Mango fruit quality improvements in response to water stress: implications for adaptation under environmental constraints

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Abstract: Mediterranean farming is facing increasing periods of water shortage and, in the coming decades, the water reduction is expected to exert the most adverse impact upon growth and productivity. This study was performed to assess the response of the physico-biochemical quality parameters of mango fruits to different doses of irrigation in a Mediterranean subtropical area in Spain. During two-monitoring seasons, trees were subjected to deficit-irrigation strategies receiving 33, 50, and 75% of a crop evapotranspiration (ET $_{\rm C}$), and a control at 100% ET $_{\rm C}$. According to the findings and respect to control, the yield was reduced in 8, 11, and 20% for the water-stressed trees at 75, 50, and 33% ET $_{\rm C}$, respectively, producing smaller fruits in line with the amount of applied irrigation. However, the water-stressed fruits significantly enhanced their quality, in particular at 33% ET $_{\rm C}$, with regards to the content of the health-promoting phytochemicals (total soluble solids, vitamin C, and β -carotenoids). Thus, sustainable water management without a detrimental effect on the yield could be possible, and farmers should be encouraged to adapt to the environmental constraints, producing improved quality fruits.

Keywords: mango fruit; physico-biochemical fruit parameters; sustainable water-savings; subtropical farming; water shortage

The mango (*Mangifera indica* L.), is a large evergreen tree, and belongs to the Anacardiaceae family, which originated in the foothills of the Himalayas in southern Asia bordering the Bay of Bengal (Bompard 2009). The varieties that evolved in the tropical areas have seeds with several genetically identical embryos (poly-embryonic) and oppositely, mangos that developed in the subtropical areas of the Indian sub-continent are mono-embryonic (Mukherjee,

Litz 2009). Nowadays, it is cultivated from the tropics and subtropics up to the northern latitudes of 35–37° in the south of Spain (Galán, Lu 2018).

The quality performance of mango fruits depends on external and internal quality parameters. That is, the internal quality attributes comprise a uniform and intense flesh colour, and contain adequate acidity, vitamins, and a pleasant sweetness (Kader 2002). Mangos contain both provitamin A carotenoids,

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such as α -carotene, β -carotene, and γ -carotene; and oxygenated carotenoids (xanthophylls), such as β -cryptoxanthin, violaxanthin, auroxanthin, neoxanthin, among others (Palafox et al. 2012).

In the European Mediterranean basin, concretely in Spain, and according to ESYRCE (2018), the area devoted to subtropical crops is approximately 4.3% of the total surface with fruits trees, and 2.2% of the total production. The subtropical fruits are mainly established in the coast of Malaga and Granada, and in the Canary Islands. In this sense, in 2018, there were 4 276 ha of irrigated mangos in Spain of which 3 994 ha were located in Andalusia. On the other hand, the cultivars most used by farmers are the Florida cultivars, such as Osteen, Keitt, Tommy Atkins, among others, also being the most used by the main mango producing countries (Durán et al. 2003; Durán, Franco 2006; Gentile et al. 2019).

The expansion and intensification of land use in agriculture have promoted an increase in the water demand, especially in the Mediterranean area (Durán et al. 2013; García, Durán 2018), as well as in other regions (Ali et al. 2017). In this sense, a water shortage is one of the most important environmental constraints on fruit woody crops and limits the productivity, and, consequently, the economic development. Despite the relative tolerance of mangos to drought, the needed production can only be achieved by irrigation (Durán et al. 2003; Galán, Lu 2018).

All these challenges need a persistent effort to improve the agronomical practices and response to the environmental constraints. Thus, in this study, we

monitored the alterations in the mango (cv. Osteen) fruit quality parameters due to water stress by subjecting the mangos to different deficit irrigation strategies under a subtropical Mediterranean climate in south-east Spain.

MATERIAL AND METHODS

Experimental site. The experiment was executed over two-growing seasons (2018–2019) in Almuñécar, the Granada coast (SE Spain, 36°48′00″N, 3°38′0″W). According to Elias and Ruiz (1977), the local temperatures are subtropical to semihot within the Mediterranean subtropical climatic category, and has an average annual rainfall of 449.0 mm. The shallow soils formed from weathered slates, vary in depth, and some are rocky, providing generally very good drainage, and are classified as a typical xerorthent, with 684, 235, and 81 g/kg of sand, silt and clay.

The experimental mango plantation is located on terraces that are commonly found in the area (Figure 1A). Each platform had a single row of 16-year-old mango trees (*Mangifera indica* L. cv. 'Osteen' grafted onto 'Gomera-1') (Figure 1B), healthy and uniform in size, and spaced 3 m apart. Three deficitirrigation strategies that received 33%, 50%, and 75% of the ${\rm ET}_{C}$, compared with a control of fully irrigated trees at 100% ${\rm ET}_{C}$, were studied. To estimate the irrigation requirements, the reference evapotranspiration (${\rm ET}_{0}$) was calculated according to the Penman-Monteith methodology, using local crop coefficients





Figure 1. Orchard terraces with a mango plantation (A) and cv. 'Osteen' mango trees (B)



Figure 2. Field measurements of the polar (A) and equatorial (B) diameter in the mango fruits

 $K_{\rm C}$ previously defined in the studied area (Rodríguez et al. 2011). The experimental design was a completely randomised block design with three replications per treatment. Each replication had eleven trees, the five central trees of the rows were used for measurements of the fruit yield and the others served as border trees.

Physical fruit quality measurements. n the studied trees, five fruits were selected for the growth measurements (polar and equatorial diameters), using a digital calliper throughout the production cycle (Figure 2). The mango fruits were harvested at the pre-climacteric hard-green stage, thirty healthy fruits free from diseases and insect infestation were selected, determining their weight and size. The fruits were stored at 12°C and 85-90% relative humidity until they reached the proper maturity level (~ 8-10 days) (Salunkhe 1984). The mango fruits were peeled and the pulp, seed, and peel separated, and each fraction was weighed. Moreover, the texture parameter was measured through a fruit penetrometer (PCE-PTR 200) with crossheads of 6 and 8 mm. Ten fruits were used to determine the colour [L*, a^* , b^* and hue angle (h°)]. The peel colour and pulp colour of the fruits were measured using a MINOLTA CM-700d spectrophotometer (Minolta CO. Tokyo, Japan) and according to the procedure by McGuire (1992).

Biochemical fruit quality measurements. The total soluble solids (TSS) were examined by taking pulp samples previously homogenised in a blender (a few drops) with a refractometer as Brix degrees (AOAC 1984). The titratable acidity (TA) was measured in the pulp by titrating against NaOH. The fruit samples from each treatment were homogenised for the pH measurements with a digital pH-meter.

The vitamin C (ascorbic acid) content was measured following the procedure of redox titration using an iodine solution (UC 2019). The profile of the carotenoids was determined by high-performance liquid chromatography (HPLC), and extracted with acetone and saponification with KOH (10% in methanol). The extract was evaporated (Fisatom Model 801) ($T < 25^{\circ}$ C) and stored (-18° C) for quantification by HPLC (Mercadante, Rodríguez 1998). Similarly, the anthocyanins were determined by taking the fruit sample previously homogenised in an Ultra- Turrax with acidified methanol (HCl 1%) and then quantified by HPLC (Zanatta et al. 2005).

An analysis of variance (ANOVA) using a statistical analysis package (Statgraphics Centurion XVIII) was performed in order to ascertain the differences in the fruit quality parameters. The differences were tested using the least significant difference test (LSD) at a P < 0.05 level. In addition, the linear functions were adjusted between the fruit growth and the days of the year.

RESULTS AND DISCUSSION

Fruit growth and physical parameters. Figure 3 shows the growth of the fruits in response to the irrigation strategies applied during the monitoring period. In general, the fruit growth was relatively slow at the early stages, was faster at the rapidly expanding stage, and slowed down at the maturity stage. The water stress repercussions on the fruit growth were explicitly perceptible with the most severe irrigation of 33% ET_C in relation to the control (100% ET_C), being remarkable in the second season. For the study period, in average

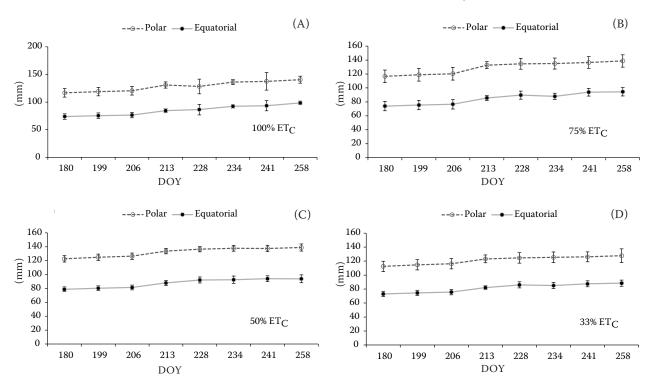


Figure 3. Average mango fruit growth rate in the polar and equatorial diameters in response to the deficit-irrigation in the control trees at 100% ${\rm ET}_{\rm C}$ (A), at 75% ${\rm ET}_{\rm C}$ (B), at 50% ${\rm ET}_{\rm C}$ (C), and 33% ${\rm ET}_{\rm C}$ (D)

DOY - day of the year; the vertical bars are the standard deviation

terms, the growth rate for the polar and equatorial diameters at 33% ET_C with respect to control were reduced by 9 and 10%, 2 and 5% with respect to the 50% ET_C, and 1 and 4% with respect to the 75% ET_C, respectively. As it is well-known, the process of cell enlargement and division need a water supply during the fruit growth period, and the lack of water at 33% ET_C inhibited the fruit growth and development. A week before the harvest, the average polar and equatorial fruit diameters in the control trees were 140.5 and 98.5 mm, and were 127.7 and 88.4 mm for the most severe deficit irrigation, respectively. In general, the size of the fruits at 50% ET_C was reasonably less affected, but had a significant water savings. This fact was clearly corroborated with the rate of growth of the mango fruit in the present study according to amount of applied irrigation water. Moreover, as was stated by Lawlor and Cornic (2002), the water stress reduces the fruit growth by slowing down the rate of cell division and expansion due to the loss of turgor and the increased abscisic acid synthesis.

Table 1 presents the functions for the fruit growth and the monitoring day of the year during the study period. In general terms, the mango fruit shape was semi elliptic and its growth fits an exponential curve (single sigmoid). The models describe the processes involved in the fruit growth and their relationship to the external conditions. For all the treatments, the fruit growth was highly correlated with the monitoring days, especially those related to the equatorial diameter. In addition, there was a decreasing trend in the relationship from the nonstressed (100% $\rm ET_{\it C}$) to the most water-stressed trees (33% $\rm ET_{\it C}$). Although the coefficients of correlation for the pooled data were less than for each treatment, these data described that the model is acceptable.

Table 2 displays the impact of the irrigation strategies on the average size and weight of the harvested fruits during the study. Moreover, the average fruit yield for the trees under the 75% ET $_{\rm C}$, 50% ET $_{\rm C}$, and 33% ET $_{\rm C}$ was of 38.8, 37.6, and 33.9 kg/tree, respectively, and the average fruit yield of the control trees (100% ET $_{\rm C}$) was 42.2 kg/tree. The reduction in fruit productivity was clearly evident by the effect of the water irrigation amounts. On the other hand, the fruits from the control trees had the highest average weight (659.2 g), the difference with respect to the severe deficit irrigation (33% ET $_{\rm C}$) being statistically significant (P < 0.05), while the rest of the fruits

Table 1. Relationships between the fruit growth and the day of the year

T	Polar diameter	•	Equatorial diameter		
Irrigation strategy	equation	r^2	equation	r^2	
100% ET _C (Control)	$y = 71.23e^{0.0027x}$	0.890	$y = 33.66e^{0.0042x}$	0.934	
75% ET _C	$y = 73.05e^{0.0026x}$	0.849	$y = 37.19e^{0.0037x}$	0.887	
50% ET _C	$y = 87.45e^{0.0019x}$	0.873	$y = 47.32e^{0.0028x}$	0.870	
33% ET _C	$y = 80.83e^{0.0018x}$	0.868	$y = 42.82e^{0.0029x}$	0.890	
Pooled data	$y = 77.88e^{0.0022x}$	0.649	$y = 39.91e^{0.0034x}$	0.805	

did not differ statistically from each other. This fact is agreed with by Madigu et al. (2009), who reported a decrease in the weight of water-stressed fruits.

The fruit weight loss for the control fruits (100% $\rm ET_{C}$) with respect to the 75% $\rm ET_{C}$, 50% $\rm ET_{C}$, and 33% $\rm ET_{C}$ was 2, 3, and 25%, respectively. The water stress in the early stage of the fruit development process provoked the fruit to drop (data not shown), which reduced the number of fruits in the most water-stressed treatments at 33% $\rm ET_{C}$. The peel and pulp fruit fractions were not affected by the irrigation; however, under deficit conditions, the seed was significantly reduced, showing a similar trend to that was found for the weight. The highest pulp:seed ratio was determined for the 33% $\rm ET_{C}$ (12.8), and the lowest for the control fruits (10.7), and the remaining treatments had an intermediate value.

The textural firmness was not affected by the water stress, although an increasing trend was fixed at 33% ET $_{\rm C}$ (Table 2). This is in contrast to the results reported by Abdel-Razik et al. (2012), who showed that a reduction in irrigation water (70% ET $_{\rm C}$) increased the fruit firmness compared with the fully irrigated trees (100% ET $_{\rm C}$). Additionally, Madigu et al. (2009) concluded that the fruit firmness of well irrigated (2.0 \pm 0.6 kg/m²) and water-stressed (2.5 \pm 0.9 kg/m²) trees was significantly different with the latter being firmer, which corroborated the findings of our study. The shape index obtained from the ratio between the polar and equatorial di-

ameters indicated a decreasing trend with the fruit development, and a more pronounced flattened shape prevailing among the control, 75%, and 50% $\rm ET_{C}$ treatments in contrast with the more severe treatment at 33% $\rm ET_{C}$ (Figure 4).

Table 3 shows the effects of the irrigation on the external and internal fruit colour attributes in response to the deficit irrigation. The changes in the pulp colour on the fruits were as follows: the pulp brightness L and hue values significantly increased from 64 and 77 in the non-stressed to 72 and 83 in the severe water-stressed trees, respectively, similarly the pulp chroma values increased from 28 (100% ${\rm ET}_{C}$) to 34 (33% ${\rm ET}_{C}$) (P < 0.05). For the peel colour, no significant changes were found in the peel brightness as well as for chroma values, in contrast with the peel hue values.

In general, the water stress encouraged the fruit ripening as did the increased peel and pulp coloration. These findings were in accordance with to Spreer et al. (2007), who stated that the peel colour (degrees hue angle) in fruits from water-stressed trees (50% $\rm ET_{\rm C}$) was greater than in the fruits from the fully irrigated trees, while the mesocarp colour did not differ in the fruit from the fully irrigated trees. On the contrary, the pulp colour changes were uniform, that is, the increase in the yellow-orange intensity of the mango cv. Osteen pulp can be associated with an augmentation in the carotenoid content, as was pointed out by Ibarra et al. (2015).

Table 2. Impact of the irrigation on the cv. 'Osteen' mango fruit size during the two-monitoring periods

Irrigation strategy	Irrigation	Diameter (mm)		W/a: ~la+(~)	Firmness	Fruit fraction (%)		
	(m³/ha)	polar	equatorial	Weight(g)	(kg/m^2)	pulp	peel	seed
100% ET _C (Control)	5,451	140.8 ± 12.4^{a}	95.9 ± 7.1 ^a	659.8 ^b	2.0 ± 0.6^{a}	84.2 ± 1.1 ^a	$7.9 \pm 0.8a$	7.9 ± 0.7^{a}
75% ET_{C}	3,933	$140.2 \pm 12.5^{\rm b}$	95.0 ± 7.6^{b}	649.1^{b}	2.1 ± 0.8^{a}	84.2 ± 2.4^{a}	$8.5 \pm 0.8a$	7.3 ± 0.8^{ab}
50% ET_{C}	2,730	141.9 ± 9.5^{b}	95.8 ± 5.9^{b}	643.2^{b}	1.8 ± 0.5^{a}	84.9 ± 1.8^{a}	$8.0 \pm 1.5a$	7.1 ± 0.9^{ab}
$33\%~{\rm ET}_{\rm C}$	2,275	130.5 ± 14.2^{b}	88.8 ± 6.5^{b}	492.5^{a}	2.5 ± 0.9^{a}	84.7 ± 3.4^{a}	$8.7 \pm 1.7a$	6.6 ± 1.6^{b}

Values with different letters within the same column are statistically different (P < 0.05; LSD); \pm standard deviation

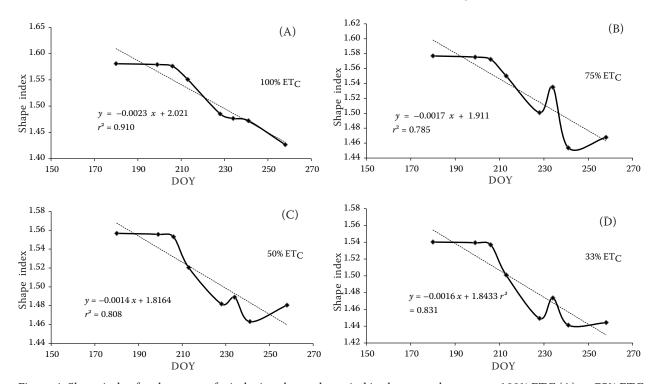


Figure 4. Shape index for the mango fruit during the study period in the control trees at at 100% ETC (A), at 75% ETC (B), at 50% ETC (C), and 33% ETC (D)

DOY - day of the year

In this sense, the peel colour development, as revealed by Wei et al. (2017), was highly affected by the fruit position on the tree and with a significant influence from the irrigation practices.

Biochemical parameters. Table 4 displays the biochemical parameters determined throughout the study. The mango fruits differed significantly in the titratable acidity (TA), registering the lowest (0.17%) values for the 33% ET_C in contrast with 0.27% for the 100% ET_C . A significantly increasing trend was fixed in the total soluble solids (TSS),

pH, and TSS/TA ratio with the amount of applied irrigation water; being higher in all the water-stressed treatments, particularly with the 33% $\rm ET_{C}$. On the other hand, the lowest vitamin C content was found in the control fruits, having a 42, 34, and 8% increase in the fruits at the 33% $\rm ET_{C}$ with respect to the 100% $\rm ET_{C}$, 75% $\rm ET_{C}$, and 50% $\rm ET_{C}$, respectively. This is in conformity with Nagle et al. (2010), who reported that abundant irrigation can reduce the TSS in the fruits due to the dilution effect. Abdel-Razik et al. (2012) concluded that the

Table 3. Effect of the irrigation on the colour attributes for the peel and pulp of the cv. 'Osteen' mango fruit

Irrigation strategy	L^*	C^*	h^*
		External peel-color	ation
100% ET _C (Control)	42 ± 2^a	54 ± 4^{a}	48 ± 11^{a}
75% ET _C	43 ± 2^a	52 ± 2^{a}	49 ± 15^{a}
50% ET _C	41 ± 3^{a}	55 ± 3^{a}	53 ± 13^{ab}
33% ET _C	44 ± 3^{a}	57 ± 5^{a}	54 ± 8^{b}
		Pulp-internal color	ation
100% ET _C (Control)	64 ± 4^{a}	28 ± 1^{a}	77 ± 2^{a}
75% ET _C	65 ± 5^{a}	28 ± 4^{a}	78 ± 5^{a}
50% ET _C	70 ± 3^{b}	31 ± 3^{ab}	81 ± 2^{a}
33% ET _C	72 ± 5^{b}	34 ± 6^{b}	83 ± 4^{b}

Values with different letters within the same column are statistically different (P < 0.05; LSD); values \pm standard deviation

Table 4. Biochemical parameters for the mango fruits during the two-monitoring periods

Irrigation strategy	TSS (°Brix)	TA $(g acid /100 cm^3)$	рН	TSS/TA ratio	Vitamin C (mg /100 g)
100% $\mathrm{ET}_{\mathrm{C}}(\mathrm{Control})$	17.0 ± 2.3^{a}	0.27 ± 0.09^{a}	4.5 ± 0.19^{a}	74.4 ± 21.7^{a}	21.7 ± 5.3^{a}
75% ET_{C}	18.1 ± 1.4^{ab}	0.21 ± 0.15^{ab}	4.6 ± 0.37^{a}	79.1 ± 25.2^{a}	24.4 ± 8.0^{ab}
50% ET _C	18.5 ± 2.2^{ab}	0.18 ± 0.08^{b}	4.8 ± 0.23^{a}	108.5 ± 27.6^{b}	34.3 ± 4.9^{ab}
33% ET _C	18.9 ± 3.0^{b}	0.17 ± 0.10^{b}	5.6 ± 0.18^{b}	126.9 ± 23.6^{b}	$37.2 \pm 17.7^{\circ}$

Values with different letters within the same column are statistically different (P < 0.05; LSD); values \pm standard deviation; TSS – total soluble solids; TA – titratable acidity (Maturity index)

TSS increased with a reduction in the irrigation water, as was found in the present study.

Besides, carbohydrate metabolism plays a significant role during the mango fruit development; according to Madigu et al. (2009), the fruits from rainfed or deficit-irrigated trees contained a higher starch content than the fruits from fully irrigated trees. The values for the TSS are generally higher than those revealed by Fernández et al. (2001) for cv. Osteen of 14%, and this may be due to the longer period of sunlight exposure, since the experimental trees were cultivated on south-facing terraces. In this context, a positive relationship between the light-exposure time and the TSS has been reported by Tombesi et al. (1993). As the TSS/TA ratio is considered a measure of the fruit quality, it is generally accepted that quality fruits have a higher ratio. Palaniswamy et al. (1975), reported a ratio for high-quality mangos from 131.3 to 162.5, being, in our conditions, the highest TSS/TA ratios for the fruits subjected to the 33% ET_C. According to our findings, the highest TSS/TA ratios were found for the cv. Osteen when the trees were subjected to most severe water-stressed treatments.

Mitra and Mitra (2001), for nineteen mango cultivars, reported a vitamin C content ranging from 21.66 to 125.40 mg per 100 g, being that such variation could be attributed to the nature and extent of the genetic variability. Therefore, in our case, the alteration was a response to the applied water stress. Similarly, Ferreira et al. (2018) reported 31.9, 29.7, 29.7, 51.4 and 34.3 mg per 100 g for the Florida cultivars 'Tommy Atkins', 'Haden', 'Kent', 'Palmer', and 'Keitt', respectively. The differences in the values for the vitamin C may be associated with such factors as the maturation stage of the fruit, the growing conditions and climate, among others.

Table 5 shows the water stress impact on the carotenoid and anthocyanin contents in the mango fruits.

In this sense, the violaxanthin, β -carotene, and antheraxanthin contents augmented by the effect of the deficit irrigation, particularly at 33% ET_C were in contrast to the neoxanthin and β -cryptoxanthin contents that showed an indefinable trend. Consequently, the water stress led to an increase in the main carotenoid contents in the fruits with respect to the fruits from the control trees. Studies regarding the impact of deficit irrigation on the carotenoid contents in mango fruits are scarce. However, there is a huge amount of literature reporting the great variability in the carotenoid contents, for example, Chen et al. (2004) reported almost similar values of 9.86, 6.4, and 1.88 μg/g for Taiwanese mango fruits with those found in the present experiment for β-carotene, violaxanthin and neoxanthin, respectively. On the other hand, the values obtained in the present study, in particular for the β -carotene in the pulp, were similar to those revealed in other studies. Rocha et al. (2007) reported from 6.61 (cv. 'Palmer') to 22.2 μg/g (cv. 'Uba'), Godoy and Rodríguez (1989) reported on the cv. 'Had'en (from 4.94 to $0.82 \mu g/g$) and the cv. 'Tommy Atkins' (from 12.09 to 14.05 μ g/g). However, the β-carotene contents found in this study are nearly similar to the values reported by the European carotenoid database for fruits (13.0 $\mu g/g$) (O'Neill et al. 2001).

Regarding the anthocyanin contents, concretely to methylcyanidin-glycoside, cyanidin-3- glycoside, and other anthocyanins, they were not clearly altered by the water stress. However, Madigu et al. (2009) reported that the β -carotene content augmented with a gradual reduction in the anthocyanins towards the fruit maturity, and the fruits from the non-irrigated trees had a higher anthocyanin content with respect to the fruits from the irrigated trees. Similarly, the results of the present experiment fixed an increasing trend in the anthocyanin content in the mango fruits from the 100% ET c to the

Table 5. Impact of the irrigation on the carotenoid and anthocyanin contents for the cv. 'Osteen' mango fruit (± standard deviation)

Irrigation strategy	Violaxanthin	β-carotene	Anteraxanthin	Neoxanthin	β-cryptoxanthin	Methylcyani- din-glycoside	•	Other anthocyanins
	(μg/g pulp)					(mg/100g peel)		
100% ET _C (Control)	1.97 ± 0.04	5.57 ± 0.76	1.28 ± 0.19	1.24 ± 0.06	2.04 ± 0.01	2.44 ± 0.21	1.22 ± 0.28	0.51 ± 0.04
$75\%~{\rm ET_C}$	1.89 ± 0.54	5.77 ± 0.83	1.28 ± 0.16	1.20 ± 0.01	2.04 ± 0.02	3.45 ± 1.24	2.35 ± 0.82	0.74 ± 0.19
$50\%~{\rm ET_C}$	1.24 ± 0.04	5.94 ± 0.87	1.12 ± 0.01	1.15 ± 0.02	2.02 ± 0.00	1.99 ± 0.70	1.29 ± 0.72	0.59 ± 0.06
$33\%~{\rm ET_C}$	3.05 ± 1.40	7.65 ± 1.22	1.52 ± 0.11	1.38 ± 0.15	2.09 ± 0.06	2.64 ± 1.07	1.68 ± 0.23	0.50 ± 0.19

33% ET $_{\rm C}$. In addition, similar values were reported by Melo et al. (2006) for cv. Espada and Rosa mango fruits, the total proanthocyanidins amounted to 1.96 and 2.44 mg per 100 g, respectively. In short, these findings evidenced that the fruits from the waterstressed trees contained a higher TTS, ascorbate, and β -carotene, their contents are markedly different from the fruits under the non-water stressed trees. In this sense, the effect of the reduced irrigation represents a potential tool in producing natural antioxidants. Thus, this fact could be considered as a strategy for providing rich sources of antioxidant compounds for mango products (juice and pulp) that could favour its preservation without the need for synthetic antioxidants.

Sustainable intensification of subtropical farming under environmental constraints. Agricultural land use expansions have dramatically increased the pressure on the availability of water. The increasing water shortage has caused the need to explore proper strategies for the sustainable use of irrigation water. That is, effective water-saving irrigation systems, without causing a significant detrimental impact on the crop production, need to be adopted urgently, which will be one of the main goals in agricultural sustainable intensification (Figure 5).

Habitually, the mango fruit is sold in Europe based primarily on the fruit size and, in some cultivars, the colour, both being the main commercial characteristics of the cv. Osteen that makes it the most cultivated and marketable fruit. Since the fruit weight is not a decisive aspect for quality in commercial terms, the medium-sized fruits are more appreciated by consumers. Therefore, the characterisation of this mango fruit grown in the subtropical region is essential in order for it to vie in the European market. Additionally, the fruit yields in SE Spain can be equated with the fully tropical zones, due to the high-density plantations in terraces (< 600 tree/ha) with an average fruit

yield from non-stressed (100% ET_C) or from waterstressed trees (33% ET_c) of 42.2 and 33.9 kg/tree, respectively. Moreover, the mango cultivation could provide environmental benefits and the feasibility of sustainable intensification of subtropical farming by offering possibilities for fruit production with a lower amount of irrigation water, as has been demonstrated in the present experiment. Thus, a reasonable fruit yield, by boosting the sustainable water savings, has a crucial importance as an adaptation and mitigation tool to meet water shortage situations. In addition, as was highlighted in the present experiment, the fruit quality in terms of the physico-biochemical parameters were improved with the deficit irrigation and this fact is vital to establish an environmentally friendly market diversification—that is, to produce mango fruits with small or medium sizes containing high levels of various health-enhancing substances (i.e., TTS, carotenoids, vitamin C and dietary fibre). Therefore, rational water irrigation requirements for the growth and development of mango tree could be ensured and an optimum water-use efficiency and improvements in the quality of the fruit could be achieved (Figure 5).

In this context, according to Martínez and Gómez (2016), consumers are willing to pay for singular foods, especially those cultivated and associated with environmentally friendly farming practices. In this line, Noguera et al. (2016) suggested an identity brand to preserve this type of produced food as a hydroSOStainable product. For this, it will be crucial to establish a hydroSOStainable index in order to certify those products that have been produced under sustainable-irrigation programmes. The consumer demand could be augmented, as would the price of the hydroSOS products and the profit for the farmers by convincing them about the economic benefits of deficit irrigation strategies. In this sense, Noguera et al. (2016) reported

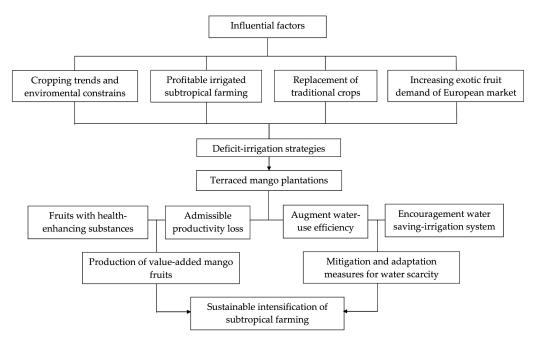


Figure 5. Main influential factors and shift in the irrigation strategy to the sustainable intensification of subtropical farming in a Mediterranean environment

that consumers were agreeable to pay a reasonably higher price for hydroSOS pistachios, if they are properly labelled and identified. Lipan et al. (2019) with almonds and Sánchez et al. (2019) with olives published studies with hydroSOS products. However, further research is needed to ascertain whether this willingness to pay could be similar for other fruits such as the mango.

CONCLUSION

The data found convey that taking advantage of the water stress will demand a better understanding of the underlying mechanisms of the water shortage adaptation. That is, agricultural development is currently facing unprecedented challenges and it will be crucial in how to meet these challenges, in which the sustainable intensification of agriculture plays a significant role, relying on the integrated use of a wide range of strategies to manage the water, plant nutrients, pests and diseases. This work highlights the environmental, nutritional and economic benefits resulting from the application of deficit irrigation as a part of sustainable intensification practices in subtropical farming, for farmers as well as for consumers. Additionally, the mango fruits imported from overseas are usually harvested unripe to finally reach the EU market, and are frequently lacking in taste, scent and bioactive components that are highly appreciated by consumers. Distinctively, the Spanish mango fruit offers a quality, commercially ripe and consumption product in line with the market requirements by providing fruits completely ripened in their trees that could reach the European market within one or two days. Thus, the mango cultivation in south-east Spain offers promising possibilities for supplying an environmentally friendly production and exporting high-quality fresh fruits.

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