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Effect of heat stress on common bean under natural growing conditions in three locations in different climate zones in the state of São Paulo, Brazil

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Common bean (*Phaseolus vulgaris* L.) originated in medium to high altitude regions and is sensitive to high temperatures. Climate changes from an increase in global temperatures are foreseen, and therefore better understanding of the mechanisms of heat tolerance is necessary. In this context, the aim of this study was to investigate the effects of heat stress on twelve common bean genotypes under natural growing conditions in three locations (Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil) and in two growing seasons (fall-winter 2016 and summer 2016/2017). Data were analyzed by combined analysis of variance in a 2 × 3 × 12 factorial arrangement, considering two crop seasons, three locations, and twelve genotypes as factors. This was followed by the Scott-Knott mean comparison test (P<0.05), genetics, genetics×environment (GGE)-biplot analysis for grain yield and Pearson correlation for the summer season. Significant differences were found for the crop season, location, and genotype for most of the traits evaluated. It was found that the high temperatures, reached in summer, negatively affected the performance of cultivars, resulting in a reduction of 40% in grain yield. Votuporanga, which reached the highest temperatures during the summer, was considered as the most unfavorable environment. The genotypes that proved to be more productive in the summer for the locations of Campinas were BRS Agreste and FT Nobre; for Votuporanga, the genotypes Pérola and IPR Tangará; and for Ribeirão Preto, the genotypes SEA 5 and BRS Estilo. The highlighted correlations observed by the Pearson test were the highest leaf temperature reducing grain yield and, the highest relative index of chlorophyll contributed to higher productivity.

Key words: High temperature, *Phaseolus vulgaris*, selection, genotype × environment interaction, plant breeding.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of the main crops produced in Brazil and in the world. Its importance

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goes beyond economic factors considering its use as a basic food for the Brazilian population. According to CGIAR (2018), common bean is a highly nutritious food, containing protein, fiber, complex carbohydrates, vitamins and micro-nutrients. As such, beans strongly reinforce food and nutrition security among poor consumers, while also reducing the risk of cardio-vascular disease and diabetes. It is the most important grain legume for direct human consumption with 23 million hectares grown worldwide, and approximately 12 million metric tons produced annually.

Bean crop is grown in a wide range of latitudes with mean air temperature from 14 to 35°C, and due to its origin in medium to high altitude regions, it is sensitive to heat, whereas day and night temperatures above 30 or 20°C, respectively, result in significant yield reduction (Beebe et al., 2011). According to Araújo et al. (2015), common bean of Andean gene origin typically adapts better to cooler climate and high altitude (1400-2800 m) regions, whereas genotypes of Mesoamerican origin adapt to higher temperatures in low to medium altitude (400-2000 m) regions.

According to IPCC (2014), the surface temperature is projected to raise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. This increase in global temperature is most due to the continued emission of greenhouse gases and it will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.

Thus, if there are no efforts to reduce carbon intensity in the atmosphere most crop areas of the world will be susceptible to high mean air temperatures, which may compromise agricultural production and food security, increasing the risk of drought, limiting and reducing rates of photosynthesis, interception of light, accelerating the phenological development and influencing the biomass, fruit, and grain production (Teixeira et al., 2013).

Souza et al. (2011), mentioned that an increase in temperature above the critical value for a sufficient period of time can cause irreversible damage, recognizing that the base temperature or tolerance limit of the plant may vary according to the species and the genotypes of the same species, and among the phenological phases of the same genotype. According to Talukder et al. (2014), thermotolerance in the field occurs under natural circumstances and, although high temperature is a frequently occurring phenomenon, little is known about the critical genes that control heat tolerance in plants. To maintain growth and yield, plants must adapt to stress conditions and activate specific tolerance mechanisms.

According to Mcclean et al. (2011), due to the short time available for changing the genetic composition of germplasm in the face of predictions of climate change, efforts should be concentrated on the best understanding of the physiological mechanisms of tolerance to high temperatures and to water deficit, as well as on identification of genetic factors that control physiological responses to pyramid these factors in new cultivars leading to maximization of yield under drought alone and drought combined with heat stress.

In this context, the aim of this study was to investigate the effects of heat stress in twelve genotypes of common bean under natural growing conditions in three locations with different climate zones and in two crop season evaluating agronomical and morpho-physiological traits to test our hypothesis that the high temperatures reached in the summer season negatively affects the bean production and it is also possible to identify tolerant genotypes in these conditions.

MATERIALS AND METHODS

Field experiments were set up in the Grains and Fibers Center of the Instituto Agronômico - IAC (Santa Elisa Farm, Campinas, SP, Brazil), in the Polo Regional do Noroeste Paulista (Rubber Tree and Agroforest Systems Center, Votuporanga, SP, Brazil), and in the Polo Regional do Centro Leste (Sugarcane Center, Ribeirão Preto, SP, Brazil); all institutional bodies were connected with the Agência Paulista de Tecnologia do Agronegócio (APTA). The municipalities were chosen through their belonging to different climate zones, with medium to high temperatures, being presented in the climatic history of the last ten years (Table 1). Sowing was carried out in two crop seasons, fall-winter 2016 and summer 2016-2017, in order to synchronize the flowering period with the months of highest and lowest mean temperature.

Twelve common bean genotypes were used with different color of tegument and with different growth habits as I, II and III (upright determinate, indeterminate and prostrate indeterminate) (Table 2), being chosen considering their known performance for water deficit tolerance in regions where high temperatures occur, such as in the North of the State of São Paulo and in the Center-West of Brazil. A randomized block experimental design was adopted with four replications. Each experimental plot consisted of four four-meter rows, at a spacing of 0.5 m between rows and 0.1 m between plants.

The climate data regarding mean, maximum, and minimum temperatures during the growing period were acquired by the Centro integrado de informações agrometeorológicas - CIIAGRO ONLINE (http://www.ciiagro.sp.gov.br/ciiagroonline/).

In the period of full flowering (R6), four plants from the two center rows were sampled at random for the following evaluations.

Physiological evaluations

(1) Stomatal conductance (SC): A porometer (Type AP4 – Delta T Devices) was used, in a state of dynamic equilibrium. Readings were made between 9:00 and 11:00 in the morning on the abaxial surface of completely expanded leaves from the middle part of plants exposed to solar radiation.

(2) Leaf temperature (LT) was measured by an infrared thermometer (Telatemp model AG- 42D, Telatemp, Fullerton, CA, USA). The measurement was performed at 0.50 m from the leaf surface at an angle of 45° from the middle part of the plants; the readings were made at 9:00 in the morning.

(3) Relative chlorophyll index (RCI) was determined in the leaves

Table 1. Location, Koeppen climatic classification, climatic historical from 01/2008 to 12/2017 according to the Integrated Agrometeorological Information Center – CIIAGRO of the locations of Campinas, Votuporanga and Ribeirão Preto.

CAMPINAS

Lat 22° 31m; Long 47° 2m; Alt 680 m

Koeppen Climate Classification

Cwa

Month	TMAXA	TMINA	TMAXM	TMINM	TMED	ETP	PRECIP
January	33.59	15.97	29.15	19.10	24.15	137.6	263.98
February	33.83	17.43	30.61	19.67	25.14	127.9	152.6
March	32.92	15.93	29.09	19.00	24.07	115	182.32
April	31.66	12.78	27.94	17.30	22.62	83.5	83.53
May	29.34	9.98	25.12	14.18	19.64	61.5	63.54
June	28.36	7.95	24.00	12.58	18.29	49.4	70.68
July	29.32	7.53	24.85	12.45	18.63	55	30.46
August	32.19	9.27	26.74	13.44	20.1	69.6	28.7
September	34.31	11.08	28.47	15.56	22.02	90.1	60.39
October	35.35	13.12	29.22	17.5	23.37	117.4	89.3
November	33.63	14.94	29.09	18.2	23.65	121.9	163.54
December	33.72	16.27	29.73	19.25	24.5	143	197.08

VOTUPORANGA

Lat 20° 15 m; Long 49° 34 m; Alt 525 m

Koeppen Climate Classification

Aw

Month	TMAXA	TMINA	TMAXM	TMINM	TMED	ETP	PRECIP
January	35.6	18.44	31.49	20.87	26.19	161.7	260.03
February	35.66	19.1	32.18	20.87	26.53	141.2	180.21
March	38.98	17.4	31.79	20.47	26.14	140.6	181.46
April	40.73	8.74	30.75	18.03	24.37	103.1	58.38
May	32.27	9.03	28.53	15.19	21.88	74.6	48.59
June	32.11	7.65	27.72	14	20.88	60.7	33.32
July	32.63	7.9	28.73	13.87	21.31	66	20.4
August	35.6	8.24	30.88	14.92	22.89	85.5	18.78
September	37.59	12.23	32.48	17.31	24.91	114.6	70.78
October	38.46	14.22	32.86	19.24	26.05	149.3	89.94
November	36.26	16.49	32.13	19.96	26.06	151.9	136.69
December	35.95	18.12	32.03	20.92	26.48	161.6	183.05

RIBEIRÃO PRETO

Lat 21° 6 m; Long 47° 28 m; Alt 531 m

Koeppen Climate Classification

Aw

Month	TMAXA	TMINA	TMAXM	TMINM	TMED	ETP	PRECIP
January	33.76	17.32	29.91	19.48	24.71	140.9	245.36
February	34.07	17.51	30.87	19.51	25.21	128.3	160.03
March	33.19	16.41	29.72	18.93	24.34	118.7	167.48
April	32.14	12.07	28.99	17.2	23.11	87.5	59.24
May	30.15	8.84	26.61	14.24	20.43	66.4	53.21
June	29.53	7.26	25.91	12.88	19.4	55.3	35.32
July	30.37	7.3	26.76	12.74	19.76	60.9	16.54
August	32.95	8.05	28.88	13.92	21.4	76.4	21.2
September	35.58	10.9	30.76	16.3	23.52	100.2	61.57

Table 1. Contd.

October	36.71	13.16	31.37	18.29	24.83	132.9	85.76
November	34.73	15.09	30.43	18.71	24.56	132.7	166.17
December	34.18	15.73	30.33	19.45	24.89	143.7	210.04

ABMAXT- Absolute maximum temperature, ABMINT - Absolute minimum temperature, AVMAXT- Average maximum temperature, AVMINT- Average minimum temperature, AVT - Avarage temperature, PET - Potencial evapotranspiration.

Table 2. Genotypes to be used in the study of heat tolerance.

Genotype	Grain type	Growth habit	Origin
1-SEA 5	Mulatto	Type I	CIAT
2-IAC Imperador	Carioca	Type I	IAC
3-SER 16	Red	Type I	CIAT
4- Pérola	Carioca	Type III	EMBRAPA
5-IAC Milênio	Carioca	Type III	IAC
6-FT Nobre	Black	Type II	FT-SEMENTES
7-BRS Estilo	Carioca	Type II	EMBRAPA
8-IAPAR 81	Carioca	Type II	IAPAR
9- IAC Diplomata	Black	Type II	IAC
10- IPR Tangará	Carioca	Type III	IAPAR
11- BRS Agreste	Mulatto	Type II	EMBRAPA
12-IAC Sintonia	Carioca	Type II	IAC

from the middle part of plant using the non-destructive method SPAD-502Plus (Konica Minolta) in the flowering stage (R6).

Morphological traits

(1) Plant height (PH) in centimeters;
(2) Number of nodes per plant (NNP);
(3) Shoot dry matter (SDM) in grams;
(4) Leaf area (LA) in cm², checked with the leaf area meter LI-COR (LI-3100C).

Agronomical traits

At physiological maturity, the two center rows of each plot were harvested to evaluate total grain yield (GY) and 100 seed weight (100SW) and three plants were sampled at random for the following evaluations: Number of pods per plant (NPP); Number of seeds per plant (NSP); Number of viable seeds per pod (NVSP); Number of aborted seeds per pod (NASP).

The experimental areas were irrigated in the absence of rainfall with the use of sprinklers. Soil moisture was kept at -40 kPa according to technical recommendation of the Watermark® measuring device. Crop treatments were made according to the needs of the crop.

The data were subjected to combined analysis of variance in a 2 × 3 × 12 factorial arrangement considering two crop seasons, three locations, and twelve genotypes as factors. This was followed by the Scott-Knott means comparison test at 5% probability, and GGE biplot analysis was performed to decompose the effects of the interactions among the factors for grain yield (GY). To verify the correlations between the variables, Pearson correlation analysis ($P>0.05$) was performed considering only the data referring to the mean values of each variable in each location in the summer crop season.

RESULTS AND DISCUSSION

According to Porch (2006), common bean is adapted to mild climate regions and, daytime and nighttime temperatures higher than 30 and 20°C, respectively, result in reduction of grain yield. The mean temperatures observed during the growing period in Campinas, Votuporanga, and Ribeirão Preto were 20.35, 21.27, and 22.88°C in the fall-winter season and 24.40, 26.26, and 23.87°C in the summer season, respectively. The peak of the absolute maximum temperatures reached in the summer, considered stressful to the common bean crop, were 33.5, 37.2, and 34.5°C, and the mean maximum temperatures were 31.35, 33.38, and 30.96°C for Campinas, Votuporanga, and Ribeirão Preto, respectively. This had a negative effect on genotype performance for grain yield. The Votuporanga environment in the summer crop with higher temperatures was the most unfavorable environment for grain yield (Figure 1). Analyses of variances (Table 3) for the crop season, location, and genotype factors showed significant effects for most of the traits studied. The significant effects of the blocks within the location were isolated from analysis for the traits leaf temperature (LT), stomatal conductance (SC), shoot dry matter (SDM), leaf area (LA), and grain yield (GY). Significant effects were also found for the crop

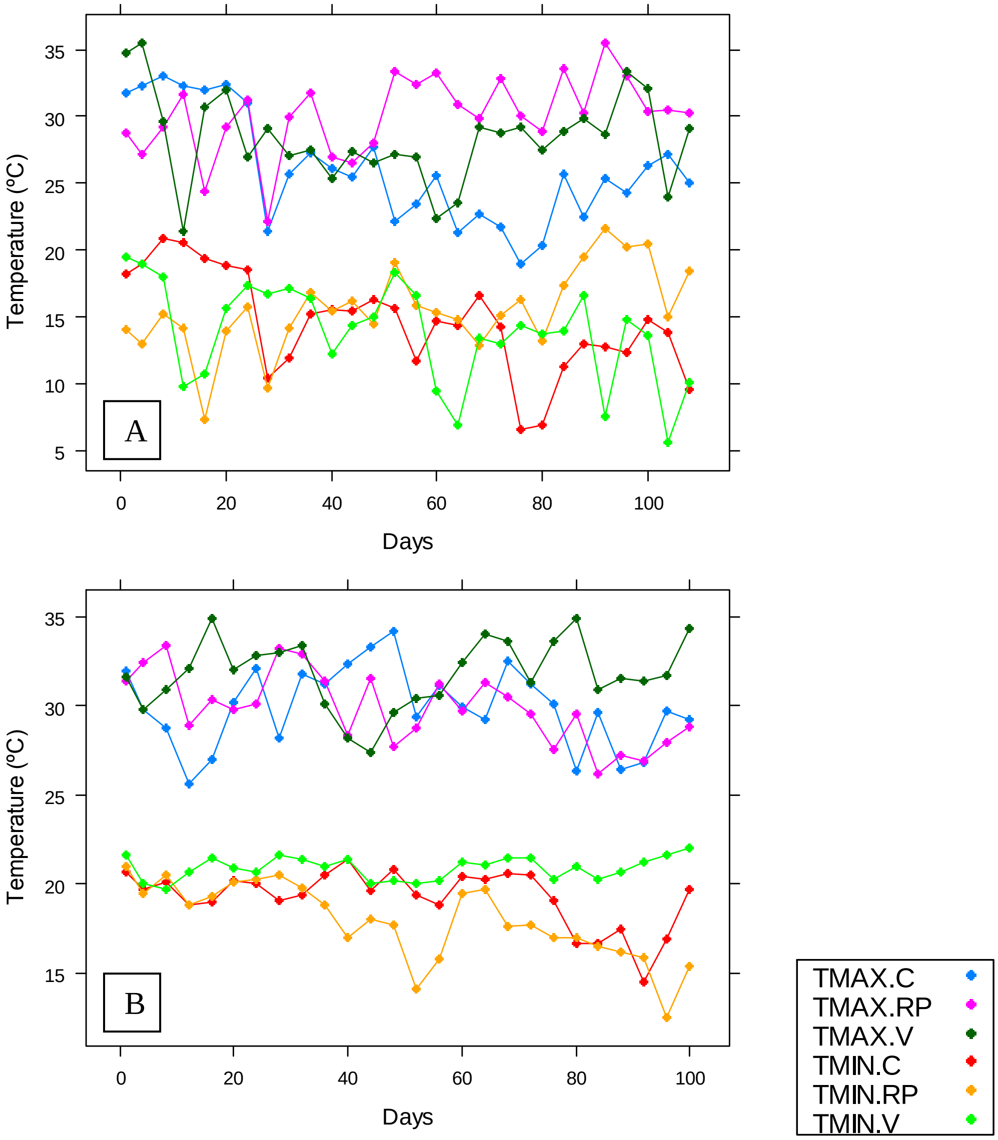

Figure 1. Absolute maximum and minimum temperatures of the environments of Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil, registered over the crop cycle for each environment. A. Winter, B. Summer.

season × location interactions in all the traits studied; effects of crop season × genotype for plant height (PH), number of aborted seeds per plant (NASP), and 100 seed weight (100SW); effects of location × genotype for PH, LA, NASP, 100SW, and GY; and effects of the triple interaction of crop season × location × genotype for relative chlorophyll index (RCI), PH, LA, number of viable seeds per plant (NVSP), NASP, and 100SW. The coefficients of variation, exhibiting low to medium magnitude, ranged from 5.98 to 30.13%, indicating good experimental precision.

The crop season factor significantly affected the performance of the traits, except for SDM and number of pods per plant (NPP) (Table 3). In the fall-winter, greater development was observed of the LA characteristics and of the production and grain yield components number of seeds per plant (NSP), NVSP, NASP, 100SW, and GY. Thus, this crop season was more favorable to grain yield, with increases of 37.22, 5.01, 15.22, 36.45, 2.90, and 67.95% in these factors, respectively, in comparison to summer. In the summer, an increase in performance was observed in the characteristics LT, RCI, PH, NNP, SC, SDM, and NPP of 30.76, 7.69, 12.15, 10.53, 123.32, 9.27, and 5.21%, respectively, in comparison to performance in the winter crop season.

Uddin et al. (2007) studying the seasonal influence on yield and yield components characters of four lablab bean genotypes covering one main season (winter) and

Table 3. Summary of analyses of variance in relation to cultivation of twelve genotypes of common bean grown in the winter 2016 and summer 2016/2017 crop seasons in Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil.

Source of variance	DF	LT	RCI	SC^t	PH	NNP	SDM^t	LA	NPP^t	NSP^t	NVSP	NASP^t	100SW	GY
							Mean square							
Crop season	1	2298.3**	468.7**	3092**	4386**	119.43**	0.02	64526687**	0.099	14.86*	24.44**	1.2524**	32.3**	33487544**
Location	2	640.2**	1543.2**	748.2**	16671**	90.52**	34.27**	21236758**	15.487**	69.93**	1.44	0.177**	912.2**	10593267**
Genotypes	11	2.8	143.9**	10.9	4711**	30.54**	0.33	1565274**	1.455**	2.95	3.85**	0.097**	132.2**	285626
Location:Block	9	11.2**	21.4	52.6**	142	9.48	0.7*	2337088**	0.407	1.14	0.66	0.0417	0.6	389657*
Crop season: Location	2	223.5**	367.3**	1514.1**	20465**	20.64*	55.38**	54264197**	10.597**	169.28**	39.69**	0.1411**	2007.1**	53888634**
Crop season:Genotypes	11	2.5	31.7	5.6	351*	5.93	0.19	911224	0.523	2.96	0.61	0.0714**	9.8**	220859
Location:Genotypes	22	1.7	20.7	8.3	303**	7.78	0.38	1237468**	0.611	3.56	0.71	0.0663**	10.1**	392903**
Crop season:Location:Genotypes	22	1.5	31*	9	529**	5.76	0.47	1165877*	0.432	2.13	0.87*	0.0444**	7.7**	157051
Residuals	207	3	17.7	15.1	156	5.78	0.33	640082	0.518	2.59	0.49	0.0223	2	162347
CV (%)	-	8.13	12.22	21.39	18.34	18.78	14.77	26.52	17.9	20.42	17.12	10.02	5.98	30.13

^{t}Data transformed √x+1. DF: degree of freedom; LT: leaf temperature (°C); RCI: relative chlorophyll index (SPAD); CS: stomatal conductance (mmol m^{-2} s^{-1}); PH: plant height (cm); NNP: number of nodes per plant; SDM: shoot dry matter (g); LA: leaf area (cm^2); NPP: number of pods per plant; NSP: number of seeds per plant; NVSP: number of viable seeds per pod; NASP: number of aborted seeds per pod; 100SW: 100 seed weight (g); GY: grain yield (g).

two off-seasons (early summer and late summer) also verified that all the genotypes performed better for all the parameters during winter. Pod setting was reduced during late summer in all the genotypes as the number of seeds per pod. They also verified that most of the agronomic traits as number of inflorescence per plant, number of flower buds per inflorescence, number of pod set per inflorescence, number of pod per plant, and single pod weight were severely affected.

Román-Avilés and Beaver (2003) also observed the high temperature influence in the common bean production studying the inheritance of heat tolerance in Andean genotypes and, observing that the Indeterminate Jamaica Red and DOR 303 genotypes presented, respectively, the double and 4 times greater mean of seed yields in the winter season than the summer season. However, the performance of the other lines in the trials suggests that selection for seed yield in the winter months would not guarantee the identification of high-yielding lines for the summer months. Selection for adaptation to high temperature environments requires the evaluation of bean lines during the summer months.

According to Kaushal et al. (2016), heat stress has harmful effects on plants, affecting growth, development, metabolism, and yield. Exposure to high temperatures causes a series of morpho-anatomical, physiological, and biochemical changes, reducing the life cycle, increasing senescence, and severely affecting yield. A mean temperature of 21.3°C in the winter and 24.84°C in the summer and a maximum absolute temperature of 32.31°C in the winter and 35.06°C in the summer were registered in this study. Thus, these temperatures negatively affected the performance of cultivars in the summer crop season, resulting especially in higher leaf temperature, with a mean increase of 5.65°C and, consequently, less development of leaf area and of production components and mean reduction of 40% in grain yield.

According to Kumar et al. (2015), lower temperature of the plant canopy is frequently associated with higher grain yield, with a deeper root system, and with greater stomatal conductance in environments subjected to high temperature. Therefore, selection for temperature of the plant canopy, combined with greater initial vigor and delayed senescence to improve interception of light, as well as greater stability of the membrane, the presence of photoprotective pigments, and wax to improve the efficiency of the use of radiation, are desirable for making selection for heat tolerance.

The heat stress intensity index was verified according to Fisher and Maurer (1978), considering the fall-winter crop season as non-stressful and summer as stressful, for the combined data and for the locations of Campinas, Votuporanga, and Ribeirão Preto, obtaining indexes of 0.40, 0.14, 0.82, and -0.47%, respectively. Thus, the Votuporanga location, which reached the highest temperatures during the summer crop season, had the highest stress intensity index, and it was considered drastic, reducing the mean yield from 2885 kg.ha^{-1} observed in fall-winter to 513 kg.ha^{-1} in summer. A lower heat stress intensity index was also found for Campinas. This may be explained by the low yield also achieved in the fall-winter crop season of 1124 kg.ha^{-1}, in which a mean minimum temperature of 13.5°C and an absolute minimum of 5.5°C were observed, while in the summer, a grain yield of 968 kg.ha^{-1} was observed. However, a negative stress intensity index was registered in Ribeirão Preto since the mean yield achieved by the genotypes in the winter season was 1026 kg.ha^{-1}, less than the yield observed in the summer, of 1508 kg.ha^{-1}. The mean, mean maximum, and absolute maximum temperatures reached in the summer were 23.87, 30.96, and 34.5°C, respectively. In addition, in that season, the mean of the maximum temperatures was the lowest among the locations, which favored the highest grain yield in the summer among the locations.

Porch (2006) found a heat stress intensity index of 0.66 in cultivation of 14 genotypes in two locations with high and low temperature in field experiments, and an index of 0.98 in experiments evaluating the same genotypes in a greenhouse. The mean temperatures in the different environments ranged from 25.2 to 29.2°C. According to the author, due to the higher heat stress intensity observed in the experiments in the greenhouse, these experiments were less informative and, furthermore, it reinforced that moderate indexes are more adequate for differentiation of the genotypes.

For the location factor, significant effects were also observed for the characteristics, except for NVSP. In location 1, Campinas, the variables LT, and NASP exhibited their highest mean values, which were 24.08ºC and 1.39 aborted seeds, respectively. In location 2, Votuporanga, the best mean performances were found for RCI, SC, LA, NVSP, and GY, with values of 37.4 SPAD units, 493.86 (mmol m^{-2} s^{-1}), 3425.66 cm², 4.22 viable seeds per pod, and 1699.0 kg.ha^{-1}, respectively. In location 3, Ribeirão Preto, the variables that exhibited the best mean performances were PH, NNP, SDM, NPP, NSP, and 100SW, with values of 83.40 cm, 13.92 nodes.plant^{-1}, 21.16 g, 4.48 pods.plant^{-1}, 83.10 seeds.plant^{-1}, and 26.94 g (Table 4).

For the genotype factor, significant effects were detected for the variables RCI, PH, NNP, LA, NPP, NVSP, NASP, and 100SW, showing variability among the genotypes for the characteristics evaluated. There was variation from 37.9 to 30.46 SPAD units for the RCI variable, and the genotypes that exhibited the highest mean values were Pérola, IAC Milênio, IPR Tangará, and FT Nobre. PH exhibited mean variation from 95.14 to 49.47 cm, and the genotypes with the greatest and smallest height were Pérola and IAC Imperador, respectively. The mean values exhibited for NNP were 14.33 to 9.98 and nine genotypes exhibited more than 13.49 nodes per plant. Mean production in regard to LA ranged from 3311.61 to 2454.83 cm². Eight genotypes stood out with production greater than 3000 cm², and the highest and lowest LA values found were for the genotypes FT Nobre and IAC Imperador, respectively.

Siddiqui et al. (2015) also observed significant differences in ten bean genotypes that were subjected to a control and two high temperature treatments (25, 31, and 37°C) evaluating morphophysiological traits. Data revealed that the growth attributes of all the genotypes were significantly affected by temperature in all the cultivars. Plant height, shoot dry and fresh matter, leaf area, and total chlorophyll synthesis exhibited gradual reductions from the control to the treatments with high temperature. The decrease observed in these parameters was attributing to loss of turgidity, altering cell division and lengthening, and reduction in total biosynthesis of chlorophyll due to inhibition of photosynthetics in the electron transport chain.

Mean production of NPP ranged from 18.58 to 11.18. Ten genotypes exhibited mean values higher than 14 pods per plant, and the highest and lowest mean values observed were for IAC Sintonia and SEA 5, respectively. The NVSP ranged from 4.67 to 3.48, eight genotypes exhibited values of more than four seeds per pod, and the genotypes with the highest and lowest number of pods were SEA 5 and IAC Sintonia, respectively. For NASP, there was a mean from 1.51 to 0.77 aborted seeds, with only the genotype SEA 5 standing out with the lowest index of seed abortion. In relation to 100 seed weight, mean values from 26.92 to 18.35 were found, highlighting the genotypes with highest and lowest weight, IAC Milênio and IAC Sintonia, respectively (Table 3). Porch et al. (2010) field evaluated two genotypes of heat tolerant common bean, TARS-HT1 (PI 98059-6-2-1) and TARS-HT2 (PI 98059-10-2-1), and the lines resulting from hybridization between the two genotypes under mild conditions and under high temperature in two climate zones and in two seasons of the year. These authors found that the genotype TARS-HT1, one of the parents, proved to be the genotype most tolerant to heat among the 24 tested in the trials, showing 0% reduction in number of pods and reduction of 22% in number of seeds under high nighttime temperature conditions, compared to the treatment without stress.

Rainey and Grif (2005) assessed the production components of 24 common bean genotypes after exposure to four treatments of daytime/nighttime temperature (24/21, 27/24, 30/27, and 33/30°C). The treatment with the highest temperature showed decreases in number of seeds, number of pods, seed weight, and seed/pod weight of 83, 63, 47, and 73% on average, respectively. The heat tolerant genotypes showed different responses to high temperatures, suggesting

Table 4. Mean performance (Scott-Knott 5%) in relation to cultivation of twelve genotypes of common bean grown in the fall-winter 2016 and in the summer 2016/2017 crop seasons in Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil.

Crop season	LT	RCI	SC	PH	NNP	SDM	LA	NPP	NSP	NVSP	NASP	100SW	GY
1	18.38^{b}	33.15^{b}	229.07^{b}	64.30^{b}	12.15^{b}	14.34^{b}	3489.63^{a}	15.45^{a}	66.91^{a}	4.39^{a}	1.46^{a}	23.75^{a}	1678.23^{a}
2	24.03^{a}	35.70^{a}	511.54^{a}	72.10^{a}	13.44^{a}	15.67^{a}	2542.95^{b}	16.30^{a}	63.72^{a}	3.81^{b}	1.07^{b}	23.08^{b}	996.25^{b}
Location													
1	24.08^{a}	36.01^{b}	247.35^{c}	61.05^{b}	12.26^{a}	12.10^{b}	2502.53^{c}	13.81^{b}	55.82^{b}	3.97^{a}	1.39^{a}	22.07^{b}	1045.94^{c}
2	19.09^{c}	37.40^{a}	493.86^{a}	60.14^{b}	12.21^{b}	11.76^{b}	3425.67^{a}	13.69^{b}	57.02^{b}	4.21^{a}	1.27^{a}	21.23^{c}	1699.00^{a}
3	20.43^{b}	29.87^{c}	369.70^{b}	83.41^{a}	13.92^{a}	21.16^{a}	3120.67^{b}	20.13^{a}	83.10^{a}	4.12^{a}	1.14^{b}	26.94^{a}	1266.79^{b}
Genotype													
1	20.99^{a}	32.61^{c}	445.90^{a}	56.58^{d}	11.82^{b}	17.61^{a}	3189.71^{a}	11.18^{b}	52.29^{a}	4.67^{a}	0.77^{b}	25.97^{b}	1560.79^{a}
2	21.65^{a}	32.48^{c}	328.38^{a}	49.47^{e}	9.99^{c}	15.46^{a}	2454.83^{b}	17.71^{a}	63.79^{a}	3.61^{b}	1.51^{a}	21.53^{e}	1258.05^{a}
3	21.75^{a}	30.47^{c}	368.85^{a}	59.69^{d}	12.07^{b}	15.86^{a}	3025.18^{a}	17.83^{a}	66.75^{a}	3.59^{b}	1.23^{a}	22.74^{d}	1305.41^{a}
4	21.08^{a}	37.90^{a}	323.82^{a}	95.14^{a}	14.33^{a}	13.57^{a}	2740.25^{b}	13.79^{b}	60.21^{a}	4.29^{a}	1.40^{a}	24.50^{c}	1328.37^{a}
5	20.99^{a}	37.76^{a}	344.50^{a}	82.31^{b}	12.97^{a}	14.01^{a}	2879.44^{b}	14.92^{a}	55.63^{a}	3.77^{b}	1.19^{a}	26.92^{a}	1297.32^{a}
6	21.11^{a}	35.88^{a}	370.14^{a}	57.93^{d}	13.38^{a}	15.08^{a}	3311.61^{a}	16.33^{a}	70.79^{a}	4.53^{a}	1.21^{a}	18.35f	1223.40^{a}
7	21.60^{a}	34.56^{b}	389.22^{a}	55.32^{d}	13.43^{a}	14.27^{a}	3268.14^{a}	15.58^{a}	71.21^{a}	4.38^{a}	1.15^{a}	23.14^{d}	1386.25^{a}
8	21.44^{a}	33.85^{b}	378.35^{a}	62.19^{c}	12.49^{a}	15.02^{a}	3106.93^{a}	17.25^{a}	69.46^{a}	4.02^{a}	1.33^{a}	23.22^{d}	1297.47^{a}
9	20.67^{a}	34.80^{b}	387.39^{a}	69.47^{c}	12.76^{a}	15.81^{a}	2780.82^{b}	15.29^{a}	66.71^{a}	4.32^{a}	1.36^{a}	21.68^{e}	1175.45^{a}
10	21.27^{a}	37.24^{a}	355.69^{a}	84.88^{b}	13.36^{a}	13.68^{a}	3097.78^{a}	16.25^{a}	71.83^{a}	4.41^{a}	1.22^{a}	25.33^{c}	1502.14^{a}
11	21.01^{a}	31.35^{c}	376.95^{a}	67.81^{c}	13.75^{a}	14.56^{a}	3104.56^{a}	15.75^{a}	68.04^{a}	4.16^{a}	1.33^{a}	22.39^{d}	1334.24^{a}
12	20.87^{a}	34.25^{b}	374.49^{a}	77.63^{b}	13.21^{a}	15.16^{a}	3236.22^{a}	18.58^{a}	67.08^{a}	3.48^{b}	1.46^{a}	25.18^{c}	1378.02^{a}

DF: Degree of freedom; LT: leaf temperature (°C); RCI: relative chlorophyll index (SPAD); CS: stomatal conductance (mmol m^{-2} s^{-1}); PH: plant height (cm); NNP: number of nodes per plant; SDM: shoot dry matter (g); LA: leaf area (cm^{2}); NPP: number of pods per plant; NSP: number of seeds per plant; NVSP: number of viable seeds per pod; NASP: number of aborted seeds per pod; 100SW: 100 seed weight (g); GY: grain yield (g).

differential genetic control of the heat tolerance mechanisms, and the authors indicated the treatment at 30/27°C as the optimum treatment for selection of materials for heat tolerance.

GGE-biplot analysis was carried out for the grain yield and, the Figure 2 shows that the six environments are divided in the biplot in four sectors, showing high correlation among the environments of Ribeirão Preto in fall-winter, Ribeirão Preto in the summer, and Campinas in the fall-winter (PGIRP, PGVRP, and PGIC), with grain yield of 1025.50, 1508.08, and 1123.93 kg.ha^{-1}, respectively, and the other sectors represent the environments of Campinas in the summer (PGVC) with mean yield of 969.93 kg.ha^{-1}, Votuporanga in the summer (PGVV) with mean yield of 512.74 kg.ha^{-1}, and Votuporanga in the fall-winter (PGIV) with mean yield of 2885.26 kg.ha^{-1}.

GGE-biplot analysis also shows that the most efficient genotypes in the summer for the Campinas locations were 11 - BRS Agreste (1121.356 kg.ha^{-1}) and 6 - FT Nobre (961.3063 kg.ha^{-1}); for Votuporanga, the genotypes 4 - Pérola (921.2375 kg.ha^{-1}) and 10 - IPR Tangará (660.5313 kg.ha^{-1}); and for Ribeirão Preto, the genotypes 1 - SEA 5 (2065.75 kg.ha^{-1}) and 7 - BRS Estilo (1486.268 kg.ha^{-1}). It can be inferred that the genotypes BRS Pérola and IPR Tangará were those that exhibited the best heat tolerance

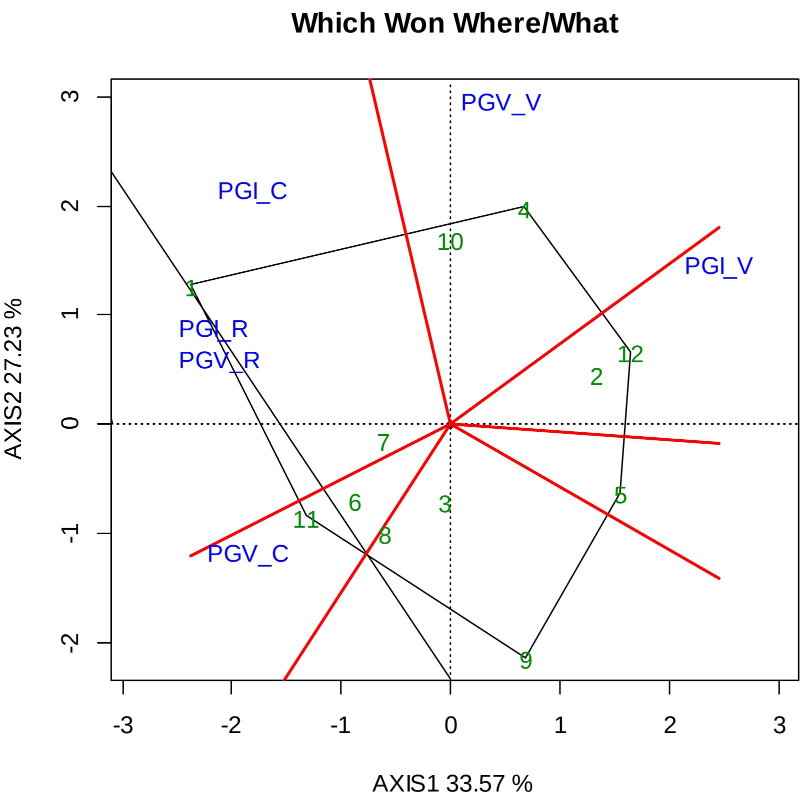

Figure 2. GGE-biplot in relation to grain yield (kg.ha^{-1}) of twelve common bean genotypes grown in the winter 2016 and in the summer 2016/2017 crop seasons in Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil.

since they exhibited the highest yields under high temperature conditions in the environment of Votuporanga in the summer (PGVV), which was the environment that exhibited the highest mean temperature (27°C) and the highest absolute maximum mean value (37°C) among all the environments.

The genotypes SEA 5 and BRS Estilo were the best in grain yield also for the environments Ribeirão Preto and Campinas in the fall-winter (PGIRP PGIC). These results corroborate Pereira et al. (2012), who, in their studies, identified the cultivar BRS Estilo with high grain yield in the dry and winter crop seasons in regions of the *Cerrado* (Brazilian tropical savanna) in the state of Mato Grosso. In the environment of Votuporanga in the fall-winter, which exhibited higher yield than the other environments (2885.26 kg.ha^{-1}), the genotypes IAC Sintonia (3401.25 kg.ha^{-1}) and IAC Imperador (3157.5 kg.ha^{-1}) stood out with the highest mean yields.

According to Didonet (2010), high temperature may be the environmental factor that has the greatest influence on flower abscission, low setting and final retention of pods, inadequate grain filling, reduction in the number of seeds per pod, and lower seed weight in common bean. This corroborates the results found in these experiments since the production components and grain yield were affected by crop season, thus showing the differential behavior of the genotypes when exposed to different growing environments.

Around 1000 lines of common bean (including Andean and Mesoamerican groups, interspecific crosses, and advanced lines) were evaluated for heat tolerance under field conditions in Armero, Colombia, by the Plant Breeding Program of CIAT (International Center for Tropical Agriculture), where the temperatures during the crop season considered stressful were 35°C for maximum temperature and 23°C for minimum temperature and 22.8°C for nighttime temperature. In this study the germplasm tested for heat tolerance proved to be very sensitive; nevertheless, it was possible to identify 40 superior genotypes based on visual observation in regard to pod formation. The authors infer that better pod formation observed in these genotypes occurred due to the presence of viable pollen and, consequently, successful pollination, as well as due to the differences observed in grain filling (CGIAR , 2015).

Pearson correlation analyses were performed (Table 5) among all the variables studied considering the mean values obtained in the three locations in the summer crop season. Thus, Table 5 shows the presence of negative and highly significant correlations at 1% probability

Table 5. Pearson correlation relative to cultivation of twelve genotypes of common bean grown in the winter 2016 and in the summer 2016/2017 crop seasons in Campinas, Votuporanga, and Ribeirão Preto, SP, Brazil.

Correlation	RCI	PH	NNP	SC	LA	SDM	NPP	NSP	NVSP	NASP	100SW	GY
LT	-0.2045	-0.0817	0.0067	0.3298*	0.209	0.2834	0.021	0.0934	0.065	0.1551	-0.4868**	-0.5141**
RCI		0.4016*	0.311	0.3484*	0.538**	0.1323	-0.0641	0.3933*	0.6161**	-0.1255	0.3482*	0.6089**
PH			0.4754**	-0.0893	0.2804	0.1536	0.0228	0.0035	-0.029	0.1451	0.3004	0.1013
NNP				-0.1526	0.178	-0.1813	0.1039	-0.0058	-0.1263	-0.0557	-0.0874	-0.2183
SC					0.4774**	0.3375*	-0.1465	0.3158	0.5707**	0.0217	-0.0676	-0.0652
LA						0.6211**	0.1296	0.5658**	0.5958**	-0.0318	-0.1315	0.2293
SDM							0.1167	0.383*	0.3723*	-0.0742	-0.1259	0.0948
NPP								0.6749**	-0.2625	0.2797	-0.1493	-0.2028
NSP									0.5144**	-0.0507	-0.1736	0.0603
NVSP										-0.3865*	-0.0662	0.3307*
NASP											-0.1922	-0.1806
100SW												0.6502**

DF: Degree of freedom; LT: leaf temperature (°C); RCI: relative chlorophyll index (SPAD); CS: stomatal conductance (mmol m^{-2} s^{-1}); PH: plant height (cm); NNP: numer of nodes per plant; SDM: shoot dry matter (g); LA: leaf area (cm^2); NPP: number of pods per plant; NSP: number of seeds per plant; NVSP: number of viable seeds per pod; NASP: number of aborted seeds per pod; 100SW: 100 seed weight (g); GY: grain yield (g).

between the LT variables and 100SW (-0.4868) and LT and GY (-0.5141). In other words, the higher temperature in the leaves of the plant canopy hurt pod filling, resulting in lower grain yield, as well as formation of lower weight grain. In addition, negative interaction was found between the number of viable seeds (NVSP) and the number of aborted seeds (NASP).

Twenty positive correlations were observed: LT with SC (0.3298), RCI with PH (0.4016), RCI with SC (0.3484), RCI with LA (0.538), RCI with NSP (0.3933), RCI with NVSP (0.6161), RCI with 100SW (0.3482), PH with NNP (0.4754), SC with LA (0.4774), SC with SDM (0.3375), SC with NVSP (0.5707), LA with SDM (0.6211), LA with NSP (0.5658), LA with NVSP (0.5958), SDM with NSP (0.383), SDM with NVSP (0.3723), NV with NSP (0.6749), NSP with NVSP (0.5144), NVSP with GY (0.3307), and 00SW with GY (0.6502).

The correlations observed between leaf temperature and stomatal conductance corroborate the plant responses described by Sicher and Bunce (2015) in which, CO_2 enrichment is able to attenuate the effects of moderate heat stress in plants that have the C_3 photosynthesis pathway, and mitigation of heat stress declines as temperatures increase. According these authors, high concentrations of CO_2 induce stomatal closing in many plant species, reducing the rates of leaf evapotranspiration, and the higher leaf water potential would benefit plants in the field during prolonged exposures to heat stress and high air temperatures create a demand for lower leaf temperatures, inducing stomatal opening and an increase in evapotranspiration rates. Thus, very high temperatures block the effects of CO_2 enrichment on stomatal opening and the growth of plants in high CO_2 concentration, that is, interfering at the beginning of senescence of various annual crops.

Furthermore, positive correlations were also found between stomatal conductance and more extensive formation of leaf area, shoot dry matter, and a higher number of viable seeds. According to Pimentel et al. (2013), in addition to biochemical limitation to photosynthesis, carbon supply is also physically limited on the leaf surface, through stomatal conductance (gs) and through mesophyll conductance (gm). Under high temperatures, diffusion limitations may occur in which gs, the main regulatory control that limits CO_2 diffusion in the leaf, is affected by the differences in atmospheric vapor pressure deficit (VPD), and gm is affected both by metabolic activity and by leaf anatomy.

Porch and Hal (2013) also report the occurrence of a positive correlation between grain yield and photosynthetic rate, and also between grain yield and stomatal conductance in spring wheat growing in hot. This indicates that more fully open stomates of heat resistant cultivars may lead to improved photosynthesis, facilitating diffusion of CO_2 in the leaves and increasing transpirational cooling, that is, creating temperatures lower than the damage threshold. In addition, yield differences of a cultivar in a hot and irrigated environment were positively correlated with the number of kernels per spike.

The relative chlorophyll index checked in the middle third of the plants showed positive correlations with the plant shoot traits of PH and LA, the physiological trait of SC, and with the production components of NSP, NSV, 100SW, and GY. According to Signorelli et al. (2015), various studies have reported correlation between changes in the parameters of chlorophyll fluorescence in response to environmental stresses such as high temperature, reducing the quantity of photosynthetic pigments, reduces photosynthetic and respiratory activity of the plant. Thus, the positive correlations observed between the relative chlorophyll index contributed significantly to an increase in grain yield and to better performance of genotypes in the summer crop season.

Greater development of the morphological parameters LA and SDM also contributed to greater development of seeds per plant, just as to a higher number of viable seeds per pod. This behavior was expected since the increase in photosynthetic area resulted positively in higher production of photosynthates and, consequently, better development of the production components.

Pearson correlation analyses allowed assessment of the relations among the variables that in the summer crop season contributed to the performance of the cultivars exposed to high temperatures.

Conclusions

The crop season factor significantly influenced the performance of genotypes and the high temperatures observed in the summer crop season drastically reduced the grain yield of the cultivars, and the mean heat stress intensity index was 0.4;

The environment Votuporanga in the summer season was the most unfavorable environment, reaching the highest absolute average temperatures, which resulted in a grain yield reduction of 82.2%.

Due to the high interaction of genotype vs. location and season vs. location for grain yield, it was observed that these genotypes do not have wide adaptability for high temperature, being necessary to carry out the evaluations and selections in unfavorable environments, as Votuporanga.

The genotypes that proved to be more productive in the summer for the locations of Campinas were BRS Agreste and FT Nobre; for Votuporanga, the genotypes Pérola and IPR Tangará; and for Ribeirão Preto, the genotypes SEA 5 and BRS Estilo.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Araújo SS, Beebe S, Crespi M, Delbreil B, González EM, Gruber V, Patto MCV (2015). Abiotic Stress Responses in Legumes : Strategies Used to Cope with Environmental Challenges. Critical Reviews in Plant Sciences, (October 2014), pp. 37-41. https://doi.org/10.1080/07352689.2014.898450

Beebe S, Ramirez J, Jarvis A, Rao IM, Mosquera G, Bueno JM, Blair MW (2011). Genetic improvement of common beans and the challenges of climate change. In: Yadav SS, Redden RJ, Hatfield JL, Lotze-Campen H, Hall AE. Crop Adaptation to Climate Change, First Edition. Blackwell Publishing Ltd. pp. 356- 369.

CGIAR- Consultative Group on International Agricultural Research (2018). Common bean. http://grainlegumes.cgiar.org/crops/common-bean/. Accessed: April 6, 2018.

CGIAR- Consultative Group on International Agricultural Research. (2015). Developing Beans that Can Beat the Heat. https://ccafs.cgiar.org/publications/developing-beans-can-beat-heat#.Wsdvd9TwYdU. Accessed:April 6, 2018.

Didonet AD (2010). Importância do período de pré-floração na produtividade do feijoeiro (Importance of the pre-flowering growth stage for common bean yield). Pesq. Agropec. Trop. Goiânia 40:(4)505-512.

Fisher RA, Maurer R (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912.

IPCC – Intergovernmental panel on climate change. (2014). Climate change 2014 synthesis report. https://www.ipcc.ch/news_and_events/docs/ar5/ar5_syr_headlines_en.pdf. Accessed: April 6, 2018.

Kaushal N, Bhandar K, Siddique KHM, Nayyar H (2016). Food crops face rising temperatures: An overview of responses, adaptive mechanisms, and approaches to improve heat tolerance. Cogent Food Agric. 2(1):1-42.

Kumar J, Pratap A, Kumar S (2015). Phenotyping Crop Plants for Drought and Heat-Related Traits. In: Kumar, J., Pratap, A., & Kumar, S. Phenomics in Crop Plants: Trends , Options and Limitations. Springer. 296 p. DOI 10.1007/978-81-322-2226-2

McClean PE, Burridge J, Beebe S, Rao IM, Porch TG (2011). Crop improvement in the era of climate change: an integrated, multi-disciplinary approach for common bean (*Phaseolus vulgaris*). Functional Plant Biol. 38(12):927.

Pereira HS, Almeida VM, Melo LC, Wendland A, Faria LC, Peloso MJD, Magaldi MCS (2012). Influência do ambiente em cultivares de feijoeiro-comum em cerrado com baixa altitude (Environmental influence in common bean cultivars grown in Brazilian savannah with low altitude). Bragantia, Campinas 71: 2.

Pimentel C, Ribeiro RV, Machado EC, Santos MG, Oliveira RF (2013). In vivo temperature limitations of photosynthesis in *Phaseolus vulgaris* L. Environ. Exp. Bot. 91:84-89. doi:10.1016/j.envexpbot.2013.03.005

Porch TG, Hal AE (2013). Heat Tolerance.in: Kole, C. Genomics and Breeding for Climate-Resilient Crops. Springer Heidelberg New York Dordrecht London. pp. 167-202. ttps://doi.org/10.1007/978-3-642-37045-8

Porch TG, Smith JR, Beaver JS, Griffiths P D, Station E, Street WN, Canaday CH (2010). 2010. TARS-HT1 and TARS-HT2 Heat-tolerant Dry Bean Germplasm. Hort Sci. 45(8):1278-1280.

Porch TG (2006). Application of stress indices for heat tolerance screening of common bean. J. Agron. Crop Sci. 192(5):390-394. https://doi.org/10.1111/j.1439-037X.2006.00229.x

Rainey KM, Grif PD (2005). Differential Response of Common Bean Genotypes to High Temperature. J. Am. Society Hort. Sci. 130(1):18-23.

Román-Aviles B, Beaver JS (2003). Inheritance of heat tolerance in common bean of Andean origin. J. Agrie. Univ. P.R. 87(3-4):113-121.

Siddiqui MH, Al-Khaishany MY, Al-Qutami MA, Al-Whaibi MH, Grover A, Ali HM, Al-Wahibi MS (2015). Morphological and physiological characterization of different genotypes of faba bean under heat stress. Saudi J. Biol. Sci. 22(5):656-663. https://doi.org/10.1016/j.sjbs.2015.06.002

Sicher RC, Bunce JA (2015). The Impact of Enhanced Atmospheric CO2 Concentrations on the Responses of Maize and Soybean to Elevated Growth Temperatures. In: Ramamurthy Mahalingam. Combined Stresses in Plants. Springer International Publishing Switzerland. pp. 27-48. DOI 10.1007/978-3-319-07899-1

Signorelli S, Casaretto E, Monza J, Borsani O (2015). Combined Abiotic

Stresses in Legumes. In: Ramamurthy Mahalingam. Combined Stresses in Plants. Springer International Publishing Switzerland. pp. 123-146. DOI 10.1007/978-3-319-07899-1

Souza MA, Pimentel AJB, Ribeiro G (2011). Melhoramento para tolerância ao calor. In: Fritsche-Neto, R. & Borém, A. Melhoramento de Plantas para Condições de Estresses Abióticos. Viçosa, MG. 250 p.

Talukder SK, Babar MA, Vijayalakshmi K, Poland J, Prasad PVV, Bowden R, Fritz A (2014). Mapping QTL for the traits associated with heat tolerance in wheat (*Triticum aestivum* L.). BMC Genet. 15(1):1-13. doi:10.1186/s12863-014-0097-4

Teixeira EI, Fischer G, Van Velthuizen H, Walter C, Ewert F (2013). Global hot-spots of heat stress on agricultural crops due to climate change. Agric. For. Meteorol. 170:206-215. https://doi.org/10.1016/j.agrformet.2011.09.002

Uddin MZ, Chowdhury AR, Hossain MM, Moniruzzaman M (2007). Seasonal influence on yield and yield contributing characters of lablab bean *Lablab purpureus* (L.) Sweet. The Agriculturists 5(1&2):109-119.