



Synergistic effects of elevated CO₂ and high temperature on productivity, plant and soil nitrogen in chickpea (*Cicer arietinum*) varieties

BIDISHA CHAKRABARTI^{1*}, SUDHA KANNOJIYA¹, MATHIYARASI K¹, ARTI BHATIA¹,
A SHARMA¹, V KUMAR¹ and R C HARIT¹

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 25 March 2025; Accepted: 20 March 2026

ABSTRACT

An experiment was conducted in temperature gradient tunnels (TGTs) under elevated CO₂ and temperature levels to evaluate their interactive effects on growth, yield, plant nitrogen, and soil nitrogen in chickpea (*Cicer arietinum* L.) varieties during winter (*rabi*) season of 2020–21 and 2021–22 at ICAR-Indian Agricultural Research Institute, New Delhi. Both *desi* (BG 372) and *kabuli* (Pusa 5023) varieties were exposed to temperature rise of 1.1°C and 3.0°C while elevated CO₂ concentration was around 550 ppm. Temperature rise by 3°C significantly reduced LAI_{max} of both the varieties. Temperature rise by 1.1°C did not have any effect on seed yield, but 3°C temperature rise significantly reduced seed yield in both the chickpea varieties. Yield reduction in *kabuli* chickpea was more than in *desi* variety. In elevated CO₂ plus high temperature treatment, reduction in seed N uptake due to temperature rise got compensated by 9.7–15.9% in ‘BG 372’ variety and by 11.4–11.6% in ‘Pusa 5023’ variety. Elevated CO₂ partly mitigated the negative effects of temperature on chickpea yield. Seed N concentration as well as soil available N increased under elevated CO₂ condition, which is attributed to the fact that, chickpea being a leguminous crop can fix more atmospheric N₂ under elevated CO₂ condition. This suggests that, although, high temperature alone reduces yield, plant and soil nitrogen, but when combined with elevated CO₂, yield and nitrogen levels increased in chickpea due to the beneficial effect of higher CO₂ concentration.

Keywords: Leaf area index, Seed nitrogen uptake, Temperature gradient tunnels

Climate change is occurring globally and it is evident with the rise in both temperature and atmospheric carbon dioxide (CO₂) levels. The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) reported that the temperature will rise globally by 3.3–5.7°C by the end of this century (IPCC 2021). Agriculture is one major sector affected by the changing climate. High temperature shortens the crop growth period and might decrease yields while elevated CO₂ concentration enhances crop growth and yield through increased carbon (C) accumulation in crops (Singh *et al.* 2013, Dey *et al.* 2019). Climate change poses a threat to legume productivity by increasing temperatures, altering precipitation patterns, intensifying extreme weather events, and changing pest dynamics (Dave *et al.* 2024). Elevated atmospheric CO₂ levels increase crop productivity and it has been reported that leguminous crops will get advantage over non-legumes under such condition (Rogers *et al.* 2006, Dey *et al.* 2017a). The increase in atmospheric CO₂ concentration also contributes to nutrient assimilation

and the productivity of crops (Gojon *et al.* 2023, Bhardwaj *et al.* 2025). Among different food crops, legumes hold great promise for future as they are the main sources of dietary protein. The significance of legume crops is widely recognized as they fix atmospheric nitrogen, improve soil physical conditions, and also helps in boosting biodiversity (Dhaliwal *et al.* 2020).

Chickpea (*Cicer arietinum* L.) is a very important legume crop grown in around 52 countries (FAO 2018). India is the leading producer of chickpea in Asia with a production of 11.08 mt from 10.94 mha of cultivated area in the year 2020 (Kumar *et al.* 2023). The *desi* and *kabuli* seeds are the two primary genotypes of farmed chickpeas, and they are distinguished by their size, shape, and colour. Production of chickpea is limited by different abiotic stresses like low and high temperature, drought etc. (Jha *et al.* 2014). The changing climate accompanied with increased temperature extremes is a major constraint for this crop as the yield gets significantly affected (Kadiyala *et al.* 2016). Although, chickpea crop adapts to high temperatures, yet high temperature stress during the reproductive period can harmfully affect the crop (Haris and Chhabra 2014). Under late sown condition, the crop experiences high temperature

¹ICAR-Indian Agricultural Research Institute, New Delhi.

*Corresponding author email: bidisha2@yahoo.com

at reproductive and pod filling stages resulting in yield losses (Rani *et al.* 2020). Although, high temperature has several negative effects on chickpea crop, legumes have a competitive advantage over non-legumes grown under elevated CO₂ condition. Under elevated CO₂ condition, legumes fix more amount of atmospheric nitrogen (N₂) resulting in positive yield responses and improved quality of the crop (Dey *et al.* 2017b). Comprehensive reports on the interactive effects of elevated temperature and CO₂ on chickpea are scarce. Therefore, it was hypothesised that elevated CO₂ may partially offset the adverse effects of increased temperature and improve growth, yield, plant nitrogen, and soil nitrogen in *desi* and *kabuli* chickpea varieties.

MATERIALS AND METHODS

The field experiment was carried out during winter (*rabi*) season of 2020–21 and 2021–22 at ICAR-Indian Agricultural Research Institute (28°38'N, 77°09'E; 228.6 m amsl), New Delhi. The climate at the location is semi-arid, subtropical, and subhumid. The experiment was set up in two independent temperature gradient tunnels (TGTs), one with ambient CO₂ levels of 400 ppm. TGTs enable the establishment of a controlled temperature gradient for studying crop responses to different temperature regimes. In the other TGT, CO₂ concentration was elevated to 550 ± 20 ppm by supplying CO₂ gas from cylinders (30 kg capacity), to elevate the atmospheric CO₂ concentration. As CO₂ is used by the plants for photosynthesis during the day, therefore, elevated CO₂ concentration was maintained during 9 AM to 5 PM. The seasonal mean CO₂ concentration in elevated CO₂ treatments ranged from 532–570 ppm during the first year and from 529–571 ppm during second year of study.

Each TGT was made up of UV stabilised 90% transparent polythene sheet and covered an area of 15 m × 2.5 m. Exhaust fans on one side of the tunnels sucked ambient air and released to the other end which helped in developing a temperature gradient inside (Chakrabarti *et al.* 2021). The tunnels were separated into three parts (3 m × 2.5 m) having three different temperature regimes. Temperature sensors were installed in each part and temperature data was logged at every 5 min interval by the data logger. The data was downloaded and seasonal mean temperature was calculated for the different plots. At the inlet point, mean seasonal temperature was less than the other two plots. Hence, temperature elevation in those two plots was calculated as compared to the plot (control plot) near the inlet point. Mean seasonal temperature elevation in those two plots was +1.1°C and +3.0°C as compared to the control plot.

Standard agronomic practices were followed for growing the crop. One *desi* (BG 372) and one *kabuli* (Pusa 5023) variety of chickpea was grown by sowing seeds during second week of November in both the years. Recommended doses of NPK (20:50:20 kg/ha) were applied to the crop during sowing. Two irrigations were applied, one at flowering and the other at pod formation stage.

Plant parameters

Crop growth and yield: Leaf Area Index (LAI) was recorded using Plant Canopy Analyzer LAI 2200C, in the morning for each treatment. The LAI of chickpea varieties was maximum at flowering stage of the crop which was reported as LAI_{max}. LAI_{max} was recorded from five plants in each plot at this stage, and the mean value was reported. After harvest of the crop, both seed and straw weight were recorded.

Percent change in seed yield was calculated for elevated temperature treatments as compared to seed yield recorded in control treatment and represented in graphical form.

Collection and analysis of plant and soil samples: Plant samples were collected after harvest and soil samples were collected at the flowering stage of the crop. Nitrogen concentration in plant samples was determined using the method given by Jackson (1973). Nitrogen uptake in samples was calculated as:

$$\text{Seed N uptake (g/m}^2\text{)} = \text{Seed nitrogen concentration (\%)} / 100 \times \text{seed yield (g/m}^2\text{)}$$

Soil available nitrogen was estimated by the method given by Subbiah and Asija (1956).

Statistical analysis of data: The experiment was laid out in a factorial completely randomised design (F-CRD) with 12 treatments, each having three replications. Data were analysed using the R software, version 4.3.2. The means were compared between the treatments and their interactions by critical difference (CD) at $p \leq 0.05$ level of significance.

RESULTS AND DISCUSSION

Maximum leaf area index (LAI_{max}): Growth of chickpea crop was less under elevated temperature treatment. LAI of both the varieties significantly decreased in elevated temperature treatment. LAI_{max} (maximum LAI) of 'BG 372' variety (*desi*) varied from 3.2–3.5 in control plots. Temperature rise by 3°C reduced LAI_{max} to 2.8–2.9 in T₃ treatment (Fig. 1). In case of 'Pusa 5023' variety, LAI_{max} ranged from 3.0–3.4 in control plots, which significantly reduced to 2.7–2.8 with 3°C temperature rise. In elevated CO₂ plus temperature treatment the reduction in LAI_{max} due to increased temperature, got compensated. LAI_{max} ranged from 3.2–3.3 in 'BG 372' variety, grown under elevated CO₂ concentration even with 3°C temperature elevation. Similarly, LAI_{max} of 'Pusa 5023' variety ranged from 3.0–3.1 under elevated CO₂ concentration with temperature rise of 3.0°C. Elevated CO₂ increases photosynthetic carbon assimilation, leading to greater biomass accumulation and leaf expansion, which results in increased leaf area index of the crop. Sanyal *et al.* (2022b) also reported that leaf area of soybean crop at flowering stage got reduced with temperature rise of 2.5–2.8°C while elevated CO₂ concentration increased leaf area of the crop. No significant difference in LAI_{max} was observed between the two varieties.

Seed yield: Results showed that, both the chickpea varieties (BG 372 and Pusa 5023) were affected over the course of two years by high temperatures. Seed yield of

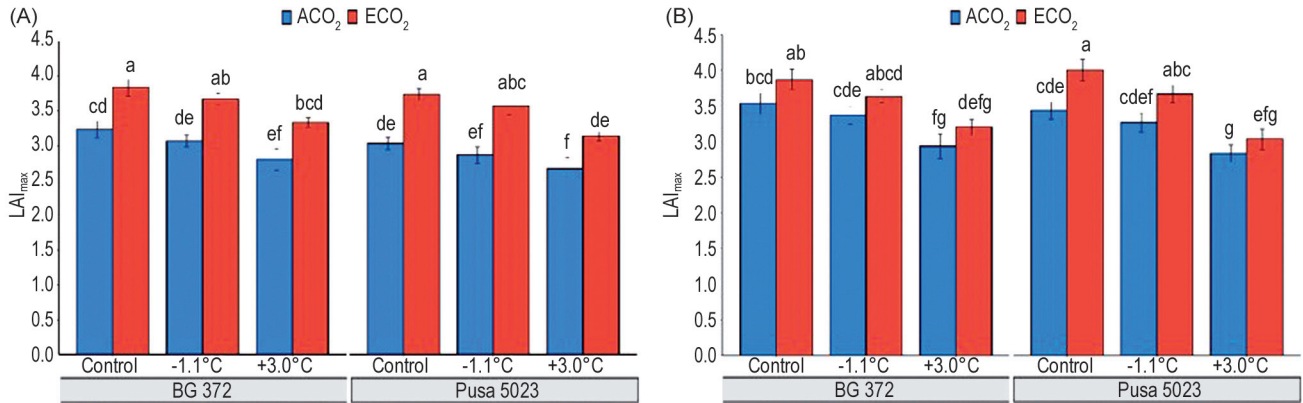


Fig 1 LAI_{max} of chickpea varieties in different treatments during (A) first and (B) second year of study. ACO₂, Ambient CO₂; ECO₂, Elevated CO₂.

chickpea varieties was not significantly affected by 1.1°C rise in temperature. But rise in temperature by 3°C caused significant reduction in seed yield of both the varieties. Seed yield of ‘BG 372’ variety decreased by 9.7–11.6%, while seed yield of ‘Pusa 5023’ variety reduced by 12.1–13.6% with 3°C higher temperature (Fig. 2). Results showed that yield reduction in ‘BG 372’ ranged from 5.3–6.6%, while in ‘Pusa 5023’, it ranged from 6.8–7.9% under elevated CO₂ plus 3°C treatment compared with control temperature plus ambient CO₂; however, the reductions were not statistically significant. This shows that elevated CO₂ concentration of 550 ppm was able to compensate yield loss due to temperature rise of 3°C by 4.4–5% in ‘BG 372’ and by 5.3–5.7% in ‘Pusa 5023’ varieties. Our results indicated that a 3°C rise in temperature negatively impacted chickpea yield, with the *kabuli* variety showing greater sensitivity than the *desi* variety. It was earlier reported that, the reduction in growth in *kabuli* genotypes due to drought stress was more as compared to *desi* genotypes (Farooq *et al.* 2018).

The fertilisation effect of increased CO₂ concentration on crops could offset the harmful effects of increased temperature in future climatic condition (Ainsworth *et al.* 2008). Results reported by Singh *et al.* (2013) indicated that the harmful effect of 4°C temperature rise could be mitigated by elevated CO₂ concentration of 550 ppm in chickpea crop.

Findings of other researchers also highlighted the beneficial impact of increased CO₂ concentration in compensating yield losses in other crops like rice, wheat, mustard, groundnut, green gram, potato etc. due to increased temperature (Singh *et al.* 2013, Maity *et al.* 2022, Sanyal *et al.* 2023).

Seed nitrogen: Nitrogen concentration in chickpea seeds ranged from 3.5–3.9% in ‘BG 372’ and from 3.6–4.0% in ‘Pusa 5023’ under ambient CO₂ and control temperature condition in two years (Table 2). Rise in temperature by 3°C marginally reduced seed N content in both the varieties than control temperature treatment. But seed N concentration significantly increased with increase in CO₂ concentration. In elevated CO₂ treatment with control temperature, seed N content ranged from 4.0–4.6% in ‘BG 372’ variety, and from 4.1–4.7% in ‘Pusa 5023’ variety, while in high temperature treatment (+3°C) seed N content ranged from 3.5–3.8% and 3.4–4.0% in ‘BG 372’ and ‘Pusa 5023’ variety, respectively in the two years of study (Table 2). Similar results in soybean crop were reported by Sanyal *et al.* (2022a), who found that N content in soybean seeds increased under elevated CO₂ concentration while it decreased in high temperature treatment. Earlier studies have reported that legumes gain an advantage over non-legumes under elevated CO₂ conditions (Ross *et al.* 2004, Rogers *et al.* 2006). In the present study, seed N in chickpea varieties increased under elevated CO₂,

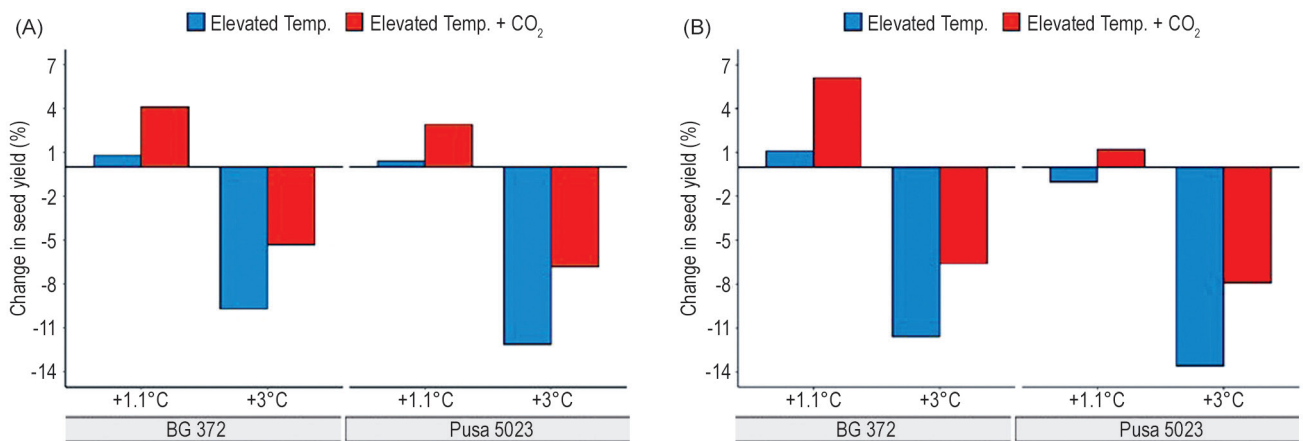


Fig. 2 Change in seed yield in chickpea varieties in different treatments during (A) first and (B) second year of study.

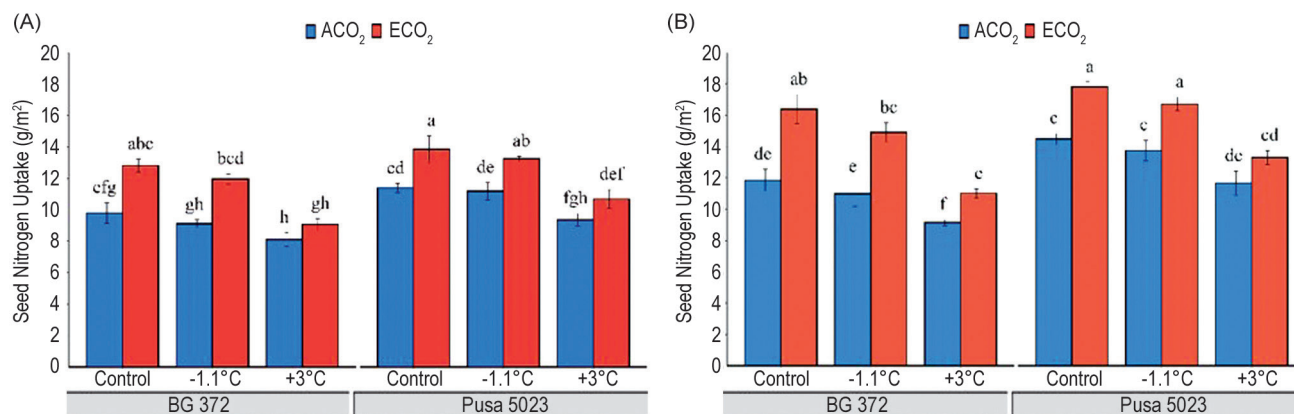


Fig. 3 Seed N uptake in chickpea in different treatments during (A) first and (B) second year of study. ACO₂, Ambient CO₂; ECO₂, Elevated CO₂.

which may be attributed to enhanced photosynthetic carbon assimilation and greater carbohydrate supply to root nodules. This stimulates biological N₂ fixation by rhizobia (Bellido *et al.* 2023, Cabeza *et al.* 2024), leading to increased N assimilation and consequently higher N accumulation in plant tissues and seeds.

Nitrogen uptake in chickpea seeds significantly increased under elevated CO₂ condition, while temperature

rise of 3°C reduced seed N uptake in both the years. High CO₂ concentration, increased seed N uptake of ‘BG 372’ variety by 30.7–38.3% in control temperature treatment while in ‘Pusa 5023’ variety, it increased by 21.5–23.0%. In high temperature treatment (+3°C), seed N uptake reduced by 17.2–22.9% and by 17.9–19.5% in ‘BG 372’ and ‘Pusa 5023’ varieties, respectively (Fig. 3). In high temperature along with elevated CO₂ treatment (+3°C; 550 ppm CO₂),

Table 2 Seed nitrogen and soil available nitrogen in chickpea varieties grown under elevated CO₂ and temperature condition

Treatment	Seed N (%)		Soil available N (kg/ha)	
	1 st yr	2 nd yr	1 st yr	2 nd yr
Control temp. + ambient CO ₂ , ‘BG 372’	3.5 ^b	3.9 ^{cd}	165.8 ^{cd}	176.0 ^{cdef}
Elevated temperature (+1.1°C) + ambient CO ₂ , ‘BG 372’	3.4 ^b	3.7 ^e	158.7 ^{cd}	170.4 ^{def}
Elevated temperature (+3.0°C) + ambient CO ₂ , ‘BG 372’	3.3 ^b	3.7 ^e	134.3 ^e	155.4 ^f
Control temp. + ambient CO ₂ , ‘Pusa 5023’	3.6 ^b	4.0 ^{cd}	175.4 ^{bc}	192.8 ^{cde}
Elevated temperature (+1.1°C) + ambient CO ₂ , ‘Pusa 5023’	3.5 ^b	4.0 ^{cd}	163.3 ^{cd}	180.1 ^{cdef}
Elevated temperature (+3.0°C) + ambient CO ₂ , ‘Pusa 5023’	3.3 ^b	3.8 ^{de}	149.6 ^{de}	167.6 ^{ef}
Control temp. + elevated CO ₂ , ‘BG 372’	4.0 ^a	4.6 ^{ab}	191.1 ^b	202.9 ^{bc}
Elevated temperature (+1.1°C) + elevated CO ₂ , ‘BG 372’	3.9 ^a	4.3 ^{bc}	180.6 ^{bc}	198.3 ^{bcd}
Elevated temperature (+3.0°C) + elevated CO ₂ , ‘BG 372’	3.5 ^b	3.8 ^{de}	162.7 ^{cd}	176.6 ^{cdef}
Control temp. + elevated CO ₂ , Pusa 5023’	4.1 ^a	4.7 ^a	216.2 ^a	244.2 ^a
Elevated temperature (+1.1°C) + elevated CO ₂ , ‘Pusa 5023’	3.9 ^a	4.4 ^{ab}	192.3 ^b	222.6 ^{ab}
Elevated temperature (+3.0°C) + elevated CO ₂ , ‘Pusa 5023’	3.4 ^b	4.0 ^{cd}	175.8 ^{bc}	189.4 ^{cde}
ANOVA	F value			
CO ₂	40.3 ^{***}	52.6 ^{***}	44.5 ^{***}	37.8 ^{***}
Temperature	17.7 ^{***}	20.0 ^{***}	18.2 ^{***}	12.8 ^{***}
Variety	0.01 ^{ns}	1.5 ^{ns}	9.5 ^{**}	14.2 ^{***}
CO ₂ × Temperature	3.1 ^{ns}	6.2 ^{**}	0.29 ^{ns}	1.1 ^{ns}
CO ₂ × Variety	0.01 ^{ns}	0.10 ^{ns}	0.63 ^{ns}	1.6 ^{ns}
Temperature × Variety	0.41 ^{ns}	0.16 ^{ns}	0.39 ^{ns}	0.91 ^{ns}
CO ₂ × Temperature × Variety	0.08 ^{ns}	0.18 ^{ns}	0.35 ^{ns}	0.45 ^{ns}

ns, Non-significant. ***, 5% level of significance.

reduction in seed N uptake got compensated by 9.7–15.9% in ‘BG 372’ variety and by 11.4–11.6% in ‘Pusa 5023’ variety in the two-year study period.

Higher seed N concentration as well as more seed yield in chickpea under elevated CO₂ concentration resulted in higher seed N uptake than ambient treatment. Earlier researchers reported that N uptake in legumes like chickpea and cowpea increased at high CO₂ levels (Dey *et al.* 2017b, Chakrabarti *et al.* 2020). Ainsworth and Rogers (2007) demonstrated that elevated CO₂ increases nitrogen fixation, leading to higher grain protein content in legumes.

Soil nitrogen: Soil available N at flowering stage of the crop decreased with rise in temperature while it increased under elevated CO₂ condition. In ‘BG 372’ variety, soil available N in control temperature with ambient CO₂ treatment ranged from 165.8–176.0 kg/ha during both the years while in ‘Pusa 5023’ variety, it ranged from 175.4–192.8 kg/ha (Table 2). Under high temperature (+3°C) and increased CO₂ concentration of 550 ppm, soil available N ranged from 162.7–176.6 kg/ha in ‘BG 372’ variety and from 175.8–189.4 kg/ha in ‘Pusa 5023’ variety. Chickpea being a leguminous crop might have benefitted under elevated CO₂ condition due to higher N₂ fixation which has resulted in higher available N of soil. Available N of soil under elevated CO₂ is also influenced by enhanced root growth and rhizodeposition, increased microbial activity and N mineralisation, and greater return of plant residues to the soil. Soil available N was significantly higher in ‘Pusa 5023’ than in ‘BG 372’, possibly due to greater biomass production and root growth in the *kabuli* variety, which may have contributed to higher soil available N.

The study concluded that rising temperature (+3°C), adversely affected chickpea growth and yield, with a more pronounced reduction observed in the *kabuli* variety compared to the *desi* variety. However, elevated CO₂ (550 ppm) partly mitigated the negative effects of temperature on chickpea yield by 4.4–5% in *desi* and by 5.3–5.7% in *kabuli* varieties. In elevated CO₂ condition, seed nitrogen concentration increased and higher soil available nitrogen was observed. Overall, the findings suggest that although rising temperature alone is detrimental to chickpea yield and plant nitrogen status, its combined effect with elevated CO₂ can partially offset these negative effects.

ACKNOWLEDGEMENT

The authors acknowledge the funding provided by the National Innovations in Climate Resilient Agriculture, NICRA project (IARI-12-115).

REFERENCES

- Ainsworth EA and Rogers A. 2007. The response of photosynthesis and stomatal conductance to rising CO₂: Mechanisms and environmental interactions. *Plant, Cell and the Environment* **30**: 258–70. <http://dx.doi.org/10.1111/j.1365-3040.2007.01641.x>
- Ainsworth EA, Beier C and Calfapietra C. 2008. Next generation of elevated CO₂ experiments with crops: A critical investment for feeding the future world. *Plant, Cell and Environment* **31**: 317–24.
- Bellido E, de la Haba P and Aguera E. 2023. Responses in nodulated bean (*Phaseolus vulgaris* L.) plants grown at elevated atmospheric CO₂. *Plants* **12**(9): 1828. <https://doi.org/10.3390/plants12091828>
- Bhardwaj A, Prasanna R, Chakrabarti B, Kannojiya S, Kumar M, Ansari W A, Srivastava A K, Kumar V, Bhowmick P K and Shivay Y S. 2025. Diazotrophic cyanobacteria alleviate the impact of elevated CO₂ and beneficially influence the growth of rice. *Discover Plants* **2**: 121. <https://doi.org/10.1007/s44372-025-00199-z>
- Cabeza R A, Perez-Diaz R, Amigo R, Salinas-Roco S, Morales-González A and del Pozo A. 2024. Biomass and nitrogen fixation dataset of *Pisum sativum* L. and *Vicia faba* L. cultivated under elevated CO₂ and nitrogen addition. *Data in Brief* **55**: 110644. <https://doi.org/10.1016/j.dib.2024.110644>
- Chakrabarti B, Bhatia A, Pramanik P, Singh S D, Jatav R S, Das Saha N, Raj A, Joshi R and Kumar V. 2021. Changes in thermal requirements, growth and yield of wheat under the elevated temperature. *The Indian Journal of Agricultural Sciences* **91**(3): 435–39.
- Chakrabarti B, Singh S D, Bhatia A, Kumar V and Harit R C. 2020. Yield and nitrogen uptake in wheat and chickpea grown under elevated carbon dioxide level. *National Academy Science Letters* **43**: 109–13. <https://doi.org/10.1007/s40009-019-00816-y>
- Dave K, Kumar A, Dave N, Jain M, Dhanda P S, Yadav A and Kaushik P. 2024. Climate change impacts on legume physiology and ecosystem dynamics: A multifaceted perspective. *Sustainability* **16**(14): 6026. <https://doi.org/10.3390/su16146026>
- Dey S K, Chakrabarti B, Prasanna R, Singh S D, Purakayastha T J, Datta A and Pathak H. 2017a. Productivity of mungbean (*Vigna radiata*) with elevated carbon dioxide at various phosphorus levels and cyanobacteria inoculation. *Legume Research* **40**(3): 497–505.
- Dey S K, Chakrabarti B, Prasanna R, Pratap D, Singh S D, Purakayastha T J and Pathak H. 2017b. Elevated carbon dioxide level along with phosphorus application and cyanobacterial inoculation enhances nitrogen fixation and uptake in cowpea crop. *Archives of Agronomy and Soil Science* **63**(13): 1927–37. <http://dx.doi.org/10.1080/03650340.2017.1315105>
- Dey S K, Chakrabarti B, Purakayastha T J, Prasanna R, Mittal R, Singh S D and Pathak H. 2019. Interplay of phosphorus doses, cyanobacterial inoculation and elevated carbon dioxide on yield and phosphorus dynamics in cowpea. *Environmental Monitoring and Assessment* **191**(4): 223. <https://doi.org/10.1007/s10661-019-7378-3>
- Dhaliwal S K, Talukdar A, Gautam A, Sharma P, Sharma V and Kaushik P. 2020. Developments and prospects in imperative underexploited vegetable legumes breeding: A review. *International Journal of Molecular Sciences* **21**: 9615.
- FAO. 2018. *FAOSTAT Statistical Database of the United Nation Food and Agriculture Organization*. FAO Statistical Division, Rome.
- Farooq M, Ullah A, Lee D-J, Alghamdi S S and Siddique K H M. 2018. *Desi* chickpea genotypes tolerate drought stress better than *kabuli* types by modulating germination metabolism, trehalose accumulation and carbon assimilation. *Plant Physiology and Biochemistry* **126**: 47–54. <https://doi.org/10.1016/j.plaphy.2018.02.020>
- Gojon A, Cassan O, Bach L and Nacry P. 2023. The decline of plant mineral nutrition under rising CO₂: Physiological and

- molecular aspects of a bad deal. *Trends in Plant Science* **28**(2): 185–98.
- Haris A A and Chhabra V. 2014. Climate change impact on chickpea yield over a sub humid climatic environment. *International Journal of Research in Agricultural Sciences* **1**(4): 2348–3997.
- IPCC. 2021. Summary for Policymakers. (In) *Climate change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 3–32. Cambridge University Press, Cambridge, United Kingdom. 10.1017/9781009157896.001.
- Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall India Pvt. Ltd, New Delhi.
- Jha U C, Chaturvedi S K, Bohra A, Basu P S, Khan M S and Barh D. 2014. Abiotic stresses, constraints and improvement strategies in chickpea. *Plant Breeding* **133**: 163–78. <https://doi.org/10.1111/pbr.12150>
- Kadiyala M D M, Kumara C D, Nedumaran S, Moses S D, Gumma M K and Bantilan M C S. 2016. Agronomic management options for sustaining chickpea yield under climate change scenario. *Journal of Agrometeorology* **18**: 41–47.
- Kumar K N R, Reddy M J M and Babu S C. 2023. Climate change effects on chickpea yield and its variability in Andhra Pradesh, India. *Journal of Applied and Natural Science* **15**(1): 178–93. <https://doi.org/10.31018/jans.v15i1.4102>
- Maity P P, Chakrabarti B, Bhatia A, Kumar S N, Purakayastha T J, Chakraborty D, Sharma A, Kannojiya S and Kumar V. 2022. Elevated carbon dioxide (CO₂) and temperature interaction effect on growth of rice crop. *Journal of Agricultural Physics* **22**(2): 208–14.
- Rani A, Devi P, Jha U C, Sharma K D, Siddique K H M and Nayyar H. 2020. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. *Frontiers in Plant Science* **10**: 1759. 10.3389/fpls.2019.01759
- Rogers A, Gibon Y, Stitt M, Morgan P B, Bernacchi C J, Ort D R and Long S P. 2006. Increased C availability at elevated carbon dioxide concentration improves N assimilation in a legume. *Plant, Cell and Environment* **29**: 1651–58.
- Ross D J, Newton P C D and Tate K R. 2004. Elevated (CO₂) effects on herbage production and soil carbon and nitrogen pools and mineralization in a species-rich, grazed pasture on a seasonally dry sand. *Plant and Soil* **260**: 183–96.
- Sanyal S, Chakrabarti B, Bhatia A, Kumar S N, Purakayastha T J, Kumar D, Pramanik P, Kannojiya S, Sharma A and Kumar V. 2023. Response of *aestivum* and *durum* wheat varieties to elevated CO₂ and temperature under OTC condition. *Journal of Agrometeorology* **25**(4): 498–502.
- Sanyal S, Chakrabarti B, Prasanna R, Bhatia A, Kumar S N, Purakayastha T J, Joshi R and Sharma A. 2022a. Influence of cyanobacterial inoculants, elevated carbon dioxide and temperature on plant and soil nitrogen in soybean. *Journal of Basic Microbiology* **62**(10): 1216–28. <https://doi.org/10.1002/jobm.202200046>
- Sanyal S, Chakrabarti B, Prasanna R, Bhatia A, Kumar S N, Purakayastha T J, Sharma A, Joshi R, Kannojiya S and Sharma D K. 2022b. Growth and yield of soybean as affected by elevated carbon dioxide, temperature and cyanobacterial inoculation. *Journal of Agricultural Physics* **22**(1): 116–22.
- Singh S D, Chakrabarti B, Muralikrishna K S, Chaturvedi A K, Kumar V, Mishra S and Harit R. 2013. Yield response of important field crops to elevated air temperature and CO₂ levels. *The Indian Journal of Agricultural Sciences* **83**(10): 1009–12.
- Subbiah B and Asija G L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Current Science* **25**: 259–60.