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RESEARCH ARTICLE

Variability in Phenology, Physiology and Yield Response of Different Maturity Duration Pigeon Pea Genotypes at Elevated CO_2

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Abstract 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. It was observed that elevated CO_2 significantly increased the photosynthetic rate (A_{net}), decreased the transpiration rate and increased water use efficiency (WUE). Higher impact of elevated CO_2 on the earliness of flowering was observed as the duration of the genotype was increased. 50% flowering at 550 ppm was early by 1.3 days in ICPL-88039 and 12 days in GT-1 and 20 days in AKP-1 as compared with ambient. All the selected genotypes improved their biomass and seed yield with elevated CO_2; however, the response of individual component and magnitude of the response was genotype specific. As the duration of the pigeon pea genotypes was increasing from extra-short to short and short-medium, the response of vegetative biomass was increasing under elevated CO_2 as compared with reproductive biomass and influencing the harvest Index (HI).

Keywords Net photosynthetic rate, Stomatal conductance, Transpiration rate, WUE, Biomass, HI

1. Introduction

With expected increase in atmospheric CO_2 from current concentration of 390 ppm to 550 ppm by 2050 (Carter *et al*., 2007) and different manifestations of its impact on plant production, the researchers need to consider the direct effects of increasing atmospheric CO_2 concentrations on crop enhancement efforts (Ainsworth *et al.,* 2008; Hatfield *et al.,* 2011; Tausz *et al*., 2013).

The efforts to improve the productivity and production of pulse crops are the need of the hour in order to meet the demand of food requirement especially the supply of pulses as protein source. An almost stagnation in the productivity of majority of the pulse crops and their sensitivities to both biotic and abiotic stresses as well as climate extremes made this task further difficult. Pigeon pea is widely cultivated in tropical and subtropical climates of the world mostly in drier areas and is the sixth most important legume crop. Currently the popularity of this crop is on the rise in many countries due to its multiple uses as a source of food, feed, fuel and fertilizer.

The present investigation was aimed to assess the effects of elevated CO_2 on variability in phenology, physiology, biomass and yield parameters of pigeon pea genotypes.

2. Materials and Methods

2.1 Plant Material and Experimental Design

Three pigeon pea genotypes (*Cajanus cajan* L. Millsp.) ICPL-88039, GT-1 and AKP-1 with varying crop duration, growth habit and flowering pattern are selected to assess their response to elevated CO_2 in terms of phenology, physiology, biomass and yield. ICPL-88039 is an extra-short duration genotype with spreading plant habit and indeterminate flowering pattern obtained from ICRISAT, Hyderabad. GT-1 was short duration genotype with spreading plant habit and determinate flowering pattern and AKP-1 was short-medium genotype with spreading semi-determinate flowering pattern and was obtained from IIPR, Kanpur.

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These contrasting genotypes were raised in open top chambers (OTCs) at two CO_2 levels i.e. ambient (390 ppm) and elevated (550 ppm) during kharif 2013. The OTCs having 3m´3m´3m dimensions lined with a transparent polyvinyl chloride (PVC) sheet having 90% transmittance of light were used. The elevated CO_2 level of 550 ppm was maintained in two OTCs and the other two OTCs without any additional CO_2 supply served as ambient control. The CO_2 concentrations within the OTCs were maintained and monitored continuously throughout the experiment as illustrated by Vanaja *et al*. (2006a). Every chamber has six plants of each genotype planted with 0.30 m spacing within row and 0.90 m between rows. The crop was irrigated at regular intervals and maintained pest and disease free with plant protection measures.

2.2 Physiological Parameters

Net photosynthetic rate (A_{net}), stomatal conductance (g_s), and transpiration rate (T_r) were measured with a portable photosynthesis system (LI-6400, LI-COR) at the vegetative stage on a fully expanded young leaf of the three plants for each genotype at the two CO_2 levels. Photosynthetic measurements were performed between 10:00 and 12:00 hours, with irradiance set to 1200 µmol m^{-2} s^{-1} and the CO_2 concentration was maintained in the leaf chamber similar to the growth condition by inserting a CO_2 cylinder. Water use efficiency (WUE) was calculated as the ratio of A_{net} and T_r using the formula $WUE = A_{net} / T_r$.

2.3 Phenological Observations

The phenological observations of days to 50% flowering and 50% poding of individual genotype were recorded at each CO_2 level.

2.4 Biomass and Yield Parameters

At maturity, three plants for each genotype at each CO_2 level were uprooted and separated into different plant components. The roots were washed carefully to make them free from adhered soil particles and were used for biomass estimation. The biomass of leaves and stems was measured after drying them in a hot air oven at 55°C till constant weights were attained. The data on yield parameters such as per plant pod number, pod weight, seed number, seed weight and test weight (100 seed weight) were recorded. From the recorded data sets total biomass, vegetative biomass, reproductive biomass and HI was calculated.

The analysis of variance (ANOVA) was carried out to assess the significance of CO_2 levels and genotypes and their interaction for the traits studied.

3. Results and Discussion

The study showed that the response of selected pigeon pea genotypes was different with elevated CO_2 for all the physiological, growth, biomass and yield parameters.

3.1 Physiological Parameters

Elevated CO_2 significantly increased the photosynthetic rate (A_{net}) in ICPL-88039 (14%), GT-1 (22%) and AKP-1 (29%) (Table 1). It is linearly increased from extra-short to short-medium duration genotypes at elevated CO_2 levels (Figure 1A). The response of stomatal conductance of three genotypes was found to be different with elevated CO_2 and reduced g_s values were recorded for AKP-1 (10%) (Figure 1B) and ICPL 88039 (13%) whereas GT-1 recorded increased g_s by 10%. A similar decrease in g_s of soybean crop was observed with elevated CO_2 (Rogers *et al*., 2004). Enhanced CO_2 condition reduced the transpiration rate in all the three pigeon pea genotypes as compared with ambient control and the lowest observed in GT-1 (4%) followed by ICPL 88039 (5%) and AKP-1 (10%) (Figure 1C). The genotypes, CO_2 levels and genotypes×CO_2 levels are significant for A_{net} and non-significant for g_s and T_r revealing that the enhanced CO_2 impact is more for A_{net}. With increased A_{net} and decreased T_r under elevated CO_2 condition, the WUE of all the three genotypes improved (Figure 1D). In rice, a significant increase in P_N and WUE at elevated CO_2 conditions whereas reduced evapo-transpiration was reported (Baker and Allen, 2005). The higher improvement of WUE in GT-1 (33%) was mainly due to its better response of A_{net} to elevated CO_2 levels rather reduction in T_r. Significant increase in biomass, WUE and yield of soybean at elevated CO_2 conditions was reported by Booker *et al*. (2004). In majority of C_3 plants, the increased photosynthesis at elevated CO_2 condition results in increased plant biomass and the response of nitrogen fixing legumes is higher compared with other non-leguminous C_3 crops (Vanaja *et al*., 2006b; Rogers *et al*., 2009).

3.2 Phenology

Elevated CO_2 influenced the phenology of flowering and poding in the selected pigeon pea genotypes. In extra-short genotype ICPL-88039, the 50% flowering was early by 1.3 days while no change in days to 50% poding was observed. In AKP-1-short-medium genotype it was 12 days and 16 days for 50% flowering and 50% poding respectively. In short duration genotype GT-1, the earliness to 50% flowering and 50% poding was 20 days and 10 days respectively as compared with the performance of respective genotypes at ambient control condition (Figure 2A). In potato (*Solanum tuberosum*) 5–7 days earlier flowering was recorded at elevated CO_2 levels in Free Air Carbon Dioxide Enrichment (FACE) experiments (Miglietta *et al*., 1998). The effect of CO_2 on growth and development has been studied in many crop species. Springer and Ward (2007) reviewed

Table 1 Physiological, biomass and yield traits under ambient (390 ppm) and elevated (550 ppm) CO_2 conditions of different pigeon pea genotypes

Parameters	ICPL-88039extra-short		GT-1short		AKP-1short-medium		Significant differences		
	CO_2^a	CO_2^e	CO_2^a	CO_2^e	CO_2^a	CO_2^e	G	CO_2	$G´CO_2$
Physiological									
Photosynthetic rate	36.5	44.5	35.9	46.1	39.2	44.6	ns	**	ns
Stomatal conductance	0.569	0.499	0.518	0.569	0.569	0.513	ns	ns	ns
Transpiration rate	11.12	10.54	11.51	11.06	11.74	10.55	ns	ns	ns
Water use efficiency	3.41	4.38	3.21	4.27	3.37	4.4	ns	**	ns
Biomass									
Vegetative biomass (g/pl)	227.8	203.5	880.8	806.3	578.2	1211.0	**	**	**
Reproductive biomass(g/pl)	30.5	63.4	126.2	432.8	327.3	481.3	**	**	**
Total biomass (g/pl)	258.3	266.8	1007	1239.1	905.6	1692.3	**	**	**
Yield									
Pod number/pl	95.3	162.3	243	599.6	996.6	1330.2	**	**	**
Number of seed/pl	207.6	400.0	562	1658	1645	2794.3	**	**	**
Pod weight (g/pl)	30.5	63.4	126.2	432.6	327.3	481.8	**	**	**
100 seed weight (g)	9.5	9.2	12.3	12.6	11.2	11.3	**	ns	ns
Seed yield (g/pl)	20.9	42.1	76.0	217.3	208.2	296.5	**	**	**
Harvest Index (%)	8.1	15.8	7.6	17.5	23.0	17.5	**	**	**

Note: ns – non-significant; G – genotypes, CO_2 – CO_2 levels.

$^aCO_2$ – ambient (390 ppm), $^eCO_2$ – elevated (550 ppm) CO_2 conditions, *Significant at $P< 0.05$, **Significant at $P<0.01$.

the effect of CO_2 on flowering time in 23 crop species from 33 research papers with experiments conducted in growth cabinets/glasshouses, OTCs, and field-based FACE facilities and stated that half of the studies showed earlier flowering. This early flowering was observed in short day plants such as soybean (*Glycine max*), rice (*Oryza sativa*), and cowpea (*Vigna unguiculata*) as well as in long-day plants such as barley (*Hordeum vulgare*), pea (*Pisum sativum*), and faba bean (*Vicia faba*) species.

3.3 Biomass and Yield Components

The three pigeon pea genotypes showed highly significant ($P>0.01$) positive response to elevated CO_2 for both biomass and seed yield components (Table 1). At harvest, the genotypes differed significantly ($P>0.01$) in their response for all the parameters and their interaction with CO_2 levels was also highly significant ($P>0.01$). Among the three genotypes, ICPL-88039 has lowest values for total biomass, pod number and seed yield whereas AKP-1 has highest values under both ambient and elevated CO_2 conditions. It was interesting to observe that with enhanced CO_2 condition, the proportion of vegetative biomass significantly decreased and reproductive biomass increased with ICPL-88039 and the reverse was with AKP-1, and it influenced the HI in a similar pattern.

A different response pattern of leaf, stem, root and pod weights of three pigeon pea genotypes was observed with elevated CO_2. The total biomass improved with elevated CO_2 in all the three genotypes and the contribution of pod weight was significant though, the magnitude varied with genotype. In genotype GT-1, the improvement in total biomass (23.4%) at elevated CO_2 condition was solely contributed by improved pod weight (245%) whereas the biomass of leaf (-39%), stem (-2.2%), and root (-8.4%) decreased (Figure 2B). Marginal improvement of total biomass (3.3%) at elevated CO_2 condition in genotype ICPL-88039 was mainly contributed by improved leaf biomass (137%) and pod weight (108%) while the biomass of stem (-41%) and root (-49%) reduced. The genotype AKP-1 recorded highest improvement (87%) in total biomass which has also highest *per se* total biomass under both ambient and elevated CO_2 conditions. It is very prominent that with elevated CO_2 this is the only genotype that has recorded the improved biomass of all the components – leaf (30%), stem (119%), root (131%) and pod (47%). Mung bean recorded higher biomass at elevated CO_2 conditions (Das *et al*., 2002). The pulse crops are sensitive to abiotic stresses and flower and pod drop with stress conditions lead to reduction in yield. The seed yield in these crops mainly contributed by number of pods per plant, seed number and test weight. The seed yield of

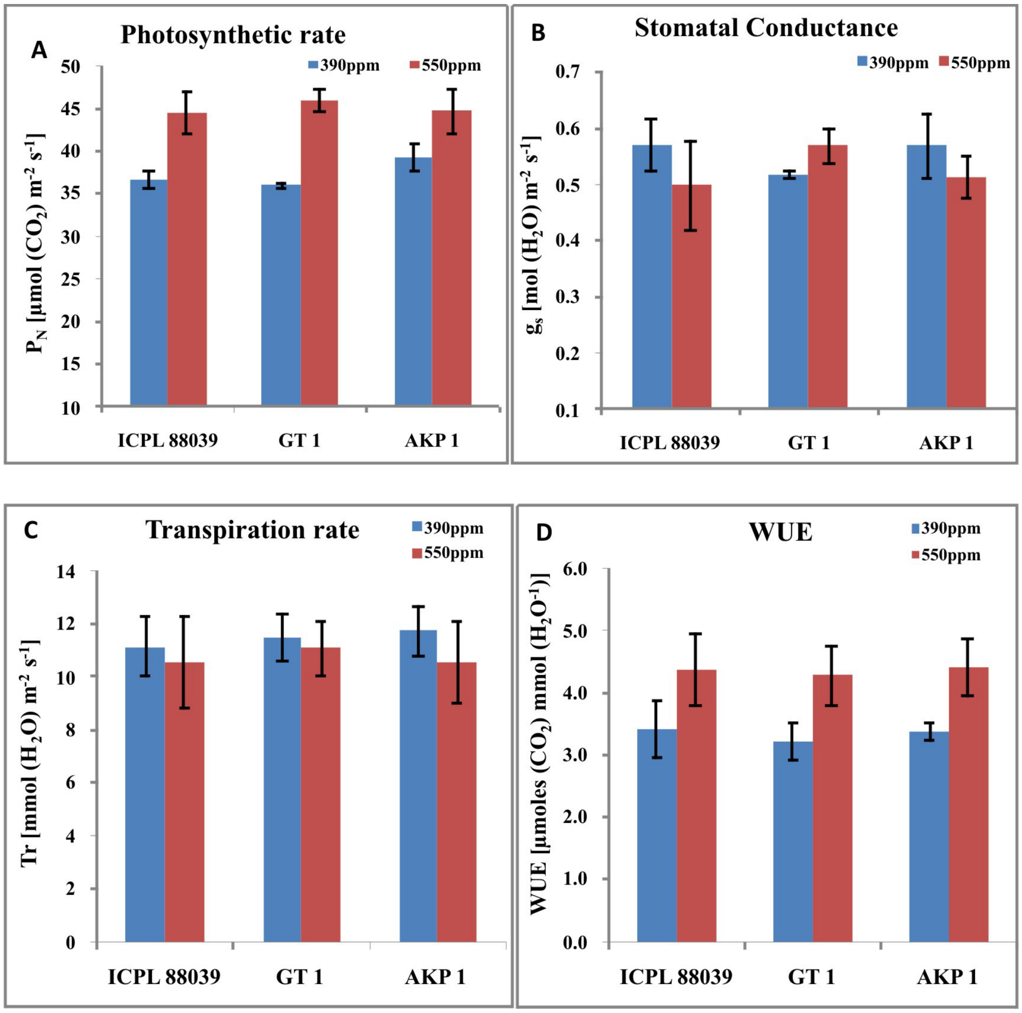

Figure 1 (A) Photosynthetic rate, (B) stomatal conductance, (C) transpiration rate, (D). WUE of pigeon pea genotypes – ICPL-88039, GT-1 and AKP-1 – at ambient (390 ppm) and elevated (550 ppm) CO_2 levels

selected three pigeon pea genotypes improved significantly (P>0.01) with 550 ppm CO_2 and GT-1 recorded the highest (185%) response. The highest seed yield response of genotype GT-1 to elevated CO_2 was mainly due to the significant improvement in pod number (147%), pod weight (246%) and seed number (228%). With increased seed number, it also recorded an improvement in test weight (2.8%). In mung bean and soybean, significant increases in pod number, pod weight and total seed weight were reported at elevated CO_2 concentration (Ziska and Blowsky, 2007; Hao *et al*., 2012). The superior yield response of GT-1 at elevated CO_2 level was due to better retention of flowers and enhanced flower to pod conversion as well as improved seed filling. Similarly the extra-short duration genotype ICPL-88039 also recorded improved seed yield (101%) with elevated CO_2 along with improved pod number (71%), pod weight (108%) and seed number (97%) whereas the test weight was reduced. The response of reproductive parts of GT-1 and ICPL-88039 with enhanced CO_2 also improved their HI (132% and 95%, respectively). A significant increase in the HI in blackgram was recorded due to the improved partitioning efficiency under elevated CO_2 condition (Vanaja *et al*., 2007). The short-medium duration genotype AKP-1 which has high seed yield potential at ambient condition also recorded improved seed yield from 208 to 297 g/pl with an improvement of 43% at 550 ppm. Though it recorded better response for pod number (34%), pod weight (47%) and seed number (81%) at 550 ppm CO_2, the HI was reduced by 24% due to higher allocation of biomass to stem and root as compared with ambient control. This high biomass and high seed yield short-medium duration genotype response was found to be different from the extra-short and short duration genotypes in proportioning the extra biomass accumulated due to elevated CO_2. Similar increase of dry matter (52%) and seed yield (55%) was recorded in narrow-leafed lupin with elevated CO_2 (Palta and Ludwig, 2000)

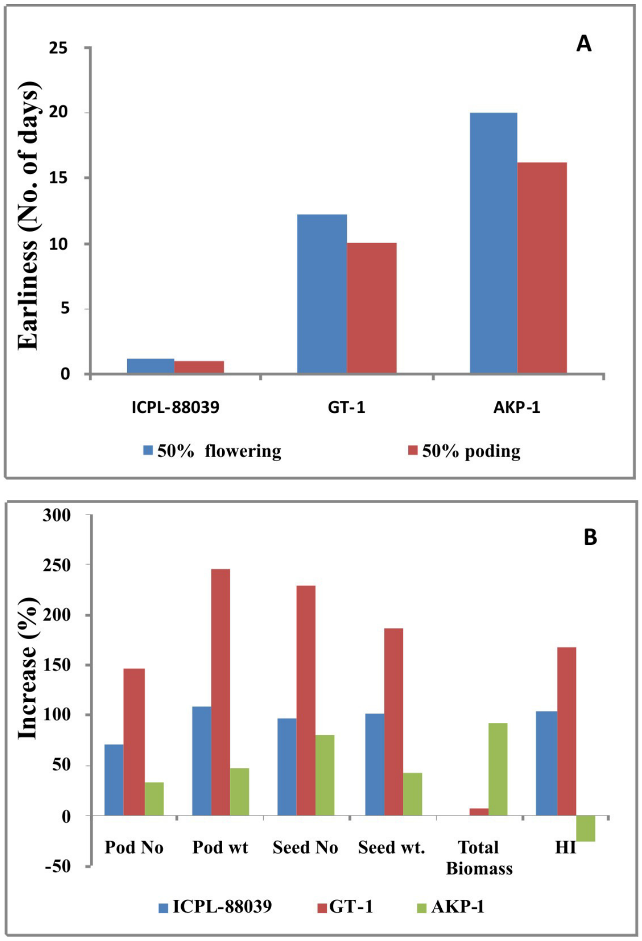

Figure 2 (A) Earliness in phenology (B) % increase of total biomass, seed yield and its components and HI of pigeon pea genotypes – ICPL-88039, GT-1 and AKP-1 – at ambient (390 ppm) and elevated (550 ppm) CO_2 levels

and in soybean cultivars (Hao *et al*., 2012).

Pigeon pea- a C_3 crop registered improved physiological, biomass and seed yield parameters with elevated CO_2 and the magnitude of the response differed with genotype. The three genotypes with varying crop duration, growth habit and flowering pattern responded differently with elevated CO_2. The phenology of flowering was early with elevated CO_2 and it was more prominent with short and short-medium duration genotypes when compared with extra-short genotype. The enhanced CO_2 improved A_{net} and reduced T_r, thereby improving the WUE of all the three genotypes, and highest values for WUE were recorded at 550 ppm with the genotype having highest A_{net}. The improvement of yield components was found to be more with short duration genotype GT-1 followed by extra-short (ICPL-88039) and short-medium (AKP-1), and the reverse trend was observed for biomass. This clearly indicated that as the crop duration is increased, the plants tend to accumulate more vegetative biomass than reproductive biomass under elevated CO_2 condition, and hence reduced HI.

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