Impact of elevated CO₂ on high temperature induced effects in grain yield of chickpea (Cicer arietinum)

PUJA RAI¹, ASHISH K CHATURVEDI², DIVYA SHAH³ and MADAN PAL⁴

Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

High temperature and increasing atmospheric CO₂ 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 CO₂ (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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂, 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 4.5°C 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 CO₂ 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 CO₂ (Kant et al. 2012, Shimono and Okada 2013). Increase in CO₂ 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 CO₂ (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 CO₂ 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% HgCl₂ (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 CO₂, eCO₂ (570±45 µmol/mol) from emergence onwards as described...
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 $P \leq 0.05$ using SPSS v.10 for Windows (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

Exposure of chickpea genotypes to eCO$_2$ resulted 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 square 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 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

![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.](image)

### 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)

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Treatment</th>
<th>Shoot biomass (g/m$^2$)</th>
<th>Number of pods/m$^2$</th>
<th>Pod weight (g/m$^2$)</th>
<th>Seed weight (g/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pusa 1103</td>
<td>Control</td>
<td>616.5±10.2c</td>
<td>1180.7±17.3c</td>
<td>301.8±3.1bc</td>
<td>360.2±7.3c</td>
</tr>
<tr>
<td></td>
<td>eCO$_2$</td>
<td>857.2±8.1e</td>
<td>1660.7±23.8e</td>
<td>428.3±13.2d</td>
<td>530.4±8.8e</td>
</tr>
<tr>
<td></td>
<td>eTemp</td>
<td>586.0±2.5b</td>
<td>953.3±5.2b</td>
<td>253.4±17.8ab</td>
<td>290.6±12.6b</td>
</tr>
<tr>
<td>Pusa 1105</td>
<td>Control</td>
<td>527.4±4.8a</td>
<td>910.7±6.2b</td>
<td>313.4±12.9a</td>
<td>322.1±4.4b</td>
</tr>
<tr>
<td></td>
<td>eCO$_2$</td>
<td>816.6±13.2d</td>
<td>1259.8±15.2d</td>
<td>405.5±17.1d</td>
<td>432.1±8.7d</td>
</tr>
<tr>
<td></td>
<td>eTemp</td>
<td>501.6±10.7a</td>
<td>630.4±27.9a</td>
<td>243.6±28.4a</td>
<td>226.1±18.3a</td>
</tr>
</tbody>
</table>

*Values within the column with the same small letters do not statistically differ by the Duncan’s test at $P \leq 0.05$.
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%, 29.3%) 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 CO2 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 CO2 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 instead of temperature induced portioning towards vegetative plant parts. We do not conclude that these responses are exclusive as the multifactorial studies are required to confirm the amelioration response of CO2. Although, these results from different experiments could provide a simple strategic planning for further research on combination experiments under elevated CO2 and high temperature to work out a realistic yield response in future climate change scenario.

REFERENCES


**Fig 2** Biomass partitioning of chickpea genotypes viz. Pusa 1103 (desi) and Pusa 1105 (kabuli) under elevated CO2 (570±86 μmol mol⁻¹) and high temperature (5.93±0.22°C above ambient) in different plant parts. Solid arc represents partitioning under CO2, while dotted arc represent biomass partitioning under temperature experiments.


Shimono H and Okada M. 2013. Plasticity of rice tiller production is related to genotypic variation in the biomassresponse to elevated atmospheric CO2 concentration and low temperatures during vegetative growth. **Environmental and Experimental Botany** 87: 227–34.


