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Research Article

Growth and yield response of winter blackgram (*Vigna mungo*) under high temperature and elevated CO_2 conditions

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Abstract

Blackgram is the most important legume crop grown throughout India. It is mostly cultivated during the rainy and winter seasons in central and southern India. An investigation was carried out during winter 2021 to evaluate the effect of High Day Temperature (ambient+3°C) and Elevated CO_2 (600ppm) (HDT and eCO_2) and High Day and Night Temperature (ambient+3°C) and Elevated CO_2 (600ppm) (HDNT and eCO_2) on growth and yield of blackgram (*Vigna mungo*) under soil plant atmospheric research (SPAR) and ambient conditions with eleven treatments (T_1 to T_{11}). The results revealed that significant (P=0.05) increase in photosynthetic rate, stomatal conductance, transpiration rate, number of pods per plant and grain yield by 22.3%, 80.6%, 29.2%, 28% and 41.3%, respectively, under HDT and eCO_2 conditions from 46 to 60 DAS (days after sowing) in comparison with HDNT and eCO_2 and ambient conditions. The increase in chlorophyll index under HDT and eCO_2 during 16 to 30 DAS by 12.9%. The significant increase in the number of flowers per plant and biomass of the blackgram was increased under HDT and eCO_2 during 31 to 45 DAS by 7% and 38.1%, respectively. However, the plant height and leaf area index of the blackgram were found to have significantly increased under HDT and eCO_2 during the early stage (1 to 15 DAS) by 29.3% and 44.5%, respectively. This experiment indicated a significant increase in crop growth, leaf photosynthesis and yield of blackgram under HDT and eCO_2 at flowering stage to pod development stage (31 to 60 DAS) followed by HDNT and eCO_2 and ambient condition. The overall findings of the study showed that increased temperature and CO2 levels would result in greater biomass production and increased yield for the black gram.

Keywords: Blackgram, Elevated CO_2, High day temperature, Photosynthetic rate, Soil plant atmospheric research (SPAR), Stomatal conductance

INTRODUCTION

Blackgram is normally a warm-weather crop. Hot and humid conditions are favourable for the best growth and development. Its optimal growth temperature is between 24°C and 35°C, however, it can tolerate temperatures as high as 42°C (Joseph *et al.,* 2015). India produces over 70% of the world's blackgram production and is also the largest producer as well as consumer of blackgram. India and Tamil Nadu produced about 36 and 3.08 lakh tonnes of blackgram, respectively in 2020-21 (agricoop.nic.in). Recent reports by the Intergovernmental Panel on Climate Change (IPCC) predicted that climate change will significantly increase or intensify environmental disasters on Earth, particularly extreme weather events. Atmospheric CO_2 (carbon dioxide) level is predicted to increase from 417 to 730 ppm by the end of the 21st century (IPCC report, 2021). The radiative balance of the atmosphere is predicted to be altered by an increase in greenhouse gas concentration, increasing temperature and modifications to precipitation patterns. The rise in temperature (>4°C) and extreme weather occurrences are causing elevated variations in substantial reductions of grain yields in legume crops, ultimately resulting in food insecurity (Ul Hassan *et al.,* 2021). Many high CO_2 level experiments have been conducted in control chambers (Zheng *et al.,* 2019; Dunn *et al.,* 2019). The productivity of important agricultural crops increased under high CO_2 levels from 14 to 40% for C_3 crops and 6 to 11% for C_4 crops (Lara & Andreo, 2011). Vanaja *et al.* (2015) showed that responses of eighteen blackgram varieties to doubled CO_2 concentration would enhance the overall yield by 31%. Compared with other crops, nitrogen (N) fixation activity has increased through soil gas permeability by the acceleration of CO_2 exchange rate. Most legume crops' responses to the elevated CO_2 are higher than the prevailing conditions.

1.The past 60 years' temperature data show an increase in trend by 0.18^{o}C/decade, while recent years' temperature has increased drastically. India's future mean temperature is expected to rise for the SSP2-4.5 (Shared Socioeconomic Pathway) from 1.3 to 3.8°C in the period 2030–2100 with reference to the period 1951–2010 (Nayak and Takemi. 2022; IPCC report 2021). The effect of short episodes of exposure to elevated temperature (more than 32^{o}C) on blackgram biomass and grain yield is thought to be equivalent to more than 3^{o}C warming of the seasonal average temperature (Raza *et al.,* 2019). Maximum temperature (more than 34^{o}C) is critical for flowering to the pod developing stage and also reduces the date of maturity, which leads to a reduction in biomass and grain yield (Sita *et al.,* 2017). High temperature and elevated CO_2 interaction cause 0.8^{o}C increase in canopy temperature coupled with an 18% grain yield increase in C_3 crops (Pasricha. 2014). In USA, a rise in yield by 2% per year is witnessed specifically in legume crops (Foyer *et al.,* 2021). There are limited findings on the effect of high temperature and elevated CO_2 concentration on blackgram under the control chamber. The most relevant agrometeorology methods to investigate the high temperature and elevated CO_2 concentration in response to the crops are soil plant atmospheric research (SPAR) and open-top chamber (OTC). This study aimed to evaluate the effects of elevated temperature and CO_2 concentration on leaf photosynthesis and yield response of blackgram (*Vigna mungo*) under soil plant atmospheric research (SPAR).

MATERIALS AND METHODS

Study area

The present study was conducted between December 2021 to February 2022 (winter season) under ambient conditions (15.5 to 34 ^{o}C) and at Soil Plant Atmosphere Research (SPAR) at the Agro Climate Research Centre (ACRC), Tamil Nadu Agricultural University (TNAU), Coimbatore (11.01^{o}N, 76.90^{o}E). The weather data concerning maximum and minimum temperature (^{o}C), rainfall (mm), average relative humidity (%), and evaporation (mm/day) during the study period were collected at SPAR data logger, ACRC, TNAU, Coimbatore. December 2021 to February 2022 was cold, with daily night and day temperatures ranging from 15.5 to 24.5^{o}C and 26 to 34^{o}C, respectively. Total rainfall, mean daily evaporation and average relative humidity were 71.1mm, 4.9mm and 55.5 to 82%, respectively (Fig. 1).

SPAR unit

The SPAR system includes an air conditioner and other necessary equipment, like a humidifier and dehumidifier, mounted on a strong metallic frame made of plexiglass with a 6 mm thickness. The plexiglass is 2 x 1.5 metres in cross section and 2.5 metres tall. The SPAR facility consisted of ten outdoor, naturally lit chambers, which was used to understand the ruling variety of blackgram (*Vigna mungo*) CO6 growth and physiological responses to the environment and create process-level physiological models. By EMCON (environment control), automatic temperature, relative humidity, and increased CO_2 technology were introduced to automatically maintain the required and accurate levels of temperature and CO_2 inside the SPAR unit.

Treatment details

The pot culture experiment was laid out in CRD (Completely Randomized Design) with three replications and data was recorded at 15 days intervals from the date of sowing. The stress was: (i) High Day Temperature (ambient maximum temperature+3^{o}C) and elevated CO_2 (600ppm) and all the pots were kept in an open environment during the nighttime (HDT and *e*CO_2) and (ii) High Day and Night Temperature (ambient temperature+3^{o}C) and elevated CO_2 (600ppm) (HDNT and *e*CO_2). The eleven treatments were designed based on stress *viz.,* T_1: control (ambient condition), T_2: HDT and *e*CO_2 during 1 to 15

DAS (Days After Sowing), T_3: HDT and eCO_2 during 16 to 30 DAS, T_4: HDT and eCO_2 during 31 to 45 DAS, T_5: HDT and eCO_2 during 46 to 60 DAS, T_6: HDT and eCO_2 during 61 to 70 DAS, T_7: HDNT and eCO_2 during 1 to 15 DAS, T_8: HDNT and eCO_2 during 16 to 30 DAS, T_9: HDNT and eCO_2 during 31 to 45 DAS, T_{10}: HDNT and eCO_2 during 46 to 60 DAS, T_{11}: HDNT and eCO_2 during 61 to 70 DAS. Following the guidelines from the TNAU crop production guide, the pot culture was given RDF (Recommended dose of fertilizer) at a rate of 25kg N + 50kg P_2O_5 + 25kg K_2O + 40kg S per hectare. Effective pest and disease management strategies were implemented during the entire crop season, and irrigation did not pose any limitations. Pots having a size of 30 cm in diameter and 27 cm in height were used for the experiment, with the inclusion of sandy loam soil.

Leaf physiological measurements and yield attributes

To measure the leaf-level gas exchange parameters (photosynthesis, stomatal conductance and transpiration rate) on the tagged leaf of each replication, an LI-COR 6400XT portable photosynthesis system from LI-COR in Lincoln, NE, USA was utilized. At daytime growth temperature (measured with LI-COR 6400XT), the gas exchange measurements were recorded under ambient CO_2 conditions (415ppm) as well as elevated CO2 levels (600ppm). The chlorophyll content was measured using a soil plant analysis development (SPAD) meter (Model 502, Spectrum Technologies, Plainfield, IL, USA) and expressed in SPAD units. After the crop was harvested, data on the number of flowers shed per plant, number of pods per plant, grain yield per plant, and biomass per plant for the yield attributes were recorded.

Data analysis

The statistical software SPSS 16.0 (SPSS Inc., Chicago, IL) was used to analyse the data. The data was statistically analysed by calculating the mean and standard deviation for all values, and using the Least Significant Difference (LSD) at a 5 % probability level as recommended by Gomez and Gomez (1984) to evaluate the significant differences between mean values.

RESULTS AND DISCUSSION

Among various treatments, plant height and leaf area index (LAI) differed significantly (P=0.05). Plant height and leaf area index was stimulated by the HDT and

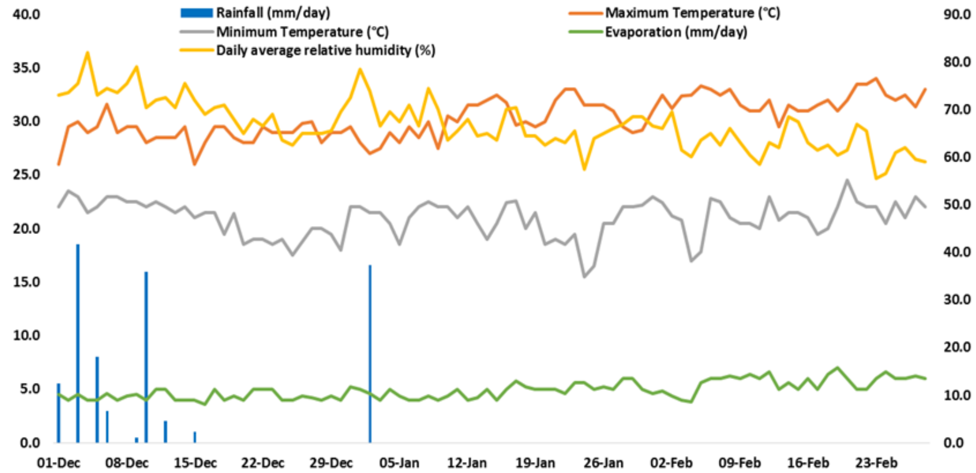

Fig. 1. *Showing daily weather conditions from December 2021 to February 2022*

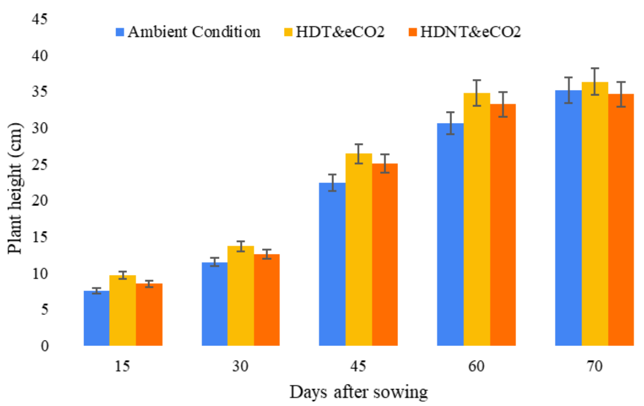

Fig. 2. *Effect of ambient and elevated temperature and CO_2 enrichment on plant height in blackgram.*

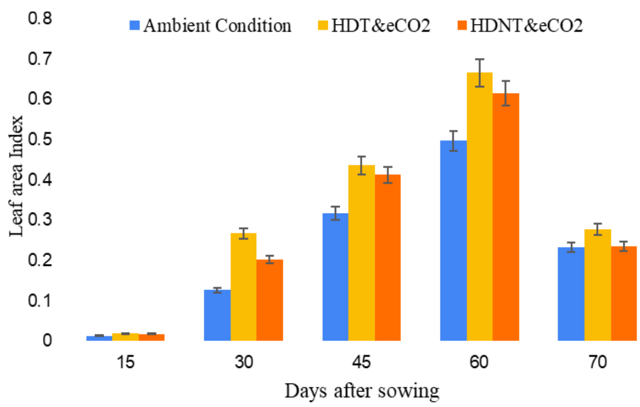

Fig. 3. *Effect of ambient and elevated temperature and CO_2 enrichment on Leaf area index in blackgram.*

eCO_2 during the early stage (1 to 15 DAS) (T_2) by 29.3 and 44.5 % followed by 15 to 30 DAS (T_3) when compared to HDNT and *e*CO_2 and ambient conditions (Fig. 2 and Fig. 3). Similar findings were reported by Wang *et al.* (2020), who found that increased CO_2 levels (550 and 770ppm) resulted in increased biomass and leaf area index of C_3 crops like wheat and rice by 45% and 58.7% respectively, at 45 days after sowing. Dier *et al.* (2018) also stated that elevated CO_2 and high-temperature stress during the germination stage to vegetative stage crop accelerates the cell deviation and cell metabolism, which leads to an increase in plant height and LAI of both C_3 and C_4 crops like rice, wheat, maize and sorghum.

The SPAD value (chlorophyll content) was significantly (P=0.05) increased in daytime exposure (HDT and *e*CO_2) followed by both day and night exposure (HDNT and *e*CO_2) and ambient conditions. An increasing trend in chlorophyll index was observed from 1 to 45 DAS and thereafter it starts declining (Fig. 4). Rangaswamy *et al.* (2021) reported that increasing CO_2 (>700 ppm) and temperature (>35^oC) will have a positive effect on the leaves' greenness on tomato crop.

Among the different stages of stresses, 30 to 45 DAS under HDT and *e*CO_2 (T_4) show significantly higher photosynthetic rate (34.1µmol m^{-2} s^{-1}), stomatal conductance (0.76 mmol m^{-2} s^{-1}) and Transpiration rate (11.3 mmol m^{-2} s^{-1}) followed by the HDNT and *e*CO_2 (Fig. 5, 6 &7). Mean photosynthetic rate was increased to 18 % by HDT and *e*CO_2. Overall, stomatal conductance increased from 1 to 45 DAS and declined thereafter. Average transpiration rate increased by 37.9 and 8.2 % under HDT and *e*CO_2 and HDNT and *e*CO_2, respectively. Crop growth is primarily decided by photosynthesis accumulation. Under higher temperatures, the effect of CO2 fertilization appears to be magnified, up to a defined level. The optimum temperature (18 to 34^oC) plays an important role in producing photosynthates (Das *et al.,* 2022). Since the blackgram belongs to the C_3 crop, it can convert the higher CO_2 level into photosynthesis and utilization of water and nutrition. Results of Pradipa *et al*. (2022) showed that C3 crops like rice, wheat, and legumes exhibit higher gas exchange activities than C4 crops.

The highest number of flowers per plant was observed in HDT and *e*CO_2 during 31 to 45 DAS (82.1/plant) and the lowest flowers were noticed when blackgram was exposed to ambient conditions (76.7/plant). There was a significant increase in the impact on the number of pods per plant, grain yield, and dry matter per plant under daytime exposure (HDT and *e*CO_2) (Table 1). The average number of pods per plant increased by 15.2 and 9 %, under HDT and *e*CO_2 and HDNT and *e*CO_2 compared to ambient condition. Similarly, biomass and grain yield per plant increased under HDT and *e*CO_2 and HDNT and *e*CO_2 by 18.8%, 12.1%, 21.3%, and 11.2%. This present study supports Rogers *et al.* (2009), who reported that the high CO_2 levels (700ppm) and temperature (>34^oC) of the blackgram C_3 crop were the optimum conditions for the production of photosynthates that will help to maximize the pod setting of the black gram. The current findings corroborate with the results of Guna *et al.* (2022), who concluded that a combination of higher daytime temperatures and increased CO_2 levels can lead to a 25% increase in greengram yield. In general, CO_2 enrichment from 410 to 700ppm would increase the yield attributes of legumes when the temperature is below optimum level (Dutta *et al.,* 2022). Ainsworth and Long (2005) also found that elevated CO_2 levels (700ppm) resulted in a significant increase in grain yield and dry matter of blackgram, with a 129% and 65.4% increase,

Table 1. Impact of high temperature and CO_2 on number of flowers/plant, number of pods/plant, grain yield, and biomass on black gram

Treatments	Number of flowers/plant	Number of pods/plant	Grain yield (g/plant)	Dry matter (g/plant)
T_1 - Control	76.7^{bc}	36.1^{f}	10.4^{e}	13.4^{e}
T_2 - HDT and *e*CO_2 imposed from 1 to 15 DAS	77.3^{bc}	38.3^{cd}	11.2^{d}	14.2^{d}
T_3 - HDT and *e*CO_2 imposed from 16 to 30 DAS	78.6^{bc}	39.4^{c}	12.5^{c}	16.7^{b}
T_4 - HDT and *e*CO_2 imposed from 31 to 45 DAS	82.1^{a}	45.9^{a}	13.5^{b}	18.5^{a}
T_5 - HDT and *e*CO_2 imposed from 46 to 60 DAS	79.7^{ab}	46.2^{a}	14.7^{a}	16.8^{b}
T_6 - HDT and *e*CO_2 imposed from 61 to 70 DAS	76.4^{bc}	38.1^{cd}	11.2^{d}	13.4^{e}
T_7 - HDNT and *e*CO_2 imposed from 1 to 15 DAS	76.2^{c}	36.2^{ef}	10.3^{e}	14.1^{d}
T_8 - HDNT and *e*CO_2 imposed from 16 to 30 DAS	77.2^{bc}	37.7^{def}	11.5^{d}	15.3^{c}
T_9 - HDNT and *e*CO_2 imposed from 31 to 45 DAS	79.3^{abc}	43.1^{b}	12.2^{c}	16.8^{b}
T_{10} - HDNT and *e*CO_2 imposed from 46 to 60 DAS	78.2^{bc}	42.0^{b}	13.2^{b}	15.3^{c}
T_{11} - HDNT and *e*CO_2 imposed from 61 to 70 DAS	76.4^{bc}	37.8^{cde}	10.6^{e}	13.6^{d}
Mean	78.0	40.1	11.9	15.3
Sed	1.63	0.79	0.22	0.32
CD(P=0.05)	3.39	1.65	0.46	0.67

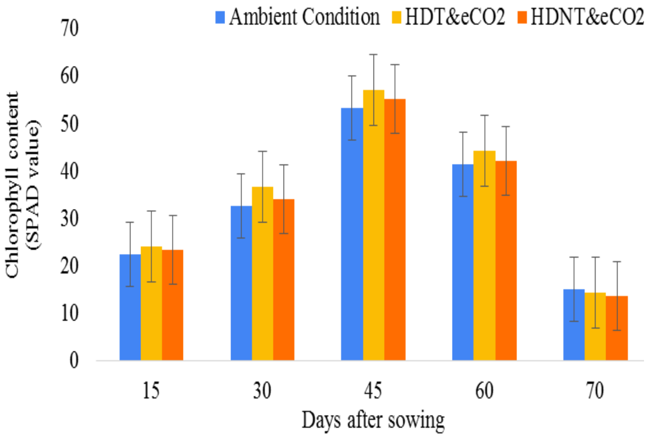

Fig. 4. *Impact of ambient and high temperature and elevated CO_2 on Chlorophyll Index (SPAD unit) in blackgram*

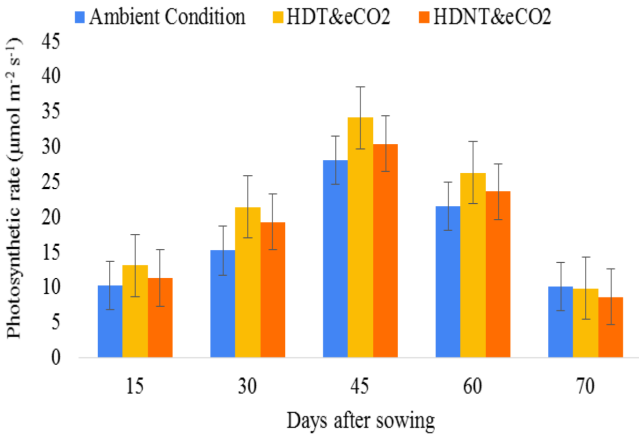

Fig. 5. *Impact of ambient and high temperature and elevated CO_2 on photosynthetic rate (µmol m^{-2} s^{-1}) in blackgram*

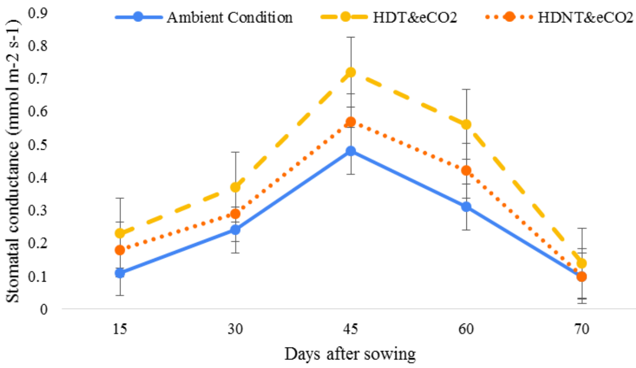

Fig. 6. *Impact of ambient and high temperature and elevated CO_2 on stomatal conductance (mmol m^{-2} s^{-1}) in blackgram*

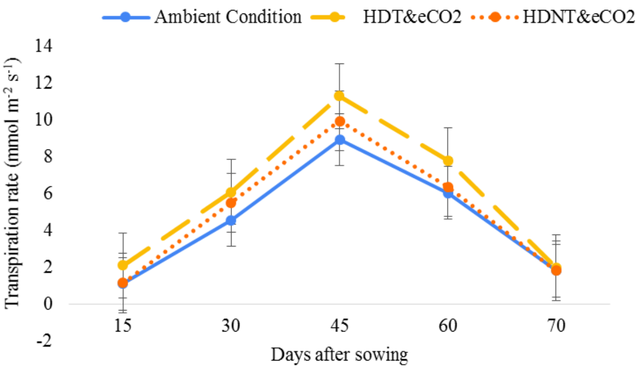

Fig. 7. *Impact of ambient and high temperature and elevated CO_2 on transpiration rate (mmol m^{-2} s^{-1}) in blackgram*

respectively.

Conclusion

Blackgram (*Vigna mungo*) is a drought-resistant crop that grows both in the winter and the summer, usually in rotation with rice but occasionally in mixed farming. Based on this study, an increase in daytime and day & nighttime temperatures along with CO_2 enrichment, could have a greater effect on the growth and development of black gram. The present study concluded that the range between 18-37°C of minimum and maximum temperatures and elevated CO_2 (600 ppm) would not affect the winter blackgram's gas exchange activities and production.

Conflict of interest

The authors declare that they have no conflict of interest.

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