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Interaction of irrigation rates and fertilization doses on postharvest quality of papaya 'Formosa '

Lígia Borges Marinho[1*], Fernanda Nery Vargens[1], Acácio Figueiredo Neto[2], Vanessa Rodrigues da Silva[1], Aureliano Roberto Rodrigues Ramos[1], Lucas Melo Vellame[3], Eduardo Santana Aires[4]

[1]University of the State of Bahia, Department of Agronomy, Juazeiro, Brazil
[2]Federal University of the San Francisco Valley, Engineering Department, State of Bahia, Brazil
[3]Federal University of Recôncavo of Bahia, Cruz das Almas, Bahia, Brazil
[4]School of Agriculture, Department of Horticulture, São Paulo State University, Botucatu, Sao Paulo, Brazil

***Corresponding author: ligia.bmarinho@gmail.com**

Abstract

Water deficit is a water-saving strategy that might nevertheless negatively affect fruit quality. In the present study, the papaya quality was evaluated after application of different irrigation rates and nitrogen fertilization doses at harvest and postharvest. The study was conducted on 'Formosa' cultivar in semiarid region. The experiment was performed in a completely randomized design in a 2 x 5 x 3 scheme; two storage times (0 and 5 days), five irrigation rates (50, 75, 100, 125, and 150% of crop evapotranspiration), and three nitrogen doses (150, 180, and 210 $Kg.ha^{-1}$), with four replicates. Total Soluble Solids (TSS), Titratable Acidity (TA), and fruit skin colour (Luminosity - L, intensity of green/red coloration - a*, and intensity of yellow coloration - b*) were evaluated. Reduced irrigation rates and lower nitrogen doses resulted in increased soluble solids and SS/TA ratio. The latter was increased during storage. Irrigation deficit and a lower amount of nitrogen (150 Kg. ha^{-1}) did not reduce papaya quality, even after 5 days of storage in an environment with controlled temperature and humidity. In order to ensure net productivity in rural properties, this water-saving strategy of maintaining the crop under water restriction conditions must take into consideration not only in the curves of papaya quality-related variables, but also fruit productivity curve.

Keywords: *Carica papaya*, Harvest, Water deficit.
Abbreviations: TTA_ titratable acidity; TSS-TTA_ ratio; TTS_total soluble solid; ETc_ crop evapotranspiration; DAT_days after transplanting; N_ nitrogen; B.O.D. _ biological oxygen demand – chamber; PCA_ principal component analysis.

Introduction

The Submedium São Francisco River Valley stands out for its irrigated fruit farming activities, with large cultivated areas (12,015 and 1,196 ha) of mangoes and (12,015 and 1,196 ha) table grapes, respectively, in the municipalities of Petrolina-PE and Juazeiro-BA. These two cities account for 35% and 32.5% of the national mango and grape production (676,808 and 349,429 tons, respectively), which generates both direct and indirect employment (IBGE, 2017).

However, the majority of fruits produced in this semiarid region are exported to other states or countries, and are highly dependent on product price in the domestic market. Therefore, the net productivity of farms and fruit commercialization are more susceptible to international financial crisis, which implies the need for crop diversification.

A total of 26,060 ha of papaya were cultivated in Brazil in 2016. Of these, 51.4% were grown in the northeastern region, accounting for 61.1% of national production (IBGE, 2017). Therefore, papaya is a crop with potential to increase diversification in this semiarid region, especially with high water availability, due to edaphoclimatic and logistic conditions. However, more information is required, particularly related to water and fertilizers (e.g. nitrogen fertilizers), which are used to ensure a good produce quality. Better knowledge of productivity and fruit quality is required before adopting a water-saving strategy, e.g. water deficit, so that farmers are not at risk of losing net productivity.

Nitrogen is the second most required element by papaya crops, as it is important in photosynthesis rate regulation, carbohydrate synthesis, and biomass generation, among other plant functions. It is also required for early plant development and growth stages (Brito Neto et al., 2011). In a study conducted by these authors, the fruit productivity per plant of 'Sunrise Solo' cv. had a linear increase with increased nitrogen application, attaining maximum productivity (7.8 $Kg.plant^{-1}$) with 400 g nitrogen $plant^{-1}$, in Areia-PB. There was also a linear effect on SS and a quadratic effect on TA. Increased nitrogen fertilization has also affected TSS-TTA ratio in 'Sunrise' papayas.

In a study conducted on 'Formosa' papayas, cv. 'Caliman 01', using different planting spacings and doses of fertilization with NK combination in the region of Bom Jesus-PI. The nitrogen dose of 400 g $plant^{-1}$ was the best fit in a single spacing indicated by the nutrients detected in the plant and the soil (Silva Junior et al., 2016).

Papaya fruits might be evaluated based on several physico-chemical parameters. The major physical parameters are weight, length, diameter, shape, colour, and firmness, while chemical parameters include pH, titratable acidity, total soluble solids (TSS) (Fagundes and Yamanishi, 2001). Overall, papaya quality might be affected by several factors, such as edaphoclimatic conditions (Moretti et al., 2010), cultivars, seasons of the year, harvest site (Barros et al., 2017), and temperature and relative humidity during storage.

Providing suitable water and nutrient rates to crops has been one of the major difficulties faced by farmers who search for increased net productivity in the Submedium São Francisco River Valley. There is scarce information regarding the effect of different irrigation rates and nitrogen fertilizer doses on papaya quality, either before or after storage, especially on papaya's Formosa group.

Excess or scarce soil water is known to either cause reduced productivity or depreciate the final quality of papayas. Therefore, the aim of this study was to evaluate variations in irrigation rates and nitrogen doses, and how they affect papaya quality at harvest and postharvest.

Results and discussion

Physico-chemical characteristics

The quality of Formosa papayas varied according to different irrigation rates, nitrogen doses, and storage time in a B.O.D. chamber, both separated and combined, which particularly affected the chemical characteristics of fruits (Table 1).

There were significant differences ($p<0.05$, F-test) in mean values of skin and pulp firmness, a* and b*, titratable acidity (TTA), and TSS-TTA ratio of fruits between harvest time and 5 days of storage in an environment with controlled temperature and relative air humidity. This was not observed when only the effect of storage time on other variables was analysed (Table 2).

'Formosa' papayas were harvested at ripening stage 2 (with 25% of yellow coloration), and the influence of ripening was indicated by a* values, showing higher mean b*, TTA and TSS-TTA ratio at 5 days of storage in a controlled environment. This also indicates that papaya ripening continued to develop even in a refrigerated environment, with increase of 11.64, 19.40, and 35.63% of titratable acidity, TSS-TTA ratio, and b coloration, respectively, after storage.

Total Soluble Solids (TSS)

Although TTS increased (2.14%) after 5 days of storage in a controlled environment, this storage period was not enough to cause a significant increase in mean TSS values compared to harvest (time zero). This is due to controlled temperature and humidity, which might have possibly slowed down sugar synthesis, reduced ripening, and increased fruit shelf life (Melo et al., 2000) who studied pitangas. These authors found that refrigeration prolonged the conservation of ripe and semi-ripe fruits up to 10 days. In the case of green pitangas, conservation was prolonged up to 20 days.

Similar responses were observed by Costa et al. (2014), with linear increase in TSS in 'Sunrise Solo' papayas, both with and without $KMnO_4$, and wrapped with low-density polyethylene, stored at room temperature.

Silva et al. (2013) reported different responses in papaya quality to different irrigation managements in Catolé da Rocha-PB. These authors did not observe significant effects on titratable acidity, TSS, and TSS/TTA ratio of 'UENF/Caliman' papayas according to irrigation rates, which were defined based on reference evapotranspiration. Mean values varied from 0.166 to 0.146 (TTA), from 14.2 to 13.9 °Brix (TSS), and from 86.89 to 96.92 (TSS/TTA) in papayas produced in the first year. The authors attributed these results to the high rainfall that occurred during the study, which could have affected all irrigation management treatments.

The chemical characteristics of 'Formosa' papayas grown in Juazeiro-BA did not reach limiting values for commercialization. The TSS values in fruits of this papaya group can vary from 9 to 11 °Brix (Fioravanço et al., 1994; Fagundes, 2001). The lower acidity values and higher TSS/TTA make a better fruit flavour.

Papaya sweetness is characterized by low TTA values and high TSS values (Luz et al., 2015). Inverse acidity and TSS curves were observed in Formosa papayas from Juazeiro-BA, resulting in better fruit flavour, especially under restricted irrigation water conditions.

Increased TSS might be attributed to the fact that reserve carbohydrates turn into single sugars, which results in higher concentration of total soluble sugars (Chitarra and Chitarra, 2005), especially during ripening, possibly benefiting from water restriction in papaya crops (Table 3). On the other hand, increased TSS might have occurred due to the nitrogen fertilizers and boron that were provided to the plants (Brito Neto et al., 2011).

However, TSS value was lower in 'Formosa' papayas when a dose of 210 kg ha^{-1} $year^{-1}$ was used. There was linear decline in TSS and TSS/TA with increased nitrogen doses (Fig. 1), possibly due to higher fertilizer fractioning, which consequently allows a higher use of lower N doses throughout papaya development.

Papaya skin coloration

Papaya skin luminosity varied from 44.82 to 45.09, with lower mean value in fruits irrigated with 75% ETc, according to Tukey's test.

The intensity of green/red coloration on papaya skin varied from -5.22 to -9.40, with maximum value at -7.03, under irrigation rate of 122% ETc. Coloration components tend to vary from green to red, following the variation in a* from more negative to positive values. There was higher chlorophyll degradation, as expected for 'Formosa' papaya. This fruit has a climacteric type respiration, which is high in the ripening phase and has a subsequent reduction (Yamanishi et al., 2006), resulting in ethylene accumulation in the fruit. This accumulation enables ripening of fruit even after harvest.

A higher irrigation rates changes the a* of papaya towards positive values. Since harvests were performed only once a week, some fruits had reached suitable harvest point (10% yellow coloration) and others were beyond harvest point (over 10% of yellow coloration). Fruits under water deficit of 50% ETc were greener, meaning they could have a longer shelf life.

Variation in yellow skin coloration (b*) was low (8.92) at different irrigation rates. Yellow coloration in fruits expands over green coloration during fruit ripening, due to the synthesis and prevalence of carotenoids over the pigments, which particularly results from chlorophyll degradation.

Yamanishi et al. (2006) also attributed shifts in papaya skin coloration to changes in the amounts of dry mass and total soluble solids in the fruit. A similar response was observed in 'Formosa' papayas in Juazeiro-BA. Thee variation in skin luminosity was quadratic with increased TSS content in the fruits, and soluble solids contributed up to 74% (R^2) to skin luminosity values (Luminosity = $12.83\ SS^2 - 295\ SS + 1743.2$).

The interaction between storage time in B.O.D. chamber and different irrigation rates had a significant effect on the absorbance index of papaya crops. The three-way interaction of the factors affected the intensity of green/red coloration -a*, titratable acidity, and TSS/TTS ratio, with significance of $p<0.01$ (Table 1 and 4).

Absorbance index was decreased quadratically in fruits under increased irrigation water ($p<0.05$) prior to storage (Tstor=0) (Table 4). This was supported by a high coefficient of determination. Mean absorbance index (1.55) was attained under irrigation of 50% of ETc and the minimum point was 0.98. On the other hand, after 5 days of storage, the quadratic model was the best fit for results with low coefficient of determination (R^2), indicating that other factors had higher influence on the composition of this index.

There was a cubic tendency at nitrogen dose of 150 kg $ha^{-}1$, as well as less negative green/red coloration intensity values (a*) with increased irrigation rates, especially from the lowest rate (50% ETc) onwards to Tstor = 5 days (Table 4).

Regarding skin coloration, a gradual increase in rates and extreme N doses (150 and 210 $kg.ha^{-1}$) led to a predominance of negative values, resulting in papaya fruits with less green skin coloration.

Titratable acidity and ratio

There was a significant reduction in TTA of papayas irrigated with nearly 75% Etc., with a subsequent increase up to 125% ETc. From this point onwards, there was a decline, with values varying from 0.07 to 0.278g of citric acid/100 g of fruit juice.

Regarding TSS/TTA ratio, papaya flavour quality decreased with increased irrigation rates, considering that the lowest mean irrigation rate was calculated according to 150% of the water demand in papaya crops. There was an increase of 1.33% in TSS/TTA ratio with a 10% decrease in irrigation rate in the second production cycle. TSS/TTA ratio is related to fruit flavour, and higher values were detected in 'Formosa' papayas with the lowest irrigation rates in the second production year, according to Tukey's test. This indicates improved quality rather than depreciation, especially in 'Formosa' papayas under water deficit.

A cubic regression of TTA was also reported by Yamanishi et al. (2006), who studied 'Tainung 1' papayas. They evaluated fruit quality at different ripening stages in Brasilia-DF, and observed that variation in TTA ranged from 0.038 to 0.07% of citric acid, with maximum value of 10.3° Brix in fruit ripening and a TTA variation range of (0.036%).

Silva et al. (2013) studied different responses in papaya quality to different irrigation managements, and observed no significant effects on titratable acidity, TSS, and TSS/TTA ratio of 'UENF/Caliman' papayas according to irrigation rates, which were defined based on reference Evapotranspiration, in Catolé da Rocha-PB. Mean values varied from 0.166 to 0.146 (TTA), 14.2 to 13.9 ° Brix (TSS), and from 86.89 to 96.92 (TSS/TTA) in papayas produced in the first year. These were attributed to the high rainfall that occurred during the study, which could have affected all irrigation management treatments.

Barros et al. (2017), also studied quality of papayas from Solo and Formosa groups in Pinheiros-ES. The TSS/TTA ratio in 'Formosa' cultivars of the Formosa (Table 2) group was lower under the study conditions than the lowest values (129.03 and 131.87) achieved by genotype L 47-P8 (developed by State University of Norte Fluminense Darcy Ribeiro in partnership with Caliman agrícola S/A (UENF/Caliman) from the Formosa group during both winter and summer harvest seasons, respectively. The harvests were performed in the period between 210–300 DAT and 450–540 DAT.

This discrepancy in TSS/TTA between the different studies is due to genetic variations in papaya Formosa group (which results from lower TSS values) as well as from cultivation season and climatic characteristics of the study sites. The chemical quality of the fruits (TTA, TSS, and TSS/TTA) is affected by the prevailing climatic conditions at the cultivation site (Moretti et al., 2010), as well as by the development stage of fruits at harvest (Bron et al., 2006).

Barros et al. (2017) observed variation in TSS/TTA values in papayas in two seasons of the year, winter and summer; during winter (June to August 2013), mean temperature (Tmean) was 21.9 °C , minimum temperature Tmin was 13.4 °C , relative air humidity (RH) was 78%, and accumulated rainfall (R) was 55.2 mm in Pinheiros-ES. These values were lower than those found in Juazeiro-Ba during the winter of 2018: 24.8 °C (Tmean), 15.7 °C (Tmin), 54.5% (RH), and 1.5 mm (R).

Papaya sweetness is characterized by low TTA values and high TSS values (Luz et al., 2015). Inverse acidity and TSS curves were observed in Formosa papaya from Juazeiro-BA, resulting in better fruit flavour, especially under restricted irrigation water.

Acidity values varied from (0.079 to 0.278 g of citric acid/100 g of juice) in Formosa papayas. There was a cubic effect as a function of irrigation rates and different storage times under controlled temperature and humidity conditions. The pattern of TTA reduction was maintained in fruits under moderate deficit (75% ETc) and excess irrigation, under both storage conditions.

A similar effect of the three-way interaction of these factors on TTA was observed (Table 1 and 4). Prior to storage, papayas were nitrogen fertilized with 150 and 180 kg ha^{-1} $cycle^{-1}$. The maximum acidity values in fruits were approximately 0.15 g of citric acid/100 g of juice with irrigation rates of 116.67 and 50% ETc, respectively, and the lowest TTA values occurred under irrigation with 110 and 100% ETc, respectively, when quadratic behaviour was considered.

Acidity is known to decrease during fruit ripening (Chitarra and Chitarra, 2005). This effect was observed in our study after storage under controlled air humidity and temperature.

Increased irrigation rates prior to storage negatively affected TSS/TTA ratio and had a positive correlation with TSS/TTA ratio after 5 days of storage. The minimum TSS/TTA value was obtained using an irrigation rate of 96.97% ETc at harvest and the maximum value (70.17) was obtained under 122.76% ETc at 5 days of storage. A reduced TSS/TA ratio was observed using 150% ETc, compared to the irrigation rates required to meet total water requirement in papayas (Table 4).

Papaya flavour was increased in plants that were exposed to water restriction, especially after storage in a controlled environment.

TSS and TSS/TTA ratio was decreased with increased irrigation rates, using different N doses (Fig. 2a and 2b),

Table 1. Summary of the variance analysis of 'Formosa' papaya quality according to storage time (Tstor), irrigation rates (RA), and nitrogen doses (DO), Juazeiro-BA, 2018.

F.V.	Mean Square								
	Skin f.	Pulp f.	L	a*	b*	da	TSS	TTA	TSS/TTA
Tstor	1674.90**	354.13**	0.62NS	6.64*	81.45**	11.23**	3.55NS	14.88**	28.97**
RA	38.76**	73.09**	0.81NS	2.07NS	8.76**	0.99NS	5.02**	5.97**	12.20**
DO	228.43**	54.61**	1.73NS	0.78NS	2.24NS	7.16**	10.29**	1.25NS	10.34**
Tstor xRA	29.84**	20.39**	1.10NS	0.86NS	10.47**	4.62**	1.94NS	4.16**	10.77**
TstorxDO	260.53**	40.25**	0.03NS	0.25NS	5.35**	1.33NS	0.64NS	1.30NS	0.64NS
RAxDO	96.94**	43.46**	0.73NS	1.70NS	2.79**	3.54**	2.27*	4.61**	4.29**
TstorxRAxDO	63.76**	35.62**	0.59NS	2.11*	3.51**	1.35NS	1.08NS	4.82**	3.59**
Mean value	50.02	13.55	54.8	7.94	43.33	1.28	11.4	0.15	76.89
C.V	14.68	15.76	9.18	53.6	15.76	20.23	11.19	15.42	16.35

VS - Variation source; Soluble Solids (TSS); Skin f (Skin firmness); Pulp f (Pulp firmness); Skin coloration (Luminosity - L*, intensity of green/red coloration – a*, and intensity of yellow coloration - b*); Absorbance index (A.I.); titratable acidity (TTA), and TSS/TTA ratio in papayas. **Significant according to the F-test, 5% of probability; NS- Non-significant.

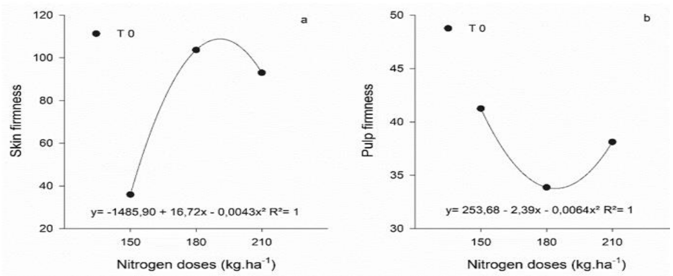

Figure 1. Regression analysis of papaya skin (a) and pulp (b) firmness as a function of different nitrogen doses and storage time, Juazeiro-BA. 2018.

Table 2. Mean skin and pulp firmness values, Titratable acidity (TTA), TSS/TTA, Mean absorbance index (AI), skin coloration a* - intensity of green/red coloration; b* – intensity of yellow coloration of 'Formosa' papayas according to storage time in an environment with controlled temperature and humidity. Second production year, Juazeiro-BA, 2018.

Storage (days)	Skin firmness	Pulp firmness	TTS	TSS-TA	A	a*	b*
0	77.47 a	19.55 a	0.16 a	0.17 a	1.46 a	8.94 a	37.70 b
5	22.57 b	7.55 b	0.14 b	0.13 b	1.20 b	6.94 b	48.96 a

Means followed by the same letter in the columns do not differ from each another by the Tukey test at 5%.

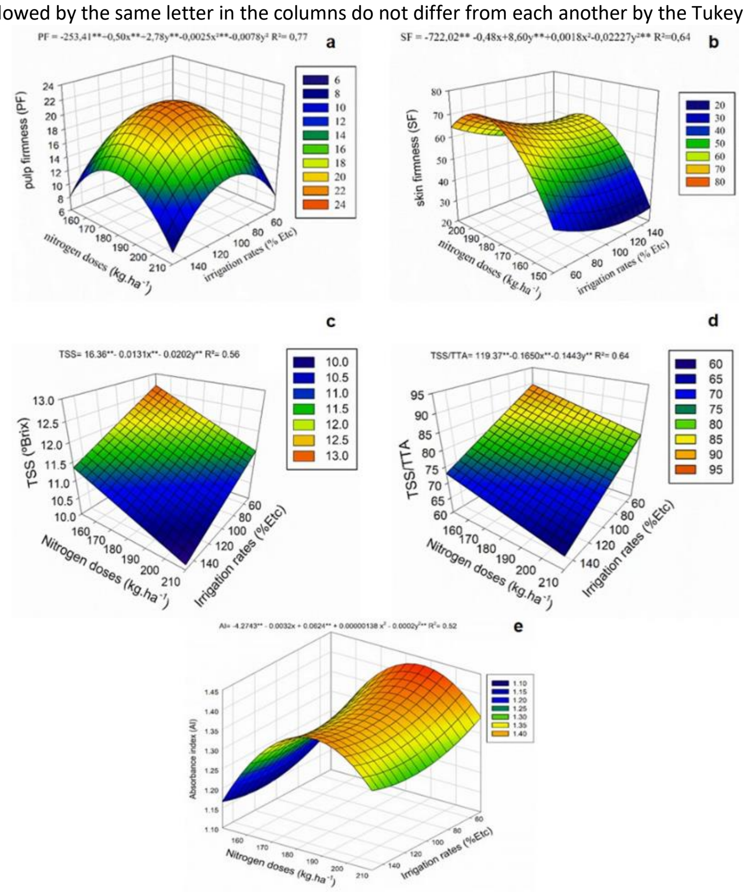

Figure 2. Response surface of 'Formosa' papaya pulp (a) and skin (b) firmness, TSS (c), TSS/TTA ratio (d), and absorbance index- AI (e) in 'Formosa' papayas as a function of different nitrogen doses and irrigation rates. Juazeiro-BA, 2018.

Table 3. Regression analysis of Titratable acidity (TTA), Soluble Solids (TSS), TSS/TTA, absorbance index (AI), intensity of green/red coloration – a*, of skin firmness (SF) and pulp firmness (PF) of papayas as a function of different irrigation rates and interaction of the factors 'different irrigation rates' and 'storage time' in an environment with controlled temperature and humidity. Juazeiro-BA, 2018.

Irrigation rates				
Variables	Regression equation	R^2		
TSS	y= 0.0151x + 12.819	0.949		
TTA	y= 4E-0.7x^3+0.0001x^2- 0.11x	0.804		
TTS/TTA	y = - 0.1594x + 91.3	0.565		
AI	y = 1.60 - 0.0023x	0.660		
a*	y = - 0.0005x^2 + 0.1212x	0.609		
Storage time x Irrigation rates				
	Tstor = 0 days		Tstor = 5 days	
Variables	Regression equation	R^2	Regression equation	R^2
AI	y= 5E - 05 - 0.0152 x + 2.14x^2	0.901		
TTA	y= - 4E - 07 x^3 + 0.0001x^2 - 0.0115x + 0.5042	0.912		
TSS/ TTA	y =- 0.0023x2 +0.4461x + 49.513	0.915	y = - 0.0068x^2 -1.6696x + 172.66	0.661
SF	y = 98.20 – 0.20x	0.27	Y = 76.99 – 1.20x + 0.005x^2	0.780
PF	y = - 24.20 + 0.96x – 0.004x^2 R^2 = 0,48	0.480	y = 10.43 – 0.028x	0.390

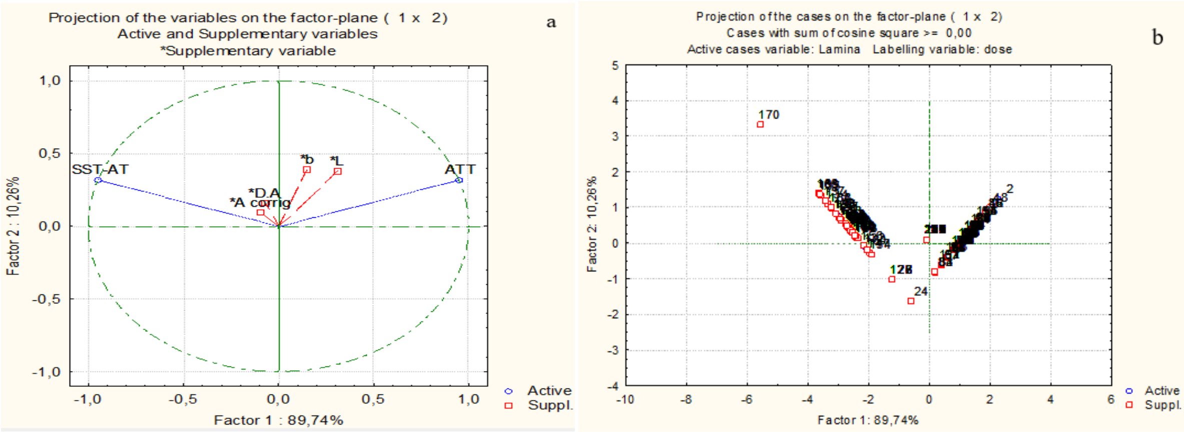

Figure 3. Two-dimensional projection of results obtained from the principal component analysis I and II for the variables analysed in fruits (a) and for the dispersion of active and supplementary variables (b) as a function of irrigation rates and nitrogen doses applied in papaya crops, 2018, Juazeiro-BA.

Table 4. Effect of a three-way interaction of factors 'different irrigation rates', 'nitrogen doses', 'storage time' in a B.O.D. chamber on skin colour (intensity of green/ red coloration – a*), Titratable acidity (SS), and TSS/TTA ratio of 'Formosa' papayas, second production year, in Juazeiro-BA. 2018.

Skin colour (intensity of green/red coloration – a*)				
N (Kgha^{-1})	Tstor = 0 days		Tstor = 5 days	
	Regression equation	R^2	Regression equation	R^2
150	y = -8E-05x3 + 0.0247x2 - 2.2463x + 52.278	0.9497		
180	y= 0.0918x - 16.493	0.5741	y = -4E-05x^3 + 0.0119x^2 - 1.1246x + 25.79	0.7426
210	y = 0.0001x^3 + 0.0412x^2 + 4.0347x - 129.17	0.991		
	Titratable acidity			
150	y = 9E-06x^2 - 0.0021x + 0.2767	0.6982	y = -2E-05x2 + 0.0044x - 0.0621	0.7588
180	y = 2E-07x^2 + 0.0002x + 0.1461	0.4637	y = -3E-06x^2 + 0.0006x + 0.1248	0.4356
210	y = -1E-06x^3 + 0.0004x^2 - 0.0379x + 1.236	0.921	y = -9E-07x^3 + 0.0003x^2 - 0.0233x + 0.7601	0.8092
	TSS/TTA			
150			y = 0.0154x2 - 3.5685x + 268.57	0.8465
180	y = -0.0021x^2 + 0.3701x + 50.463	0.7284	y = 0.0037x2 - 0.762x + 113.73	0.6092
210			y = 0.0004x3 - 0.1186x2 + 10.464x – 179.1	0.7223

especially at postharvest (Fig. 2c and 2d), which can be observed by the linear slope of the response surface.

Other factors, such as decreased oxygen availability, can also reduce plant respiration and photosynthesis, decreasing effect of irrigation rates on fruit flavour (TSS/TTA). The lowest TSS/TTA value (67.8) was observed in papayas fertilized with a nitrogen dose of 210 kg ha^{-1} $cycle^{-1}$ and irrigated with 140% of crop evapotranspiration. The maximum TSS/TTA value was 90 in papayas irrigated with 80 % of ETc and fertilized with N dose of 150 Kg ha^{-1} $cycle^{-1}$, respectively (Fig. 2d). The same was observed for SST (Fig. 2c), where the sugar content was decreased under the maximum nitrogen dose and irrigation rate.

Plants might not use high nitrogen doses via ferti-irrigation. This is due to N-NH_3 volatilization, as sufficient N is supplied to foliar tissues. Malavolta et al. (1997), suggested an optimal value of 40 to 50 g kg^{-1} during papaya flowering. Silva Junior et al., (2016), applied different N sources and doses to 'Caliman 01' papayas of the Formosa group. They reached a maximum productivity (5.5 kg.$plant^{-1}$) at 500.9 g of conventional urea per plant, and the highest productivity (8.8 kg) was obtained using 525 g $plant^{-1}$ coated urea. Polymers used in fertilizer coatings reduce nitrogen loss by leaching and/or volatilization, leading to a more effective use of N by the plants. This might have not occurred in the present study, although losses via N leaching were not evaluated in the soil profile.

Maintenance or improvement in quality of 'Formosa' papaya (Formosa) group in Juazeiro-BA might also have resulted from fertilizer fractionation, weekly, or by-weekly distribution of nitrogen fertilizer, etc. Fertilizer fractionation helps to meet demands of this nutrient according to plant development.

There was decreased titratable acidity of fruits, and the maximum TTA value was 0.22 g of citric acid/100 g of papaya juice in plants irrigated with 118.88 %ETc and fertilized with a nitrogen dose of 140 kg ha^{-1} $cycle^{-1}$. However, this behaviour of reduced total titratable acidity in papaya fruits has also been attributed to fruit ripening development, in environments with or without refrigeration, associated with the release of galacturonic acids and to the action of enzymes.

An oscillating behaviour of TTA was observed in 'Golden' papaya under different temperatures (6°, 8°C, and 10°C) up to 35 days of storage. They decreased up to the 23rd day of storage, and their lowest concentration was occurred at a temperature of 6°C. In a study conducted by Costa et al., (2010), there was a subsequent slight increase in TTA values in the fruits, with higher concentration between 27 and 30 days of storage at 10 °C.

Fruit firmness

Firmness is an important attribute related to commercialization and postharvest shelf life of fruits. The lower values of this attribute increase physical damages during transportation, thus reducing quality. Both skin firmness and pulp firmness were affected by irrigation rates and nitrogen doses (Fig. 2a and b). Regarding pulp firmness, there was surface slope for intermediate values of water and N, reaching approximately 24 newtons of firmness for 100% Etc combined to 180 kg ha^{-1}.

Regarding skin firmness, the nitrogen dose of 180 kg ha^{-1} also had the highest values but when it was combined with an irrigation rate of 80% of ETc, which is a water restriction condition.

Castricini et al. (2019), analysed 'Tainung 1' papaya quality under partial root drying. They observed higher firmness values in fruits submitted to 50% of the required irrigation rate during 14-day cycles. There is an inverse relationship between rainfall and papaya fruit firmness. The higher the rainfall, the lower is the firmness (Silva et al., 2005). This is the reason that fruits from irrigated plants had higher pulp and skin firmness values with the amount required according to crop evapotranspiration (100 % Etc) and water deficit (80% Etc), respectively.

Skin and pulp firmness were individually reduced during the storage time (Table 2). This might be explained by the degradation of cell walls of the fruit with increased time reducing postharvest firmness and quality.

A similar result was reported by Nunes et al. (2017), who observed decreased fruit and pulp firmness of 'Formosa' papayas with longer storage time, with firmness values varying from approximately 40-28.93N (fruit) and 30-18.78N (pulp), from harvest until 12 days of storage and under refrigeration of 10º C ± 2º C. The authors identified changes in consistency as fruits ripened, resulting from carbohydrate metabolism and changes in cell walls, which was mitigated by the use of manioc film. The percentage that allowed increased shelf life and better control of papaya quality was 2%.

Analysis of principal components

Components I and II of the PCA (Fig. 3) explained 89.74% and 10.26% of variability in the samples, respectively, adding up to 100% of explanation of projections for each attribute on the axes (Fig. 3a). There was a relationship between variables 'b*', 'luminosity', and 'titratable acidity' in fruits that underwent water deficit. There are positive correlations between TTA, L, and b*, as well as between TSS/TTA, absorbance index, and papaya skin coloration (Fig. 3b). The selection of genotypes based on simultaneous responses to different characteristics is an essential strategy in plant choice, as observed by Moreira et al. (2019). They studied a selection index based on REML/BLUP-predicted phenotypic and genotypic values for papayas.

Despite the differences found in papaya quality due to irrigation rates, nitrogen fertilizer doses, and storage time in a controlled environment, there were no changes in TSS/TTA values that would render them unsuitable for commercialization. Therefore, lower amounts of fertilizer could be used, reducing production costs and environmental impacts, as well as lower water rates in the face of scarce water resources.

This water-saving strategy of maintaining the crop under water restriction must consider not only the curves of variables related to papaya quality, but also the productivity curve (not shown in this study), in order to ensure net productivity in rural properties.

Materials and methods

Experimental site

This study was conducted with papayas from the Formosa group, 'Formosa' variety, grown in an experimental field in the Submedium São Francisco River Valley, municipality of Juazeiro-BA (9° 24 S; 40° 30 W; 368 m of altitude). Climate in the region is classified as semiarid, with mean annual rainfall ranging from 400 to 600 mm. Papayas were cultivated in soil with sandy loam texture, in single rows and 2.0 x 1.50 m of spacing, and were drip-irrigated with four emitters per plant, and outflow of 2.1 $L.h^{-1}$, 10 mca.

Prevailing meteorological conditions during the experiment period (June-August/2018) were the following: mean air temperature of 24.8 °C, minimum air temperature of 15.7 °C, and maximum air temperature of 34.8 °C; mean relative air humidity of 54.5%, accumulated rainfall of 1.5 mm over the period, mean solar radiation of 17.3 $MJ.m^{-2}.day^{-1}$, and reference evapotranspiration of 4.9 $mm.day^{-1}$.

The following were applied in 2018: 981.25; 1471.887; 1962.49; 2453.11; 2943.74 mm, respectively, for the treatments with irrigation rates used according to 50, 75, 100, 125, and 150% of crop evapotranspiration, in Juazeiro-BA.

Experimental design and treatments evaluated

The experiment was performed in a completely randomized design in a 2 x 5 x 3 scheme; two storage times in a controlled environment (0 and 5 days), five irrigation rates (50, 75, 100, 125, and 150% of crop evapotranspiration), three nitrogen doses (150, 180, and 210 $Kg.ha^{-1}$), with four replicates and in two production cycles. Fruits were collected manually according to Frutiséries (2000).

Analysed variables

Harvests were conducted on July 25 (565 days after transplantation) and August 09 (580 days after transplantation) 2018. Four fruits were randomly selected per treatment, totally 60 fruits for each storage time in a controlled environment with temperature of 12ºC and relative air humidity of 85%. In order to protect papayas from physical damages, they were maintained in containers in the field. Fruits were disinfested with sodium hypochlorite and the following were determined: Total Soluble Solid (TSS), using a refractometer and expressed in ºBrix; and titratable acidity (TA), by titration, expressed in g of citric acid/100 g of juice according to (IAL, 2008). The ratio was calculated by the relationship between TSS and TA. Additionally, skin and fruit pulp firmness were determined by measuring resistance to perforation at the median and basal regions of the fruit, using a fruit hardness tester (PTR 300) with a cylindrical pointer with 8 mm diameter, and results were expressed in N.

Papaya skin coloration was determined using a CR-400 Chroma Meter photoelectric colorimeter, considering the mean value of two sampled points for each component, ‘a*’, ‘b*’, and ‘L’; positive a* values tend to red coloration and negative a* values tend to green coloration; positive b* values tend to yellow coloration and negative b* values tend to blue coloration; and L values near 100 tend to white and near 0, they tend to black.

Statistical analysis

Data were previously submitted to the Anderson Darling homogeneity test, and results were submitted to an analysis of variance to define the effect of irrigation rates, nitrogen doses, and storage time in a B.O.D. chamber. When papaya quality values were significant according to the F-test, a single repression analysis was employed, choosing the best-fit model for the data, and mean values were used according to Tukey's test using the statistical program AgroEstat 1.0 (Barbosa and Maldonado Jr, 2010).

Response Surface methodology (RSM) was used for significant values and for the interaction between factors 'irrigation rates' and 'nitrogen doses', with the help of SIGMAPLOT 12.5. Data were also submitted to a principal component analysis (PCA) using a correlation matrix. Additionally, multivariate regression graphs were generated using Statistica 7.0 (Statsoft, 2008).

Conclusion

Water deficit improves ‘Formosa’ papaya flavour and skin firmness and does not depreciate coloration or skin luminosity. The nitrogen dose of 150 Kg ha^{-1} can be adopted to decrease production costs in ‘Formosa’ papayas without reducing papaya quality. Irrigation deficit and lower nitrogen doses applied to ‘Formosa’ papaya crops did not cause loss of fruit quality, even after 5 days of storage in an environment with controlled temperature and humidity. Irrigation rates reduced by 50% did not compromise papaya quality for commercialization and increased shelf life.

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