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Physiological Response of Common Bean (*Phaseolus vulgaris* L.) to Varying Temperature and Irrigation Regimes

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ABSTRACT

Background: Elevated temperature and water stress are the key limiting factors affecting the kidney bean yield. Climate change is projected to enhance these risks for successful crop production. However quantified information, which is limited, on temperatures stress at various growth phases in combination with water regimes, becomes important for optimizing management decisions for higher productivity of kidney bean. The current study is aimed to fill this gap.

Methods: A field experiment was conducted during January-April 2020, to investigate the effect of irrigation and temperature regimes on growth parameters and yield of kidney bean. Temperature treatments imposed were elevated temperature for entire crop period i) ~4.6°C ii) ~3.1°C iii) ~2.8°C above mean ambient (19.6°C), iv) ambient temperature Tmax and Tmin regime of 25.9/13.4°C (mean 19.6°C), v) elevated temperature during pre-flowering phase (~3.7°C above mean ambient during that period, 19.6°C), vi) flowering phase (~5.3°C above mean ambient during that period, 23.1°C) and pod-filling phase (~5.2°C above mean ambient during that period, 28.9°C). These were combined with i) two irrigations (applied at sowing and seedling phase) and ii) three irrigations (additional irrigation at pod-filling phase).

Result: Elevated temperature regimes led to shortening of the crop duration. LAI, NDVI, net photosynthesis and seed yield were higher in plants exposed to continuous elevated temperature. Heat shock during pre-flowering and flowering led to reduction in yield. Despite exposure to elevated temperature, supplemental irrigation led to higher yield. Seed yield loss was greater when temperature stress coincided with water stress. The negative effects of high temperature were significantly curtailed by provision of supplemental irrigation.

Key words: Heat stress, Irrigation, Kidney bean, *Phaseolus vulgaris* L., Yield.

INTRODUCTION

Kidney bean (*Phaseolus vulgaris* L.) is considered “a nearly perfect food” by nutritionists due to its high protein content, substantial amounts of fibre and complex carbohydrates. Consumption of one serving of kidney beans also contributes to about 50% of the recommended daily folic acid, 25-30% of iron, 25% of magnesium and copper and 15% of potassium and zinc levels (CIAT, 2008). Approximately 12 million tonnes of kidney beans are produced annually across the world. The global average productivity is estimated at 762 kg ha^{-1} which varies across countries as well as different kidney bean types. In India, estimated area under kidney bean cultivation is estimated at 90,000 ha with a national average yield ranges from 421-1,000 kg ha^{-1} (Gupta *et al.*, 2019). Though production has increased in last decade, farmers still face challenges such as infertile soils, water scarcity, pest and disease attacks as well as climate change (Mikić, 2018).

Exposure of kidney bean to high temperature and water stress particularly affects production of the crop. In most kidney bean varieties, water stress leads to a reduction in seed yield by 34-50% (Rai *et al.*, 2020). Under full irrigation, kidney bean yield can be about 4 Mg ha^{-1} while with deficit irrigation it is less than 1 Mg ha^{-1} (Fereres *et al.*, 2017). The effects of water stress can be intensified by high temperatures and intense solar radiation (Omae *et al.*, 2012; Kazai *et al.*, 2019). Generally, cool temperatures (<14°C) early in the growth season tend to delay plant development whereas high temperatures (>30°C) later in the cropping season tend to accelerate crop development leading to the shortening of the days to physiological maturity (Rai *et al.*, 2020). Additionally, exposure of flower buds to high temperatures (>34/24°C) causes decreased pod-set from 67 to 15 per cent. Overall, under elevated temperatures, a significant reduction in the number of filled pods, seeds per pod and number of plump seeds are reported (Prasad *et al.*, 2002).

In most plant species, simultaneous occurrence of heat and water stress can be detrimental to yield and productivity as opposed to when these stresses occur separately

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(Carlos *et al.*, 2020). In the case of kidney bean, limited studies have been carried out on the interactive effect of both these abiotic stresses, particularly for varieties grown in India. Therefore, this study was conducted to investigate the physiological response of kidney bean to different temperature and irrigation regimes.

MATERIALS AND METHODS

The experiment was conducted in two field conditions *i.e.* temperature gradient tunnel (TGT) and open field, from January-April 2020 at ICAR-Indian Agricultural Research Institute, New Delhi. Randomized block design (RBD) was used comprising of 14 treatments of irrigation (2) and temperature (7) in three replicates. Temperature regimes imposed were (i-iii) continuous elevated temperature from sowing to maturity based on demarcated zones of varying temperature in the TGT. In the open field, (iv) continuous ambient temperature from sowing to maturity (v) elevated temperature during the pre-flowering phase (vi) elevated temperature during the flowering phase and (vii) elevated temperature during the pod-filling phase. Phase-wise temperature regimes in the open field were imposed by covering the crop with structures constructed of UV-stabilized polyvinyl chloride sheets. These temperature treatments were superimposed with two irrigation treatments i) irrigation at sowing and seedling phase and ii) additional irrigation during the pod-filling phase.

Daily weather parameters *i.e.* maximum and minimum temperature were recorded using digital temperature sensors placed in every plot and from IARI weather observatory. The soil of the experimental field (0-30 cm depth) is sandy loam in texture with neutral pH (6.65-6.69), low electrical conductivity (0.42-0.53 dS/m) and is well-drained. The soil had low organic carbon content (0.31-0.41%), low nitrogen (125.49-129.71 kg ha^{-1}) and phosphorus content (19.95-20.96 kg ha^{-1}) and medium potassium levels (108.52-115.84 kg ha^{-1}). Soil moisture was monitored in every plot at 5-day intervals using FieldScout TDR-300 soil moisture meter. Seeds of Chitra variety were sown at row to row and plant to plant spacing of 40 × 20 cm, at 5 cm depth. At sowing nitrogen @ 100 kg ha^{-1} and phosphorus @ 50 kg ha^{-1} through urea and DAP were applied. Weeding was done a per requirement.

The following parameters were observed; i) duration of phenological phases, (ii) leaf area index (LAI) recorded using plant canopy analyzer (LAI-2000; Li-COR, USA) at a weekly interval, (iii) gas exchange parameters measured using the portable photosynthesis system Infrared Gas Analyzer (Li-6400xt; Li-COR, USA) at the flowering phase, (iv) normalized difference vegetation index (NDVI) recorded at weekly intervals using a handheld green seeker (Trimble), (v) dry matter production and partitioning, (vi) seed yield (kg ha^{-1}) and (vi) harvest index (%)based on random representative plant samples selected in each plot. The data recorded were statistically analyzed using SPSS (version 21) software for RBD (Gomez and Gomez, 1984). The critical difference was calculated at a 5% level of significance to test the significance of treatment main effects and their interaction.

RESULTS AND DISCUSSION

Observed temperature conditions under different treatments

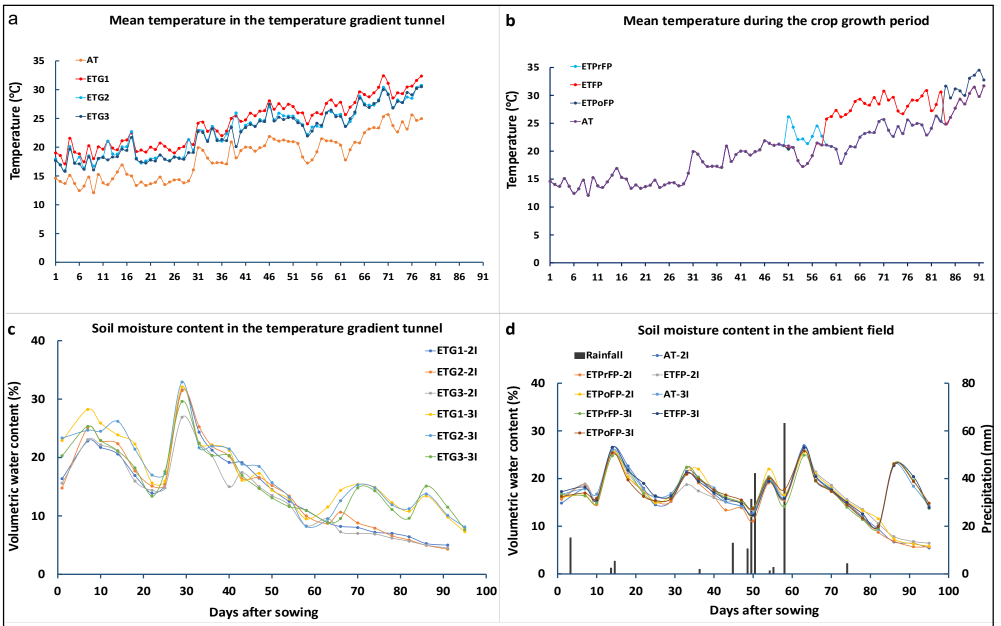
The seasonal maximum and minimum temperatures recorded under different treatments (Fig 1a and b) were as follows; elevated temperature for entire crop period at i) Tmin and Tmax regime of 36.7/11.7°C(~4.6°C above seasonal mean ambient *i.e.* 19.6°C); ii) Tmin and Tmax regime of 33.9/11.6°C (~3.1°C above seasonal mean ambient) iii) Tmin and Tmax regime of 33.1/1.7°C (~2.8°C above seasonal mean ambient), iv) AT- ambient Tmin and Tmax regime of 25.9/13.4°C (seasonal mean, 19.6°C), v) elevated temperature during pre-flowering phase (~3.7°C above mean AT during that period-19.6°C), vi) elevated temperature during flowering phase (~5.3°C above mean AT during that period ~23.1°C) and elevated temperature during pod-filling phase (~5.2°C above mean AT during that period ~28.9°C) .

Variation in soil moisture

In temperature gradient tunnel, all plots were irrigated at sowing and 25 DAS. During this period, soil moisture content ranged from 13-28% among all treatments. After which, water-stress treatments were not irrigated up to physiological maturity and soil moisture decreased to 5% at 91 DAS (Fig 1c). In remaining treatments, soil moisture ranged from 29-32% at 29 DAS, decreased to ~12% at 63 DAS and with 3rd irrigation soil moisture increased to 15% and maintained higher moisture level. In ambient field, total rainfall received during the entire crop period was about 199.1 mm. All plots were irrigated at sowing and 29 DAS. The soil moisture content ranged from 14-27%. In water-stress treatments, soil moisture declined from 18-21% at 33 DAS to 16% at 58 DAS. Rainfall on 62 DAS increased soil moisture to 25% which declined to 5% at crop maturity. In other treatments, soil moisture declined from 21% at 33 DAS to 15% at 58 DAS. Rainfall received at 62 DAS and 3rd irrigation at 84 DAS caused an increase in soil moisture to 23% and declined to 13% at the end of the crop season (Fig 1d). In treatments with additional irrigation, soil moisture was maintained above 10% during the crop season.

Effect of temperature and irrigation on the duration of phenological phases

Days to 50% germination, 50% flowering and 50% physiological maturity among the treatments ranged from 14-22 DAS, 47-60 DAS and 73-92 DAS respectively. The duration from germination to flowering was shorter for plants under continuous high temperature which took about 40 days compared to 42-45 days for plants in the ambient field. Similarly, duration from flowering to physiological maturity was shorter in these treatments (28 days) by three days (Fig 2). Plants under elevated temperature from sowing had shortened crop growth duration followed by plants under



*ETG1- continuous elevated Tmin and Tmax regime of 36.7/11.7°C (~4.6°C above seasonal mean ambient *i.e.* 19.6°C; ETG2- continuous elevated Tmin and Tmax regime of 33.9/11.6°C (~3.1°C above seasonal mean ambient); ETG3-continuous elevated Tmin and Tmax regime of 33.1/1.7°C (~2.8°C above seasonal mean ambient); AT- ambient Tmin and Tmax regime of 25.9/13.4°C (seasonal mean, 19.6°C); ETPrFP-elevated temperature during pre-flowering phase (~3.7°C above mean AT during that period-19.6°C); ETFP-elevated temperature during flowering phase (~5.3°C above mean AT during that period ~23.1°C); ETPoFP-elevated temperature during pod-filling phase (~5.2°C above mean AT during that period ~28.9°C).

Fig 1: Daily mean temperature and soil moisture during the crop growth period for different temperature treatments.

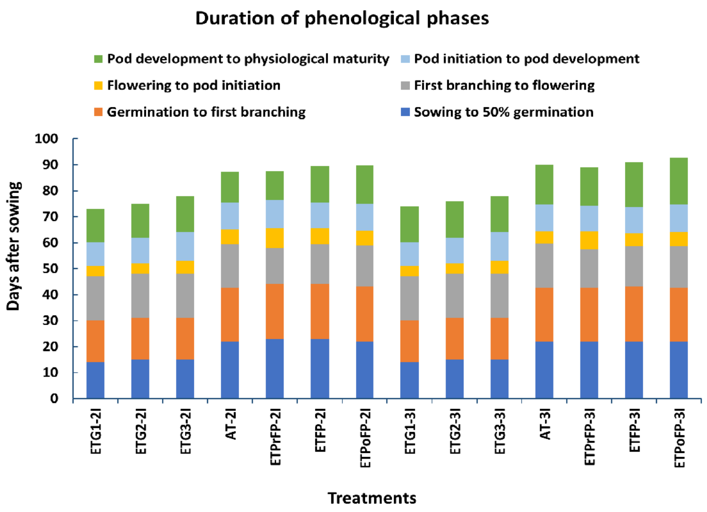


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Fig 2: Duration of phenological phases of kidney bean as influenced by elevated temperature and irrigation regimes.

elevated temperature during pre-flowering and flowering. On the other hand, exposure of plants to elevated temperature during the pod-filling phase delayed maturity. Additionally, irrigation during pod-filling prolonged crop duration. Pod development duration was 26-30 days in plants with two irrigations and 27-34 days in plants with 3 irrigations. These results indicate that while temperature regimes significantly influenced days to all phenological events, the main effects of irrigation were significant only for post flowering phenological events. Consequently, interaction effect of irrigation and temperature was significant post flowering. Shortened crop duration under elevated temperature and limited water indicates the crop's adaptive capacity in avoiding the effects of heat and water stress, particularly later in the crop season (Kazai *et al.*, 2019).

Correlation between LAI and NDVI

Leaf area index and NDVI steadily increased from emergence till 75 DAS and declined as the crop approached physiological maturity (Fig 3a). NDVI was highest (0.48-0.62) during pod filling (Fig 3b). A positive linear relationship was deduced between LAI and NDVI in all treatments (Fig 4). The best regression was found for plants under continuous elevated temperature regime (33.9/11.6°C) where LAI explained 75% of the variation in NDVI. Other treatments under continuous elevated temperature had R^2 values ranging from 0.56-0.75. The lowest R^2 value was observed for crop under continuous ambient temperature for the entire crop growth period. Overall, plants in treatments with continuous elevated temperature during crop season showed higher R^2 values than those in other treatments. Also, plants in treatments with supplemental irrigation maintained higher LAI and NDVI for a longer period. These results indicate that leaf area development, persistence and greenness was better in plants under elevated temperature regimes particularly with supplemental irrigation. Elevated temperatures during the vegetative phase lead to increased leaf area in kidney bean along with increased photosynthetic rate and carbon allocation to vegetative parts like leaves and stem (Soltani *et al.*, 2019). On the other hand, water stress leads to reduced leaf greenness, leaf senescence and decreased number of leaves (De Medeiros *et al.*, 2016; Silva *et al.*, 2016).

Gas exchange parameters

Observations on gas exchange parameters during the flowering phase indicated that net photosynthetic rate (Pn) was highest in crops under continuous elevated temperature regimes (36.7/11.7°C, 33.9/11.6°C and 33.1/11.7°C) and plants under high temperature during the pre-flowering phase (26.8/13.2°C). The lowest net photosynthetic rate was recorded for plants under ambient temperature (25.9/13.4°C). This indicated that the Pn rates increased up to temperature regimes of 36.7/11.7°C. A similar trend was observed for transpiration rate, stomatal conductance and both instantaneous and intrinsic water use efficiency of the

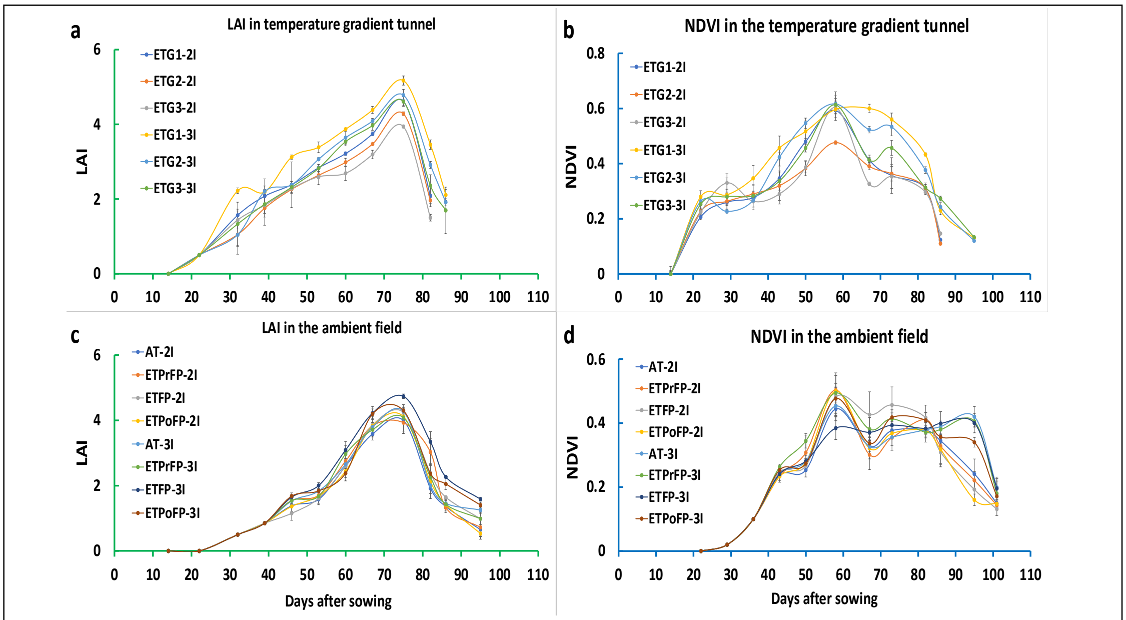

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Fig 3: LAI (a, c) and NDVI (b, d) observed under different elevated temperature and irrigation regimes.

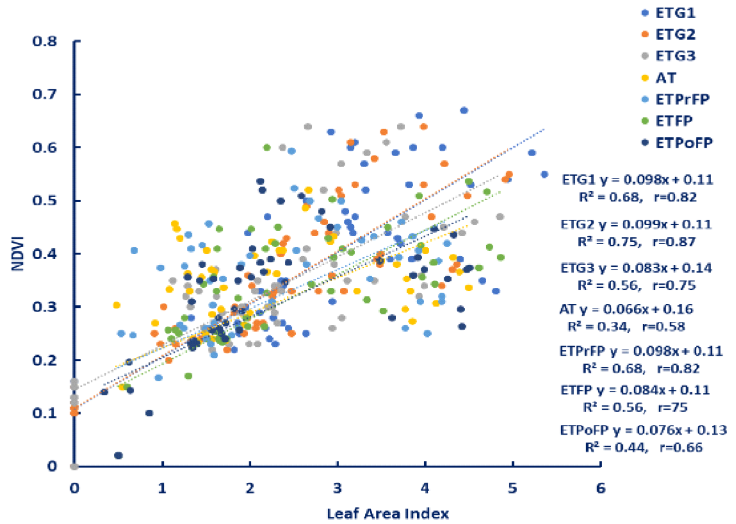

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Fig 4: Regression between LAI and NDVI in kidney bean as influenced by elevated temperature regimes.

Table 1: Gas exchange parameters of kidney bean crop as influenced by different temperature and irrigation regimes.

Treatments		Gas exchange parameters				
Irrigation	Temperature	Pn (μmol CO_2 $m^{-2}s^{-1}$)	gs (mmol m^2s^{-1})	E (mmol H_2O m^{-2} s^{-1})	Instantaneous WUE (μmol CO_2 $mmol^{-1}$ H_2O)	Intrinsic WUE (μmol CO_2 $mmol^{-1}$ H_2O)
2I	ETG1	37.19	0.08	4.75	7.83	481
	ETG2	28.78	0.08	4.49	6.41	373
	ETG3	35.32	0.09	5.40	6.54	393
	AT	28.06	0.12	5.53	5.63	264
	ETPrFP	30.53	0.17	6.99	7.80	181
	ETFP	29.71	0.07	6.72	4.42	420
	ETPoFP	31.19	0.08	6.57	4.75	392
3I	ETG1	33.90	0.10	4.46	7.59	337
	ETG2	39.46	0.11	4.71	8.38	374
	ETG3	29.80	0.09	4.49	6.64	340
	AT	25.27	0.10	6.05	4.19	271
	ETPrFP	31.27	0.20	6.65	4.65	159
	ETFP	30.50	0.13	6.49	5.33	262
	ETPoFP	35.53	0.14	7.52	4.96	281
CD at p=0.05						
Irrigation (I)		NS	0.01	NS	NS	35.3
Temperature (T)		4.26	0.03	NS	2.00	65.9
I × T		6.02	NS	NS	NS	93.3
SEM± (I × T)		2.06	0.016	1.07	0.96	31.9

*NS- Not significant; Pn = Net photosynthesis; gs = Stomatal conductance; E = Transpiration; WUE = Water Use Efficiency. *ETG1- continuous elevated Tmin and Tmax regime of 36.7/11.7°C (~4.6°C above seasonal mean ambient *i.e.* 19.6°C; ETG2- continuous elevated Tmin and Tmax regime of 33.9/11.6°C (~3.1°C above seasonal mean ambient); ETG3-continuous elevated Tmin and Tmax regime of 33.1/1.7°C (~2.8°C above seasonal mean ambient); AT- ambient Tmin and Tmax regime of 25.9/13.4°C (seasonal mean, 19.6°C); ETPrFP- elevated temperature during pre-flowering phase (~3.7°C above mean AT during that period ~19.6°C); ETFP- elevated temperature during flowering phase (~5.3°C above mean AT during that period ~23.1°C); ETPoFP- elevated temperature during pod-filling phase (~5.2°C above mean AT during that period ~28.9°C).

plants (Table 1). Transpiration rate observed in all treatments ranged from 4.46-7.52 mmol H_2O m^{-2} s^{-1} and stomatal conductance ranged from 0.07-0.20 mmol m^2s^{-1}. Intercellular CO_2 ranged from 194-287 µ mol CO_2 mol air^{-1} for plants under continuous elevated temperature and 257-306 µ mol CO_2 mol air^{-1} for plants under ambient and phase-wise temperature regimes. Generally, leaf temperature was higher than ambient temperatures by 0.2-2.7°C among treatments. Net photosynthesis, instantaneous and intrinsic water use efficiency showed an increasing trend with respect to increased leaf-air temperature while transpiration rate, stomatal conductance and intercellular CO_2 decreased with high leaf-air temperature.

Variation in dry matter production and partitioning at different growth stages

Plants grown under continuous elevated temperature regimes had highest leaf, stem, root, pod and total dry matter at physiological maturity (Fig 5a-f). Under phase-wise temperature regimes, exposure of the crop to high temperature during pre-flowering and flowering led to lower dry matter compared to plants under elevated temperature during pod-filling and ambient conditions (Fig 5g-n). On the other hand, plants supplied with additional irrigation during pod-filling accumulated high leaf, stem and total dry matter than plants under water stress. This is due to higher accumulation of photosynthates under high temperatures as consequence of high Pn rates, LAI and longer leaf area duration.

Effect of irrigation and temperature regimes on yield

Overall, treatments under continuous elevated temperature had higher seed yield and harvest index compared to other treatments in the ambient field (Table 2). Plants exposed to high temperature at pod filling also had relatively higher seed yield compared to plants under ambient temperature. Plants exposed to high temperature during pre-flowering and flowering had lowest yield. In terms of irrigation effect, plants under supplemental irrigation recorded higher seed yield compared to those in water stress treatments. The results were similar for the harvest index which ranged from 35-47%. From the findings, it can be deduced that temperature

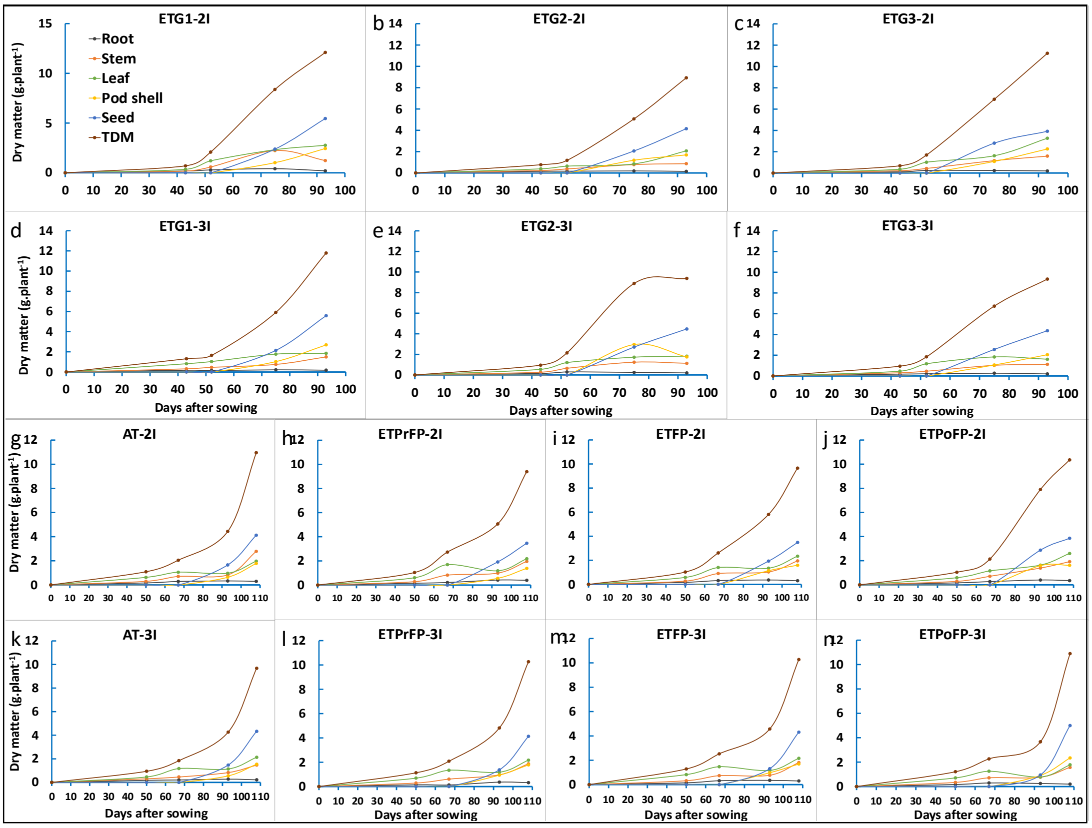

Fig 5: Variation in dry matter for treatments in the temperature gradient tunnel and in ambient field.*ETG1- continuous elevated Tmin and Tmax regime of 36.7/11.7°C (~4.6°C above seasonal mean ambient *i.e.* 19.6°C; ETG2- continuous elevated Tmin and Tmax regime of 33.9/11.6°C (~3.1°C above seasonal mean ambient); ETG3-continuous elevated Tmin and Tmax regime of 33.1/1.7°C (~2.8°C above seasonal mean ambient); AT- ambient Tmin and Tmax regime of 25.9/13.4°C (seasonal mean, 19.6°C); ETPrFP- elevated temperature during pre-flowering phase (~3.7°C above mean AT during that period ~19.6°C); ETFP- elevated temperature during flowering phase (~5.3°C above mean AT during that period ~23.1°C); ETPoFP- elevated temperature during pod-filling phase (~5.2°C above mean AT during that period ~28.9°C).

Table 2: Effect of irrigation and temperature regimes seed yield and harvest index.

Treatments	Yield components			
	Seed yield (kg ha^{-1})		HI (%)	
	2I	3I	2I	3I
ETG1	1229	1255	40	47
ETG2	934	1005	46	51
ETG3	883	982	36	39
AT	928	974	38	43
ETPrFP	781	929	40	37
ETFP	784	970	42	35
ETPoFP	868	1126	39	39
CD at p=0.05				
Irrigation (I)	30.49		NS	
Temperature (T)	57.03		3.35	
I × T	80.23		4.73	
SEM± (I × T)	27.59		1.62	

*NS- Not significant; HI- Harvest Index. *ETG1- continuous elevated Tmin and Tmax regime of 36.7/11.7°C (~4.6°C above seasonal mean ambient *i.e*. 19.6°C; ETG2- continuous elevated Tmin and Tmax regime of 33.9/11.6°C (~3.1°C above seasonal mean ambient); ETG3-continuous elevated Tmin and Tmax regime of 33.1/1.7°C (~2.8°C above seasonal mean ambient); AT- ambient Tmin and Tmax regime of 25.9/13.4°C (seasonal mean, 19.6°C); ETPrFP- elevated temperature during pre-flowering phase (~3.7°C above mean AT during that period ~19.6°C); ETFP- elevated temperature during flowering phase (~5.3°C above mean AT during that period ~23.1°C); ETPoFP- elevated temperature during pod-filling phase (~5.2°C above mean AT during that period ~28.9°C).

shock during pre-flowering and flowering led to reduction in seed yield. This may be attributed to reduced pollen viability, flower drop or failed fertilization which may lead to decreased pod development. Flowers per inflorescence and number of pods per plant are the most important characters influencing pod yield under current (Lyngdoh *et al.,* 2017) and in elevated CO_2 conditions (Rao *et al*., 2015). Water stress post-flowering accelerated the leaf and pod senescence (Cayetano-Marcial *et al.,* 2021).

Additionally, water stress significantly lowered seed yield. Generally, moderate soil moisture is sufficient to attain maximum yield in kidney bean (Saleh *et al*., 2018). However, water stress significantly reduces the number of pods per plant, number of plump seeds per plant and ultimately seed dry weight per plant (Kazai *et al*., 2019). Since the timing of the water stress is crucial, irrigation during the vegetative, flowering and pod maturation has been found to positively improve the yield of the crop (Admasu *et al*., 2019).

CONCLUSION

The present study indicates that exposure of plants to continuous elevated temperature (36.7/11°C) from sowing accelerated plant growth and increased leaf area growth. This led to increased photosynthesis and ultimately better yield. However, heat shock during pre-flowering and flowering proved to have significant reduction in seed yield. Additionally, greater seed yield loss was observed when heat stress coincided with water stress. Nevertheless, negative effects of high temperature were curtailed when available soil moisture content was maintained above 10% during the crop growth season.

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Conflict of interest: None.

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