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Gas exchange and post-harvest quality of 'Kent' mango subjected to controlled water deficit in semi-arid region

Trocas gasosas e pós-colheita da mangueira 'Kent' submetida a déficit hídrico controlado no semiárido

Victor P. M. de Andrade[1]*, Welson L. Simões[2], Nildo da S. Dias[3], Jucicléia S. da Silva[2], Kaio V. F. Barbosa[4]

[1]Farm department, Instituto Federal do Sertão Pernambucano, Petrolina, PE, Brazil. [2]Research department, Empresa Brasileira de Pesquisa Agropecuária Semiárido, Petrolina, PE, Brazil.[3]Teaching department, Universidade Federal Rural do Semiárido, Mossoró, RN, Brazil. [4]Biology collegiate, Universidade de Pernambuco, Petrolina, PE, Brazil.

ABSTRACT - Brazil is the seventh largest producer of mangoes in the world, and the São Francisco Valley is the main producing region, with 'Kent' as one of the main cultivars. Considering that irrigation management affects physiological events, production and fruit quality, the objective of this work was to evaluate the gas exchange in the leaves and fruit quality of 'Kent' mango subjected to controlled water deficit in the semi-arid region. The experiment was carried out in Petrolina-PE, semi-arid region of the São Francisco Valley. The experimental design used was randomized blocks, in a triple factorial scheme, with four irrigation depths (40, 60, 80 and 100% of crop evapotranspiration - ETc), three phenological stages (F1 - flowering, F2 - fruit growth, F3 - fruit maturation) and two production cycles (2018 and 2019), with four replicates. During the phenological stages, the physiological parameters of gas exchange were evaluated. After harvesting, the following parameters were evaluated: soluble solids content, titratable acidity, pH, firmness and peel color. Irrigation with a depth between 79.5 and 83.6% ETc during the evaluated stages promoted greater gas exchange in the leaves, greater firmness and acidity in the fruits. The reduction in irrigation depth in F1 and F3 reduced the soluble solids content, while in F2 the highest soluble solids content was obtained with irrigation between 68.24 and 74.5% ETc. The most suitable irrigation depth for 'Kent' mango cultivation depends on the purpose of the producer and on the phenological stage of the crop.

Keywords: Mango. Irrigation. Fruit quality. *Mangifera indica* L.

RESUMO - O Brasil é o sétimo maior produtor de mangas do mundo e o Vale do São Francisco é a principal região produtora, tendo a 'Kent' como uma das principais cultivares. Considerando que o manejo da irrigação afeta a fisiologia, a produção e a qualidade dos frutos, o objetivo deste trabalho foi avaliar as trocas gasosas nas folhas e a qualidade dos frutos da mangueira 'Kent' submetida a déficit hídrico controlado no Semiárido. O experimento foi conduzido em Petrolina-PE, semiárido do Vale do São Francisco. O delineamento experimental utilizado foi o de blocos casualizados, em esquema fatorial triplo, com quatro lâminas de irrigação (40; 60; 80 e 100% da evapotranspiração da cultura - ETc), três estádios fenológicos (F1 - floração, F2 - crescimento de frutos e F3 - maturação de frutos) e dois ciclos produtivos (2018 e 2019), com quatro repetições. Durante os estádios fenológicos, foram avaliados os parâmetros fisiológicos de trocas gasosas. Após a colheita, foram avaliados: teor de sólidos solúveis, acidez titulável, pH, firmeza e coloração da casca. A irrigação com lâmina entre 79,5 e 83,6% da ETc durante as fases avaliadas proporcionou maiores trocas gasosas nas folhas, maior firmeza e acidez nos frutos. A redução na lâmina de irrigação na F1 e F3 diminuiu o teor de sólidos solúveis, enquanto que na F2 o maior teor de sólidos solúveis foi obtido com irrigação entre 68,24 e 74,5% da ETc. A lâmina de irrigação mais adequada para o cultivo da manga 'Kent' depende do propósito do produtor e da fase fenológica da cultura.

Palavras-chave: Manga. Irrigação. Qualidade de frutos. *Mangifera indica* L.

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***Corresponding author:**
<victor.pimenta@ifsertao-pe.edu.br>

INTRODUCTION

Mango (*Mangifera indica* L.) is a crop of great economic importance for Brazilian agriculture, with production of 1.4 million tons and an average yield of 21 tons per hectare in 2019. The Northeast is the largest producing region, accounting for about 77% of the national production, with the states of Pernambuco and Bahia being the largest producers, with 518.2 and 442.2 tons, respectively (IBGE, 2020). 'Kent' mango, which is one of the main cultivars produced in the region, is the second most commercialized cultivar in the European Union and Japan, with great prospects in the main European markets, gaining more and more space due to the absence of fibers and the appreciated flavor (ARAÚJO; MORAES; CARVALHO, 2017).

In the São Francisco Valley, the scarce and irregular rainfall does not meet the water demand of crops, so it is necessary to use irrigation to obtain an economically adequate yield. However, considering the characteristics of this region such as the availability of good quality water for irrigation associated with efficient irrigation management and the climatic conditions appropriate to cultivation, better fruit production and quality have been observed, promoting greater success in the orchard (LEÃO; MOUTINHO; CAMPOS, 2016).

It is important to highlight that the productive and qualitative response of fruits of the species cultivated under irrigated conditions depends mainly on the frequency, moment, method and form of installation of the irrigation system, stage of the crop, edaphoclimatic conditions and exploited cultivars (COELHO et al., 2015).

Although mango is considered a drought-tolerant plant, studies indicate that inadequate irrigation management affects its physiology, growth and, consequently, the production and quality of its fruits (PRAKASH et al., 2015). On the other hand, some studies show that controlled water deficit, which consists in reducing the irrigation depth in less sensitive phenological stages may not impair and can even improve fruit production and quality, with greater water use efficiency (COTRIM et al., 2011; COTRIM et al., 2017; SANTOS et al., 2014). Water supply by irrigation is directly related to the stomatal opening of the leaves, which conditions the gas exchange and consequently the absorption of CO_2 from the atmosphere, substrate of photosynthetic production (TAIZ et al., 2017).

The main quality attributes required by the mango consumer market are fruit size and mass, pulp firmness, peel color, soluble solids content, titratable acidity and pH (SHI et al., 2015), which are used as parameters to determine different commercial standards around the world. These parameters are closely related to gas exchange rates and photosynthetic production of mango (TAIZ et al., 2017), which in turn are responses especially to the water management of the crop (SIMÕES et al., 2020a).

In this context, considering the importance of reducing the amount of irrigation water, without affecting the physiology and quality of fruits, the objective of this work was to evaluate leaf gas exchange and post-harvest characteristics of fruits in ‘Kent’ mango subjected to controlled water deficit in the northeastern semi-arid region.

MATERIAL AND METHODS

The study was conducted in the orchard of the Special Fruit Farm, located in the municipality of Petrolina-PE (09º 08’ South, 40º 18’ West and average altitude of 370 m), in the Sub-Middle São Francisco Valley. According to Köppen’s classification, the climate is classified as BSh, i.e. very hot semi-arid with rainy season in summer extending to the beginning of autumn (ALVARES et al., 2013). The soil of the experimental area was classified, according to Santos et al. (2018), as *Argissolo amarelo eutrófico* (Ultisol), which was sampled to characterize the chemical attributes in specialized laboratory (Table 1).

Table 1. Chemical characterization of the soil in the orchard with ‘Kent’ mango.

Layer	EC	pH	P	K	Na	Ca	Mg	Al	H+Al	SB	CEC	V
m	mS cm^{-1}		mg dm^{-3}	cmolc dm^{-3}								%
0-0.2	0.46	4.3	41.76	0.43	0.13	3.7	0.9	0.0	0.5	5.2	5.7	91.5
0.2-0.4	0.23	4.5	40.53	0.36	0.11	2.2	1.1	0.0	1.4	3.8	5.2	72.4

EC= electrical conductivity of saturation extract; P= available phosphorus extracted by Mehlich; Ca= exchangeable calcium; Mg= exchangeable magnesium; Na= exchangeable sodium; K= exchangeable potassium; Al= exchangeable acidity; CEC= cation exchange capacity at pH 7.0; V= base saturation.

The experiment was conducted in a ‘Kent’ mango orchard in October 2017, in two cultivation cycles, using spacing of 2.0 m between plants and 6.0 m between rows, with 5-year-old plants in the production stage. In the experiment, pruning, fertilization, phytosanitary practices and floral induction were carried out as described by Mouco (2015). Harvest was carried out in October 2018 for the first cycle and in November 2019 for the second cycle.

The experimental design used was randomized blocks, in a triple factorial scheme, with the application of four irrigation depths (40, 60, 80 and 100% of crop evapotranspiration - ETc), three phenological stages (F1 - flowering, F2 - fruit growth, F3 - fruit maturation and harvest) and two consecutive productive cycles (2018 and 2019), with four replicates, each plot consisting of four plants. Crop evapotranspiration (ETc) was obtained by the FAO-Penman-Monteith method (ALLEN et al., 2006), from daily data collected from a weather station installed near the experimental site and the crop coefficients (Kc), as suggested by Teixeira et al. (2008) (Table 2) for ‘Tommy Atkins’ mango, since there is no recommendation in the literature of Kc values for ‘Kent’ mango.

Figure 1 shows climatic data of the region, obtained from the above-mentioned weather station for the experimental period.

Irrigation was performed daily to replace the ETc of the previous day. A drip irrigation system was used, with two lateral lines per row of plants and emitters spaced 0.30 m apart, with a flow rate of 1.7 L h^{-1}.

The evaluations of variables related to plant physiology were: photosynthesis (A), stomatal conductance (gs), transpiration (E) and leaf temperature (T_L), using the Infrared Gas Analyzer (Licor® Li 6400 model). The analyses were performed in the phenological stages of flowering (F1), fruit growth (F2) and fruit maturation (F3), between 10 and 12 h of a cloud-free day, in physiologically mature leaves, in the second third of the branches, exposed to the sun and free of mechanical damage, nutritional deficiency symptoms, pests and diseases.

Table 2. Phenological stages of mango, with their respective durations and the crop coefficients (Kc) of ‘Tommy Atkins’ mango used in the experiment.

Phenological stage	*Kc	Beginning (dapp**)	Duration (days)
Rest	0.7		
Vegetative growth	0.8	0	130
Branch maturation	1.0	130	30
Floral induction	0.3	160	20
Flowering (F1)	1.0	180	30
Fruit growth (F2)	0.9	210	60
Fruit maturation (F3)	0.8	270	20
Harvest (F3)	0.6	290	10

*Teixeira et al. (2008). **dapp: days after production pruning.

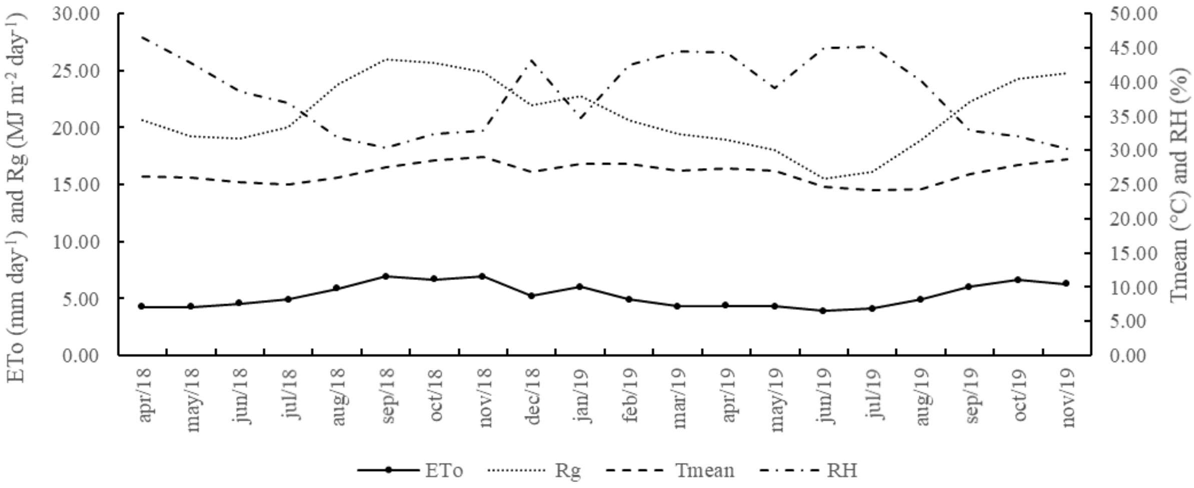

Figure 1. Average monthly values of daily reference evapotranspiration (ET_0), average temperatures (Tmean), global solar radiation (Rg) and relative air humidity (RH), from a weather station installed in the experimental area, in Petrolina-PE, during 2 production cycles of ‘Kent’ mango. F1: Flowering; F2: Fruit growth; F3: Fruit maturation.

The fruits were harvested in the maturity stage E2 (initial phase of maturation), adopted as a standard for export (BRECHT et al., 2011). After harvest, all fruits were weighed to determine the yield per plant. Then, 4 fruits were selected with the following characteristics: absence of mechanical damage, free of pest attacks and diseases, with size, color and maturation appropriate to the market requirements, for the analysis of quality parameters. Pulp firmness analysis was determined with a manual penetrometer (Effegi, FT 327 model), and the measurements were carried out after removal of the peel, at two opposite points, in the equatorial region of the fruits, while soluble solids content was determined with a manual refractometer (Pocket pal-1 model). Titratable acidity was determined according to IAL (2008). Pulp pH was determined by the potentiometric method, with a digital benchtop pH meter, calibrated with pH 4.0 and 7.0 buffer solutions (IAL, 2008). Color analysis was performed by checking the values of lightness (L), hue angle (°Hue) and chromaticity (C), measured by reflectance, using a portable colorimeter CR-400 from Konica Minolta, following the recommendations of Vasconcelos et al. (2020).

The results were subjected to the Shapiro-Wilk residual normality test and Bartlett’s variance homogeneity test. After verifying that the data met the assumptions of normality and homogeneity, analysis of variance was performed using the F test at 5% probability level. When there was a significant difference between treatments, Tukey means comparison test was performed at 5% significance level for qualitative factors and regression analysis at 5% significance level was performed for quantitative factors, to select the models that best represent the data. Statistical analyses were carried out with SISVAR software (FERREIRA, 2017).

RESULTS AND DISCUSSION

The different irrigation depths applied and the production cycles influenced the leaf gas exchange of mango, with interaction between these sources of variation, except for leaf temperature, which was influenced only by the irrigation depths (Figure 2).

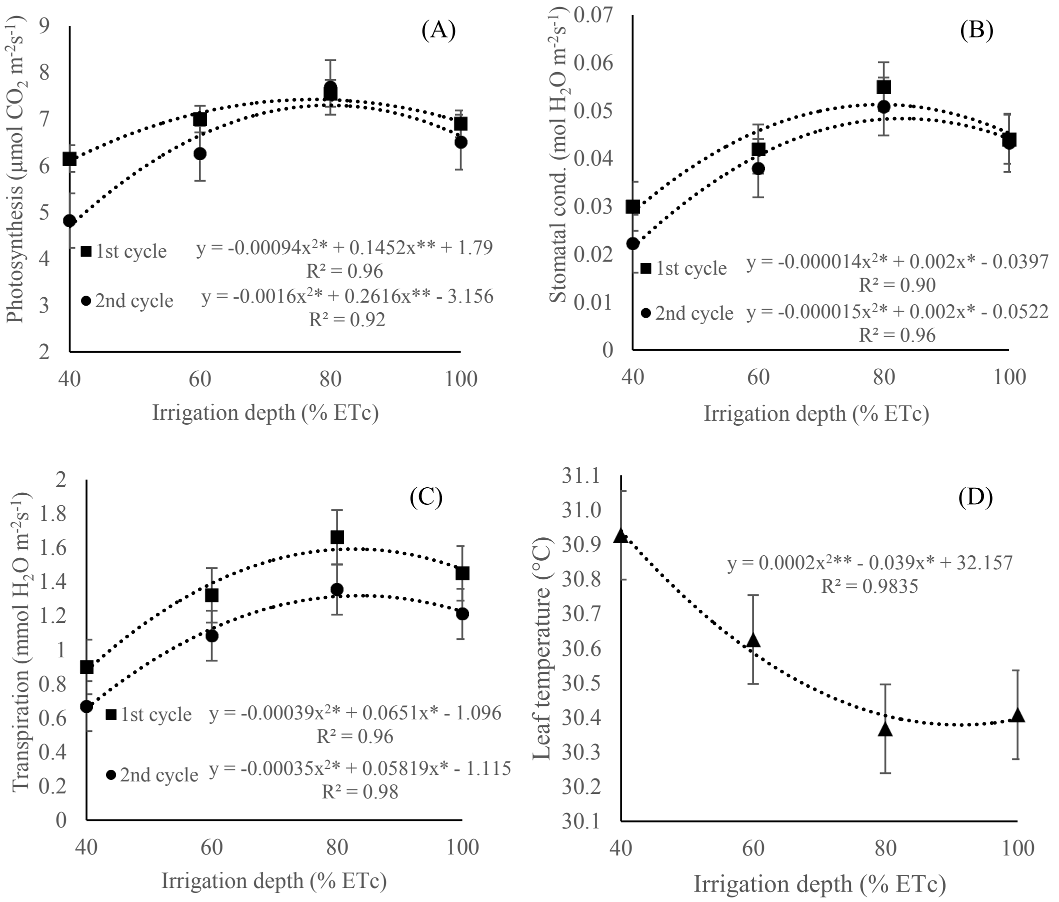

Figure 2. Photosynthesis (A), stomatal conductance (B), transpiration (C) and leaf temperature (D) as a function of different irrigation depths, in two production cycles. Vertical bars indicate the standard error of the means. * Significant at 5% probability level. ** Significant at 1% probability level.

The responses of the variables photosynthesis, stomatal conductance and transpiration as a function of irrigation depths were described by the quadratic polynomial model, with the highest values in the first crop cycle. Maximum photosynthetic rates of 7.4 and 7.5 µmol CO_2 m^{-2} s^{-1} were estimated for irrigation depths of 80.7 and 81.75% ETc in the first and second cycle, respectively (Figure 2A). The highest estimates of stomatal conductance were 0.051 and 0.048 mol H_2 m^{-2} s^{-1} for irrigation depths of 79.5 and 83% ETc, in the first and second cycle, respectively (Figure 2B). For transpiration, maximum values of 1.58 and 1.31 mmol H_2 m^{-2} s^{-1} for irrigation depths of 82.5 and 83.6% ETc were estimated in the first and second cycle, respectively (Figure 2C). For leaf temperature, a minimum value of 30.38 ºC was estimated for an irrigation depth of 91.1% ETc (Figure 2D). The maximum values of photosynthesis, stomatal conductance and transpiration were similar to those reported by Simões et al. (2021) for ‘Kent’ mango irrigated along the entire production cycle with depths between 71 and 79% ETc.

Considering that leaf gas exchange reached maximum value when plants were irrigated with 80% of the water need recommended for the crop, it can be inferred that the Kc values used were overestimated for this cultivar, and the irrigation depths below or above this optimal point were considered scarce or excessive, respectively. The scarcity and excess of water in the soil are stressful factors for plants, as they induce stomatal closure (SILVA et al., 2015). Stomatal closure indicates that photosynthesis is being limited, denoting that there is low availability of carbon dioxide for the photosynthetic process, with biochemical limitation of photosynthesis (CHAVES; FLEXAS; PINHEIRO, 2009), which negatively affects several physiological processes, causing reduced yield (SIMÕES et al., 2018).

Leaf temperature shows an inverse behavior to that of gas exchange, since the increase in stomatal conductance cools the leaf surface (MORAIS; ROSSI; HIGA, 2017). The association of factors such as high leaf temperatures and water stress can drastically reduce plant growth and development, since CO_2 assimilation is linked to a high water requirement and requires sufficient water supply for growth (SILVA et al., 2013).

Regarding production, there was interaction between phenological stages and production cycles (Figure 3). The first production cycle showed higher temperatures, resulting in higher gas exchange and higher photosynthetic production than the second cycle, which resulted in higher fruit production, as also observed in ‘Tommy’ mango by Almeida et al. (2015). According to Taiz et al. (2017), the increase in stomatal conductance may lead to a higher CO_2 influx in leaf mesophyll, allowing an increase in photosynthesis rates. Sukhvibul et al. (1999) found higher flowering and higher pollen viability in mango trees subjected to average temperatures of 30 ºC during the day and 20 ºC at night, a climatic condition similar to that which occurred in the second cycle. According to Sandip et al. (2015), higher temperatures are associated with a higher number of hermaphrodite flowers compared to staminate flowers, which may also have contributed to the greater number of fruits obtained in the first cycle.

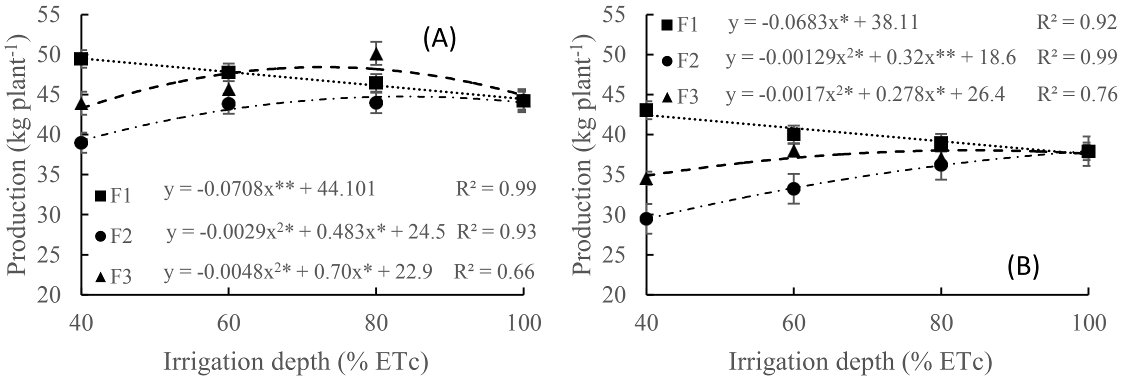

Figure 3. Fruit production per plant of 'Kent' mango subjected to controlled water deficit in two production cycles: 2018 (A) and 2019 (B). F1 - flowering, F2 - fruit growth, F3 - fruit maturation. Vertical bars indicate the standard error of the means. * Significant at 5% probability level. ** Significant at 1% probability level.

In the first cycle, the highest production of 'Kent' mango was estimated at 44.6 and 48.4 kg plant^{-1} for the irrigation depths of 83.37 and 72.76% ETc, in the F2 and F3 stages, respectively. In the second cycle, the highest production was estimated at 37.72 and 37.69 kg plant^{-1} for irrigation depths equivalent to 100 and 81.52% ETc, in the F2 and F3 stages, respectively.

In F1, mango production increased linearly with the reduction of irrigation depth up to 40% ETc in both cycles evaluated. Considering that 'Kent' mango is a vigorous cultivar and its flowering management is difficult (SILVA et al., 2012), the reduction in the applied irrigation depth can influence a decline in plant vigor, favoring flowering, as reported by Sandip et al. (2015) and, consequently, higher fruit production per plant. In treatments F2 and F3, the production of plants showed a quadratic response, similar to those of gas exchange and photosynthesis, pointing to a close relationship between these variables. Photosynthetic production is responsible for about 90% of the dry matter produced by plants (MARSCHNER, 2011), being directly related to fruit production (VAN BUEREN; STRUIK, 2017). In addition, mango has about 82% of water in its composition (MARQUES et al., 2010), which highlights the importance of maintaining a recommended water availability so that it maintains adequate levels of gas exchange and photosynthetic production, especially in the fruit growth and maturation stages.

Irrigation depths, phenological stages and cultivation cycle influenced the soluble solids content of 'Kent' mango, with interaction between irrigation depths and production cycles (Figure 4).

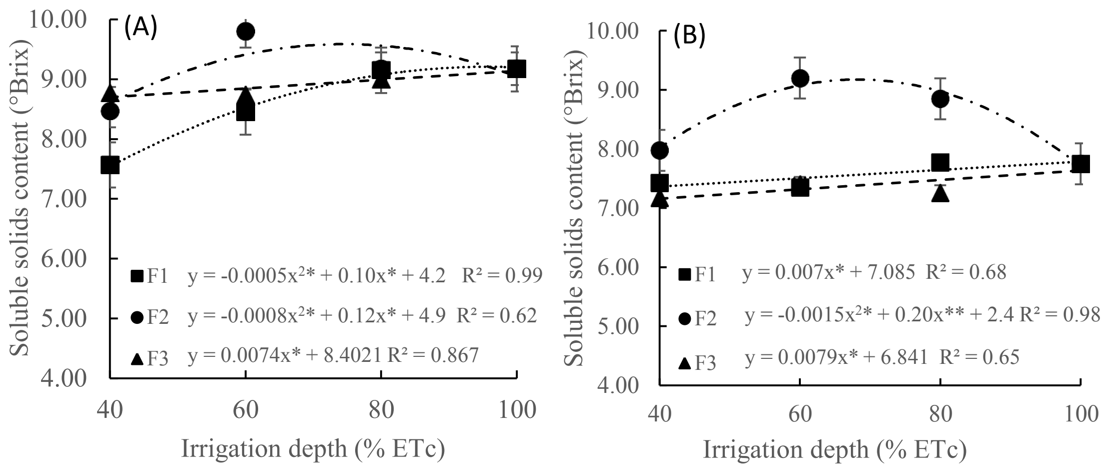

Figure 4. Soluble solids content of 'Kent' mango subjected to controlled water deficit, in different phenological stages, in two production cycles. (A): 2018, (B): 2019. F1 - flowering, F2 - fruit growth, F3 - fruit maturation. Vertical bars indicate the standard error of the means. * Significant at 5% probability level. ** Significant at 1% probability level.

As the water restriction was applied in the flowering and fruit maturation stages, a significant reduction in soluble solids content was observed, probably due to the higher fruit load of these plants, reducing the source/sink ratio and distributing less sugar per fruit, as observed by Oliveira et al. (2019) with 'Palmer' and 'Espada' mangoes. In the fruit growth stage, the maximum soluble solids content was obtained when the irrigation depth approached the range that promoted higher gas exchange, between 79.5 and 83.6% ETc, resulting in higher production of photoassimilates, hence contributing to the accumulation of sugars in the fruits. Reis et al. (2011) and Wei et al. (2017) also reported higher soluble solids content in mango with the reduction of irrigation supply. Reduction of water availability also contributes to increasing the concentration of soluble sugars in fruits (SIMÕES et al., 2021), which was observed with the water deficit applied in F2. However, the higher source/sink ratio promoted by treatments with deficit in F1 and F3 was probably a more relevant factor for the soluble solids content of the fruits, reducing the concentration of solutes due to higher fruit load.

In the first cycle, the highest estimated contents of soluble solids (9.21 and 9.58 °Brix) were found when using irrigation depths of 95.6 and 74.5% ETc, in F1 and F2, respectively. In the second cycle, the highest content was estimated at 9.17 °Brix for an irrigation depth of 68.24% ETc, in F2.

Regarding titratable acidity (TA) and pH of fruits, there was interaction between the applied irrigation depth and the production cycles, with no difference between phenological stages (Figure 5).

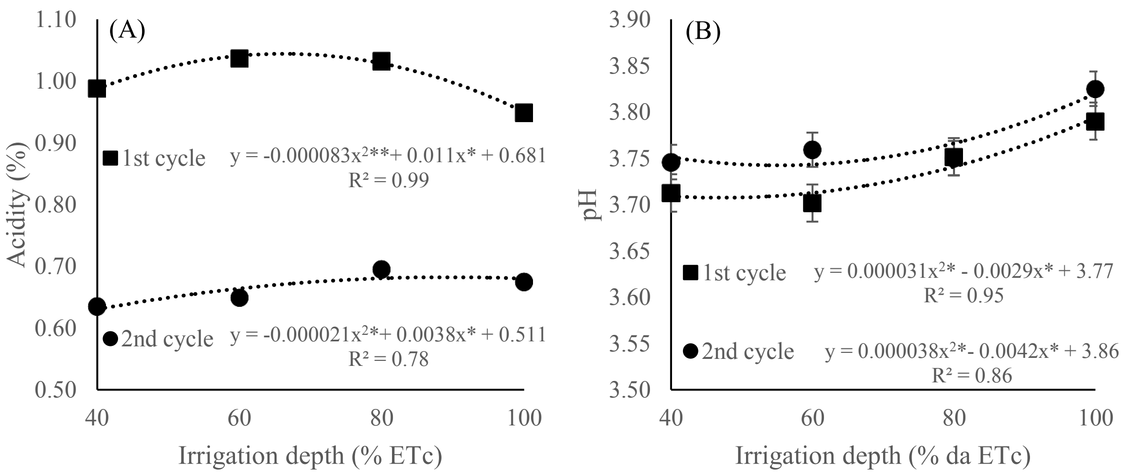

Figure 5. Titratable acidity (A) and pH (B) of 'Kent' mango as a function of different irrigation depths, in two production cycles. Vertical bars indicate the standard error of the means. * Significant at 5% probability level. ** Significant at 1% probability level.

The soluble solids (SS) content and titratable acidity (TA) were higher in the first cycle, which can be explained by the lower number of fruits produced, causing greater leaf area per fruit and fewer sinks for the synthesized photoassimilates, such as sugars and organic acids, as observed in 'Palmer' mango by Oliveira et al. (2019) and Simões et al. (2020b). Fruit pH showed an inverse behavior to that of titratable acidity, which was already expected, because the pH is an inverse logarithmic scale of the concentration of H^+ and H_3O^+ ions. Therefore, the increase in titratable acidity reduces fruit pH, as also observed by Souza et al. (2018), who found pH between 3.7 and 3.8, values close to those of the present study.

The SS and TA values observed are close to those suggested by Brecht et al. (2011). According to the authors, the harvesting of mangoes for export should be carried out when the soluble solids content of the fruits is between 7 and 9° Brix and the titratable acidity is between 0.6 and 1.14%. The same authors point out that, for being a climacteric fruit, the mango increases the soluble solids content and reduces the titratable acidity by about 3% per day at room temperature, which is a way to adjust fruit quality according to the market demands. The highest levels of titratable acidity observed were 1.04 and 0.68%, for irrigation depths of 66.26 and 89.34% ETc, in the first and second cycle, respectively. The lowest pH values were 3.70 and 3.74 for irrigation depths of 45.9 and 40% ETc in the first and second cycle, respectively.

The different irrigation depths, cycles and phenological stages influenced pulp firmness, with interaction between the applied irrigation depths and the phenological stage (Figure 6).

In the second cycle, the values of pulp firmness were higher than in the first cycle, probably due to the lower progress of the maturity point, corroborated by the lower values of soluble solids and higher values of titratable acidity observed. During maturation, starch is degraded into soluble sugars, gradually reducing fruit firmness (CORDEIRO et al., 2017).

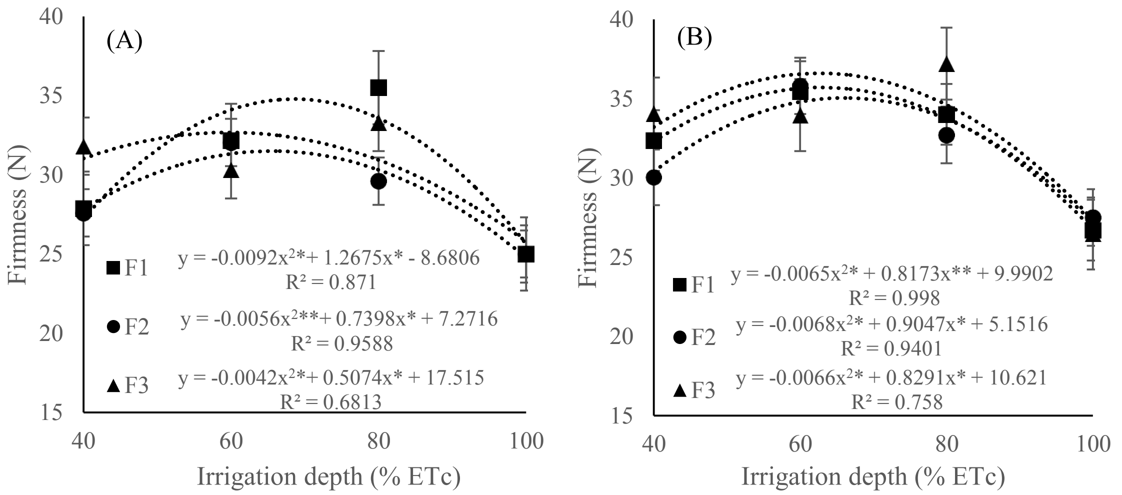

Figure 6. Pulp firmness in fruits of 'Kent' mango subjected to controlled water deficit, in two production cycles: 2018 (A) and 2019 (B). F1 - flowering, F2 - fruit growth, F3 - fruit maturation. Vertical bars indicate the standard error of the means.

The highest values of firmness are also related to the more turgid state of the fruits due to adequate water availability for the plants, corroborating the results obtained by Simões et al. (2018) in an experiment with 'Keitt' mango. The higher photosynthetic activity observed in this irrigation range possibly resulted in greater accumulation of reserve carbohydrates, promoting greater firmness in the fruit tissues (TAIZ et al., 2017). According to Veiga et al. (2019), in addition to biochemical reactions, firmness also decreases with the loss of turgor, as the turgor of fruit cells is reduced.

In the first cycle, the highest firmness in the fruit pulp was estimated at 34.9, 31.7 and 32.47 N for irrigation depths of 68.4, 66.0 and 60.4% ETc, in F1, F2 and F3 stages, respectively. In the second cycle, the highest firmness was estimated at 35.68, 35.24 and 36.65 N for the irrigation depths of 62.8, 66.5 and 62.8% ETc, in F1, F2 and F3 stages, respectively.

Regarding fruit color, there was interaction between the factors irrigation depth and phenological stage, with no difference between production cycles (Figure 7).

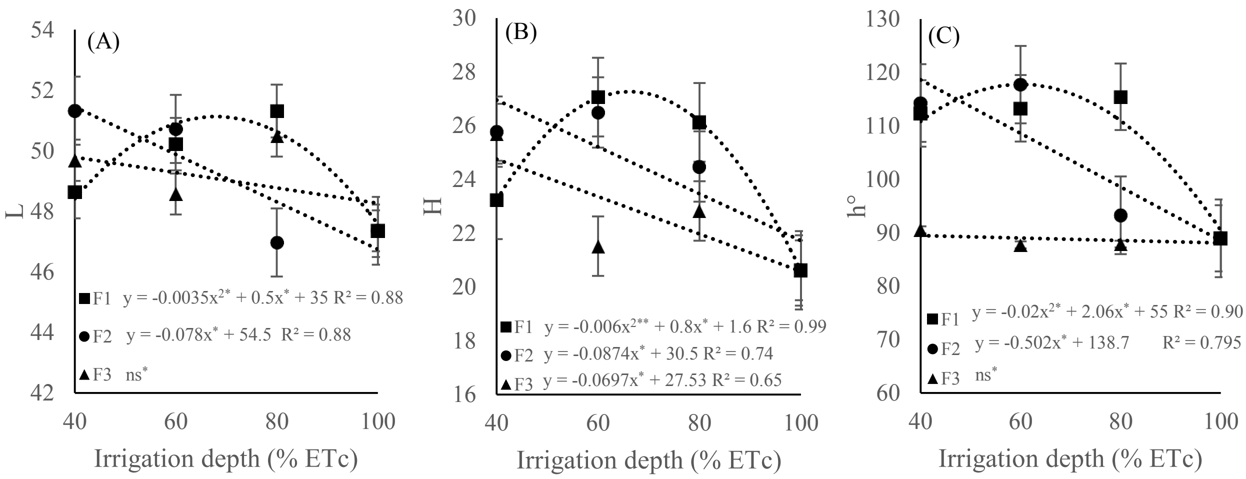

Figure 7. Lightness - L (A), chromaticity - C (B) and hue angle - h° (C) of fruits of 'Kent' mango subjected to different irrigation depths, in the phenological stages: F1 - Flowering, F2 - Fruit growth, F3 - Fruit maturation. Vertical bars indicate the standard error of the means. * Significant at 5% probability level. ** Significant at 1% probability level.

Lightness, chromaticity and hue angle decreased with the increase in irrigation depth, indicating more opaque fruits. Graphically, hue angle of 0º is considered as the red color, hue angle of 90º, yellow, hue angle of 180º, green, and hue angle of 270º, blue (MCGUIRE, 1992). Therefore, the color of the fruits ranged from green to yellow, and at the highest irrigation depth the fruits were more yellow, indicating a more advanced point of maturation, corroborating the results of soluble solids and firmness observed. The results of lightness and hue angle corroborated those obtained by Serpa et al. (2014) in a study with the cultivar 'Palmer', which showed higher values for more mature fruits. However, the results of chromaticity contrasted with those found by these authors, possibly because it is an intrinsic characteristic of cultivars.

The highest values of L, C and h° were 5.96, 27.4 and 117.87 for irrigation depths of 67.3, 66.6 and 61.57 in the F1 stage.

CONCLUSION

Irrigation with a depth between 79.5 and 83.6% ETc during flowering, fruit growth and fruit maturation promotes greater gas exchange in the leaves of ‘Kent’ mango, as well as greater firmness and acidity of fruits.

Reduction in irrigation depth in the flowering and fruit maturation stages reduces the soluble solids content in the fruits, while in the fruit growth stage the highest soluble solids content is obtained with irrigation depth between 68.24 and 74.5% ETc.

Irrigation with 40% ETc in the flowering stage increases fruit production in ‘Kent’ mango, while irrigation with 80% ETc increases production in the fruit growth and maturation stages.

The most suitable irrigation depth for ‘Kent’ mango cultivation depends on the purpose of the producer and on the phenological stage of the crop.

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