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Water deficit tolerance of bean cultivars

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Abstract – The objective of this work was to evaluate the response of the Garapiá, Triunfo, and BRS-FC104 bean (*Phaseolus vulgaris*) cultivars to the water deficit represented by the fraction of transpirable soil water (FTSW). The experimental design was completely randomized in a 3×2 bifactorial arrangement (cultivars × irrigation and no irrigation). Transpiration, growth, and yield were evaluated in the crop season and off-season. In the crop season, with a low atmospheric air demand (below 15 hPa in 55% of the days), 'Garapiá' presented early stomatal closure with the critical FTSW (FTSWc) of 0.36, but had the same yield as 'Triunfo', whose stomata closed late (FTSWc = 0.23). In the off-season, with a high atmospheric air demand (greater than 15 hPa in 83.3% of the days), 'Garapiá' presented an early stomatal closure (FTSWc = 0.17) and a higher yield (392.2 kg ha^{-1} more than 'Triunfo'). In the crop season and off-season, 'Garapiá' showed tolerance to water deficit in the reproductive period. Water deficit resulted in lower values of height, shoot dry mass, root dry mass, and leaf area. Both 'Garapiá' and 'Triunfo' showed a high yield in the crop season, but only 'Garapiá' in the off-season. 'Garapiá' presents tolerance to water deficit, with efficient stomatal control and high growth and yield.

Index terms: *Phaseolus vulgaris*, drought tolerance, FTSW, grain yield.

Tolerância ao déficit hídrico de cultivares de feijão

Resumo – O objetivo deste trabalho foi avaliar a resposta das cultivares de feijão (*Phaseolus vulgaris*) Triunfo, Garapiá e BRS-FC104 ao déficit hídrico representado pela fração de água transpirável no solo (FATS). O delineamento experimental foi inteiramente casualizado, em arranjo bifatorial 3×2 (cultivares × irrigação e sem irrigação). Avaliaram-se a transpiração, o crescimento e a produtividade na safra e na safrinha. Na safra, com baixa demanda atmosférica do ar (inferior a 15 hPa em 55% dos dias), 'Garapiá' apresentou fechamento precoce dos estômatos com FATS crítica (FATSc) de 0,36, mas teve a mesma produtividade que 'Triunfo', cujos estômatos fecharam tardiamente (FATSc = 0,23). Na safrinha, com alta demanda atmosférica do ar (superior a 15 hPa em 83,3% dos dias), 'Garapiá' apresentou fechamento estomático precoce (FATSc = 0,17) e maior produtividade (392,2 kg ha^{-1} a mais que 'Triunfo'). Na safra e na safrinha, 'Garapiá' apresentou tolerância ao déficit hídrico no período reprodutivo. O déficit hídrico resultou em menores valores de estatura, massa seca da parte aérea, massa seca da raiz e área foliar. Tanto 'Garapiá' como 'Triunfo' apresentaram alta produtividade na safra, mas apenas Garapiá na safrinha. 'Garapiá' apresenta tolerância ao déficit hídrico, com controle estomático eficiente e com altos crescimento e produtividade.

Termos para indexação: *Phaseolus vulgaris*, tolerância a seca, FATS, produção de grãos.

Introduction

Bean (*Phaseolus vulgaris* L.) is one of the major staple foods consumed daily, mainly in developing countries, and is a source of proteins (up to 25.2%) and minerals (selenium, zinc, iron), essential for nutritional and food safety (Celmeli et al., 2018).

Despite socioeconomic importance, there is a fluctuation in grain supply related mainly to water deficit, which is one of the main yield limitations (Devi et al., 2013; Zadraznik et al., 2013; Schwerz et al., 2017). The average yield of the bean crop in Brazil is 66.2% lower than its potential, with an average of 1,014.6 kg ha^{-1} in 2015/2016 to 2019/2020 crops (Conab, 2021). However, experimental and high-tech irrigated crop yields are close to 3,000 kg ha^{-1} with less yield variability (Justino et al., 2019). Reducing this gap vertically and sustainably is crucial to meet the rise in the probable global food demand by 2050 (Tian et al., 2021).

One of the main mitigation and adaptation strategies to current and future food production scenarios is the choice of cultivars that most resourcefully use the available soil water (tolerant to water deficit), and are adapted to production in regions with edaphoclimatic conditions (Peter et al., 2020), as water deficit will become more and more recurrent in subtropical regions due to scarcer rainfall and greater evaporative air demand (Vicente-Serrano et al., 2020; Schwerz et al., 2017). In Latin America, the water deficit is one of the key limiting factors for bean production (Rosales et al., 2012). Nevertheless, fewer studies are aimed at testing the water use efficiency of bean cultivars. In the state of Rio Grande do Sul (RS), Brazil, beans that are planted in the main season, whose sowing occurs from August, are exposed to more favorable development conditions. The intensified cultivation of the off-season, whose sowing occurs in January and February, may affect the offer of markets due to low production, as it is susceptible to drought periods, due to irregular rains and available solar radiation (Schwerz et al., 2017). The authors perceived that the water deficit in the off-season in municipality of Frederico Westphalen, RS occurred in the flowering, filling, and maturation stages of the pods, and negatively impacted yield, as it needs the use of irrigation.

To select cultivars that are tolerant to water shortages, the method of fraction of transpirable soil water (FTSW) is one of the most robust tools, since plants whose transpiration is reduced at the beginning of soil water stress can respond more rapidly to environmental signals (Devi et al., 2013; Sinclair et al., 2018), and early closure of the stomata can favor acclimatization of these plants due to long exposure to hostile conditions (Taiz et al., 2017). In FTSW, it is considered that the soil water content absorbed by the plant and released by transpiration varies between maximum transpiration, field capacity condition, and up to 10% of maximum transpiration (Sinclair & Ludlow, 1986).

The critical fraction of transpirable soil water (FTSWc) corresponds to the start of plant stomatal closure and its values differ according to species and genotypes, such as potato (FTSWc: 0.28–0.49) (Lago et al., 2012), common bean (FTSWc: 0.40–0.54) (Serraj & Sinclair, 1998; Devi et al., 2013), chrysanthemum (FTSWc: 0.51–0.63) (Kelling et al., 2015), peanut (FTSWc: 0.53) (Sinclair et al., 2018), soy (FTSWc: 0.15–0.51) (Riar et al., 2018; Winck et al., 2022), faba bean (0.22–0.60) (Kibbou et al., 2022) and creole corn (FTSWc: 0.64–0.73) (Langner et al., 2021). Consequently, the importance of conducting this study with genotypes adapted to the edaphoclimatic conditions of southern Brazil is emphasized.

However, in Brazil, water deficit is the main limiting factor in bean crop yield, and studies have not yet been carried out focusing on understanding which cultivars are more tolerant to soil water deficit.

The objective of this work was to evaluate the response of the Garapiá, Triunfo, and BRS-FC104 bean cultivars to the water deficit represented by the fraction of transpirable soil water.

Material and Methods

The experiments were carried out in a 150 m² shelter, covered with 200 µm low-density polyethylene, with side walls coated with an anti-aphid screen, located in the experimental area of the department of crop science of the Universidade Federal de Santa Maria (UFSM), in the state of Rio Grande do Sul, Brazil (29º43'S; 53º49'W at 90 m above sea level). Two experiments were carried out with these cultivars: Fepagro Triunfo, Fepagro Garapiá, and BRS FC104. Sowing was carried out in the crop season (EI) on 08/31/2019 ('Triunfo' and 'Garapiá') and 09/20/2019 ('BRS-FC104') and off-season (EII) on 01/27/2020 ('Triunfo' and 'Garapiá') and 02/16/2019 ('BRS-FC104'). The sowing of

'BRS-FC104' (super early) occurred on a different date to concur with the preflowering of all cultivars. The cultivar Triunfo belongs to the black bean group, the most consumed in Rio Grande do Sul, and 'Garapiá' and 'BRS-FC104' belong to the pinto bean group.

The experimental design was a completely randomized block with 6 treatments, in a 3×2 factorial scheme (cultivars × irrigation and non-irrigation), with one plant per pot as an experimental unit. The number of repetitions in EI and EII were, respectively, 10 and 19 in irrigated 'Triunfo', 12 and 21 in non-irrigated 'Triunfo', 9 and 22 in irrigated 'Garapiá', 12 and 23 in non-irrigated 'Garapiá', 13 and 24 in irrigated 'BRS-FC104', and 12 and 17 in non-irrigated 'BRS-FC104', totaling 68 EI and 126 EII experimental units. The number of repetitions varied due to removal of pest-damaged plants or due to irrigation error. Each experimental unit consisted of an 8-L plastic pot filled with an A horizon of a soil classified as Argissolo Bruno-Acinzentado alítico típico, according to the Brazilian Soil Classification System (Santos et al., 2018), i.e., Ultisol. The pots were white painted to reduce heating and placed on a 70 cm high bench. Seeds were inoculated with nitrogen-fixing bacteria, and soil acidity and nutrients were corrected according to soil analysis (Manual…, 2016).

The meteorological data were obtained from the automatic meteorological station A803 of the Brazilian National Institute of Meteorology (Inmet), located nearly 100 meters from the experiment. The mean, minimum, and maximum air temperature, relative humidity, global solar radiation considering a transmittance of the plastic coverage of 80%, and vapor pressure deficit (VPD) at 3 pm values were determined.

Irrigation treatments occurred in pre-flowering (R5) (Oliveira et al., 2018) in EI and, for 'Triunfo' and 'Garapiá', in EII. The 'BRS-FC104', in EII, was submitted to water deficit in stage V4, as there was a delay in sowing as mentioned before. Water deficit was forced according to the method proposed by Sinclair & Ludlow (1986). At the beginning of irrigation, all pots were saturated, covered with white plastic film to prevent water evaporation, and the soil was allowed to drain for 24 hours to reach field capacity. After 24 hours of drainage, the initial mass of each pot was determined. From that day, in nonirrigated treatment, the pots did not receive more irrigation until the plants reached 10% of the irrigated treatment plants. From 15:30 daily, all pots mass was determined on a 50 kg capacity precision electronic scale, in which each pot without water deficit was irrigated with the amount of water lost by the plant's daily transpiration.

Transpiration data went through two normalizations. The first one intended to minimize the influence of large variations in the daily transpiration rate over the days, called relative transpiration (RT) according to Sinclair & Ludlow (1986):

$$RT = (NIM_j - NIM_{j-1})/\{[\sum(IM_{initial} - IM_j)]/n\},$$

in which NIM is the mass of each non-irrigated pot (g pot^{-1}); IM is the mass of each irrigated pot (g pot^{-1}); 'j' refers to the day; 'initial' indicates IM on the day the water deficit is applied, and n represents the number of repetitions in the irrigated treatment. The second normalization took place to reduce variations between plants caused by dissimilarities in microenvironmental conditions and sizes; for this purpose, FTSW values above 0.6 were verified for RT values close to the maximum. Later, RT average values with FTSW equal to or greater than 0.6 were calculated for each plant, and all initial RT estimates were divided by these averages, obtaining the normalized relative transpiration (NRT) (Sinclair & Ludlow, 1986).

At the end of the experiment, the FTSW was calculated for each day using the following equation:

$$FTSW = (NIM_j - NIM_{final}) / (NIM_{initial} - NIM_{final}),$$

in which NIM is the mass of each pot in the non-irrigated treatment (g pot^{-1}); 'j' refers to the day; 'initial' indicates the day NIM water deficit is applied; and 'final' indicates the last day NIM water deficit is finished. Treatment of the water deficit ended when all nonirrigated plants reached RT < 10% of the average transpiration of the irrigated plants because when lower than this value, the stomata are completely closed, and water loss occurs only through epidermal conductance (Sinclair & Ludlow, 1986). In the IE, the water deficit was applied from 10/24/2019 to 11/10/2019 for 'Triunfo' and 'Garapiá' and until 11/12/2019 for 'BRS-FC104'. In the EII, it went from 03/04/2020 to 03/10/2020 for 'Triunfo' and 'Garapiá', and until 03/21/2020 for 'BRS-FC104'.

At the beginning and end of the water deficit, three replicates per plants of each treatment were evaluated for height (cm), aerial part dry matter (g), root length (cm), root dry matter (g), and leaf area (cm^2), using the equation $LA = 1.092L^{1.945}$, in which L is leaf length (cm). Daily, at 15 hours, leaf temperature was measured in the central leaflet in the upper third of 4 repetitions per plants in the EI and of 6 repetitions per plants in the EII with an infrared thermometer (DT-8380 Infrared Digital LCD Thermometer Gun, Wenmeice, Xi'an, China). After the end of the water deficit, some plants were rehydrated and kept in field capacity condition until the end of the cycle to determine the estimated yield, considering the pot area of 0.05 m^2 of the dry matter of the grains at 13% moisture.

The number of repetitions was 12 and 9 in 'Triunfo', 15 and 13 in 'Garapiá', and 10 and 9 plants in 'FC104' in the irrigated and non-irrigated treatment (EI), respectively, while in the EII, there were 11 plants in all combinations' cultivars per water stress.

A logistic equation was fitted to the NRT versus FTSW data for each plant:

$$Y = 1/\{1 + \exp [- a(x – b)]\},$$

in which Y is the NRT; x is the FTSW; and 'a' and 'b' are empirical coefficients (Sinclair & Ludlow, 1986), adjusted by non-linear regression analysis using SAS software (SAS Institute Inc., Care, NC, USA). FTSWc values for transpiration were estimated using the logistic equation as the value of FTSW when the NRT was 0.95 (Lago et al., 2012).

Data were analyzed for normality of errors (Shapiro-Wilk) and homogeneity of variances (Bartlett), and when they were not met, they were transformed by Box-Cox with Action software. The data were subjected to analysis of variance, and the means were compared by the Scott-Knott test at 5% probability of error with Sisvar software (Ferreira, 2011).

Results and Discussion

The higher daily air temperatures were observed in EII, the average air temperature was 21.3°C in the EI and 24.6°C in the EII, complemented by a lower relative humidity, with an average of 80.2% in the EI and 69.7% in the EII (Figure 1). These weather conditions resulted in a higher VPD in EII, with VPD at 15 hours greater than 12 hPa (Devi & Reddy, 2020) in 94.1% of days (16/17) and, in EI, in 45% (9/20). Thus, the EII can be considered to have between medium and high evaporative demand from the atmosphere, in contrast to the EI. With higher VPD, EII duration for the cultivars Triunfo and Garapiá was only 7 days, while in the EI it was 18 days. VPD is an environmental variable that should be considered in treatments with water shortages, especially when the experiments are carried out on small vessels (Riar et al., 2018). The average daily global solar radiation was 17.8 MJ m^{-2} day^{-1} (EI) and 16.4 MJ m^{-2} day^{-1} (EII).

The FTSWc values for the Triunfo, Garapiá, and BRS-FC104 cultivars were, respectively, 0.23, 0.36, and 0.27 in the EI and 0.13, 0.17 and 0.23 in the EII (Figure 2). Higher values of FTSWc indicate that the plant begins to decrease transpiration at the beginning of soil dryness, with high values of available water, which results in water conservation and allows the maintenance of biochemical and physiological activities in the water deficit period, as well as in future periods of soil drying during the development cycle (Devi et al., 2013; Sinclair et al., 2018). In regions with a history of yield losses due to water shortages, the selection of genotypes with rapid stomatal response to changes due to environmental conditions can be performed by a breeding program for must selection to obtain stable yields (Faralli et al., 2019). Comparing Garapiá and Triunfo cultivars, Garapiá continued with the highest FTSWc in crop season and off-season, signifying that this cultivar has efficient stomatal control and can be tolerant to water deficit. In EI, with low atmospheric air demand (45% days below 12 hPa), all cultivars started stomatal closure with higher available soil water content (higher FTSWc) compared to EII under high atmospheric demand (94.1% days higher than 12 hPa) (Figure 2). In soybean, Riar et al. (2018) observed that differences in FTSWc values were related to VPD, in which high values (23.4 hPa) resulted in low FTSWc values (0.19 to 0.20), and as its NRT increases daily, FTSW decreases. In gladiolus, the higher value of FTSWc (0.73) in relation to NRT was attributed to lower atmospheric demand and crop stage (reproductive phase demanding more water consumption) (Becker et al., 2021). In potatoes, Lago et al. (2012) also concluded that the FTSWc is distorted by the atmospheric demand, with the lowest values observed in the autumn harvest (FTSWc = 0.28 to 0.33) and the highest in the spring harvest (FTSWc = 0.39 to 0.49). The authors also called attention to the lower radiation offered in the off-season, as well as in the EII, which results in less transpiration, which is why plants close stomata with less soil water available, as a growth scheme. Furthermore, there was granter variability in the RT values in the EI, as stated by Lago et al. (2012) in experiments with lower air temperature and radiation and by Sinclair & Ludlow (1986) in a situation of temperatures below 15ºC.

Under low atmospheric demand condition, characterized in the spring period of Rio Grande do Sul state and by the EI, the FTSWc values ranged from 0.23 to 0.36 (Figure 2). These values are close to those observed in other studies on beans, of 0.40 (Serraj & Sinclair, 1998) and from 0.40 to 0.54 (Devi et al., 2013). They were also analogous to those observed for mung beans, pigeon peas and soybeans, 0.40, and cowpea beans, 0.30 (Sinclair & Ludlow, 1986). However, if rivaled to other values of crops recently surveyed, such as potato, from 0.28 to 0.49 (Lago et al., 2012), chrysanthemum, from 0.51 to 0.63 (Kelling et al., 2015), peanuts, from 0.38 to 0.69 (Sinclair et al., 2018), gladiolus, from 0.35 to 0.73 (Becker et al., 2021), soybeans, from 0.15 to 0.51 (Riar et al., 2018; Winck et al., 2022), creole corn, from 0.64 to 0.73 (Langner et al., 2021), and faba bean, from 0.22 to 0.60 (Kibbou et al., 2022), it is confirmed that beans are sensitive to water deficit, since stomatal control was less effective than most agricultural crops studied.

In high-demand atmospheric conditions, as in typical Rio Grande do Sul summer days, beans are inclined to close stomata when the FTSWc is between 0.13 and 0.23. When likening these values to those found for other crops mentioned above, it appears that these values are even lower than those verified in a situation of low atmospheric demand. These results distress production in the future scenario, showing

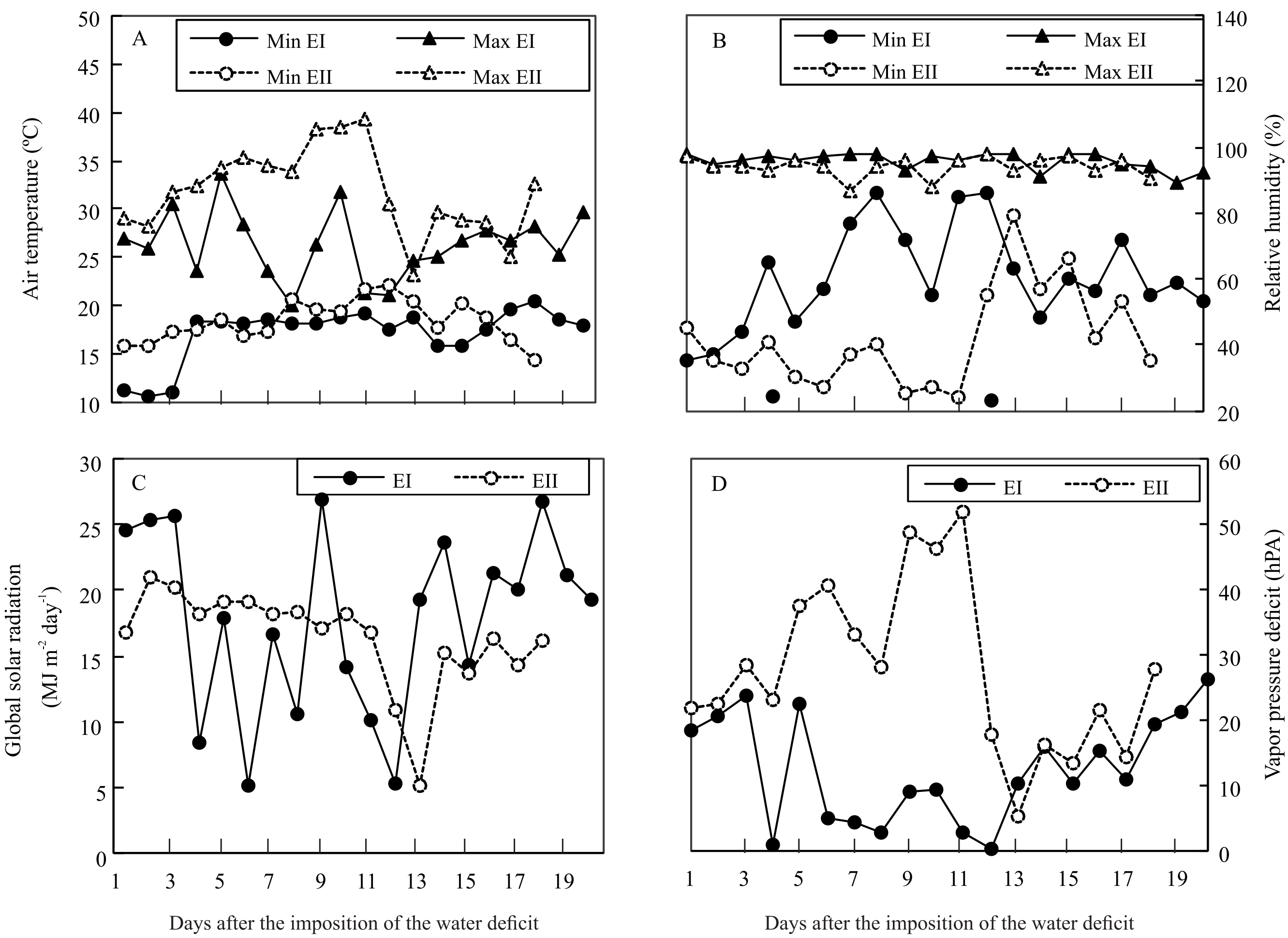

Figure 1. Air temperature (A), relative humidity (B), global solar radiation (collected from the A803 INMET automatic station) (C), and vapor pressure deficit for the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil, in crop season (EI) in 2019 and off-season (EII) in 2019/2020 (D).

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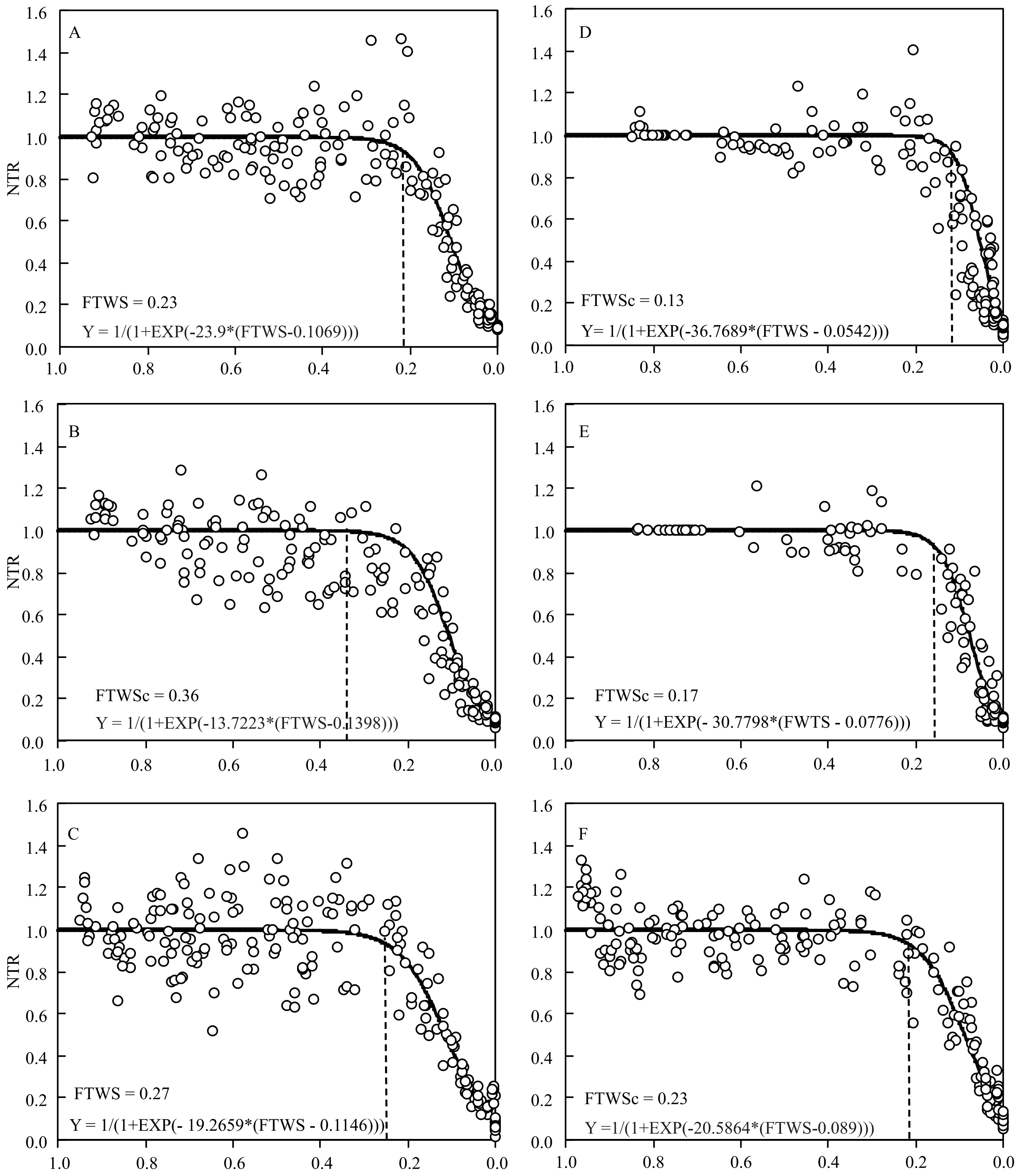

Figure 2. Normalized relative transpiration (NRT) as a function of the fraction of transpirable soil water (FTSW) for the Triunfo (A, D), Garapiá (B, E), and FC104 (C, F) bean (*Phaseolus vulgaris*) cultivars in 2019 crop season (EI – A, B, C) and 2019/2020 off-season (EII – D, E, F). The FTSWc is the value of FTSW that, in the graph, corresponds to the value of NRT = 0.95, estimated by the logistic equation presented in each graph.

the need for additional research to assess the largest possible number of cultivars in search of those that are the most water efficient (Schwerz et al., 2017).

One of the practical tools for assessing the water status in crops is the measurement of the canopy temperature. In this study, the water deficit resulted in higher average leaf temperature in EII with high atmospheric demand, while EI did not show significant differences (Figure 3). Ghanbari et al. (2013) found that bean plants under water deficit showed higher values of bean leaf temperature.

The Triunfo and FC104 cultivars showed low decrease values of FTSWc and had the same behavior with respect to leaf temperature. In a low-demand (EI) environment, with milder temperatures, Garapiá cultivar closed the stomata early and had lower leaf temperature. There is a possibility that the longer period of exposure to water deficit (18 days) may have expressed some internal metabolic control mechanism that resulted in lower temperature. In the high demand experiment (EII), which lasted only 7 days, perhaps the time to trigger metabolic defense was scarce; also, early stomatal closure in 'Garapiá' may have weakened because, due to high temperatures, water may have heated up inside of the mesophile and, since transpiration decreased, it became difficult to disperse its energy, becoming hotter (Nguyen et al., 2022). In an environment of high atmospheric demand, in Iran, Ghanbari et al. (2013) observed that tolerant bean genotypes had lower stomatal conductance linked with higher temperatures, but the most sensitive genotypes had higher conductance and lower leaf temperatures.

Regarding the growth response variables, height, dry matter weight of the aerial part, root length, and dry matter weight of the root, there was not a notable interaction between cultivars and the irrigation treatment, and each factor was analyzed separately in the two experiments. The irrigated regime showed higher heights, aerial part dry matter weight, and root dry matter weight (Table 1). In the EI, the variables did not differ before the water deficit, with the exception of the root dry matter, for which 'Triunfo' had higher values. In EII, 'Triunfo' and 'Garapiá' were in R5, and 'FC104' in V4 before the water deficit, so 'FC104' had lower values in all evaluated characteristics.

In a research with two old bean cultivars, Serraj & Sinclair (1998) obtained 5.3 to 7.8 g aerial part dry matter weight at the end of the deficit, regarding irrigated plants, and 4.0 to 4.6 g in non-irrigated. These values were lower than in the present study (11.12 to 14.21 for

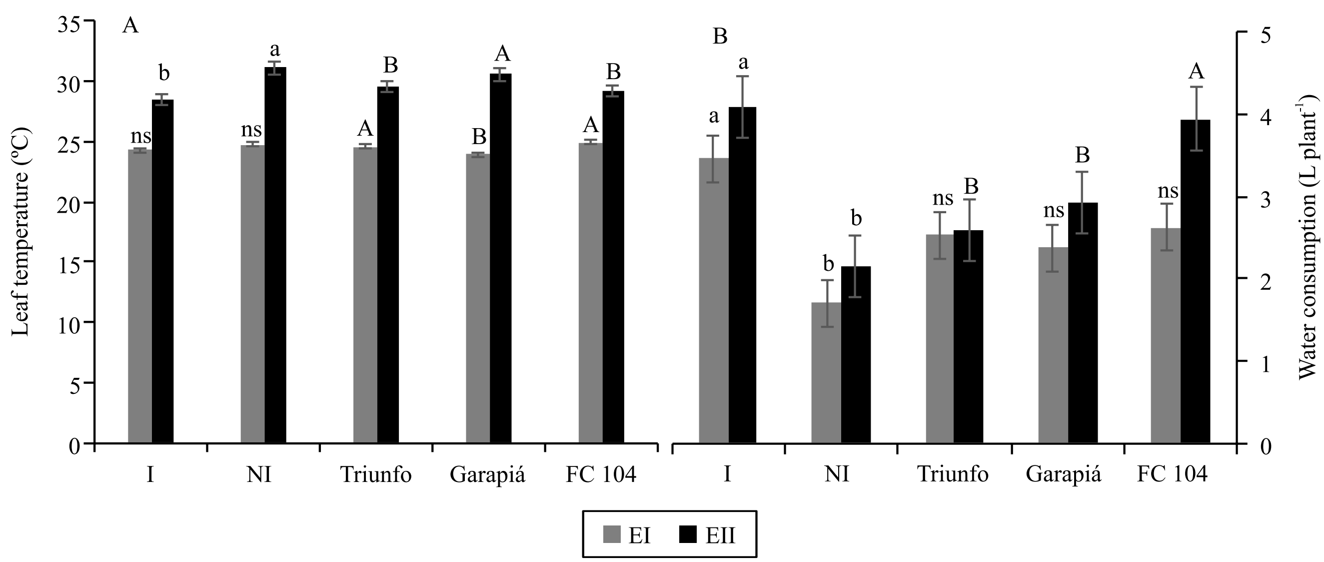

Figure 3. Leaf temperature (A) and water consumption (B) of the Triunfo, Garapiá, and FC104 bean (*Phaseolus vulgaris*) cultivars, irrigated (I) and non-irrigated (NI) systems in 2019 crop season (EI) and 2019/2020 off-season (EII). Bars with equal letters, lowercase above irrigation treatments and uppercase above cultivars, do not differ by Skott-Knot's test, at 5% probability. [ns]Nonsignificant.

irrigated plants, and 8.40 to 10.94 for non-irrigated). The authors did not inform the phenological stage in which the deficit was imposed; they only stated that it occurred six weeks after the emergency. In addition to the plant size, the plants' water consumption via transpiration differs from others studies such as Serraj & Sinclair (1998) (1.2 to 2.1 L) and Devi et al. (2013) (0.5 L), whose results were lower than the results of the present study (1.7 to 4.1 L). Yet, data demonstrates that the FTSWc values of the above-mentioned cultivars cannot be used as guidance for the cultivars used in the present study, due to the variance in growth and

Table 1. Height, aerial part dry matter (APDM), root length (RL), root dry matter (RDM), leaf area (LA), and grain yield in the Triunfo, Garapiá, and FC104 bean (*Phaseolus vulgaris*) cultivars under irrigation and without irrigation, at the beginning and end of the water deficit treatment in 2019 crop season (EI) and 2019/2020 off-season (EII).

Cultivar	Crop season (EI)				Off-season (EII)			
	Initial	Final		Mean	Initial	Final		Mean
		Irrigated	Not irrigated			Irrigated	Not irrigated	
				Height (cm)				
Triunfo	21.6^{ns}	107.0	69.2	88.1B	40.3B	127.5	102.2	114.8A
Garapiá	26.8	83.1	70.4	76.7B	86.7A	106.2	99.67	102.9A
FC104	16.7	124.1	115.0	119.6A	10.5C	54.5	25.00	39.7B
Mean		104.7a	84.9b			96.1a	75.6b	
CV (%)	22.5	15.1			6.9	12.0		
				Aerial part dry matter (APDM, g)				
Triunfo	4.99^{ns}	11.69	8.58	10.13^{ns}	5.391B	17.7	15.39	16.545A
Garapiá	6.74	10.92	8.66	9.79	15.46A	19.02	12.23	15.62A
FC104	4.01	10.74	7.97	9.3553	0.86C	5.93	3.84	4.88B
Mean		11.12a	8.40b			14.21a	10.49b	
CV (%)	24.13	10.8			9.81	17.07		
				Root length (RL, cm)				
Triunfo	48.7^{ns}	56.8	56.67	56.7^{ns}	75.7A	57.0	51.7	54.3^{ns}
Garapiá	50.7	62.0	53.57	57.8	68.8A	62.3	65.7	64.0
FC104	39.8	50.7	55.5	53.1	43.7B	52.8	59.2	56.0
Mean		56.5^{ns}	55.2			57.4^{ns}	58.8	
CV (%)	18.6	18.5			16.7	22.4		
				Root dry matter (RDM, g)				
Triunfo	4.0A	11.4	5.9	8.6ns	4.8B	10.9	8.2	9.5A
Garapiá	1.8B	10.0	7.3	8.7	7.5A	10.4	7.9	9.2A
FC104	1.6B	12.7	4.9	8.8	1.3C	5.5	3.4	4.4B
Mean		11.7a	6.0b			8.9a	6.5b	
CV (%)	38.7	34.9			20.1	16.1		
				Leaf area (LA, cm^2)				
Triunfo	490.9^{ns}	1,631.8	996.7	1,314.3^{ns}	843.0B	2,033.5A	1,100.8B	1,567.1
Garapiá	695.8	1,489.8	1,225.3	1,357.6	2,393.8A	2,621.0A	1,255.7B	1,938.4
FC104	520.6	1,479.2	726.3	1,102.7	156.1C	1,286.5A	675.8B	981.2
Mean		1,533.6a	982.8b			1,980.3	1,010.8	
CV (%)	39.2	19.2			21.0	12.7		
				Grain yield ($kg\ ha^{-1}$)				
Triunfo	-	3,718.9	2,387.8	3,053.3A	-	2,225.6aB	1,974.6aA	2,100.1B
Garapiá	-	3,477.8	2,182.9	2,830.4A	-	3,087.5aA	1,897.2bA	2,492.3A
FC104	-	3,312.3	1,860.4	2,586.4B	-	1,935.0aB	1,803.8aA	1,869.4B
Mean		3,503.0A	2,143.7B			2,416.0A	1,891.9B	
CV (%)		23.9				23.7		

(1)Means followed by equal letters, uppercase in the columns and lowercase in the rows, within the experiments, do not differ by Scott-Knott's test, at 5% probability. ^{ns}Nonsignificant.

water consumption and meteorological conditions in the state of Rio Grande do Sul.

At the end of the water deficit period in EII, for leaf area there was a significant interaction between the factors, in which the three cultivars showed lower values under water deficit, denoting a plant defense mechanism that decreases transpirable area to conserve soil water, which is considered a physiological response. Early stomatal closure, despite preservation of soil water, will result in less growth, since stomatal opening directly influences the rate of assimilation of CO_2, and the more severe the water deficit, the greater the reduction in leaf area in common beans (Torabian et al., 2018). This can be observed in 'Garapiá', the cultivar that presented the lowest aerial part dry matter gain from the beginning to the end of the water deficit treatment (Table 1), only 3.05 g in the EI and 0.16 g in the EII. The same performance is recurrent for height, root length and root dry matter (EII). Another sign of plant defense against water deficit is the vaster utilization of the environment by roots (Taiz et al., 2017). Yet, the length of the roots did not show a significant difference between cultivars and water deficit treatments, which can be explained by the short period used.

The water deficit reduced the yield in both experiments (Table 1). In the EI, 'Garapiá' and 'Triunfo' presented the highest yields. In EII, 'Garapiá' showed a yield reduction under water deficit and the highest yield among cultivars under the irrigated system and in the general average. The early stomatal closure in periods of great drought can favor the final production by preserving soil water, which permits the plants to subsist. However, in short periods of drought, early closure can be detrimental as it will unnecessarily slow plant growth. As shown by the water deficit results in the reproductive phase, 'Garapiá' presents early stomatal closure in both situations of evaporative air demand, while 'Triunfo' presents late closure in both conditions.

Regarding yield, in the short water deficit periods situation, both 'Triunfo' and 'Garapiá' are indicated, as they presented the highest yield, while for long periods (FS), 'Garapiá' closed stomata early and showed greater average yield amid cultivars. 'BRS-FC104' is an intermediate response genotype when water scarcity occurs in R5 under low atmospheric demand, presents early closure when it occurs in V4 under high atmospheric demand, and is considered an excellent possibility, subject to the management since it has the benefit of a super-early cycle. Thus, this study can endow information for genetic breeding programs concerning the selection of water deficit tolerant genotypes from the 'Garapiá', as well as advancing studies on super early cycle cultivars, such as BRS-FC104, which shows potential as a short-term productive alternative to crops. The use of short-cycle cultivars can be an alternative to escape from periods of water deficit, if it is well planned.

Conclusions

1. The Garapiá bean (*Phaseolus vulgaris*) cultivar presents tolerance to water deficit, with efficient stomatal control and high growth and yield.
2. The Garapiá cultivar is tolerant to water deficit in crop season and off-season, even in the reproductive period.
3. Garapiá bean cultivar has the highest grain yield both in the crop season and off-season.

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