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Short Communication

Interactive effect of irrigation and temperature regimes on growth and development of kidney bean (*Phaseolus vulgaris* L.)

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Kidney bean (*Phaseolus vulgaris* L.) is one of the most important pulse crops in terms of global production. Despite kidney bean's role in meeting food security needs, sustainable production is limited by an array of biotic, abiotic and socio-economic factors such as pest and disease attack, global climate change, financial constraints and poor market access (Ntukamazina *et al.,* 2017). Approximately 60 percent of kidney bean produced in developing countries is cultivated under conditions of drought stress and low fertility/ input conditions. In lowlands, arid and semi-arid lands, the effects of water stress can be intensified by high temperatures and intense solar radiation (Kazai *et al.,* 2019). Experimental studies show that under fully irrigated kidney bean yield can be about 4 Mg ha^{-1} while with deficit irrigation it is less than 1Mg ha^{-1} (Fereres *et al.,* 2017). Exposure of flower buds to high temperatures (>34/24°C) causes decreased pod-set from 67 to 15 percent (Prasad *et al.,* 2002). These studies indicated that moisture stress coupled with elevated temperatures particularly during flowering and pod development are key limiting factors affecting sustainable production of kidney bean. Additionally, the limited availability of water resources for agricultural production is exacerbated by climate change due to projected changes in rainfall distribution patterns (Naresh Kumar *et al.,* 2019). Over 50 percent of the variation in yield could be explained by changes in temperature and rainfall between flowering date and harvest date (Hummel *et al.,* 2018). When water and heat stress occur simultaneously, there is more damage to crop production than when these stresses occur separately (Carlos *et al.*, 2020). It is more likely that crops will be exposed to both heat and water stress simultaneously (Vanaja *et al.*, 2017, Singh *et al.*, 2021) in changing climates. Hence, strategies aimed at matching kidney bean development to suitable soil moisture supply and temperatures regimes are key determinants of adaptation to current and future climate scenarios. An understanding of the crop's responses to these abiotic stresses may enable farmers to increase kidney bean productivity and achieve yield stability (Tahashildar *et al.*, 2017). However, thus far most studies have focused on assessing the response of kidney bean to elevated temperature and water stress as separate factors. Keeping the above in view, a field experiment was conducted during the spring season (January-April) of 2020 in the research farm ICAR-Indian Agricultural Research Institute, New Delhi-110012, India to quantify the response of growth and yield of kidney bean to different regimes of temperature and irrigation.

The experiment was carried under Randomized Block Design (RBD) in two separate field conditions. One experiment was set up in a temperature gradient tunnel (TGT), demarcated into three zones of varying temperature. The second experimental set-up was laid out in an open field. Combination of different irrigation and temperature treatments were imposed as indicated in Table 1. In open field, temperature stress was imposed by placing (3x3) m^2 structures made out of UV-stabilized polyvinyl chloride sheets. Temperature treatments were super-imposed with i) two irrigations (applied at sowing and vegetative phase) and ii) three irrigations (additional irrigation at pod-filling phase). Thus, a total of 14 treatments in three replicates were imposed i.e. combination of irrigation (2) and temperature (7) regimes. Daily maximum and minimum temperature were measured using digital temperature sensors. Additionally, daily weather data were obtained from the IARI weather observatory. Soil moisture in terms of available water volume (%) at a depth representing 0-20cm was monitored using Field Scout TDR-300 soil moisture meter in every plot at 5-day intervals. Kidney bean (Chitra variety) seeds were sown in spacing of 40 x 20 cm, at a depth of 5 cm. Nitrogen @ 100 kg ha^{-1} and phosphorus @ 50 kg ha^{-1} through urea and DAP were applied to all plots at the time of sowing. Manual weeding was carried out at 30 and 60 days after sowing (DAS). Data on phenology, leaf area index, NDVI, dry matter production and yield were recorded. The data were tabulated and statistically analyzed using SPSS (version 21) software. To test the significance of the treatment main effects (irrigation and temperature) and their interaction effect, the critical

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Table 1: Summary of temperature recorded under the different temperature regimes

Treatment	Seasonal mean T_{max}(°C)	Seasonal mean T_{min} (°C)	Seasonal mean temperature (°C)	Δ (Mean treatment– mean ambient at that stage) (°C)
ETG1	36.7	11.7	24.2	4.6 over 19.6
ETG2	33.9	11.6	22.8	3.1 over 19.6
ETG3	33.1	11.7	22.4	2.8 over 19.6
AT	25.9	13.4	19.7	-
ETPrFP	26.8	13.2	20.0	3.7 over 19.6
ETFP	29.4	12.9	21.1	5.3 over 23.1
ETPoFP	27.0	12.9	20.0	5.2 over 28.9

*T_{max}- maximum temperature; T_{min}- minimum temperature; ETG1-continuous elevated temperature at ~4.6°C above mean ambient; ETG2- continuous elevated temperature at ~3.1°C above mean ambient; ETG3- continuous elevated temperature at ~2.8°C above mean ambient; AT- ambient temperature @ 25.9/13.4°C; ETPrFP- elevated temperature during pre-flowering phase at ~3.7°C above mean ambient; ETFP- elevated temperature during flowering phase at ~5.3°C above mean ambient; ETPoFP- elevated temperature during pod-filling phase at ~5.2°C above mean ambient

Table 2: Interactive effect of irrigation and temperature regimes on phenology of the crop

Treatments		Days to 50% germination	Days to 50% flowering	Days to 50% pod initiation	Days to 50% pod development	Physiological maturity
IR	TMP					
2I	ETG1	14	47	51	60	73
	ETG2	15	48	52	62	75
	ETG3	15	48	53	64	78
	AT	22	60	65	76	88
	ETPrFP	23	58	65	76	87
	ETFP	23	59	65	75	89
	ETPoFP	22	59	65	75	90
3I	ETG1	14	47	51	60	74
	ETG2	15	48	52	62	76
	ETG3	15	48	53	64	78
	AT	22	59	64	74	90
	ETPrFP	22	57	64	74	89
	ETFP	22	58	63	73	91
	ETPoFP	22	58	64	74	92
CD at p=0.05						
Irrigation (I)		NS	NS	0.43	0.64	0.27
Temperature (T)		1.17	0.97	0.80	1.20	0.50
I x T		1.64	1.36	1.12	1.69	0.70
SEM± (I x T)		0.57	0.47	0.39	0.58	0.24

*IR; irrigation; TMP; temperature; NS- Not significant; * for details please refer to Table 1; 2I- 2 irrigations; 3I-3 irrigations.

difference (C.D.) was calculated at a 5% level of significance.

Phenological response to temperature and irrigation regimes

Exposure of plants to continuous elevated temperature regimes from sowing to emergence hastened developmental stages. Plants in these temperature regimes emerged 14 DAS as against 22 DAS in ambient temperature. Succeeding phenological events were also hastened in plants grown under continuous elevated temperature regimes compared to plants under ambient temperature (Table 2). Also, exposure of the crop to elevated temperature during pre-flowering and flowering led to a shorter crop growth period compared to plants under elevated temperature during the pod-filling phase. Overall, plants under seasonal mean temperatures of 36.7/11.7°C, 33.9/11.6°C and 33.1/11.7°C had shortened crop duration with 73-78 DAS. Plants under seasonal mean temperatures of 26.8/13.2°C (pre-flowering phase temperature regime) and 29.4/12.9°C (flowering phase temperature regime) attained physiological maturity earlier (87-88 DAS) compared to those under high temperature (27/12.9°C) during pod-filling phase and those under ambient temperature (25.9/13.4°C) which matured in 90-92 DAS. Additionally, supplemental irrigation provided during the pod-filling phase led to delayed physiological maturity. These results indicate that the crop has phenological plasticity response to temperature and water regimes. Early flowering and maturation is an avoidance mechanism that enables plants to utilize available resources and attain physiological maturity before the onset of

Table 3: Interactive effect of irrigation and temperature regimes on yield and yield components

Treatments*		Pod number per plant	Seed number per pod	Seed yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Test weight (g)	Shelling percentage	Harvest Index (%)
IR	TMP							
2I	ETG1	8	6	1229	2629	21	65	47
	ETG2	5	4	934	1821	18	80	51
	ETG3	7	5	883	2261	20	55	39
	AT	4	4	928	2151	24	71	43
	ETPrFP	4	4	781	2110	23	71	37
	ETFP	4	5	784	2224	24	62	35
	ETPoFP	4	5	868	2200	25	68	39
3I	ETG1	9	5	1255	3152	26	58	40
	ETG2	6	5	1005	2195	24	70	46
	ETG3	7	5	982	2752	23	61	36
	AT	7	4	974	2533	23	71	38
	ETPrFP	7	4	929	2338	23	70	40
	ETFP	6	4	970	2323	23	76	42
	ETPoFP	6	5	1126	2907	25	63	39
CD at p=0.05								
Irrigation (I)		0.90	NS	30.49	89.04	0.70	NS	NS
Temperature (T)		1.69	NS	57.03	166.59	1.31	5.59	3.35
I x T		NS	NS	80.23	235.59	1.85	7.90	4.73
SEm (I x T)		0.82	0.41	27.59	80.60	0.63	2.70	1.62

intense heat stress and water stress later in the crop growth season (Kazai *et al*., 2019).

Leaf area index (LAI) and Normalized difference vegetation index (NDVI)

Crop exposed to continuous elevated temperature regimes showed higher LAI and NDVI. Maximum LAI and NDVI, ranging from 3.93-5.17 and 0.48-0.62 respectively, was observed during the pod-filling phase. Also, exposure of plants to elevated temperature during the pre-flowering phase led to higher LAI and NDVI compared to other phase-wise treatments. Plants under ambient temperature for the entire season recorded the lowest LAI and NDVI. Overall, continuous elevated temperature regimes were more suitable for leaf area development, persistence and greenness as compared to ambient temperature treatments. Plants with supplemental irrigation during the pod-filling phase maintained higher LAI and NDVI compared to water-stressed treatments that showed early leaf senescence. Water stress leads to decreased number of leaves, senescence and abscission of leaves and ultimately lower LAI and NDVI, affecting the dry matter production and yield of the crop.

Dry matter production, yield and yield components

Plants under continuous elevated temperature regimes (36.7/11.7°C and 33.1/11.7°C) during the entire crop growth period maintained higher leaf dry matter (data not shown). Lowest leaf dry matter was observed in plants under continuous ambient temperature regime of 25.9/13.4°C. Also, supplementary irrigation during the pod-filling phase led to higher leaf dry matter till physiological maturity. In the ambient field, treatments exposed to high temperature during the pod-filling phase recorded higher pod dry weight when compared to other phase-wise treatments. Additionally, provision of supplemental irrigation led to higher pod dry matter when compared to water-stressed plants. Overall, total dry matter was highest in treatments under continuous elevated temperature and high temperature during the pod-filling phase with supplemental irrigation. On the other hand, elevated temperature during the pre-flowering and flowering phase significantly reduced total dry matter accumulation.

The biomass and seed yield per hectare recorded for the treatments ranged from 1821-3152 kg ha^{-1} and 781-1255 kg ha^{-1} respectively (Table 3). Plants under seasonal temperatures of 36.7/11.7°C i.e. seasonal mean temperature of 24.2°C during the entire crop growth season had the highest yield among all treatments. Also, plants under elevated temperature during the pod-filling phase recorded higher yield compared to other phase-wise treatments while plants exposed to high temperature during pre-flowering and flowering recorded the lowest yield. Provision of supplementary irrigation during the pod-filling phase led to higher yield compared to water-stressed treatments.

Results show that mean temperature of 29.4°C during flowering led to a reduction in the number of filled pods and seed yield. Heat stress during the flowering phase leads to reduced pollen viability, failed fertilization and flower drop which consequently affects pod development and seed set. On the other hand, maximum temperature up to 34°C during the pod-filling phase positively influenced the pod and seed growth as evidenced by higher yield in plants exposed to elevated temperature during the pod-filling phase. Additionally, results indicated that water stress (i.e. available soil moisture content below 10%) significantly reduced the number of filled pods and individual seed weight, ultimately leading to low yield compared to treatments with supplemental irrigation. In conclusion, findings from this study indicated that kidney bean exhibits phenological plasticity response to temperature and water regimes. Seasonal mean temperature of 24.2°C lead to better performance of the crop while temperature shocks during pre-flowering and flowering significantly reduced seed yield. Additionally, exposure of kidney bean plants to water stress (available soil moisture content <10%) significantly reduced seed yield. Coincidence of temperature stress and water stress had more detrimental effects on seed yield. Given the climate scenarios indicating increased variability in temperature and rainfall, findings from this study indicate that climatic risks may affect kidney bean seed yield in future. Strategies such as providing supplemental irrigation can alleviate the negative effects of temperature stress and improve kidney bean yield.

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