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Yield response factor (Ky) and initial growth in black pepper in a tropical environment

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ABSTRACT: Black pepper is widely produced in Brazil, though there are few studies related to its water requirements and the effects of water deficit (WD) applied under tropical conditions. The growth, sensitivity to WD, and first-year productivity of irrigated plants from the Bragantina cultivar were evaluated, employing an irrigation system with automatic management. The plants were cultivated in plastic pots installed in the field for 391 days using emitters with different flow rates (2.2 [T1], 3.3 [T2], 4.3 [T3], and 5.3 L h^{-1} [T4 – control]). Fresh weight of the leaves, stems, and shoots, and dry weight of the leaves, stem, roots, and shoots as well as the total dry weight of the plant, were evaluated. Productivity was determined by evaluating the grains and spikes from a single harvest. Yield results and the actual versus maximum evapotranspiration rate for the entire growing season was used for calculating the Ky coefficient. Despite 1,346 mm of rainfall, the irrigation system was activated 165 times, distributing a mean volume of 19.0 (T1), 28.5 (T2), 37.1 (T3), and 45.8 L per plant (control). All traits were negatively affected by the WD, and the Ky values obtained (from 1.72 to 2.96) indicate the high sensitivity of black pepper to WD. In general, the spikes produced with at least 81 % of the crop water demand were larger and more numerous than those subjected to inferior treatments. WD occurring during the flowering stage severely hampers the size, weight, and quality of the spikes and grains of black pepper.

Keywords: *Piper nigrum* L., Bragantina, automated irrigation, water deficit, initial production

Introduction

Black pepper (*Piper nigrum* L.) is one of the most consumed spices in the world (Gomes Filho et al., 2020), because of its use in the pharmaceutical, cosmetic, and food industries (Takoore et al., 2019). This species is cultivated in several countries, including Brazil, one of the top five world producers (FAO, 2022).

Despite being considered a water-stress-sensitive crop (Krishnamurthy et al., 2016), there are no studies related to its water demand and/or its response to water deficit under tropical conditions (Cruz et al., 2022), including the initial development following the plantlet production phase. However, this information is necessary, especially in Brazil where the crop grows in different environments in terms of soil and climate. In the state of Espírito Santo, for example, where more than 45 % of Brazilian black pepper is produced (IBGE, 2019), the water deficit caused by long periods of drought has been a limiting factor in local production (Ambrozim et al., 2022).

Water stress can severely affect the productivity and development of black pepper plants. During plantlet production, irrigation and a deficit of up to 15 % proved to be viable, causing no significant changes in the biometric traits or chlorophyll content of 'Bragantina' black pepper plantlets (Cruz et al., 2022).

Irrigation is considered one of the main techniques used to increase productivity (Gerçek and Demirkaya, 2021), although it is seen as an obstacle due to water scarcity, principally in regions lacking information about the water requirements of the crop. As such, water supply strategies that produce cost-effective yields should be pursued at all stages of development (Ćosić et al., 2017). Strategies for water deficit, as well as water use efficiency (i.e., crop productivity per unit of applied water) have been adopted to save water (Yavuz et al., 2021). It is, therefore, necessary to understand crop performance at different levels of water deficit, represented by the response coefficient (Ky) (Doorenbos and Kassam, 1979), which can be applied during specific periods or throughout the crop cycle (English and Raja, 1996).

The objective of this study was to evaluate the sensitivity to water stress (Ky coefficient), growth characteristics, and production of black pepper plants from the Bragantina cultivar, grown in pots and with an automatic water supply for irrigation.

Materials and Methods

The experiment was carried out from 10 Apr 2019 to 05 May 2020 at Seropédica county (24°58″ S, 44°11″ W, altitude of 33 m), in the state of Rio de Janeiro, Brazil, and cultivated in plastic pots installed in the field. According to Köppen, the climate in the region is classified as Aw, with a rainy summer with high temperatures and a dry winter of mild temperatures. Rainfall is concentrated from Nov to Mar, with a mean annual precipitation of 1,213 mm and a mean annual temperature of 24.5 °C (Alvares et al., 2013).

'Bragantina' black pepper plantlets, standardized with six to eight leaves and 120 days old, were transplanted into flexible plastic containers with a capacity of 25 L. The substrate consisted of soil material from a Planosol (60 % clay, 30 % sand, and 10 % silt), whose chemical analysis showed: pH (in water) 5.3, 56 mg dm^{-3} phosphorus, 63 mg dm^{-3} potassium, 2.7 $cmol_c$ dm^{-3} calcium, 1.2 $cmol_c$ dm^{-3} magnesium, 0.1 $cmol_c$ dm^{-3} aluminium, and 0.09 $cmol_c$ dm^{-3} sodium.

The soil water retention curve Eq. (1), based on the model by van Genuchten (1980), was determined by the evaporation method (Schindler et al., 2017), from samples of soil material collected in the pots:

$$\theta = 0.263 + \frac{0.342}{\left[1 + \left(0.0367h\right)^{1.721}\right]^{0.4189}} \tag{1}$$

where θ is the soil moisture (cm^3 cm^{-3}) and h the matrix potential (kPa).

The experiment was conducted using a randomized block design (RBD), with four treatments (irrigation depths) and six blocks (replications), each experimental plot comprising two plants, giving a total of 48 pots, spaced 1.0 m by 1.5 m apart. All the plants were irrigated with the same frequency but received different volumes of water depending on the flow rates of the emitters. As such, the treatments consisted of a water supply corresponding to 42 % (T1), 62 % (T2), 81 % (T3), and 100 % (T4) of the crop water demand (CWD). These percentages were obtained by using self-compensating PCJ drippers (Netafim) with nominal flow rates of 2.0, 3.0, and 4.0 L h^{-1}, to achieve flows of 2.2 (T1), 3.3 (T2), 4.3 (T3) and 5.3 L h^{-1} (T4), after tests performed, which indicated a distribution uniformity for the system of above 95 %, according to the methodology proposed by Keller and Karmeli (1974).

Irrigation management was automatic, using a simplified irrigation controller - SIC (Medici et al., 2010), installed in two pots from two blocks of the treatment with the greatest flow (T4). Thus, this treatment was considered as a reference (control), since the irrigation volume applied in the other treatments corresponded to fractions of the CWD of the plants submitted to T4. The SIC consisted of a ceramic capsule placed in the pot at a depth of 15 cm and connected by a transparent hose to a pressure switch which was kept 0.4 m below the center of the capsule. The irrigation system turned on when the soil water tension reached approximately 4.0 kPa and the pressure switch allowed the passage of electric current activating the pump. The pressure switch turned off the irrigation stream when the soil water tension reached approximately 1.0 kPa. The SIC has been used in various studies and offers adequate irrigation management in the tomato (Gomes et al., 2017), onion (Mello et al., 2018), gladiolus (Santos et al., 2020), zinnia (Martins et al., 2021), and forest tree species (Bueno et al., 2020, 2021), among others, both in pots/tubs and under field conditions.

The Agricultural Ecology weather station (code A601) , maintained by the Instituto Nacional de Meteorologia – INMET, installed in Seropédica county, Rio de Janeiro, Brazil, monitored the weather conditions. The period considered was from 10 Apr 2019 to 05 May 2020. For this period, the reference evapotranspiration (ETo) was estimated by Penman-Monteith FAO-56 (Allen et al., 1998), and the effective rainfall depth (ERD) was estimated by the Curve Number method, proposed by the Soil Conservation Service (SCS) (Carvalho et al., 2014).

There were three flowering periods during the experiment beginning in Dec 2019 (around 240 days after transplanting – DAT), and in late Jan (around 300 DAT) and Apr 2020 (around 380 DAT). Three days before the end of the experiment all the spikes found on the plants were harvested, regardless of the maturation stage.

Based on this single harvest, and because the same plant can have spikes at various stages of maturation, a classification system for the spikes was proposed, which allowed for the evaluation of the impact of the irrigation levels on production for the first year (Figure 1). Shortly after classification, the length and fresh weight of the spikes were determined. To identify the dry weight, the spikes were dried in a forced air circulation oven at 65 °C for 72 h, or until reaching constant weight.

It should be noted that the harvest carried out in this study should not be compared with commercial production nor be considered production itself, as it was only carried out once, harvesting the grains at all stages of development, which is not generally done on a commercial plantation. Furthermore, in Brazil, the harvesting of black pepper for commercial purposes is traditionally carried out from the second year of production and in several operations from Oct to Mar depending on the region.

The following traits were evaluated at 391 DAT: leaf fresh weight (LFW), stem fresh weight (SFW), leaf dry weight (LDW), stem dry weight (SDW), root dry weight (RDW), shoot fresh weight (SHFW), shoot dry weight (SHDW), and total plant dry weight (PDW). The root dry weight was obtained after washing to remove the substrate. The different materials were then packed in identified paper bags and placed in a forced air circulation oven at 60 °C for 72 h, after which the material was weighed.

The sensitivity of black pepper to water deficit was calculated using the Ky coefficient Eq. (2), as per Doorenbos and Kassam (1979).

$$\left(1 - \frac{Y_r}{Y_m}\right) = K_Y \left(1 - \frac{ET_r}{ET_m}\right) \tag{2}$$

where: Y_r – actual yield (g); Y_m – maximum or potential yield (g); K_y – production response factor; ET_r – actual crop evapotranspiration (L); and ET_m – maximum crop evapotranspiration (L).

Due to the lack of production data for the crop yield traits (Y_r and Y_m), the fresh (SHFW) and dry (DMPA) shoot weight, root dry weight (RDW), and total plant dry weight (PDW) were considered. Crop

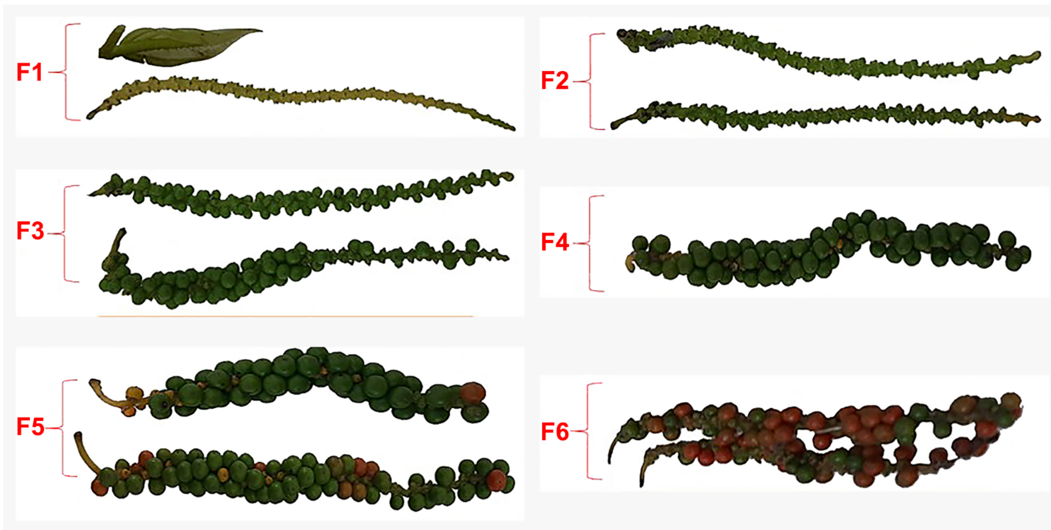

Figure 1 – Illustration of the proposed classification system for spikes of the 'Bragantina' black pepper plant F1 – emergence and opening of the flowers; F2 – start of fruit formation and growth (presence of pollinated flowers or formed grains around half the spike); F3 – presence of formed grains, easily crushed when lightly pressed with the fingers on most of the spike; F4 – predominance of fully formed and completely filled, albeit unripe, grains on the spike (greenish color); F5 – up to 50 % of the grains on the spike of a yellowish or reddish color; and F6 – more than 50 % of the grains on the spike of a yellowish or reddish color.

evapotranspiration was taken as the volumes applied in the control treatment (ET_m) and the other treatments (ET_r), plus the ERD. Since Eq. (1) represents a linear relationship, Ky corresponds to the angular coefficient of the equation or the slope of the curve and is obtained interactively by maximizing the value of ET_m when the intercept of the equation with the ordinate axis (linear coefficient) becomes zero. The procedure was carried out on an electronic spreadsheet using the Solver module (Carvalho et al., 2016).

Statistical analysis

The data were submitted to analysis of variance by F-test at 5 % probability. In the case of significance, a regression analysis at 5 % probability was carried out by t-test. In each proposed class of phenological development and when there were data for all treatments evaluated, the Scott-Knott test was performed, at 5 % significance level, for the following traits: spikes per plant (QS), the average length of the spikes (LS), fresh (FWS) and dry weight of the spikes (DWS), and dry weight of the grains (DWG). Additionally, the F-test was carried out at the same level of significance. These statistical analyses were conducted using the R software package, version 3.6.0.

Results and Discussion

During the experimental period, the air temperature exceeded 35.0 °C in 31 days, reaching 41.1 °C on 05 Nov, while the minimum temperature reached 10.5 °C on 07 July (Figure 2). The average daily temperature ranged from 15.7 to 31.4 °C, and despite the crop´s sensitivity to high temperatures (Krishnamurthy et al., 2016), no plant death was observed. ETo ranged from 1.0 to 8.2 mm d^{-1} and totaled 1,528.5 mm, while the total and effective rainfall were 1,345.8 and 1,042.0 mm (100.3 L per plant). The ERD ranged from 1.3 (13.6 mm) to 21.4 L per plant (222.3 mm). During this period, the monthly volume of irrigation water applied in the control treatment ranged from 0.777 to 7.027 L per plant.

The irrigation system was activated 165 times, with 1,564.7 L of water applied throughout the experiment (Figure 3), and no drainage depths caused by irrigation were observed throughout the experiment. There were also 156 rainfall events, resulting in approximately 103 L of water being added per plant. The average irrigation volume applied per plant was 19.0, 28.5, 37.1, and 45.8 L for treatments T1, T2, T3, and T4, respectively. The total volume applied (irrigation + ERD) per treatment was 119.25, 128.75, 137.38, and 146.02 L per plant, respectively, for treatments T1, T2, T3, and T4.

The different water supplies produced differences in SFW, LFW, and SHFW, which showed linear behavior according to regression analysis ($p < 0.05$) (Figure 4).

Treatment T4 performed better than other treatments for SFW, LFW, and SHFW. From T4 to T1, reductions in SFW, SHFW ,and LFW in the order of 63 %, 83 %, and 135 %, respectively, were observed (Figure 4). These data corroborate the study by Rasanjali et al. (2019), who found reductions in the phytomass of black pepper plants grown with the use of hydrated polymers under different irrigation intervals that followed the reduction in irrigation frequency.

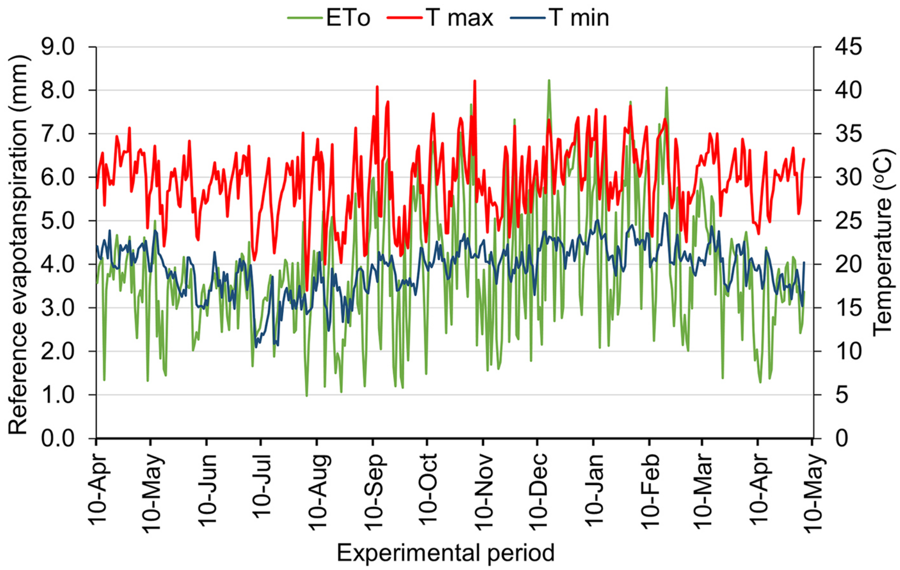

Figure 2 – Daily reference evapotranspiration (ETo), and maximum (T_{max}) and minimum (T_{min}) temperatures during the experimental period.

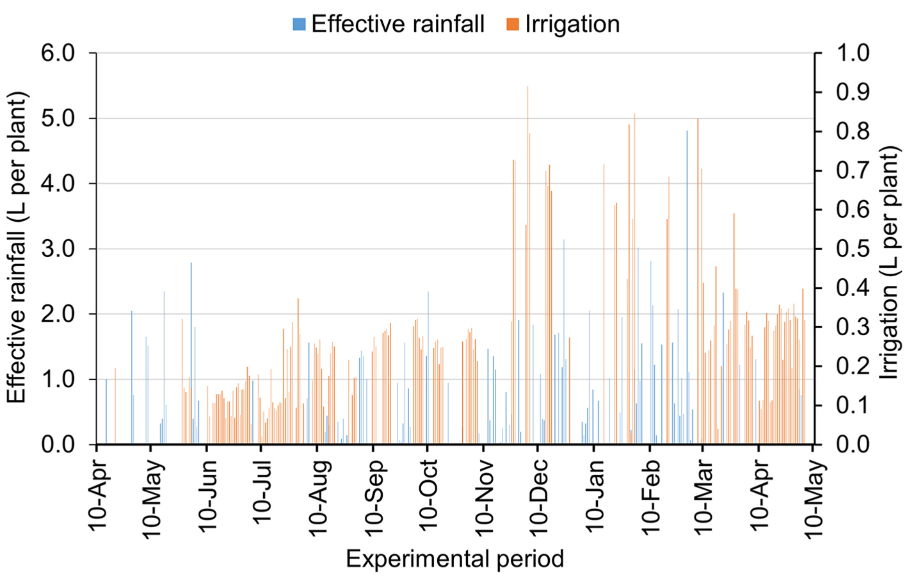

Figure 3 – Daily applied volumes recorded in plants irrigated at 100 % of the crop water demand (reference treatment) and from the effective rainfall during the experimental period.

Dry weight accumulation (SDW, LDW and SHDW) was also negatively affected by the restricted water supply applied via the irrigation system (Figure 5). A water deficit, is expected to reduce dry weight since the proportion of leaves in the dry matter is reduced. According to Parveen et al. (2019), water stress harms plant activity, reducing growth and dry matter accumulation considerably, since this stress can lead to a stomatic conductance decrease in the plant, which limits the photosynthetic processes.

The mean values for SDW, LDW, and SHDW in T4 were 47.7, 23.8, and 71.62 g, respectively, while the pepper plants subjected to T1 had mean values of 26.2 (SDW), 9.31 (LDW), and 35.53 g (SHDW). These values demonstrate dry weight accumulation by the plant as the water availability increases (Figure 5). The results corroborate those of Rasanjali et al. (2019), who found more significant dry weight accumulation in black pepper plants with increased volume of applied water and reductions in the watering frequency.

A reduction in soil water availability reduces the water potential of the leaf, resulting in loss of turgor and stomatal closure, thereby causing less dry weight accumulation in the plant under unfavorable water conditions (Munns and Tester, 2008). In black pepper, this is due to the smaller growth of the plant, as under these conditions, the plant starts to invest less in growth, thereby reducing height, the size and number of leaves, the stem diameter, and probably the photosynthetic yield and the gains in shoot dry weight. The lower accumulation of shoot dry weight in plants under a water deficit is due to an attempt through leaf reduction to curtail transpiration and maintain the cell water content, preventing the occurrence of paralyzing physiological processes (Mauri et al., 2017).

The highest values for PDW were found in the treatment that received the greatest irrigation volume since each component of the total SHDW + RDW increased with the water availability (Figure 6).

The mean values show a difference between treatments at 5 % probability and present a linear regression model. For these parameters, the plant showed a more significant increase in dry weight due to increases in the level of irrigation. Despite this, the RDW represented 37 % of the average PDW in T1, while in T4, root dry weight was equal to 29.3 % of the PDW. This trend was seen in reductions in the level of irrigation, i.e., water availability resulted in an increase in the weight of the plant root system compared to the PDW (Figure 6).

For each trait under evaluation, the Ky coefficient shows a sharp drop in black pepper yield as a function of the applied water deficit (Figure 7). The angular coefficients of the fitted equations characterize response factors (Ky) of 2.41 (SHFW), 2.96

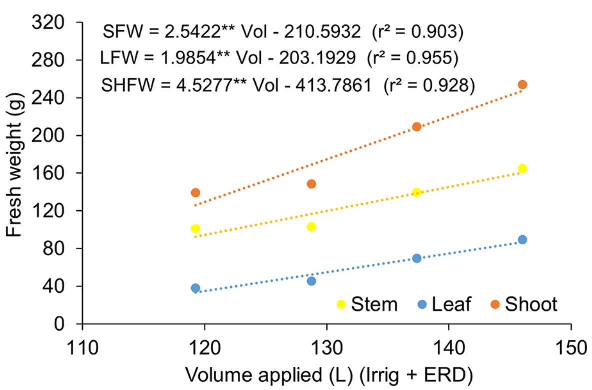

Figure 4 – Stem (SFW), leaf (LFW) and shoot (SHFW) fresh weight in the 'Bragantina' black pepper plant as a function of the water volume (Vol) applied via the irrigation system (Irrig) and from the effective rainfall (ERD). **Significant at the 0.01 level, by t-test.

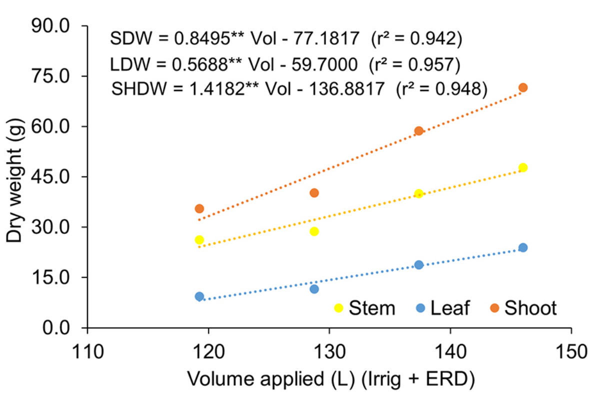

Figure 5 – Stem (SDW), leaf (LDW) and shoot dry weight (SHDW) in the 'Bragantina' black pepper plant as a function of the water volume (Vol) applied via the irrigation system (Irrig) and from the effective rainfall (ERD). **Significant at the 0.01 level, by t-test.

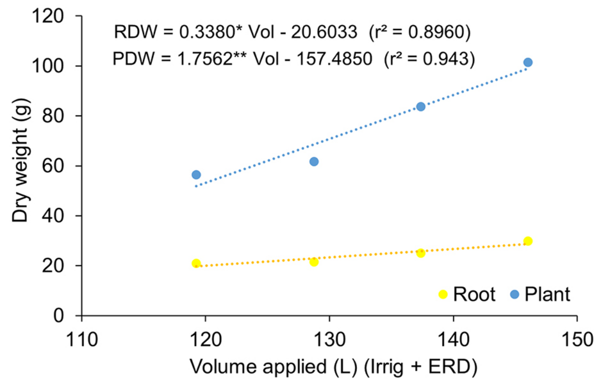

Figure 6 – Root system dry weight (RDW) and total dry weight (PDW) in the 'Bragantina' black pepper plant as a function of the water volume (Vol) applied via the irrigation system (Irrig) and from the effective rainfall (ERD). *,**Significant at the 0.05 and 0.01 levels, respectively, by t-test.

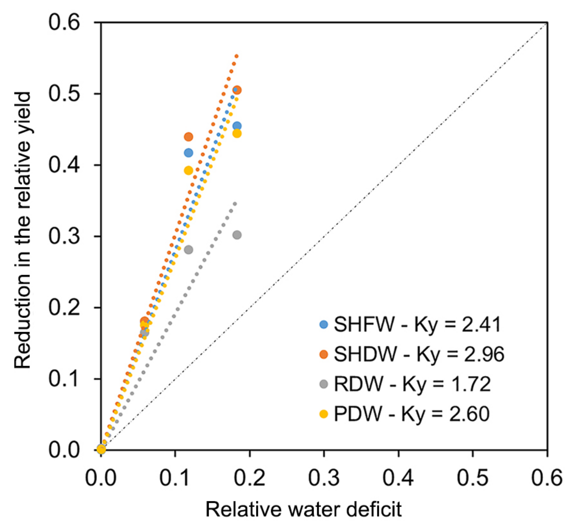

Figure 7 – Reduction in the relative yield of shoot fresh weight (SHFW), shoot dry weight (SHDW), root dry weight (RDW) and total dry weight (PDW), and respective response factors (Ky) in the 'Bragantina' black pepper plant submitted to relative water deficits.

(SHDW), 1.72 (RDW), and 2.60 (PDW). Crops can be classified into categories based on their sensitivity to water stress: low (Ky < 0.85); low/medium (0.85 < Ky < 1.00); medium/high (1.00 < Ky < 1.15), and high (Ky > 1.15) (Doorenbos and Kassam, 1979). Therefore, from the values determined for Ky, it can be concluded that 'Bragantina' black pepper is highly sensitive to water deficit. Using the value for Ky, it is possible to optimize water use according to the needs of each species (Santos et al., 2017), since using Ky makes it possible to plan the effective use of irrigation water (Pelegrini et al., 2020). Studies on sensitivity to water deficit in black pepper are scarce, and as a result, there are no reference values for comparative analysis, unlike most annual crops.

There was a significant loss of fresh and dry weight yield, with a reduction of 82.64 % in fresh weight (254 to 139 g) and 101.5 % in dry weight (71.6 to 35.5 g) in treatment T1 compared to T4. These values result from the intensification of the water deficit due to the lower irrigation volume and the lack of rainfall during the experiment, resulting in less plant growth and smaller weight gain. The significant variability in environmental conditions and crop responses to the different study environments show a wide variation in the value of Ky, both between crops and within the same crop (Stanhill, 1985).

In general, the spikes produced with up to 81 % of the CWD were larger and more numerous than those subjected to inferior treatments. The characteristics of quantity, length, fresh weight, and dry weight of the spikes decreased as the water supply was reduced (Table 1).

As only a single collection was made, including the removal of all the spikes from the plants, most of the spikes (about 92 %) were in the initial stages of development (classes F1 and F2), while the others were classified as F3 (3 %), F4 (3 %), F5 (1.2 %), and F6 (0.8 %). Of this amount, there were spikes at stages F4, F5, and F6 only in plants subjected to treatments with more significant irrigation volumes (T3 and T4), indicating a certain delay in flowering and/or grain maturation as the irrigation volume was reduced (Table 1). Corroborating this, flower drop was seen soon after emergence in plants subjected to volumes T1 and T2 during the first flowering period. This indicaters that such irrigation volumes were insufficient for satisfactory development during the reproductive phase. However, rainfall during the second flowering period (Jan to Mar 2020) may have helped pollinate and maintain some spikes, even in plants that received less water from irrigation (Rasanjali et al., 2019), since this phenomenon was not observed during this period.

Several studies show that drought causes a reduction and losses in the production process of black pepper plants. As such, the stage prior to flowering is considered the most critical period for the crop (Penella and Calatayud, 2018), and once flowering begins, water must be made continuously available to the plants until the fruit ripens to avoid low yields; water restrictions are still in place for a few days during this period (Kandiannan et al., 2014; Krishnamurthy et al., 2011; George et al., 2017).

In the present study, irrigation benefitted the precocity of the crop in terms of greater leaf area and phytomass accumulation, which, in turn, may have favored flowering and, consequently, more outstanding spike production, notably when subjected to treatments T3 and T4 (Table 1). Properly managed irrigation helped reduce the drop in inflorescence in black pepper, a positive aspect for the producer, as it affords a more extended period for flowering, grain filling, and maturation.

Table 1 – Agronomic characteristics of spikes in the 'Bragantina' black pepper plant submitted to different irrigation regimes based on the class of phenological development, 391 days after transplanting.

Treatments	Class of phenological development						Total*
	F1*	F2*	F3*	F4**	F5**	F6**	
	Quantity of spikes per plant						
T1	9.33 b	1.08 b	0.50 a	–	–	–	10.92 b
T2	11.00 b	1.50 b	0.08 a	–	–	–	12.58 b
T3	18.83 a	6.75 a	0.25 a	0.58 a	0.25 a	0.33 a	27.00 a
T4	20.92 a	7.67 a	1.67 a	2.08 a	0.83 a	0.33 a	33.50 a
	Average length of the spikes (cm)						
T1	5.97 b	5.13 a	1.77 a	–	–	–	2.14 b
T2	5.93 b	5.67 a	0.58 a	–	–	–	2.03 b
T3	8.61 a	9.40 a	2.83 a	2.88 a	1.11 a	1.06 a	4.32 a
T4	8.57 a	9.31 a	5.92 a	5.79 a	5.90 a	2.28 a	6.29 a
	Fresh weight of the spikes (g)						
T1	6.43 b	0.66 b	1.02 a	–	–	–	8.11 b
T2	7.63 b	0.88 b	0.14 a	–	–	–	7.72 b
T3	12.63 a	7.06 a	0.46 a	2.22 a	1.38 a	1.97 a	23.39 a
T4	17.37 a	6.82 a	4.83 a	12.04 a	4.50 a	2.32 a	35.38 a
	Dry weight of the spikes (g)						
T1	0.77 b	0.10 b	0.30 a	–	–	–	1.18 b
T2	0.67 b	0.16 b	0.01 a	–	–	–	0.83 b
T3	1.68 a	0.93 a	0.05 a	0.65 a	0.50 a	0.61 a	4.42 a
T4	1.89 a	1.14 a	0.38 a	3.80 a	1.96 a	0.74 a	9.93 a
	Dry weight of the grains (g)						
T1	–	–	0.26 a	–	–	–	0.26 a
T2	–	–	0.01 a	–	–	–	0.01 a
T3	–	–	0.04 a	0.57 a	0.44 a	0.54 a	1.59 a
T4	–	–	0.33 a	3.30 a	1.72 a	0.66 a	6.02 a

*,**Means followed by the same letter in the column do not differ by Scott-Knott test and F test, at 5 % probability level, respectively; F1 – emergence and opening of the flowers; F2 – start of fruit formation and growth (presence of pollinated flowers or formed grains on around half the spike); F3 – presence of formed grains, easily crushed when lightly pressed with the fingers on most of the spike; F4 – predominance of fully formed and completely filled, albeit unripe, grains on the spike (greenish color); F5 – up to 50 % of the grains on the spike of a yellowish or reddish color; and F6 – more than 50 % of the grains on the spike of a yellowish or reddish color; T1, T2, T3 and T4 – 42 %, 62 %, 81 % and 100 % of the crop water demand, respectively.

The more significant number of spikes is related to the growth in height, number of leaves, and larger number of productive branches resulting from the greater water supply. Grain yield in black pepper is correlated with the number of leaves, as the spikes are formed in opposite positions to the leaves on the plants (Nair, 2020). The results found in this study agree with Ankegowda et al. (2011), who compared black pepper plants under irrigation and rainfed conditions and found a more significant number of flowers when the plants were irrigated.

Under T4, the spikes showed lengths of around 43 % (F1) and 81 % (F2) greater than those observed in plants submitted to T1; however, it did not differ from the T3 treatment. The average total length of the spikes tended to increase due to an increase in the irrigation volume, despite only 8 % being classified in stages F3, F4, F5, and F6 (Table 1). This result may affect the economic factor, since losses may occur due reduced yield and fruit size under water stress (Negi et al., 2021).

In general, there was an increase in spike weight due to an increase in irrigation volume, where the fuller the grains, the heavier the spikes and the greater the water demand (T3 and T4) (Table 1). The results reflect the need for adequate irrigation throughout the flowering phase of black pepper (Dec 2019 to May 2020). As such, this phase is the most dependent on water resources, showing the need for adequate water during peak flower and berry production to obtain good results (Karthik et al., 2020).

The results show that the accumulation of spike dry weight was more significant during the more advanced stages of maturation (F3, F4, F5 and F6), which, despite representing only 8 % of the total number of spikes, represents around 55 % of the total spike dry weight produced (Table 1). This may have been due to grain filling from stage F4, as per the proposed classification system. Leaf area may have been another important factor during grain filling, since black pepper shows a significant reduction in berries when the leaf area is negatively affected during development (Krishnamurthy et al., 2000).

Due to the water deficit, the production of well-formed grains (above F3 class) was seen only in plants submitted to treatments T3 and T4. The grains of spikes classified as F3 have no commercial value, as the endosperm is unformed, and their weight is reduced, whereas the grains from spikes of classes F4, F5, and F6 show greater dry weight, a result of grain formation (Table 1).

There was an increase in yield during grain production, consistent with the increase in water availability, despite a reduced number of spikes with grain classified as F3 or above (Table 1). Ankegowda et al. (2011) found that the average berry production per black pepper plant was equal to 6.3 kg per plant when irrigation was used, and 1.9 kg per plant when not irrigated. The authors also reported that irrigation during the flowering stage directly influenced these results. As such, the most significant productivity in black pepper is related to water being supplied in sufficient quantity to meet the needs of the crop, from pre-flowering to fruit ripening.

The present study showed how sensitive the Bragantina cultivar of black pepper is to water stress, with values for the Ky response factor greater than 1.7. This is the first such study of the soil and climate conditions in Brazil. The sensitivity of the crop during the flowering stage was also evident, with direct effects on flower survival and grain production. Considering the various important black pepper-producing regions in Brazilwith climate characteristics that favor high rates of evapotranspiration combined with low rainfall indices, this study contributes to improving cropping systems in these regions.

Conclusions

In this study, the growth, sensitivity to water deficit and first-year productivity of irrigated plants of the Bragantina black pepper cultivar evaluated the employment of an irrigation system with automatic management. In plastic pots installed in the field, cultivation was carried out for 391 days using emitters with flow rates ranging from 2.2 to 5.3 L h^{-1}.

The Bragantina cultivar is highly sensitive to water deficit, with response coefficients (Ky) ranging from 1.72 (considering the root dry weight) to 2.96 (for shoot dry weight).

Phytomass production in black pepper is negatively affected by water deficit, which contributes to a reduction in the size, weight, and quality of the spikes and grains of black pepper, mainly where the water supply is less than 81 % of crop demand.

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Authors’ Contributions

Conceptualization: Carvalho, D.F.; Teles, G.C.; Medici, L.O. **Data curation:** Carvalho, D.F.; Teles, G.C. **Formal analysis:** Carvalho, D.F.; Teles, G.C.; Cruz, E.S.; Valença, D.C.; Medici, L.O. **Funding acquisition:** Carvalho, D.F. **Investigation:** Carvalho, D.F.; Teles, G.C. **Methodology:** Carvalho, D.F.; Teles, G.C.; Medici, L.O. **Supervision:** Carvalho, D.F.; Medici, L.O. **Writing-original draft:** Carvalho, D.F.; Cruz, E.S.; Medici, L.O. **Writing-review & editing:** Carvalho, D.F.; Cruz, E.S.; Medici, L.O.; Valença, D.C.

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