains pod^{-1}**	**Pod Length (cm)**	**Pod Weight (g plant^{-1})**
Group-1 Pigeon pea (P)	**Mean**	**63.50**	**5.00**	6	133.6667
PC_1	C_1: CO_2- ambient (400 ppm)	36.67	4.00	5.33	113.33
PC_2	C_2: CO_2-450 ppm	64.67	5.00	6.00	122.00
PC_3	C_3: CO_2- 500 ppm	109.67	6.33	7.00	180.00
PC_4	C_4 :CO_2- Natural	43.00	4.67	5.67	119.33
S.E m.±		**2.86**	**0.31**	**0.18**	**4.79**
C.D. (5%)		**8.69**	**0.93**	**0.55**	**14.52**
Group-2Blackgram (B)	**Mean**	**29.58**	**6.00**	4.88	26.08
BC_1	C_1: CO_2- ambient (400 ppm)	19.00	5.00	4.33	16.67
BC_2	C_2: CO_2-450 ppm	29.00	6.67	5.00	25.53
BC_3	C_3: CO_2- 500 ppm	47.00	7.00	5.33	38.17
BC_4	C_4 :CO_2- Natural	23.33	5.33	4.83	23.93
S.E m.±		**2.86**	**0.31**	**0.18**	**4.79**
C.D. (5%)		**8.69**	**0.93**	**0.55**	**14.52**

Table 3 **Effect of elevated CO_2 levels on crop duration & yield (g plant^{-1}) of pigeon pea and black gram**

Treatment combination	**Treatments**	**Crop Duration**	**Yield (g plant^{-1})**	
			Grain	**Straw**
Group-1 Pigeon pea (P)	**Mean**	111.5833	**107.91**	**230.08**
PC_1	C_1: CO_2- ambient (400 ppm)	113.33	99.07	167.00
PC_2	C_2: CO_2-450ppm	111.00	109.00	202.00
PC_3	C_3: CO_2- 500ppm	102.33	120.67	318.00
PC_4	C_4 :CO_2- Natural	119.67	102.90	233.33
S.E m.±		**0.79**	**2.74**	**1.16**
C.D. (5%)		**2.4**	**8.30**	**3.51**
Group-2Black gram (B)	**Mean**	84.92	**14.08**	**34.70**
BC_1	C_1: CO_2- ambient (400 ppm)	85.00	9.00	29.97
BC_2	C_2: CO_2-450ppm	83.33	13.00	36.15
BC_3	C_3: CO_2- 500ppm	81.00	23.63	37.40
BC_4	C_4 :CO_2- Natural	90.33	10.67	35.28
S.E m.±		**0.79**	**2.74**	**1.16**
C.D. (5%)		**2.4**	**8.30**	**3.51**