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Full Length Research Paper

Sub-optimal irrigation affects chemical quality attributes of dates during fruit development

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Date palm (*Phoenix dactylifera* L.) is primarily cultivated in the regions of the Middle East and North Africa that are characterized by high evapotranspiration, low and sporadic rainfall and dependency on irrigation for crop cultivation. The effects of sub-optimal irrigation on the chemical properties of dates were investigated. Chemical quality attributes of date palm (cv. Khalas) grown in northern Oman showed variable responses to reduced frequency of irrigation water applied during fruit development. Trees irrigated on a daily basis showed a significantly higher fruit water content, juice volume, and titratable acidity (TA). Deficit irrigation treatments had the highest total-and reducing sugar content. Trees under water stress that were irrigated once per week showed significantly high dry matter, total soluble solids (TSS) and pectin. Sucrose, tannin and pH were not significantly different among irrigation treatments. Manipulation of irrigation frequency can be used to enhance certain chemical fruit quality attributes of dates.

Key words: Date palm, *Phoenix dactylifera,* Oman, food properties, water stress, food chemistry.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is a major fruit crop that is well adapted to arid and semi-arid climates. The date palm is mainly cultivated in the regions of the Middle East and North Africa, where 89% of dates are produced (FAO, 2007). African countries produced 1.9 million tons of dates in 2005 or 27% of the world date production (FAO, 2007), making dates one of the most important staple fruit crops in the continent. Expansion potential of date production in the Middle East and Africa is mainly limited by availability of water resources. Date production regions are characterized by high evapotranspiration, low-frequency and sporadic precipitation and dependency on irrigation for crop cultivation. In addition, cultivation of date palm follows traditional irrigation practices (Al-Marshudi, 2002), such as flooding, where large amounts of water resources are wasted beyond tree water requirements.

Using modern irrigation systems and management methods in date palm plantations allows for conservation of water resources while maintaining high yields and fruit quality. Studies have shown that water stress adversely affects date palm growth (Djibril et al., 2005), fruit yield and quality (Al-Rawi and Al-Mohemdy, 2001). Avoiding water shortage during fruit physical and chemical development is particularly important.

Major chemical components of dates include reducing sugars, fibers, pectin, tannin, and vitamins (Rouhani and Bassiri, 1976; Sawaya et al., 1983; Ahmed et al., 1995). Chemical composition of dates vary depending on fruit developmental stages, that is Kimri, Khalal, Rutab and Tamar, and type of dates, that is soft or dry dates.

The developmental stages of dates include *Kimri*, a post-pollination stage when the fruit is rapidly growing; *Khalal* stage when the fruit attains its full color; *Rutab* is when the fruit tip softens and the (storable) dry fruit which is called *Tamar*.

Dates are commonly consumes during the two latter stages. Water plays an important role in changes in the chemical composition of dates through the developmental stages. Maintaining sufficient supply of water is critical for date growth and development. This study investigated the effects of sub-optimal water application on the

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Table 1. Irrigation frequency and amount of water applied to trees on a date palm orchard at Sultan Qaboos University's Agricultural Experiment Station in Muscat, Oman, from May 06 to August 2006.

Treatment code (Days)	Irrigation frequency per week[z]	Irrigation amount (m^3) per tree per month			
		May 06	June 06	July 06	August 06
7	7 days (daily)	558	748	740	862
3	3 days	216	300	288	336
2	2 days	144	200	192	224
1	1 day (weekly)	72	100	96	112

[z]1 Week = 7 days.

chemical quality attributes of dates during fruit development.

MATERIALS AND METHODS

Location and plant materials

This experiment was conducted at the Agricultural Experiment Station of Sultan Qaboos University in the Sultanate of Oman.

Sixteen Date palm 'cv. Khalas' trees planted at a spacing of 10 × 10 m were used for this study. Trees were 8-year old and at an average height of 2.12 m (range from 1.70 to 2.35 m). Date fruits were thinned to eight bunches per tree prior to treatment application. The experiment was started 11 weeks-after-pollination (WAP) at the Kimri fruit stage and was concluded when dates were at Tamar stage, 24 WAP.

Irrigation treatments

The date palm trees were arranged in a completely randomized experimental design. Four irrigation frequency treatments were applied with four replicate trees per treatment. Irrigation water was delivered via a bubbler system with an average flow rate of 4.5 L/min. Details of treatments are described in Table 1.

Measurements recorded

One-hundred fruits were harvested during the Khalal and Bisir stages. Fruits were pitted and placed in a juice extractor to determine juice water content per treatment tree. The juice was then used to determine the chemical properties of dates. Fruit chemical characteristics were analyzed following standard protocols according to AOAC (2000) and included fruit water content, dry matter, total soluble solids (TSS), reducing and total sugar content, pectin, tannin, ash, titratable acidity (TA) and pH.

RESULTS AND DISCUSSION

Date palm is grown extensively in the Southwestern Asia and African regions between 24°N and 34°N (Zaid and Arias-Jiménez, 1993). In the Sultanate of Oman, where this study was conducted, dates are a major staple food and constitute about 50% of all crop acreage cultivated in the country (Al-Marshudi, 2002; Al-Yahyai, 2007). The date palm cultivation regions are arid or semi-arid where irrigation is essential for optimum yield and fruit quality. Changes of chemical quality characteristics during date palm (cv. Khalas) fruit development were studied under various irrigation treatments. The range of the quantity of chemical components was similar to that previously obtained for date palm fruit grown under northern Oman conditions (El Mardi et al., 1995, 1998, 2002, 2007; Al-Kharusi et al., 2007) and change in chemical composition during fruit growth followed those previously reported.

Reducing sugars increased and sucrose decreased in soft dates, whereas, in dry dates sucrose remained higher at the later stages. As fruit matured, tannin, pectin, acidity, and water content decreased while dry matter increased (Sawaya et al., 1983; Ahmed et al., 1995; El Mardi et al., 1998). Chemical quality attributes, as detailed subsequently, varied in response to irrigation frequency treatments during fruit development.

Fruit water and dry matter content

Fruit water content was highest in the Kimri and Khalal stages and fruits tended to lose moisture during the Rutab and Tamar stages. Moisture content (%) was highest in the trees irrigated daily (7 days) during the Kimri and Rutab stages, while those irrigated once-a-week (1 day) were lowest (Table 2). Moisture content did not differ among treatments at the Tamar stage. Increased fruit water content resulted in higher juice content from fruits of daily irrigated trees compared to other treatments (Table 3). The inverse of water content is the fruit dry matter. During the harvestable stage of Rutab, daily irrigation reduced dry weight while no difference in dry matter was observed at the final harvest stage of Tamar (Table 4).

Sugars and soluble solids

Total soluble solid (TSS) was highest in weekly irrigated (1d) and lowest in fruits of daily irrigated trees (7 days) (Table 5). TSS content of fruits is generally negatively correlated with fruit size and percentage of water content. The amount of reducing sugars, total sugars and sucrose (Table 6, 7 and 8 respectively) were lowest in fruits from weekly (1 day) irrigated trees. This may be due to extreme

Table 2. Fruit water content (% of fresh to dry weight) of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	87.12^{az}	82.75^{ab}	63.31^{a}	35.94^{a}	75.18^{a}
3	86.27^{b}	84.39^{a}	50.58^{b}	33.89^{a}	71.43^{b}
	85.61^{b}	78.78^{b}	49.29^{b}	33.90^{a}	69.76^{bc}
1	84.25^{c}	79.91^{ab}	44.94^{b}	35.86^{a}	68.34^{c}

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

Table 3. Juice volume (ml) of 100 fruit of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Overall
7	220.25^{az}	258.13^{a}	230.00^{a}	241.63^{a}
3	130.00^{b}	220.63^{b}	240.00^{a}	202.81^{b}
2	140.50^{b}	229.38^{b}	230.00^{a}	207.31^{b}
1	86.00^{b}	205.63^{b}	207.50^{a}	176.19^{c}

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

Table 4. Percentage of fruit dry matter content (on dry weight basis) of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	12.88^{cz}	17.25^{ab}	36.69^{b}	64.06^{a}	24.82^{c}
3	13.73^{b}	15.61^{b}	49.42^{a}	66.12^{a}	28.57^{b}
2	14.39^{b}	21.22^{a}	50.71^{a}	66.11^{a}	30.24^{ab}
1	15.75^{a}	20.09^{ab}	55.06^{a}	64.14^{a}	31.66^{a}

[z] Columns with the same letter are not significantly different according to Duncan Multiple Range Test, P<0.05.

Table 5. Fruit total soluble solids (TSS) content (^{o}Brix) of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	10.13^{bz}	16.87^{b}	32.17^{b}	34.00^{c}	19.54^{c}
3	10.56^{ab}	18.09^{b}	33.02^{ab}	34.67^{a}	20.25^{b}
2	10.80^{ab}	20.36^{a}	33.86^{a}	34.33^{b}	20.96^{a}
1	11.50^{a}	20.38^{a}	33.00^{ab}	33.67^{d}	20.99^{a}

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

water stress that reduced photosynthate (Edwards and Dixon, 1995) and carbohydrate accumulation in fruits of severely stressed trees.

Little differences were observed among other treatments; however, moderately irrigated trees (3d) produced the highest sugar content at the Rutab stage of adjacent leaves. This may have been caused by stomatal adjustment, through which sugar accumulates during water stress to maintain tissue water content and net CO_2 assimilation (Al-Yahyai et al., 2005a, Al-Yahyai et al., 2005b).

Pectin and tannins

Pectin content was highest in weekly irrigated trees (1 day) compared to other treatments at the Kimri stage (Table 9). No significant differences were found at the Khalal stage

Table 6. Percentage of fruit reducing sugar content of date palm (cv. Khalas) (on dry weight basis) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	33.48[az]	34.29[a]	43.58[a]	55.36[a]	39.72[b]
3	37.43[a]	37.10[a]	46.58[a]	55.34[a]	42.51[a]
2	34.51[a]	37.85[a]	47.53[a]	45.88[b]	40.81[ab]
1	25.94[b]	29.78[b]	44.53[a]	46.71[b]	35.32[c]

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

Table 7. Percentage of fruit total sugar content of date palm (cv. Khalas) (on dry weight basis) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	41.54[az]	42.82[a]	49.23[b]	59.17[a]	47.08[a]
3	45.44[a]	43.73[a]	53.86[a]	56.50[a]	48.94[a]
2	43.09[a]	41.78[a]	54.11[a]	48.00[b]	46.56[a]
1	34.46[b]	35.05[b]	47.47[b]	47.66[b]	40.23[b]

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

Table 8. Percentage of fruit sucrose content of date palm (cv. Khalas) (on dry weight basis) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	7.66[az]	3.66[a]	5.37[ab]	3.62[a]	5.48[a]
3	7.61[a]	6.30[a]	6.92[a]	1.10[b]	6.10[a]
2	8.15[a]	3.73[a]	6.26[ab]	2.02[ab]	5.47[a]
1	8.09[a]	5.01[a]	2.80[b]	0.90[b]	4.67[a]

[z] Columns with the same letter are not significantly different according to Duncan multiple range test, P<0.05.

Table 9. Percentage of fruit pectin content of date palm (cv. Khalas) (on dry weight basis) irrigated daily (7days), thrice-a-week (3days), twice-a-week (2days) and once-a-week (1day) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	4.44[bz]	4.43[a]	3.28[a]	1.68[ab]	3.71[b]
3	4.15[b]	4.07[a]	2.77[b]	1.46[b]	3.38[b]
2	4.95[b]	4.18[a]	3.07[ab]	1.80[a]	3.71[b]
1	6.79[a]	4.70[a]	3.15[ab]	1.95[a]	4.46[a]

[z] Columns with the same letter are not significantly different according to Duncan Multiple Range Test, P<0.05.

and variable results were obtained during the Rutab and Tamar stages. Tannin content was reduced as fruit matured. At Kimri and Rutab, no significant differences were observed among treatments (Table 10). During Khalal and Tamar stages, trees irrigated 3 days per week had the lowest tannin content.

Ash content, titratable acidity (TA) and pH

Fruit ash content was obtained only for the Kimri stage. No significant differences in ash content were observed among treatments.

Titratable acidity (TA) was highest at the Khalal stage. Trees irrigated more frequently (7 and 3 days) had the highest TA compared to trees irrigated 2-days per week or once a week (Table 11). At the Rutab stage, daily irrigated trees (7d) and the 2d treatment had the highest TA while weekly irrigated trees (1d) had the lowest TA. At the Tamar stage, which had the lowest fruit TA, no significant differences were observed among the

Table 10. Percentage of fruit tannin content of date palm (cv. Khalas) (on dry weight basis) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	1.14[az]	0.52[ab]	0.05[a]	0.003[a]	0.49[a]
3	1.17[a]	0.47[c]	0.05[a]	0.001[b]	0.49[a]
2	1.19[a]	0.53[a]	0.07[a]	0.003[a]	0.53[a]
1	2.31[a]	0.51[b]	0.07[a]	0.004[a]	0.83[a]

[z] Columns with the same letter are not significantly different according to Duncan Multiple Range Test, P<0.05.

Table 11. Titratable acidity (TA) of fruit juice of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7d	0.66[az]	1.55[a]	0.87[a]	0.027[a]	0.88[a]
3d	0.59[a]	1.90[a]	0.39[b]	0.023[a]	0.78[ab]
2d	0.65[a]	0.70[b]	0.76[a]	0.026[a]	0.61[b]
1d	0.59[a]	0.70[b]	0.09[c]	0.025[a]	0.40[c]

[z] Columns with the same letter are not significantly different according to Duncan Multiple Range Test, P<0.05.

Table 12. Fruit juice pH of date palm (cv. Khalas) irrigated daily (7d), thrice-a-week (3d), twice-a-week (2d) and once-a-week (1d) at various stages of maturity.

Treatment (Days)	Kimri	Khalal	Rutab	Tamar	Overall
7	5.31[az]	7.78[a]	7.95[a]	6.30[ab]	6.91[a]
3	6.41[a]	7.66[a]	7.90[a]	5.65[b]	7.08[a]
2	6.04[a]	7.84[a]	7.87[a]	6.09[ab]	7.09[a]
1	6.21[a]	7.71[a]	7.84[a]	6.69[a]	7.17[a]

[z] Columns with the same letter are not significantly different according to Duncan Multiple Range Test, P<0.05.

treatments. There were no significant differences in fruit pH during the Kimri, Khalal and Rutab stages (Table 12).

At the Tamar stage, weekly irrigated trees (1d) had higher pH than the 3d treatment; nonetheless, there were no significant differences among other treatments suggesting that pH may not be significantly influenced by water stress.

Conclusion

Dates can be harvested and consumed at the Khalal stage for boiled dates, at the Rutab for fresh consumption and at the Tamar stage for dry consumption, storage and processing. Different by-products can be obtained, such as tannin, reducing sugars and date syrup, where chemical quality attributes are important considerations.

Results from this study showed that pre-harvest cultural and management practices, such as irrigation, have direct impact on the chemical quality attributes of dates.

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