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Research Article

Elevated CO_2 Promotes Plant Scenscence in *kabuli* Chickpea – A Ground-based Remote Sensing Study

SAURAV SAHA[1]*, VINAY K. SEHGAL[1] AND MADAN PAL[2]

[1]*Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi, 110012*

[2]*Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi, 110012*

ABSTRACT

Impact of elevated CO_2 level (580±20 ppm) was assessed on chickpea in an open top chamber experiment during 2010-11. Elevated CO_2 accelerated photosynthetic assimilation and widen the leaf C: N ratio in chickpea, due to higher grain carbohydrate assimilation under elevated CO_2 condition, with dilution in grain N concentration. Although the net seed protein yield plant^{-1} remained unchanged. It is evident that greater partioning of photosynthate and remobilization of leaf N towards seeds are often inhibited due to sink limitation factor during pod development in chickpea, which accelerated the crop maturity under elevated CO_2 exposure.

Key words: C:N ratio, Seed, Chickpea, Elevated CO_2

Introduction

The global atmospheric CO_2 concentration has risen from ~280 ìmol mol^{-1} (pre-industrial era) to ~398 ìmol mol^{-1} over past 200 years. The rate of increase has accelerated during the last 53 years, increasing from an average of 0.84 ppm yr^{-1} in 1960s to 2.03 ppm yr^{-1} at present (http://www.esrl.noaa.gov/gmd/ccgg/trends/ December 14, 2014). The increasing atmospheric CO_2 concentration in this century has the possibilities to significantly impact on crop growth phenology mostly in C_3 legumes. Atmospheric CO_2 enrichment often resulted in enhanced photosynthetic C acquisition and changes in C allocation in C_3 crops (Kimball *et al*., 2002; Bernacchi *et al*., 2005). That in turn increases C uptake, modifies the sugar signalling pathways and alters the balance of supply and the capacity of plants to use carbohydrates, due to inadequate 'sink' capacity and altered plant metabolism (Wingler *et al*., 2006). This sink limitation condition has the potential to trigger leaf senescence under elevated CO_2 exposure. Senescence is not only characterized by photosynthetic activity but it also plays a vital role in nutrient recycling, especially in the nitrogen remobilization from plant organs capable for photosynthtic C assimilation (source) to developing sink (Himelblau and Amasino, 2001). Reports on the effect of elevated CO_2 on the plant senescence are variable and inconsistent. For chickpea, such reports are the rarely reported. Therefore, we tested the scenescence response potential of *kabuli* chickpea towards the atmospheric CO_2 enrichment using ground based remote sensing techniques.

*Corresponding author,
Email: sauravs.saha@gmail.com
Present address: ICAR Research Complex for NEH Region, Mizoram Centre, Kolasib, 796081, Mizoram

Materials and Methods

Open-top chambers (OTC) experiment on chickpea (Pusa 1105; *kabuli* type) was conducted during the winter (November to mid-April; *rabi)* season of 2010-11 at the research farm of the ICAR-Indian Agricultural Research Institute, New Delhi (28°35' N latitude, 77°12' E longitude, 228.16 m altitude above mean sea level). The design of experiment was a completely randomized block design (CRD) with two treatments (elevated and ambient CO_2 levels) replicated twice. Detailed description of the experimentation may be obtained from Saha *et al*., 2015. In two OTCs, CO_2 was maintained at 580±20 ppm since crop emergence and the other two chambers were used as control (no external supply of CO_2). Chickpea plants were grown in one meter long thin walled perforated polythene container embedded into the soil with upper plastic cover lining over its soil surface in five sub replicates. In two of the OTCs, elevated CO_2 levels were maintained from 6:00 a.m. to 6:00 p.m., since the emergence of the crop. Amount of leaf fall was measured in terms of dry weight of the shaded leaves (per plant basis) from each sub replicates at every 25 days interval staring from 50 days after sowing (DAS). Moderate irrigation (20 mm) was given to the crop based on 20 mm cumulative pan-evaporation to avoid water stress (Saha *et al.*, 2015).

The canopy temperature was monitored using IR thermometer (AG-42, Telatemp Crop., USA), along with periodic spectral signature acquisition using the hand-held spectroradiometer (Field Spec™ 3 having 25° Field of View). Data were processed and exported to Microsoft Excel through ASD View Spec Pro software to calculate Plant Senescence Reflectance Index as $\{(R_{678} - R_{500})/ (R_{750})\}$ (Merzlyak *et al*., 1995), Where R_X is the reflectance at specified wavelength (X, nm). At 50% flowering stage (94 DAS), the physiologically mature third leaf was collected from each of the treatment, oven dried at 65°C for 48 h and ground to get a fine powder form. After harvest, seed yield was recorded and seed samples were ground, processed and analyzed in similar manner. A subsample (leaf and seed) was analyzed for total C and total N content by vario TOC Analyzer of Elementar Analysen Systeme GmbH and micro-Kjeldahl digestion, respectively. Leaf water soluble carbohydrate and total carbohydrate content of ground chickpea seeds was determined by anthrone method (Yemm and Willis, 1954).

Results and Discussion

Leaf C and water soluble carbohydrate content showed a significant rise by 10.3 % ($p < 0.05$) and 45.6% ($p < 0.01$) under elevated CO_2 with significant N dilution of 6.1% ($p < 0.05$) in chickpea leaves at 50% flowering stage (Table 1). Consequently, the leaf C: N ratio increased by 17.5% ($p < 0.05$) along with 9.65% ($p < 0.05$) increase in seed yield (per plant basis) under elevated CO_2 exposure treatment (Table 1). Compositional analysis of chickpea seeds

Table 1. Elevated CO_2 impact on leaf C (%), leaf N (%), leaf C: N ratio, leaf water soluble carbohydrate (mg/ g) content at 50% flowering stage, seed yield, C content (%), N content (%), C:N ratio, seed carbohydrate content and protein yield in chickpea (* $p < 0.05$ & ** $p < 0.01$)

Treatments	C content (%)	N content (%)	C: N ratio	Water soluble carbohydrate (mg g^{-1})
Ambient CO_2	45.07	3.23	13.95	44.82
Elevated CO_2	49.71*	3.03*	16.41*	65.28**

Seed yield (g) $plant^{-1}$	C content (%)	N content (%)	C: N ratio	Carbohydrate content (%)	Net protein yield (g) $plant^{-1}$
10.03	43.71	3.38	12.92	59.28	210.72
11.28*	49.98*	3.01*	16.45*	67.37*	211.51

revealed a significant rise in seed C content (14.2%; $p<0.05$) as well as the carbohydrate accumulation (13.4%; $p<0.05$), but a decrease in grain N content (11%; $p<0.05$). This widened the seed C: N ratio (27.1%; $p<0.05$). De la Mata *et al*. (2012) reported a similar increase in starch and soluble sugar contents (glucose and fructose) as well as C:N ratio due to enhanced photosynthetic CO_2 fixation, mostly during the primary leaf development in sunflower. In this manner, elevated CO_2 resulted in the maintenance of a positive leaf carbon balance that regulated the foliar senescence (discussed later).

Fangmeier *et al*. (2000) observed the reduction in the tissue nitrogen concentrations in the elevated CO_2 exposed barley leaves accelerated senescence due to altered N acquisition and redistribution under variable N supply with significant increase in grain N sink capacity. The net protein yield (grain N accumulation), by contrast, remained unaltered by elevated CO_2 compared to control. The significant increase in leaf assimilation accelerated the remobilization of photosynthates from leaf (sources) to grain (sink) at post flowering stage, which yielded more seed carbohydrate in other C_3 crops *viz.*, wheat (Zhu *et al*., 2009) and spring oilseed rape (Franzaring *et al*., 2011). Furthermore, the greater N-sink in developing chickpea seeds resulted in more N remobilization from leaf by diluting the leaf N concentration. This although conserved the net gain protein yield plant $^{-1}$ (seed N concentration × gain yield per plant × 6.25) but could not maintain the net gain C:N ratio. Similar observations have been reported earlier (e.g. Buchner *et al*., 2015). The seed C sink limitation accelerated the leaf senescence, and generated larger shading of leaves by 62.4% ($p<0.01$) and 16.5% ($p<0.05$) during 124 DAS (pod development stage) and 140 DAS (at maturity) respectively, under the elevated CO_2 condition (Fig. 1). The spectral reflectance confirmed the rise (12.1-15.3%), as reflected in Plant Senescence Reflectance Index values at canopy level for the elevated CO_2 plants during 100-132 DAS (Fig. 2). The indirect impacts of reduced leaf level transpiration under elevated CO_2 might be the indirect cause for premature leaf senescence in chickpea (data not presented). Our observations were in contrast to the reported no alteration effect of elevated CO_2 on canopy senescence evaluated from the hyperspectral reflectance from cotton leaves (Kakania *et al*., 2004). Early senescence under elevated CO_2 was

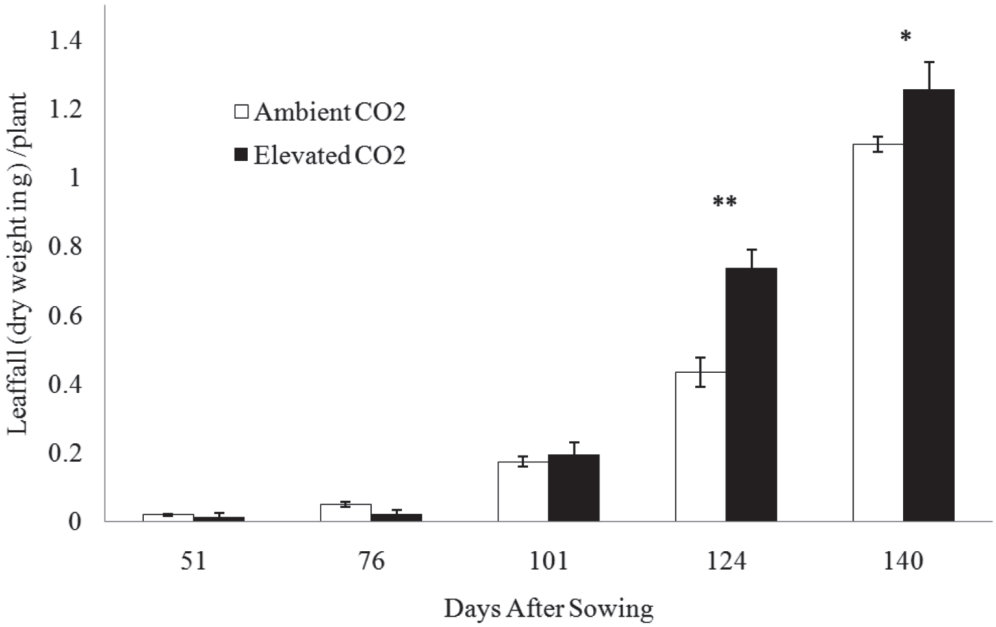

Fig. 1. Variation in amount of leaf fall plant^{-1} in chickpea under elevated and ambient atmospheric CO_2 condition (*$p<0.05$ & ** $p<0.01$)

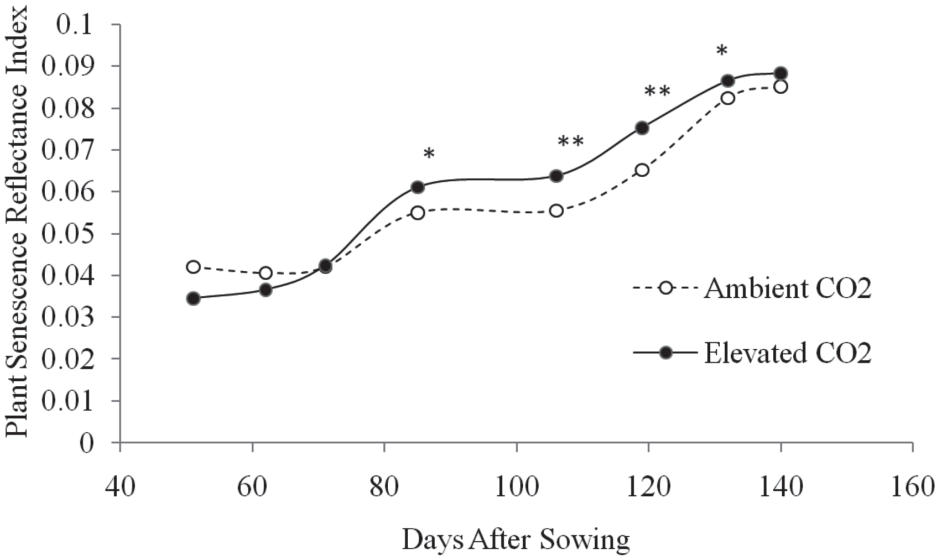

Fig. 2. Variation in Plant Senescence Reflectance Index in chickpea canopy under elevated and ambient CO_2 environment (* $p < 0.05$ & ** $p < 0.01$)

caused by accelerated leaf ontogeny that determined the sugars induced senescence (Wingler *et al*., 2006). We conclude that elevated CO_2 accelerated the leaf senescence as a result of increased soluble leaf carbohydrate levels from higher photosynthetic activity, widening the leaf C:N ratio and significant increase in grain sink capacity, mostly at post flowering stages in *kabuli* chickpea.

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