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Combined effect of UV-C, ozone and electrolyzed water for keeping overall quality of date palm

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ABSTRACT

The work presented here aims to contribute with a sustainable alternative to chemicals for avoiding deterioration of harvested date palm fruits by evaluating the single or combined use of UV-C radiation and ozonated or electrolyzed water (EW). In this way, the effects of UV-C light (0; 2.37; 6.22; 8.29 and 12.14 kJ m^{-2}) alone, and the combined effect of 6.22 kJ m^{-2} UV-C with neutral EW (NEW, pH 6.99, 870 mV ORP, 100 mg L^{-1} free chlorine), alkaline EW (AEW, pH 11.28, −880 mV ORP, 1.83 mg L^{-1} free chlorine) and ozonated (O_3, 0.55 mg/L ozone) water on overall quality of Deglet Nour dates stored for 30 days at 20 °C were studied. Microbial growth, weight loss, firmness, pH, titratable acidity, moisture, water activity, sugars and phenolics content, antioxidant activity color and sensory quality were monitored. UV-C light, mainly at 6.22 kJ m^{-2}, alone or combined with NEW, AEW and O_3, kept the overall quality of dates during storage, Moreover, those treatments reduced the most mesophilic, coliforms, yeasts and molds counts. In summary, these combined emergent sanitizers could be useful for disinfection of fresh dates while keeping quality and prolonging shelf-life.

1. Introduction

The achievement of an optimal shelf-life of date palm (*Phoenix dactylifera* L.) starts by using high quality raw material, free of insect attack, and continues with appropriated harvesting, handling, processing, packaging, storage, transport and distribution and retail sale operations. Methyl bromide is the most widely used pesticide for harvested date palm in developing countries but, because of its toxicity to applicators and to the environment, its use will be forbidden from 2015 (Bell, 2000; UNEP, 1995). Methyl bromide is used also for controlling the moth of pyrale (*Ectomyelois ceratoniae* Zeller), the major insect pest of dates both in field and in storage (Haouel, Mediouni-Ben Jemâa, & Khouja, 2010). Research on efficient and sustainable commercial alternatives for keeping overall quality and safety of harvested dates must be conducted.

The germicidal, artificial ultraviolet C (UV-C) light in the range of 200–280 nm is a non-ionizing radiation used as a sustainable technique to avoid fungicides residues in food. UV-C light at low doses reduces postharvest decay, and controls natural infection, very probably due to the accumulation of antifungal compounds in tissues, and maintains the overall quality of several fruits and vegetables (Artés-Hernández, Robles, Gómez, Tomás-Callejas, & Artés, 2010; Crupi, Pichierri, Basile, & Antonacci, 2013; Erkan, Wang, & Krizek, 2001;). UV-C light also induces antioxidant activity, reduction of respiration rates, controls rot development and delays senescence in many fruit and vegetables (Alegria et al., 2012). In addition, it offers several advantages such as it does not require extensive safety equipment and the cost is relatively low (Artés, Gómez, Aguayo, Escalona, & Artés-Hernández, 2009; Pan & Zu, 2012). UV-C radiation may be used in an industrial processing plant for disinfection of food contact surfaces and for water used for rinsing as well as for air cleaning in the handling

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area. Although the technique is subjected to some safety measures for workers, it is easily applied, being lethal to most types of microorganisms (Bintsis, Litopoulou-Tzanetaki, & Robinson, 2000).

The effect of UV-C radiation on microbial growth, changes in bioactive constituents, physico-chemical composition and sensorial quality has been investigated in many plant produce like zucchini squash (Erkan et al., 2001), watermelon (Artés-Hernández et al., 2010), fresh-cut melon (Manzocco, Pieve, & Maifreni, 2011), broccoli (Martínez-Hernández, Gómez, Pradas, Artés, & Artés-Hernández, 2011) or pineapple (Pan & Zu, 2012). However, studies analyzing its effects on date palm overall quality are very scarce (Jemni et al., 2014).

The O_3 is recognized as a safe disinfectant for foods (FDA, 1997) being authorized in many countries for direct contact with food. It was found that O_3 gas or ozonated water lowered decay during cold storage of papaya fruits (Ali, Ong, & Forney, 2014), persimmon leaves (Ikeura, Hamasaki, & Tamaki, 2013), lowbush blueberries, (Crowe, Al Bushway, & Davis-Dentici, 2012), actinidia deliciosa (Barboni, Cannac, & Chiaramonti, 2010), spinach (Klockow & Keener, 2009) and peanuts (Chen et al., 2014). Although continuous 0.1 $\mu L\ L^{-1}$ O_3 did not fully inhibit fungal growth in Autumn Seedless table grape after two months at 0 °C, it increased the total flavan-3-ol content and kept the flavonol content and the total amount of hydroxycinnamates, while shocks of 8 $\mu L\ L^{-1}$ O_3 kept the total polyphenols (Artés-Hernández, Aguayo, Artés, & Tomás-Barberán, 2007). In the same way shocks of 8 $\mu L\ L^{-1}$ of O_3 greatly increased the resveratrol and the pieced content in Napoleon table grape after six weeks at 0 °C (Artés-Hernández, Artés, & Tomás-Barberán, 2003). According to Pascual, Llorca, and Canut (2007), bacteria are more sensitive than yeasts and fungi, Gram-positive bacteria are more sensitive to O_3 than Gram-negative organisms and spores are more resistant than vegetative cells. Joshi, Alagusundaram, Norton, and Tiwari (2013) reported that O_3 induced changes in surface color of some treated products, and their antimicrobial effect during storage was variable depending on the type of microorganism, characteristics of fresh produce and prevailing storage conditions.

Electrolyzed water (EW), both acidic and neutral types, have been proposed as new sanitizers for the food industry (Artés et al., 2009; Mahmoud, 2007; Rico et al., 2008). EW is obtained by adding a small amount of NaCl to tap water in a container using a separating polyester membrane and conducting an electrical current across an anode and a cathode. The cathode area produces alkaline reducing water while the anode area produces acidic oxidizing water (Lee, Park, Jeong, Kim, & Chinnan, 2007). EW involves on-site production of the disinfectant, which means there are no chemicals to store or handling costs for dealing with them (Artés et al., 2009). EW is not corrosive to skin, mucous membranes, or organic material, while having a high oxidation reduction potential (ORP) with strong effect against microorganism (Rico et al., 2008). Aerobic bacteria grow mostly at an ORP range of +200 to +800 mV, while anaerobic bacteria grow well at −700 to +200 mV. The high ORP in the EW could alter the metabolic fluxes and ATP production, probably due to the change in the electron flow in cells. AEW has a surface-active effect due to the presence of dilute NaOH, dissolved H_2, and active H_2 (Al-Haq, Sugiyama, & Isobe, 2005). Neutral EW (NEW) is not corrosive of processing equipment due to its neutral pH and did not affect tissue pH, surface color or visual appearance, although the effects of EW on by-product formation should be more studied (Tomás-Callejas, Martínez-Hernández, Artés, & Artés-Hernández, 2011). Indeed, this treatment has been considered as a good alternative to NaClO for sanitizing plant products being hypothesized that the hereby studied sanitizing treatments, combined in the frame of the hurdle technology, could have a synergistic effect on microbial reduction (Martínez-Hernández, Artés-Hernández, Gómez, & Artés, 2013).

The main advantage of EW is its safety. In contrast with the problems with the use of NaClO, such as skin and membrane irritation and toxicity, neutral and alkaline electrolyzed water (NEW and AEW) are not corrosive to skin, mucous membranes, or organic material. When EW comes in contact with organic matter or is diluted by tap water or reverse osmosis water, it becomes ordinary water again. Thus, it is more eco-friendly than NaClO and is not potentially harmful for human health (Huang, Hung, Hsu, Huang, & Hwang, 2008). When NEW is used, free chlorine is formed as a by product. However, since it is free chlorine, it easily volatilizes avoiding most of the harmful effects of hypochlorite. The efficacy of NEW and AEW to reduce natural microflora as well as the main foodborne pathogens associated with a few fresh cut plant products has been reported. The use of AEW resulted in moderate control of bacterial growth on fresh-cut cilantro (Wang, Feng, & Luo, 2004). Reductions of viable aerobes by 2 log CFU g^{-1} were reached in lettuce washed with AEW (pH 2.6; ORP 1140 mV; 30 $mg\ L^{-1}$ of free chlorine) for 10 min (Koseki, Yoshida, Isobe, & Itoh, 2001). However, the information on the effects of NEW and AEW on the quality attributes of dates is very scarce (Jemni et al., 2014), since they are currently considered as emerging sanitizers for the food industry.

The aim of this work was to evaluate the effect of different UV-C doses alone and in a selected combination with ozonated or NEW and AEW on physicochemical parameters, sugars and phenolics content, antioxidant activity and sensory and microbial quality of palm dates handled under usual commercial conditions.

2. Materials and methods

2.1. Plant material

Date fruits of Deglet Nour cv., the most important produced in Tunisia, were hand harvested by professional pickers at the end of October at full maturity ('Tamar' stage) from a commercial farm located in an Oasis of the Governorate of Kebili (South of Tunisia). Date bunches were detached from the head of the tree palm and placed on the ground to avoid crushing and the abscission of dates. The bunch was then cut into spikelets and carefully selected. Sound spikelets were placed in polystyrene boxes which were transported for a total duration of 7 days at an average temperature of 20 °C ± 2.7 °C by car roughly 500 km to Tunis, then by plane to Madrid (Spain), and finally by car about 400 km to the Technical University of Cartagena. After arriving to the Pilot Plant they were manually detached from the spikelets, sorted looking for fruit visual quality and uniformity and those damaged were discarded.

2.2. UV-C treatment, electrolyzed and ozonated water production

The UV-C equipment consisted of two batches of 15 reflectors with unfiltered germicidal emitting lamps (TUV 36W/G36 T8, Philips, Holland) fixed to a chamber frame. The equipment has been fully described by Artés-Hernández et al. (2010). Light intensity at a wavelength of 254 nm was kept constant. The applied doses varied by modifying the exposure time.

The O_3 was generated by an industrial device (Ambicon S.L., Murcia, Spain) producing at a rate of 0.4 mg L^{-1}. The O_3 concentration was monitored by an O_3 sensor (EcoSensor, Inc., A-21ZX model, USA). The O_3 flow was mixed with tap water following Silveira, Aguayo, and Artés (2010) and the obtained ozonated water with 390 mv of ORP and at a concentration of 0.55 ± 0.5 mg/L O_3 was used for washing the dates for 2 min at about 15 °C followed with 1 min rinsing in tap water at about 15 °C.

The EW was produced by an Envirolyte EL 400 device (Aquarioja S.L., Madrid, Spain) (Tomás-Callejas et al., 2011). The characteristics of alkaline electrolyzed water (AEW) were pH 11.28 and ORP = −880 mV, free chlorine = 1.83 mg L^{-1} while for neutral electrolyzed water (NEW) were pH = 6.99 and ORP = 870 mV, free chlorine = 100 mg L^{-1}. Free chlorine and pH were determined by using a photometer (HI 94771, Hanna Instruments, Eibar, Spain) and a pH-meter (Basic 20, Crison, Barcelona, Spain) respectively, for all solutions. Dates were dipped while stirring for 2 min in NEW and AEW at about 15 °C followed by 1 min of stirred dipping in tap water at about 15 °C.

2.3. Sample preparation, treatments and storage conditions

After selection in a disinfected area at room temperature (about 20 °C) date fruits were submitted to different UV-C, NEW, AEW and O_3 sanitizing treatments. The following treatments were applied: 0 (control), 2.37, 6.22, 8.29 and 12.14 kJ m^{-2} UV-C; NEW + 6.22 kJ m^{-2}; AEW + 6.22 kJ m^{-2}; O_3 + 6.22 kJ m^{-2}. The UV-C dose to be combined with NEW, AEW and O_3 was selected according to results reached in the preliminary experiments.

Following each treatment, 200 g of dates were placed in polypropylene (PP) baskets of 750 mL capacity which were thermally sealed at the top with a bi-oriented polypropylene film of 30 μm thickness (Plásticos del Segura S.L., Murcia, Spain). The film was perforated with several holes in order to provide an air atmosphere within packages. Three replicates for each treatment were prepared and stored for 30 days in a temperature and relative humidity (RH) controlled room (20 °C, 75% RH). That temperature was selected as the commonly used by the commercializing.

2.4. Microbial counts and detection of pyrale infestation

To determine microbial growth, three randomized samples from each treatment were taken at the beginning and at the end of storage. The colonies of mold, yeast, total mesophilic and totals coliforms were determined according to NF V 08-059 (1995), NF V 08-05 (1999) and NF V 08-015 (1991) respectively. All microbial counts were reported as $\log_{10}$ colony forming units per g of sample (log CFU g^{-1}).

At handling day dates were carefully examined and no infestation by the natural pyrale was observed.

2.5. Physicochemical parameters

Physical and chemical quality of dates were evaluated by analyzing weight loss (g kg^{-1} fw), firmness (N), pH, titratable acidity (TA), expressed as g of citric acid on kg^{-1} fresh weight, moisture (g kg^{-1} fw), water activity (aw), individual and total sugars content (g kg^{-1} fw), total phenolics content, expressed as g of gallic acid equivalent on kg^{-1} fw (g GAE kg^{-1} fw), total antioxidant activity, expressed as g of ascorbic acid equivalent on kg^{-1} fw (g AAE kg^{-1} fw) and color, based on CIELab* scale.

Measurement of mentioned quality parameters was accomplished as previously described by Jemni et al. (2014). Analyses were performed on the handling day and after 30 days of storage at 20 °C and 75% RH.

2.6. Sensory evaluation

Visual appearance, color, texture, odor, flavor and overall quality were evaluated based on a five-point hedonic scale (1: extremely poor, 2: poor, 3: acceptable and limit of usability, 4: good and 5: excellent). These sensory attributes were evaluated on the processing day and after 30 days at 20 °C by a trained panel (6 members ranging between 25 and 65 years) over a representative sample coming from each treatment.

2.7. Statistical analysis

All parameters were determined on three samples. For the case of microbial growth, color, sugars and phenols, each sample was in turn analyzed by triplicate. Average of these samples determinations is presented. Statistical analysis was performed with Info Stat (version 1). Analysis of variance (ANOVA) and LSD test were applied in order to evaluate the influence of treatment and time of storage on bacteriological, physical, chemical and sensorial analysis of dates. A least significant difference (LSD) multiple range test at 5% probability level was used to determine significant differences between means.

3. Results and discussion

3.1. Bacteriological parameters and detection of pyrale infestation

The initial microbial load is presented in Table 1. As expected, microbial counts increased with storage time. All sanitizers reduced microbial growth which in turns decreased with the increased UV-C dose applied before storage. Since 6.22 kJ m^{-2} gave the best results and appeared as the optimum dose for disinfection of dates, combinations of this dose with NEW, AEW and O_3 were tested. All these combinations reduced the microorganisms load compared to 6.22 kJ m^{-2} UV-C alone, so showing between them a synergistic effect.

The combined O_3 + 6.22 kJ m^{-2} UV-C treatment was the most effective against molds and yeasts, with a reduction of 1.63 log CFU

Table 1
Yeast and mould, total mesophilic and total coliforms counts (mean log CFU g^{-1}) of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments ($n = 3$).

Treatment	Yeast and mould[a]		Total mesophilic[b]		Total coliforms[c]	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	5.38	6.55	3.35	4.89	4.11	4.29
2.37 kJ m^{-2}	5.33	6.40	2.75	4.48	3.62	3.54
6.22 kJ m^{-2}	4.89	6.40	2.70	4.41	3.50	3.51
8.29 kJ m^{-2}	4.75	6.68	2.55	4.79	3.72	3.54
12.14 kJ m^{-2}	5.24	6.43	2.73	4.47	3.53	3.54
NEW + 6.22 kJ m^{-2}	4.05	6.67	2.30	4.13	3.63	3.12
AEW + 6.22 kJ m^{-2}	4.20	6.32	2.48	4.19	3.45	3.18
O_3 + 6.22 kJ m^{-2}	3.75	6.09	2.42	4.09	3.29	3.18

[a] SE (pooled standard deviation) = 0.07, LSD ($P \le 0.05$) = 0.14.
[b] SE = 0.09, LSD ($P \le 0.05$) = 0.18.
[c] SE = 0.12, LSD ($P \le 0.05$) = 0.24.

g^{-1} after storage. The mesophilic and coliforms totals counts reached the lowest values with the O_3 + 6.22 kJ m^{-2} UV-C, NEW + 6.22 kJ m^{-2} UV-C and AEW + 6.22 kJ m^{-2} UV-C showing a reduction of about 1.05 log CFU g^{-1} and 0.82 log CFU g^{-1} respectively. The low microbial counts found after UV-C treatments could be attributed to direct microorganism elimination by causing DNA denaturation (Manzocco et al. 2011).

The current results agree with those from the literature for other plant produces. It has been found that 4.54 kJ m^{-2} UV-C substantially reduced microbial growth in Tatsoi baby leaves (Tomás-Callejas, Otón, Artés, & Artés-Hernández, 2012). Martínez-Hernández et al. (2011) reported that after UV-C treatment, broccoli initial microbial counts were lowered and this effect was more noticeable for mesophilic and yeast and molds counts. According to Manzocco et al. (2011), treatment with UV-C light greatly affected total viable counts in fresh-cut melon but this effect decreased with storage period.

Regarding the moth of date, any natural pyrale infestation was observed at both, processing day and after 30 days of storage. This was very probably due to good cultivation conditions of palm trees and to careful fruit selection.

3.2. Physicochemical parameters

3.2.1. Weight loss and firmness

Weight loss after storage period depended on sanitizers' treatment. The losses ranged from 0.75 ± 1.35 to 6.2 ± 1.35 g kg^{-1} fw (Table 2). The highest weight loss was found in the O_3 + 6.22 kJ m^{-2} treated samples. These results agree with those of Manzocco et al. (2011) who reported that the exposure of fresh-cut melon for 2 min to 20W m^{-2} UV-C caused a dehydration of a thin surface layer of melon cubes. They explained that by the fact that during light exposure water migrates from the inner parts of the sample to the dried surface, leading to moisture losses which caused a higher overall weight loss than in control (untreated sample). In addition, within the storage time, the high temperature and the moderate RH of conservation affect considerably the weight loss.

Firmness of date fruits was affected by both, kind of sanitizing treatment and storage time. In fact, dates treated with UV-C light combined with electrolyzed or ozonated water showed the highest firmness (Table 3). Values decreased at the end of storage from values ranging 1.61 ± 0.39 to 2.91 ± 0.39 N to values between 1.52 ± 0.39 and 2.39 ± 0.39 N. Compared to control UV-C light alone did not change firmness, keeping the initial value after storage period. This result agrees with those reported in tomatoes by Obande, Tucker, and Shama (2011).

3.2.2. Titratable acidity and pH

The pH decreased and the TA increased slightly with UV-C treatments (Table 4). The pH changes were relatively small (between 5.76 ± 0.08–5.98 ± 0.08 and 5.23 ± 0.08–5.59 ± 0.08).

Table 2
Weight loss of date fruits (cv. Deglet Nour) after 30 days at 20 °C previously exposed to several sanitizing treatments (n = 3).

Treatments	Weight loss (g kg^{-1})
0 kJ m^{-2}	2.30
2.37 kJ m^{-2}	3.60
6.22 kJ m^{-2}	1.04
8.29 kJ m^{-2}	4.74
12.14 kJ m^{-2}	2.25
NEW + 6.22 kJ m^{-2}	0.75
AEW + 6.22 kJ m^{-2}	1.74
O_3 + 6.22 kJ m^{-2}	6.15

SE = 1.35, LSD ($P \le 0.05$) = 2.32.

Table 3
Firmness (N) of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments (n = 3).

	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	1.72	1.39
2.37 kJ m^{-2}	1.61	1.53
6.22 kJ m^{-2}	1.79	1.65
8.29 kJ m^{-2}	1.63	1.52
12.14 kJ m^{-2}	1.70	1.68
NEW + 6.22 kJ m^{-2}	2.55	2.38
AEW + 6.22 kJ m^{-2}	2.91	2.10
O_3 + 6.22 kJ m^{-2}	2.82	1.89

SE = 0.39, LSD ($P \le 0.05$) = 0.61.

Meanwhile, the samples treated by 6.22 kJ m^{-2} and EW treatment showed the highest TA values after storage (2.5 ± 0.16 g citric acid kg^{-1} fw for NEW and 2.25 ± 0.16 g citric acid kg^{-1} fw for AEW).

Our results confirm those reported by Khali, Selselet-Attou, and Guetarni (2007) who found that the pH of fresh Deglet Nour cv. was about 6.43 which fall within the pH range of high quality. Storage at room temperature results in a significant acidification (decrease in pH and increase of acidity), which promotes the production of organic acids (lactic acid) mainly resulting from fermentative activity of yeasts and acidobacteria.

According to Pan, Vicente, Martinez, Chaves, and Civello (2004), strawberry fruit treated by 4.1 kJ m^{-2} UV-C showed the highest pH value compared to control. In addition, the TA of strawberry increased throughout storage at 20 °C in all samples, and no differences between control and treated fruits were detected.

3.2.3. Moisture and water activity

The moisture of dates was affected by the sanitizing treatment (Table 5). As expected the moisture content decreased during storage. Moisture ranged between 174 ± 21–201 ± 21 g kg^{-1} fw at the processing day and 130 ± 21–172 ± 21 g kg^{-1} fw at the end of storage. The same observation has been made for the water activity. It decreased from values ranging between 0.62 ± 0.02–0.66 ± 0.02 to values ranging between 0.58 ± 0.02–0.60 ± 0.02. This decrease of both moisture and a_w could be explained by the evaporation of water of fruit caused by the treatment by UVC, the relatively high temperature and moderate RH. Similar results have been recently reported for Deglet Nour cv. by Jemni et al. (2014).

3.2.4. Sugar content

The sugar concentration of dates was not affected immediately after treatment (Table 6). The sugar content at the processing day was between 682 ± 91 g kg^{-1} fw and 771 ± 91 g kg^{-1} fw being

Table 4
pH and titratable acidity of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments (n = 3).

	pH[a]		Titratable acidity (g citric acid kg^{-1} fw)[b]	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	5.92	5.27	1.65	1.86
2.37 kJ m^{-2}	5.76	5.59	1.76	1.73
6.22 kJ m^{-2}	5.76	5.48	1.72	1.72
8.29 kJ m^{-2}	5.78	5.59	1.65	1.88
12.14 kJ m^{-2}	5.81	5.50	1.74	1.77
NEW + 6.22 kJ m^{-2}	5.90	5.27	2.06	2.50
AEW + 6.22 kJ m^{-2}	5.95	5.23	1.92	2.25
O_3 + 6.22 kJ m^{-2}	5.98	5.32	1.62	1.60

[a] SE = 0.04, LSD ($P \le 0.05$) = 0.08.
[b] SE = 0.09, LSD ($P \le 0.05$) = 0.16.

Table 5
Moisture and water activity of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments ($n = 3$).

	Moisture (g kg^{-1})[a]		Water activity[b]	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	201	165	0.63	0.58
2.37 kJ m^{-2}	175	172	0.62	0.60
6.22 kJ m^{-2}	183	164	0.62	0.59
8.29 kJ m^{-2}	181	171	0.64	0.59
12.14 kJ m^{-2}	189	168	0.65	0.59
NEW + 6.22 kJ m^{-2}	193	130	0.63	0.60
AEW + 6.22 kJ m^{-2}	174	145	0.65	0.58
O_3 + 6.22 kJ m^{-2}	196	156	0.66	0.60

[a] SE = 12.58, LSD ($P \leq 0.05$) = 20.61.
[b] SE = 0.01, LSD ($P \leq 0.05$) = 0.02.

Table 7
Total phenolics content (A) and antioxidant activity (B) of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments ($n = 3$).

	Total phenolics content (g GAE kg $^{-1}$)[a]		Antioxidant activity (g AAE kg $^{-1}$)[b]	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	3.74	4.89	0.24	0.38
2.37 kJ m^{-2}	3.76	4.01	0.33	0.38
6.22 kJ m^{-2}	3.65	4.04	0.32	0.40
8.29 kJ m^{-2}	3.61	3.86	0.30	0.35
12.14 kJ m^{-2}	3.68	3.82	0.31	0.33
NEW + 6.22 kJ m^{-2}	3.72	4.20	0.32	0.35
AEW + 6.22 kJ m^{-2}	3.56	4.83	0.23	0.33
O_3 + 6.22 kJ m^{-2}	3.69	4.51	0.25	0.30

[a] SE = 0.17, LSD ($P \leq 0.05$) = 0.17.
[b] SE = 0.03, LSD ($P \leq 0.05$) = 0.05.

sucrose the most relevant component (415 ± 32 g kg^{-1} fw – 500 ± 32 g kg^{-1} fw). Sucrose concentration decreased during storage and, consequently, the levels of glucose and fructose increased. This phenomenon can be explained by the action of the invertase enzyme produced by yeast which converts sucrose to glucose and fructose. In addition, the decrease of total sugar can be explained also by the proliferation of microorganisms.

Kchaou, Abbès, Blecker, Attia, and Besbes (2013) showed that sugar was the predominant compound for all date cvs. ranging from 835 to 867 g kg^{-1} dry matter. In addition, the sugar fraction was essentially constituted by sucrose, fructose and glucose. Sucrose is the dominant sugar in Deglet Nour cv. (566 g kg^{-1}). In agreement to those authors, in the current experiments Deglet Nour cv. was characterized by a high total sugar of about 714 ± 91 g kg^{-1} fw and a reducing sugar content of about 291 ± 24 g kg^{-1} fw.

According to Pan et al. (2004), the total sugar content of strawberry fruit decreased slightly immediately after a treatment of 4.1 kJ m^{-2} UV-C and a decrease of total sugar was found during the storage.

3.2.5. Phenolics compounds content and antioxidant activity

Immediately after treatment, there were not differences in phenolics concentration between treated and control dates. The mean concentration was about 3.7 ± 0.17 g GAE kg^{-1} fresh weight (Table 7). This value increased slightly during storage, especially for control and samples treated with combined UV-C and O_3 or EW. These results allowed concluding that the UV-C light stabilized the phenolics concentration during storage of dates at 20 °C.

The UV-C light increases considerably the total antioxidant activity just after treatment. However, after storage period, the control sample showed a high variation of antioxidant activity (0.23 ± 0.05 to 0.38 ± 0.05 g AEAC kg^{-1} fw) (Table 7). From the obtained results it was found that the UV-C light stabilized the total antioxidant activity of Deglet Nour cv. during storage at 20 °C.

Tomás-Callejas et al. (2012) reported that the total phenolics content and the total antioxidant activity of Tatsoi baby leaves treated by 4.54 kJ m^{-2} UV-C significantly increased throughout 4 days at 5 °C. Artés-Hernández et al. (2010) found an increase of antioxidant activity of watermelon with the storage period, independently of the UV-C treatment. These results have been confirmed on fresh-cut broccoli by Martínez-Hernández et al. (2011).

3.2.6. Color

L^* values were affected by the kind of treatment and the storage period while Chrome and Hue were affected only by the storage period. Immediately after treatment, L^* and Chrome values decreased in UV-C alone treated samples and increased in samples treated by combined UV-C and O_3 or EW. Hue values decreased with 2.37 and 6.22 kJ m^{-2} UV-C remaining stable for the other treatments (Table 8).

Results found here agree with those of Tomás-Callejas et al. (2012) who reported that the treatment of Tatsoi baby leaves by 4.54 kJ m^{-2} UV-C light kept L^* values during shelf life. However Alexandre, Brandão, and Silva (2013) showed that 12.36 W m^{-2} UV-C for 2 min induced a negative impact on red bell pepper color changes.

Table 6
Sugars content (g kg^{-1} fw) of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatments ($n = 3$).

	Sucrose[a] (g kg^{-1} fw)		Glucose[b] (g kg^{-1} fw)		Fructose[c] (g kg^{-1} fw)		Total sugars[d] (g kg^{-1} fw)	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	423	397	163	189	128	145	714	731
2.37 kJ m^{-2}	415	310	162	199	126	137	703	646
6.22 kJ m^{-2}	469	338	173	191	129	132	771	661
8.29 kJ m^{-2}	461	369	162	196	112	139	735	704
12.14 kJ m^{-2}	464	314	154	190	119	137	737	641
NEW + 6.22 kJ m^{-2}	483	436	107	145	92	117	682	698
AEW + 6.22 kJ m^{-2}	489	419	141	151	108	130	738	700
O_3 + 6.22 kJ m^{-2}	500	417	132	165	100	126	732	708

[a] SE = 11.6, LSD ($P \leq 0.05$) = 79.4.
[b] SE = 11.70 LSD ($P \leq 0.05$) = 31.9.
[c] SE = 7.9, LSD ($P \leq 0.05$) = 16.1.
[d] SE = 11.8, LSD ($P \leq 0.05$) = 91.1.

Table 8
Color parameters of date fruits (cv. Deglet Nour) at harvest (handling day) and after 30 days at 20 °C, previously exposed to several sanitizing treatment ($n = 3$).

	L^*[a]		Chroma[b]		°Hue[c]	
	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C	Handling day	After 30 d at 20 °C
0 kJ m^{-2}	31	31	13	16	59	55
2.37 kJ m^{-2}	28	29	8.5	11	49	55
6.22 kJ m^{-2}	27	28	7.6	8.4	49	50
8.29 kJ m^{-2}	29	28	10	8.4	57	55
12.14 kJ m^{-2}	29	28	9.3	11	55	55
NEW + 6.22 kJ m^{-2}	35	32	18	18	58	57
AEW + 6.22 kJ m^{-2}	33	32	18	17	59	53
O_3 + 6.22 kJ m^{-2}	34	31	16	16	65	58

[a] SE = 2.4, LSD ($P \leq 0.05$) = 2.2.
[b] SE = 3.1, LSD ($P \leq 0.05$) = 2.8.
[c] SE = 4.8, LSD ($P \leq 0.05$) = 4.8.

3.3. Sensory analysis

After 30 days at 20 °C, the color was the sensory parameter affected the most, mainly due to the development of browning. However, dates from UV-C combined with O_3 or AEW kept a better color, especially when compared to the untreated samples. Additionally, a decrease for firmness, flavor, odors, visual appearance and overall quality scores was observed (data not shown) without significant differences between treatments. These results agree with those of Manzocco et al. (2011) who found that there was no difference in firmness for melon cubes exposed to 20 W m^{-2} UV-C and control, with a firmness decrease found at the end of the storage period. In the same way Tomás-Callejas et al. (2012) reported an important decrease of the overall sensory quality of baby leaves after 11 days at 5 °C.

4. Conclusions

As main conclusion, the UV-C light with an optimal dose of 6.22 kJ m^{-2} can be considered as an efficient and sustainable sanitizer for Deglet Nour dates. In addition, the selected combination of UV-C light and electrolyzed (mostly AE due to its lower chlorine concentration when compared to NE, even when it is free chlorine and easily volatilizes) or ozonated water reduced considerably the microbial proliferation while these combined emergent treatments could be recommended for commercial disinfection of fresh harvested dates while keeping their overall quality and prolonging shelf-life.

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References

Al-Haq, M. I., Sugiyama, J., & Isobe, S. (2005). Applications of electrolyzed water in agriculture & food industries. *Food Science and Technology Research, 11*(2), 133–150.
Alegria, C., Pinheiro, J., Duthoit, M., Gonçalves, E. M., Moldão-Martins, M., & Abreu, M. (2012). Fresh-cut carrot (cv. Nantes) quality as affected by abiotic stress (heat shock and UV-C irradiation) pre-treatments. *LW T – Food Science and Technology, 48*, 197–203.
Alexandre, E. M. C., Brandão, T. R. S., & Silva, C. L. M. (2013). Impact of non-thermal technologies and sanitizer solutions on microbial load reduction and quality factor retention of frozen red bell peppers. *Innovative Food Science and Emerging Technologies, 17*, 99–105.
Ali, A., Ong, M. K., & Forney, C. F. (2014). Effect of ozone pre-conditioning on quality and antioxidant capacity of papaya fruit during ambient storage. *Food Chemistry, 142*, 19–26.
Artés, F., Gómez, P., Aguayo, A., Escalona, V., & Artés-Hernández, F. (2009). Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. *Postharvest Biology and Technolology, 51*, 287–296.
Artés-Hernández, F., Aguayo, E., Artés, F., & Tomás-Barberán, F. A. (2007). Enriched ozone atmosphere enhances bioactive phenolics in seedless table grapes after prolonged shelf life. *Journal of the Science of Food and Agriculture, 87*, 824–831.
Artés-Hernández, F., Artés, F., & Tomás-Barberán, F. A. (2003). Quality and enhancement of bioactive phenolics in cv. Napoleon table grapes exposed to different postharvest gaseous treatments. *Journal of Agricultural and Food Chemistry, 51*, 5290–5295.
Artés-Hernández, F., Robles, P. A., Gómez, P. A., Tomás-Callejas, A., & Artés, F. (2010). Low UV-C illumination for keeping overall quality of fresh-cut watermelon. *Postharvest Bioliology and Technology, 55*, 114–120.
Barboni, T., Cannac, M., & Chiaramonti, N. (2010). Effect of cold storage and ozone treatment on physicochemical parameters, soluble sugars and organic acids in *Actinidia deliciosa*. *Food Chemistry, 121*, 946–951.
Bell, C. H. (2000). Fumigation in the 21st century. *Crop Protection, 19*, 563–569.
Bintsis, T., Litopoulou-Tzanetaki, E., & Robinson, R. K. (2000). Existing and potential applications of ultraviolet light in the foodindustry – a critical review. *Journal of the Science of Food and Agriculture, 80*, 637–645.
Chen, R., Ma, F., Li, P. W., Zhang, W., Ding, X. X., Zhang, Q., et al. (2014). Effect of ozone on aflatoxins detoxification and nutritional quality of peanuts. *Food Chemistry, 146*, 284–288.
Crowe, K. M., Al Bushway, & Davis-Dentici, K. (2012). Impact of postharvest treatments, chlorine and ozone, coupled with low-temperature frozen storage on the antimicrobial quality of lowbush blueberries (*Vaccinium angus tifolium*). *LW T – Food Science and Technology, 47*, 213–215.
Crupi, P., Pichierri, A., Basile, T., & Antonacci, D. (2013). Postharvest stilbenes and flavonoids enrichment of table grape cv Red globe (*Vitis vinifera* L.) as affected by interactive UV-C exposure and storage conditions. *Food Chemistry, 141*, 802–808.
Erkan, M., Wang, C. Y., & Krizek, D. T. (2001). UV-C radiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue. *Environmental Experimental Botany, 45*, 1–9.
Food and Drug Administration. (1997). Substances generally recognized as safe, proposed rule. *Federal Register, 62*, 18937–18964.
Haouel, S., Mediouni-Ben Jemâa, J., & Khouja, M. L. (2010). Postharvest control of the date moth *Ectomyelois ceratoniae* using eucalyptus essential oil fumigation. *Tunisian Journal of Plant Protection, 5*, 201–212.
Huang, Y.-R., Hung, Y.-C., Hsu, S.-Y., Huang, Y.-W., & Hwang, D.-W. (2008). Application of electrolyzed water in the food industry. *Food Control, 19*, 329–345.
Ikeura, H., Hamasaki, S., & Tamaki, M. (2013). Effects of ozone microbubble treatment on removal of residual pesticides and quality of persimmon leaves. *Food Chemistry, 138*, 366–371.
Jemni, M., Otón, M., Ramirez, J. G., Artés-Hernández, F., Chaira, N., Ferchichi, A., et al. (2014). Conventional and emergent sanitizers decreased *Ectomyelois ceratoniae* infestation and maintained quality of date palm after shelf-life. *Postharvest Biology and Technology, 87*, 33–41.
Joshi, R. K., Alagusundaram, M. K., Norton, T., & Tiwari, B. K. (2013). Novel disinfectants for fresh produce. *Trends in Food Science & Technology, 34*, 54–61.
Kchaou, W., Abbès, F., Blecker, C., Attia, H., & Besbes, S. (2013). Effects of extraction solvents on phenolic contents and antioxidant activities of Tunisian date varieties (*Phoenix dactylifera* L.). *Industrial Crops and Products, 45*, 262–269.
Khali, M., Selselet-Attou, G., & Guetarni, D. (2007). Influence de la thermisation et d'un emballage pour atmosphère modifiées sur la composition chimique de la datte Deglet Nour au cours du stockage au froid. *Sciences & Technologie, 26*, 9–16.
Klockow, P. A., & Keener, K. M. (2009). Safety and quality assessment of packaged spinach treated with a novel ozone-generation system. *LWT – Food Science and Technology, 42*, 1047–1053.

Koseki, S., Yoshida, K., Isobe, S., & Itoh, K. (2001). Decontamination of lettuce using acidic electrolyzed water. *Journal of Food Protection, 64*, 652–658.
Lee, H. J., Park, H. J., Jeong, J. W., Kim, D., & Chinnan, M. S. (2007). Effect of electrolyzed water treatments on the quality of hand- and machine- peeled yams (Dioscoreaspp.) during cold storage. *LWT – Food Science and Technology, 40*, 646–654.
Mahmoud, B. S. (2007). Electrolyzed water: a new technology for food decontamination – a review. *Deutsche Lebensmittel-Rundschau, 103*, 212–221.
Manzocco, L., Pieve, S. D., & Maifreni, M. (2011). Impact of UV-C light on safety and quality of fresh-cut melon. *Innovative Food Science and Emerging Technologies, 12*, 13–17.
Martínez-Hernández, G. B., Artés-Hernández, F., Gómez, P. A., & Artés, F. (2013). Quality changes after vacuum-based and conventional industrial cooking of kailan-hybrid broccoli throughout retail cold storage. *LWT – Food Science and Technology, 50*, 707–714.
Martínez-Hernández, G. B., Gómez, P. A., Pradas, I., Artés, F., & Artés-Hernández, F. (2011). Moderate UV-C pretreatment as a quality enhancement tool in fresh-cut Bimi broccoli. *Postharvest Bioliology and Technology, 62*, 327–337.
NF V 08-015, (1991), NF V 08–059, (1995), NFV 08-10, (1996). *Microbiologie alimentaire. Directives générales pour le dénombrement des coliformes totaux, des levures et moisissures et des mésophiles totaux. Méthode par comptage des colonies*. Norme française.
Obande, M. A., Tucker, G. A., & Shama, G. (2011). Effect of preharvest UV-C treatment of tomatoes (*Solanum lycopersicon Mill.*) on ripening and pathogen resistance. *Postharvest Biology and Technology, 62*(2), 188–192.
Pan, J., Vicente, A. R., Martinez, G. A., Chaves, A. R., & Civello, P. M. (2004). Combined use of UV-C irradiation and heat treatment to improve postharvest life of strawberry fruit. *Journal of the Science of Food and Agriculture, 84*, 1831–1838.
Pan, Y. G., & Zu, H. (2012). Effect of UV-C radiation on the quality of fresh-cut pineapples. *Procedia Engineering, 37*, 113–119.
Pascual, A., Llorca, I., & Canut, A. (2007). Use of ozone in food industries for reducing the environmental impact of cleaning and disinfection activities. *Trends in Food Science & Technology, 18*, 29–35.
Rico, D., Martín-Diana, A., Barry-Ryan, C., Frías, J., Henehan, G., & Barat, J. M. (2008). Use of neutral electrolyzed water (EW) for quality maintenance and shelf-life extension of minimally processed lettuce. *Innovative Food Science Emerging Technologies., 9*, 37–48.
Silveira, A. C., Aguayo, E., & Artés, F. (2010). Emerging sanitizers and clean room packaging for improving the microbial quality of fresh-cut 'Galia' melon. *Food Control, 21*, 863–871.
Tomás-Callejas, A., Martínez-Hernández, G. B., Artés, F., & Artés-Hernández, F. (2011). Neutral and acidic electrolyzed water as emergent sanitizers on fresh-cut mizuna baby leaves. Effects on safety and quality attributes. *Postharvest Biology & Technology, 59*, 298–306.
Tomás-Callejas, A., Otón, M., Artés, F., & Artés-Hernández, F. (2012). Combined effect of UV-C pretreatment and high oxygen packaging for keeping the quality of fresh-cut Tatsoi baby leaves. *Innovative Food Science and Emerging Technologies, 14*, 115–121.
UNEP. (1995). *Montreal Protocol on substances that deplete the ozone layer 1994. Report of the methyl bromide technical options committee*. Nairobi, Kenya: UNEP, 35 pp.
Wang, H., Feng, H., & Luo, Y. (2004). Microbial reduction and storage quality of fresh-cut cilantro washed with acidic electrolyzed water and aqueous ozone. *Food Research International, 37*, 949–956.