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Research Article

Leaf photosynthesis and yield response of winter green gram (*Vigna radiata*) to high temperature and elevated CO_2 in the soil plant atmosphere research (SPAR)

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Abstract
Legumes play an important role in India's food security, inflation rate and export values. Climate variability might significantly affect the growth, development and yield of legume crops in various regions of the globe. The present study investigated the long episodes effect of high temperature and CO_2 and ambient conditions on leaf photosynthesis and yield attributes of green gram (*Vigna radiata*) using soil plant atmospheric research (SPAR). Green gram was grown under high day temperature (HDT) (day maximum temperature + 3^{o}C) and elevated CO_2 (600ppm) (HDT and *e*CO_2), high day and night temperature (HDNT) (day maximum temperature + 3^{o}C) and elevated CO_2 (600ppm) (HDNT and *e*CO_2) and ambient conditions. Leaf photosynthesis, stomatal conductance, transpiration rate and chlorophyll index were significantly (p=0.05) increased by 25%, 24.1%, 23% and 4.6%, respectively, under HDT and *e*CO_2 from 30 to 45 DAS (days after sowing) in comparison with ambient and HDNT and *e*CO_2. The significant increase in number of flowers shed per plant increased under HDNT and *e*CO_2 by 13% during 45 to 60 DAS. The increase in the number of pods per plant and grain yield per plant under HDT and *e*CO_2 during 45 to 60 DAS by 26.9% and 25.7%, respectively. However, the biomass of the green gram was increased under HDNT and *e*CO_2 during 30 to 45 DAS. These studies indicated a significant increase in leaf photosynthesis and yield of green gram under HDT and *e*CO_2 at flower initiation to pod development stage (30 to 60 DAS) followed by HDNT and *e*CO_2 and ambient condition. Overall study indicated that increasing temperature and CO_2 would increase the biomass and yield of the green gram.

Keywords: Elevated CO_2, Green gram, High day and night temperature, High day temperature, Soil plant atmosphere research (SPAR)

INTRODUCTION

Climate projections show that increasing global temperature and CO_2 will affect future pulses production positively or negatively depending on geographical location. Temperature and CO_2 are important factors that decide crop growth and development. Current CO_2 is projected to increase from 420 ppm to 550 to 730 ppm by the end of the 21st century. The average global temperature has increased by 1.1°C compared to pre-industrial era and is projected to increase global average temperature from 2.2 to 4.5°C (IPCC report 2021). Green gram is a plant species in the legume family. The annual vine has fluffy brown pods and yellow flowers. It is a short-lived legume crop mostly cultivated as a fallow crop in a rice rotation. Green gram increases the nitrogen content of the soil similar to other leguminous pulses. A study conducted in controlled chambers reveals that an increase in average temperature from 19 to 26°C and 660 ppm CO_2 during the entire crop period increased the seed mass and grain yield in legume crop (Vadez *et al.,* 2012). (Qiao *et al.,* 2019) reported that excessive high temperature and CO_2, within the range of 29 to 36°C and 660ppm, reduced grain yield and biomass. In general, C_3 crops in the absence of biotic and abiotic stresses, will be able to capitalize on increased CO_2 concentration and consequently improve their growth and development. High-temperature stress above 40°C would cause flower shedding and grain yield and reduce the yield by 36 percent in green gram (Bourgault *et al.,* 2017). Photosynthesis is an important process that will contribute to many aspects that affect the crop yield, including pod set percent and biomass. Heat stress (36/16°C) is most sensitive during the flowering stage resulting in a significant reduction in grain yield due to the fully sterility of flowers of legume crops (Falconnier *et al.,* 2020). In addition, high temperature stress (35/19°C) is highly sensitive to the grain filling stage and shortened the crop duration, reducing the seed weight (Farooq *et al.,* 2017). Elevated CO_2 alone increases the biomass and yield of legume crops by 18 to 25 percent (Kimball. 2016). Controlled chamber studies results show that the growth and development of bean was increased by 21 percent upto 700ppm elevated CO_2. Most of the earlier studies conducted either with only elevated CO_2 or temperature alone. It is important to understand the combined impacts of elevated temperature and CO_2 in predicting the effects of climate change on crop yield. This will permit agrometeorologists to develop some adaptations for future agricultural production. The objective of the present study was to investigate the interaction effects of elevated CO_2 and temperature on growth and development of green gram.

MATERIALS AND METHODS

Location

The experiment was conducted between December 2021 to February 2022 under ambient conditions and inside the Soil Plant Atmosphere Research (SPAR) chamber available in agro climate research centre, Tamil Nadu Agricultural University, Coimbatore (11.013251°- N, 76.939725°- E). The daily weather data with respect to maximum and minimum temperature (°C), average relative humidity (%), rainfall (mm) and evaporation (mm/day) prevailed during the winter season from December 2021 to February 2022 were collected from SPAR automatic data logger and Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore (Fig. 1).

Growth conditions

The SPAR system contains plexi glass chamber 2 x 1.5 metres in cross section and 2.5 metres height where the crop is being grown. It also includes an air conditioner, as well as other required devices like a humidifier and dehumidifier, installed on a sturdy steel frame made of plexi glass with a 6 mm thickness. The software named EMCON (environment control), were used to stimulate the required and accurate levels of temperature and CO_2 inside the SPAR unit.

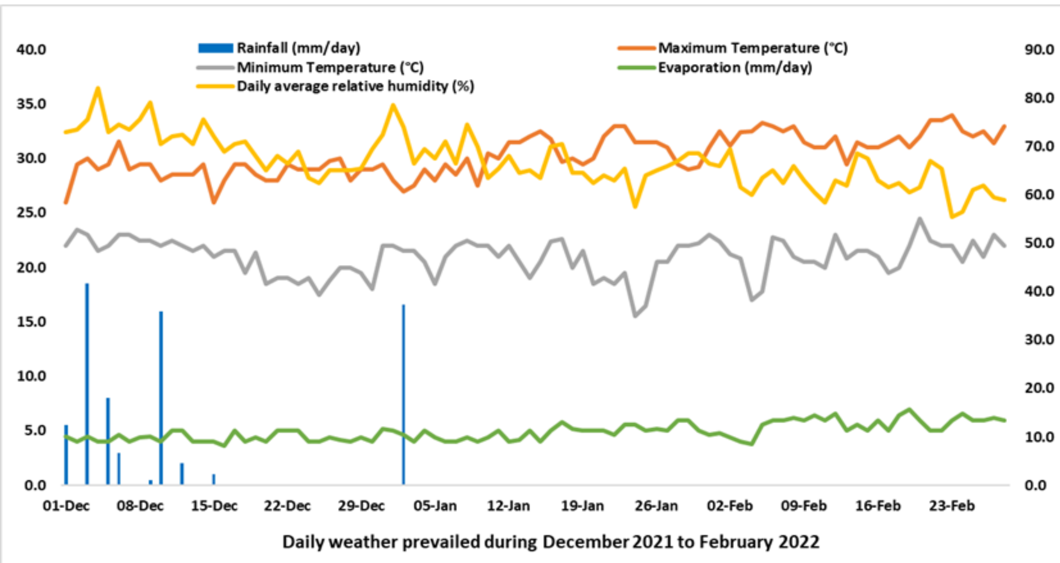

Fig. 1. *Daily weather prevailed during December 2021 to February 2022*

Treatment details

The pot culture experiment was laid out in CRD (Completely Randomized Design) with three replications. The stress was: (i) High Day Temperature (ambient day maximum temperature+3°C) and elevated CO_2 (600ppm) (HDT and eCO_2) and (ii) High Day and Night Temperature (ambient maximum and minimum temperature+3°C) and elevated CO_2 (600ppm) (HDNT and eCO_2). The experiment was designed based on the stress with 11 treatments replicated thrice *viz.,* T_1: control (ambient condition), T_2: HDT and eCO_2 imposed from 1 to 15 DAS (Days After Sowing), T_3: HDT and eCO_2 imposed from 16 to 30 DAS, T_4: HDT and eCO_2 imposed from 31 to 45 DAS, T_5: HDT and eCO_2 imposed from 46 to 60 DAS, T_6: HDT and eCO_2 imposed from 61 to 70 DAS, T_7: HDNT and eCO_2 imposed from 1 to 15 DAS, T_8: HDNT and eCO_2 imposed from 16 to 30 DAS, T_9: HDNT and eCO_2 imposed from 31 to 45 DAS, T_{10}: HDNT and eCO_2 imposed from 46 to 60 DAS, T_{11}: HDNT and eCO_2 imposed from 61 to 70 DAS. The pots were treated with RDF (Recommended dose of fertiliser) (25kg N + 50kg P_2O_5 + 25kg K_2O + 40kg S)/ ha and appropriate measurements were taken for pest and disease control during the crop season in accordance with the TNAU crop production guide. During the experimental period, the pots were maintained at 100 percent field capacity and biometric data was recorded 15 days interval from the date of sowing.

Leaf physiological measurements and yield attributes

An LI-COR 6400XT portable photosynthesis system was used to monitor the leaf-level gas exchange measurements (photosynthesis, stomatal conductance and transpiration rate) on the tagged leaf of each replication (LI-COR, Lincoln, NE, USA). The gas exchange measurements were taken between 10-12 AM (measured using LICOR 6400XT), both ambient (415 ppm) and elevated CO_2 (600ppm) conditions. A chlorophyll meter [Soil Plant Analysis Development (SPAD); Model 502, Spectrum Technologies, Plainfield, IL, USA] was used to measure the chlorophyll content and expressed in SPAD units. The yield attributes *viz.,* number of flowers shed per plant, number of pods per plant, grain yield (g/plant) and biomass (g/plant) were recorded after the harvesting of the crop.

Data analysis

The data were statistically analysed using statistical software SPSS 16.0 (SPSS Inc., Chicago, IL). Mean and standard deviation for all values were calculated and the significant differences between mean values were evaluated using the Least Significant Difference (LSD) at a 5 per cent probability level, as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The day time exposure (HDT and eCO_2) significantly (p=0.05) increased the chlorophyll content (SPAD value) compared to ambient as well as HDNT and eCO_2 conditions (Fig. 2). An increasing trend in chlorophyll index was observed from 15 to 45 DAS (days after sowing) and thereafter it starts declining. The similar research findings are reported by AbdElgawad *et al.* 2015 who stated that high temperature and CO_2 stress decrease chlorophyll degradation and enrich the chlorophyll content.

Similarly, the leaf photosynthesis, stomatal conductance and transpiration rate were significantly (p=0.05) increased by day time exposure (HDT and eCO_2) followed by both day and night exposure (HDNT and eCO_2) and ambient conditions. Mean stomatal conductance was increased to 47.2% by HDT and eCO_2 compared with the ambient condition. Overall, leaf photosynthesis rate increased from 15 to 45 DAS and it started decreasing thereafter. On average, the HDT and eCO_2 and HDNT and eCO_2 increased 19% and 7.2%, respectively compared with ambient conditions. HDT and eCO_2 and HDNT and eCO_2 increases the

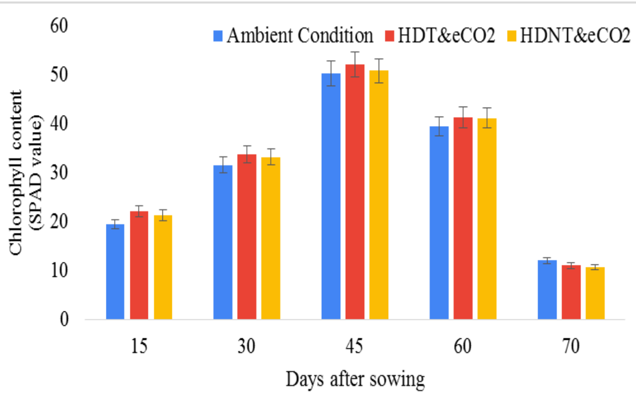

Fig. 2. *Effect of ambient and elevated temperature and CO_2 enrichment on Chlorophyll content (SPAD unit) in green gram*

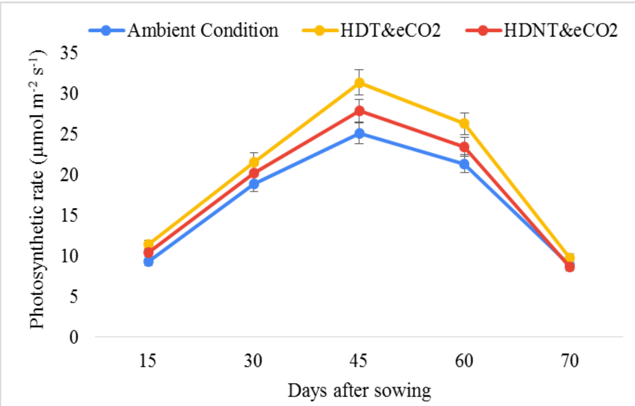

Fig.3. *Effect of ambient and high temperature and CO_2 enrichment on photosynthetic rate (µmol m^{-2} s^{-1}) in green gram*

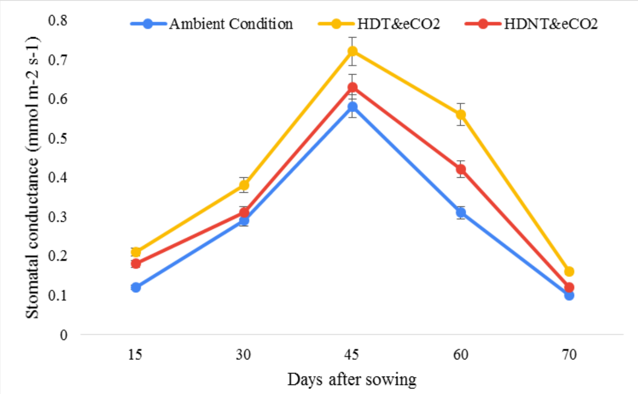

Fig. 4. *Effect of ambient and elevated temperature and CO_2 enrichment on stomatal conductance (mmol m^{-2} s^{-1}) in green gram*

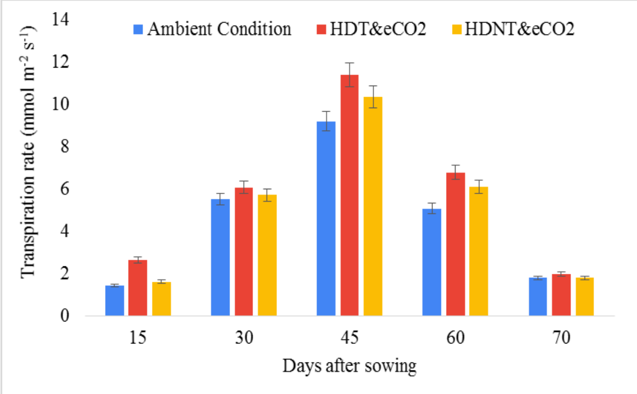

Fig. 5. *Effect of ambient and high temperature and CO_2 enrichment on transpiration rate (mmol m^{-2} s^{-1}) in green gram*

Table. 1. Effect of elevated temperature and CO_2 enrichment on number of flowers shed/plant, number of pods/plant, grain yield and biomass on green gram

Treatments	Number of flowers shed/ plant	Number of pods/plant	Grain yield (g/ plant)	Biomass (g/ plant)
T_1	29.9	26.8	9.53	10.2
T_2	30.1	27.1	9.43	11.2
T_3	32.0	29.2	9.67	13.8
T_4	32.1	31.2	11.3	14.8
T_5	31.2	34.0	11.9	12.4
T_6	28.1	28.1	10.1	11.8
T_7	28.6	26.8	9.65	10.5
T_8	28.0	28.2	9.78	13.2
T_9	33.8	30.3	10.6	14.3
T_{10}	33.4	32.4	12.3	11.6
T_{11}	28.2	27.8	10.6	11.3
Mean	30.5	29.3	10.4	12.3
SEd	0.68	0.59	0.24	0.28
CD(P=0.05)	1.42	1.22	0.51	0.59

T_1: control (ambient condition), T_2: HDT and *e*CO_2 imposed from 1 to 15 DAS (Days After Sowing), T_3: HDT and *e*CO_2 imposed from 16 to 30 DAS, T_4: HDT and *e*CO_2 imposed from 31 to 45 DAS, T_5: HDT and *e*CO_2 imposed from 46 to 60 DAS, T_6: HDT and *e*CO_2 imposed from 61 to 70 DAS, T_7: HDNT and *e*CO_2 imposed from 1 to 15 DAS, T_8: HDNT and *e*CO_2 imposed from 16 to 30 DAS, T_9: HDNT and *e*CO_2 imposed from 31 to 45 DAS, T_{10}: HDNT and *e*CO_2 imposed from 46 to 60 DAS, T_{11}: HDNT and *e*CO_2 imposed from 61 to 70 DAS.

transpiration rate by 19.4% and 12.4%, respectively. The CO_2 fertilization impact appears to be increased under the elevated temperature, up to certain level. Zhao *et al.,* 2022 showed that photosynthetic rate of soybean increased by 60% under 36/29°C and 660ppm CO_2. The photosynthetic rate and stomatal conductance of soybean whole canopy and leaves have increased by high temperature (below 36°C) and 700ppm CO_2 as reported by Kannan *et al.* (2019), further, they stated that maximum photosynthetic rate and stomatal conductance were observed up to midday (1000 to 1200hrs). A considerable increase in transpiration rate was also observed by Deuchande *et al.,* 2021 in common bean.

The lowest flower shed per plant was observed in ambient condition (29.9/plant) and next best treatment was HDT and *e*CO_2 and the highest flower shed was noticed when exposed to both day and night exposure HDNT and *e*CO_2. There was a significant positive effect observed in the number of pods per plant, grain yield per plant and biomass per plant due to day time exposure (HDT and *e*CO_2) followed by both day and night time exposure (HDNT and *e*CO_2) compared to ambient conditions. The number of pods per plant was increased by 11.6% and 8.6%, under HDT and *e*CO_2 and HDNT and *e*CO_2, respectively. Similarly grain yield and bio mass respectively increased by 11.1%, 10.1% and 25.5%, 19.5% for HDT and *e*CO_2 and HDNT and *e*CO_2 compared to ambient conditions. In general, CO_2 enrichment from 410 to 700ppm would increase the yield attributes of legumes when the temperature below optimum level (Dutta *et al.,* 2022). The results of the present experiment corroborate with findings of Hu *et al.* (2022), who reported that higher temperature below (>36/26^{o}C) and CO_2 enrichment (660ppm) increased the yield attributes of soybean like the number of pods per plant, seeds per plant, grain yield per plant by 32%, 39.5% and 37.7%, respectively.

Conclusion

The C_3 crops would produce more photosynthate and yield due to the increased temperature and CO_2. Similarly, the present investigation indicated that day, day and night exposure to elevated temperature and CO2 (600ppm) will not affect the green gram yield during winter whenever there are maximum and minimum temperatures within the range of 38/27^{o}C.

Conflict of interest

The authors declare that they have no conflict of interest.

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