Indian Journal of Agricultural Sciences **86** (3): 414–7, March 2016/Article
https://doi.org/10.56093/ijas.v86i3.57037

Impact of elevated CO_2 on high temperature induced effects in grain yield of chickpea (*Cicer arietinum*)

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Received: 28 August 2015; Accepted: 25 February 2016

ABSTRACT

High temperature and increasing atmospheric CO_2 are debatable issues under climate variability and of major concern for agricultural productivity. Field experiments were conducted with two chickpea (*Cicer arietinum* L.) genotypes, viz. Pusa 1103 (*desi*) and Pusa 1105 (*kabuli*) to examine the role of elevated CO_2 (570±86 µmol/mol) and high temperature (5.93±0.22°C above ambient) on yield and biomass using Open top chambers and temperature tunnel respectively. Elevated CO_2 enhanced the grain yield and biomass of both the chickpea genotypes by 34-47 and 39-55 percent respectively while, high temperature exposure reduced the yield of both the genotypes by 19-30 percent. Among genotypes, counter effect of CO_2 to high temperature is more prominent in *desi* compared to *kabuli* which was attributed with more partitioning of assimilates toward pods in *desi*. While in *kabuli* genotypes the biomass partitioning was more towards vegetative plant parts attributing enhanced biomass. Study concludes that elevated CO_2 could ameliorate the reductions in yield under high temperature by more dry matter partitioning towards pods instead of temperature induced partitioning towards vegetative plant parts.

Key words: Biomass partitioning, Chickpea, *Cicer arietinum*, Elevated CO_2, High temperature, Yield

Global warming beyond a certain limit may be serious for agricultural productivity because of extreme weather conditions.Temperature of earth surface is projected to increase by 2 to 4.5ºC and increase in *rabi* season temperature will be more than increase in *kharif* season.This is because of increased concentration of the green house gases; among these CO_2 concentration is increasing rapidly and will reach to 500 to 1000 µmol/mol by the end of 21st century (IPCC 2014). Studies on different crops have shown an increase in crop growth, biomass and yield in response to elevated CO_2 (Kant *et al*. 2012, Shimono and Okada 2013). Increase in CO_2 concentration will enhance, Plant growth and dry matter production (Kant *et al*. 2012, Vanaja *et al*. 2010, Wang *et al*. 2013), while high temperature during reproductive development is known to affect floral bud development (Zinn *et al.* 2010) and seed filling (Boote *et al.* 2005). Wang *et al*. (2006) has reported reduction in biomass and yield of both *desi* and *kabuli* chickpea under high temperature stress. Reduction in grain yield was more as compared to biomass and it was due to reduction in number of pods/plant, number of seeds/pod and seed weight in both *desi* and *kabuli* (Wang *et al*. 2006, Chakrabarti *et al*. 2013).

Chickpea (*Cicer arietinum* L.) is a cool season pulse crop and has been reported sensitive to high temperature (Wang *et al*. 2006). It is a good source of essential amino acids, protein and minerals (Khetarpal *et al.* 2009). Owing to its indeterminate growth nature and biological nitrogen fixation activity it possesses very high sink capacity and can be benefited by elevated CO_2 (Rogers *et al*. 2009). It incurs yield losses when exposed to high temperatures at reproductive stage.Heat stress at reproductive stage is increasingly becoming a serious constraint to chickpea production (Wang *et al*. 2006, Bahuguna *et al*. 2012). The information on the response of chickpea to climate change is scanty; therefore the present study was planned to analyze the effect of elevated CO_2 and temperature on biomass and yield of two high yielding chickpea genotypes, viz. Pusa 1103 (*desi*) and Pusa 1105 (*kabuli*).

MATERIALS AND METHODS

Two experiments were carried out during the *rabi* season of 2012-13 at Indian Agricultural Research Institute, New Delhi, India (28°35´N latitude, 77°12´E longitude and 228.16 m above mean sea level) with two chickpea genotypes, viz Pusa 1103 (*desi*) and Pusa 1105 (*kabuli*) planted in soil inside Open Top Chambers (OTCs) and temperature tunnels. The seeds were surface sterilized (0.1% $HgCl_2$ (w/v) and treated with 1% bavistin (w/v) to remove the surface contamination and sown following standard agronomic practices and irrigation was given to maintain moisture level at field capacity.

In OTCs, plants were exposed to elevated CO_2; eCO_2 (570±45 µmol/mol) from emergence onwards as described

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by Pal *et al.* (2004). For control, only pure air was injected inside OTCs and level of CO_2 was recorded as ambient CO_2; eCO_2 (393±35 µmol/mol). There were three OTCs for control and high CO_2 exposure each.

For high temperature treatment plants were raised inside the poly tunnel (15m × 3 m × 2.5m), where the mean day temperature exceeded 5.93±0.22° C above ambient. A similar set of plants were raised under normal environment (ambient temperature) to serve as control.

The concentration of CO_2 inside OTCs and level of relative humidity and temperature inside the OTCs and tunnel were monitored using the NDIR sensors (Topak, USA, for CO_2) and TRH-511 (Ambetronics, India, for RH and temperature) as described by Saha *et al.* (2011).

The shoot biomass, total number of pods, pod weight and seed weight were measured at harvest in one square meter area. Dry matter partitioning was determined from the dry mass of individual plant parts as a percentage of total plant dry mass at physiological maturity.The data were statistically verified with analysis of variation (ANOVA) and the significance of difference between the means was tested using Duncans post-hoc test at the significance level P≤0.05 using SPSS v.10 for Windows (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

Exposure of chickpea genotypes to eCO_2resulted in a significant enhancement in yield and plant biomass. Shoot biomass of *desi* and *kabuli* increased by 39% and 55% respectively (Table 1), higher biomass under eCO_2 supports the common prediction of the positive response of all C3 crops to increased CO_2 concentration (Bannayan *et al.* 2009, Pal *et al.* 2014). Under eCO_2 number of pods and seed yield per squre meter increased in both the genotypes (Table 1, Fig 1). CO_2 mediated enhancement in seed yield in *desi* and *kabuli* was 47% and 34% respectively over eCO_2. Increased seed yield was mainly due to increase in number of pods under eCO_2. In soybean increased pod number (Li *et al.* 2013) attributed to the increased seed yield (25.3%) (Hao *et al.* 2014). Under CO_2 enrichment, enhanced dry matter accumulation was attributed due to the partitioning of more assimilated carbon towards the growing organs because extra carbon fixed by the plants under elevated CO_2 translocate to the growing plant parts and ensure full

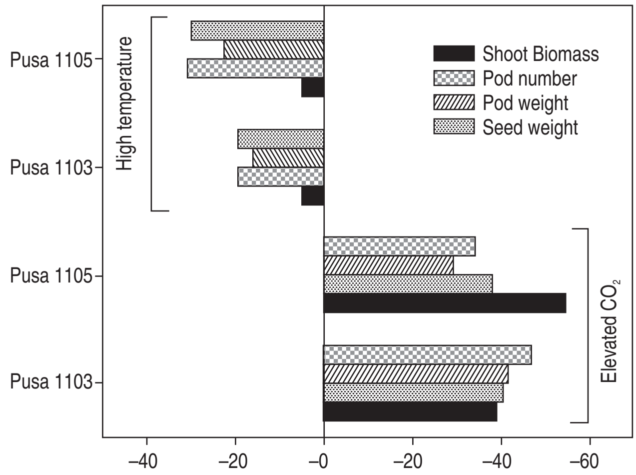

Fig 1 Cumulative response of chickpea genotypes under eCO_2 and high temperature across different condition on different yield traits. Calculations of percentage difference over ambient condition were performed keeping the same experimental setup across different experiments.

development of flowers and grains (Madhu and Hatfield 2015). Similar result was found in mungbean and other legume crops, under elevated CO_2 (Vanaja *et al.* 2006, Rogers *et al.* 2009). Ziska and Blowsky (2007) reported increased pod number, pod weight and total seed weight in mungbean under eCO_2. Increase in yield might be due to increased assimilate partitioning toward pods (Fig 2) under CO_2 enrichment as reported earlier (Madhu and Hatfield 2015).

High CO_2 exposure resulted in more dry matter allocation towards above ground parts compare to underground part. Under eCO_2 exposure maximum dry matter allocation was toward pods in *desi* (47%) and *kabuli* (40%) followed by stem (Fig 2.). In *kabuli* no change was observed in the dry matter allocation towards the stem under eCO_2, however dry matter partitioning to leaf reduced by 8% under eCO_2 as compared to eCO_2 (Fig 2), however in *desi* dry matter allocation towards leaf remain same irrespective of the treatments. Our result of dry matter partition is in agreement of previous studies in soybean, dry bean and cowpea under CO_2 enrichment studies (Li *et al.* 2013, Madhu and Hatfield 2015, Hao *et al.* 2014).

Exposure to high temperature had negative effect on

Table 1 Effect of elevated CO_2 (570±86 µmol/mol) and high temperature (5.93±0.22°C above ambient) on total biomass and yield attributes of chickpea genotypes, viz. Pusa 1103 (desi) and Pusa 1105 (kabuli)

Genotype	Treatment	Shoot biomass (g/m²)	Number of pods/m²	Pod weight (g/m²)	Seed weight (g/m²)
Pusa 1103	Control	616.5±10.2^{c}	1180.7±17.3^{c}	301.8±3.1^{bc}	360.2±7.3^{c}
	eCO_2	857.2±8.1^{e}	1660.7±23.8^{e}	428.3±13.2^{d}	530.4±8.8^{e}
	eTemp	586.0±2.5^{b}	953.3±5.2^{b}	253.4±17.8^{ab}	290.6±12.6^{b}
Pusa 1105	Control	527.4±4.8^{a}	910.7±6.2^{b}	313.4±12.9^{c}	322.1±4.4^{b}
	eCO_2	816.6±13.2 ^{d}	1259.8±15.2^{d}	405.5±17.1^{d}	432.1±8.7^{d}
	eTemp	501.6±10.7 ^{a}	630.4±27.9^{a}	243.6±28.4^{a}	226.1±18.3^{a}

*Values within the column with the same small letters do not statistically differ by the Duncan's test at P≤0.05

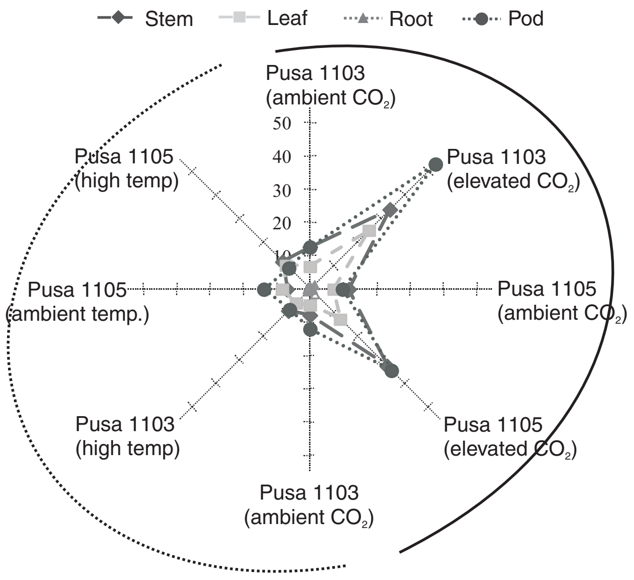

Fig 2 Biomass partitioning of chickpea genotypes viz. Pusa 1103 (desi) and Pusa 1105 (kabuli) under elevated CO_2 (570±86 μmol mol[-1]) and high temperature (5.93±0.22°C above ambient) in different plant parts. Solid arc represents partitioning underCO_2 while dotted arc represent biomass partitioning under temperature experiments.

yield components like plant shoot biomass, number of pods, pod weight, number of seeds, and seed weight (Table 1, Fig 1). Similar trend of reduction in seed yield and dry matter accumulation was reported in soybean under high Temperature (Tacarindua *et al.* 2013). Pusa 1103 (*desi*) showed lesser reduction in yield as compared to Pusa 1105 (*kabuli*). However reduction in shoot biomass and seed weight was more in *desi* (5%, 19.3%) than *kabuli* (5%, 29.8%) respectively under high temperature. These findings are supported by field and simulation studies that showed yield reduction of chickpea with rise in seasonal temperature (Kalra *et al.* 2008, Bahuguna *et al.* 2012, Singh *et al.* 2013). High temperature mediated reduction in pod number was more in *kabuli* (30%) as compared to *desi* (19%) (Table 1, Fig 1). High temperature mediated reduction in seed yield was due to inhibition of photoassimilates remobilization towards grain during grain filling (Wang *et al.* 2006), that attributes to either poor pod set per plant or decreased single-seed weight (Heinemann *et al.* 2006, Tacarindua *et al.* 2013).Yield reduction of approx 30% has been reported in soybean with the increase in temperature by~4°C (Ohe *et al.* 2007). The findings of this study indicate that the *kabuli* is more sensitive to high temperature stress as compared to the *desi* chickpea. Similarly Wang *et al.* (2006) and Bahuguna *et al.* (2012) reported that *desi* chickpea cultivars are more efficient than *kabuli* under both normal and stress conditions and produce more number of pods and seed yield. Craufurd *et al.* (2002) indicated that there is a variation among genotypes in their ability to maintain partitioning under high temperature.

Dry matter partitioning towards grain in both the genotypes was adversely affected by high temperature stress. High temperature significantly reduced the allocation of dry matter towards pods/seeds and in both the genotypes (Fig 2) in agreement with Tacarindua *et al.* (2013) in soybean. Assimilate allocation towards pod reduced to 35% under high temperature as compared to 48% under ambient conditions in *desi* chickpea (Fig 2). In *kabuli* high temperature mediated reduction in the allocation of available carbon assimilates to the seed was by 18% as compared to ambient temperature conditions (Fig 2) as supported by previous studies on other crops (Tacarindua *et al.* 2013).

We conclude that elevated CO_2 exposure enhanced the grain yield and biomass of both the chickpea genotypes while; high temperature exposure reduced the yield of both the genotypes. Counter effect of CO_2 to high temperature is more prominent in *desi* compared to *kabuli* which was attributed with more partitioning of assimilates toward pods in *desi*. While in *kabuli* genotypes the biomass partitioning was more towards vegetative plant parts attributing enhanced biomass. High temperature exposure resulted in decreased dry matter partitioning towards pods in *kabuli* compared to *desi*. Study concludes that elevated CO_2 could ameliorate the reductions in yield under high temperature by more dry matter partitioning towards pods instead of temperature induced portioning towards vegetative plant parts.We do not conclude that these responses are exclusive as the multi-factorial studies are required to confirm the amelioration response of CO_2. Although, these results from different experiments could provide a simple strategic planning for further research on combination experiments under elevated CO_2 and high temperature to work out a realistic yield response in future climate change scenario.

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