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Nutritional and Antioxidant Properties of Date Pastes and Blanching Water Obtained from by-Products of Medjoul and Confitera Cultivars

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Abstract The date industry faces economic losses due to non-conformities with quality standards (pre and post-harvest defects). The present study deals with two types of discarded date palm: Medjoul (post-harvest defects) and Confitera (pre-harvest cracks) with the aim to obtain valuable products. Dates were processed to obtain paste and blanching water. Nutritional value and antioxidant properties of the paste and blanching water were determined. Medjoul paste and blanching water have demonstrated to be a good source of sugars (33.02% and 5.44%, respectively) whereas Confitera paste and blanching water have an important content in phenols and flavonoids, which in particular confers antioxidant properties to Confitera blanching water. Furthermore both date pastes are a good source of fiber. Blanching process especially affects Confitera cultivar since a huge amount of organic acids, phenolics and flavonoids are solubilized and leaked during date processing, increasing the bioactive content in Confitera blanching water. These results showed the opportunity to incorporate these new products from non-commercial dates as functional ingredients into the food chain helping, whereas improving, waste management in the date industry.

Keywords Date Palm, Date Paste, Blanching Water, Waste Management, Valorization

1. Introduction

Date palm (*Phoenix dactylifera* L.) is one of the most important cash crops; it is especially grown in Arab region and the area bordering the Mediterranean coast [1]. The economic importance of date palm is due to its nutritionally valuable fruit, which consists of 44-88% sugar, fat (0.2-0.5%), minerals such as potassium (2.5 times more than bananas), calcium, magnesium and iron, protein (2.3-5.6%), dietary fiber (6.4-11.5%) as well as vitamins and amino acids [2]. Moreover Baliga[3] recently performed a comprehensive review of the biological and pharmacological activities of date fruits. Preclinical studies have shown that the date fruits possess free radical scavenging, antioxidant, antimutagenic, antimicrobial, anti-inflamatory, gastroprotective, hepatoprotective, nephroprotective, anticancer and immunostimulant activities [3].

The annual world date production in 2011 was 7,302,703 tonnes of which 15,327 tonnes were produced in Europe, an increase of 2.71% since 2010 [4]. However, a significant portion of dates is wasted in date producing countries (2,000,000 per year globally) due to its inferior quality, damage, and undersized fruit or unattractive appearance [5]. It is also reported that dates are also wasted during sorting, storage and conditioning. The non-use of lesser-quality dates constitutes a real economic loss since such dates are still rich in bioactive compounds which can be extracted and used as valuable ingredients [6].

Tonnes of wastes are discarded daily by the date processing industries leading to environmental problems. Date processing industries manufacture a variety of date products such as date-paste, date-syrup, date dip, date-honey, date-jam and date-vinegar. The dates are generally steamed, destoned, macerated, and converted to a semi-solid form known as paste [7,8]. Nowadays there is a growing interest in the reuse and valorization of water from the food industry and the water used for steam dates during its processing could contain an important amount of bioactive compounds presents in the date fruit. Overcome the barrier of legislation and hygienic concerns through selecting an appropriate treatment system to ensure microbiological and chemical quality [9,10] would generate new food applications for scalding water from date industries.

The aim of this study was to evaluate the nutritional quality and antioxidant properties of the paste and blanching water obtained from two date cultivars discarded during the industrialization, for its valorization as ingredients in fortified foods.

2. Materials and Methods

2.1. Plant Material

This study was conducted on non-commercial Medjoul and Confitera date fruits procured from 'Estación Phoenix' (Elche, Alicante, Spain): Medjoul dates rejected after dates selection due to low post-harvest quality (broken, uneven size or color, with unattractive appearance and/or undersized); and prematurely harvested Confitera dates. Confitera is a variety that needs high temperatures during maturation, and Elche has the palm grove located at the northern latitude, so Elche's climatic conditions are not optimal, and commonly such dates have to be collected unripened due to fruit cracks. Dates are ripen in four stages known throughout the world by their Arabic names: "kimri" (unripe; moisture content of 85 %), "khalal" (full-size, crunchy; 50-60 % moisture), "rutab" (ripe, soft; 35-40 % moisture) and "tamr" (ripe, reduced moisture about 20 %) [11]. Medjoul dates were at the "tamr" stage and Confitera dates were at "rutab" stage. Those are the ripening stages were most discarded dates are generated, for each variety. Only dates to be discarded were used.

2.2. Date Paste and Blanching Water Preparation

Date fruits were washed under running water at 40 ^{o}C to remove dust and macroscopic contamination, and afterwards scalded at 100 ^{o}C (1:1 water/fruit) for three minutes. After that, the seeds and the peels were manually removed and the flesh was crushed to obtain a homogeneous paste. This paste was vacuum-packed and kept frozen at -30 ^{o}C till analysis. Blanching water from dates was filtered through cotton gauzes to remove particles, pasteurized in a bath at 80 ^{o}C during 30 min, cooled and frozen at -30 ^{o}C till analysis.

2.3. Physicochemical analysis

2.3.1. Measurement of pH and ^{o}Brix

The pH was measured using a pH-meter (model pH/Ion 510, Eutech Instruments Pte Ltd., Singapore). The total soluble solids (TSS), expressed as ^{o}Brix, were measured using a refractometer (Mod. DR-101, Coseta S.A., Barcelona, Spain). Both measurements were taken at 20 ^{o}C.

2.3.2. Proximate composition

Ash, protein and fat content were determined according to Official Methods [12]. Moisture content was measured by loss in weight after heating a 3 g sample to constant weight at 60-65 ^{o}C in a vacuum oven. Total (TDF) and insoluble dietary fiber (IDF) were determined following the enzymatic-gravimetric AOAC method 991.43 using MES-TRIS buffer. Soluble dietary fiber (SDF) was calculated by subtracting the IDF proportion from TDF. These results were presented as percentage in the dry matter (DM).

2.3.3. Sugars and organic acids analysis

Contents of organic acids and sugars in date pastes and blanching water were analyzed. Samples (5g) were homogenized in 10 mL ultrapure water acidified with 0.1 % ortophosphoric acid and shaken vigorously (IKA® T25 digital ULTRA-TURRAX®, IKA® Werke Staufen, Germany) for 20 s at 13,500 rpm and centrifuged for 20 min at 15,000 rpm at 4 ^{o}C. The supernatants fluids were filtered through 0.45 µm membrane filters (Millipore Corporation, Bedford, USA). Samples (10 µL) were injected in a cation exchange column (Supelcogel C-610 H, 300 x 7.8 mm, Supelco, Bellefonte) with a pre-column (Supelguard-H, 50 x 4.6 mm, Supelco, Bellefonte), using 0.1 % H_3PO_4 as mobile phase, at an operating flow rate of 0.5 mL/min. A Hewlett Packard HP-1100 instrument (Woldbronn, Germany) coupled with two detectors: DAD G1315A (set at 210 nm) and RID G-1362A was used. Standards of organic acids, monosaccharides and oligosaccharides were obtained from Supelco. Samples were run at 30 ^{o}C and the run time was 30 min [13]. Peaks were identified by comparison with retention time of the standards, and quantified by regression formula obtained with the standards. Results were expressed in fresh weight basis (FW).

2.3.4. Measurement of total phenol content and total flavonoid content

Reagents and methods run were according to Viuda-Martos[14].

The total phenol content (TPC) was determined using Folin-Ciocalteu's reagent [15] and results were expressed as mg gallic acid equivalents (GAE)/g sample. For total flavonoid content (TFC), the method based on Blasa[16] was used and results were expressed as mg rutin equivalents (RE)/100 g of sample. Results were referred to fresh weight basis (FW).

2.4. Antioxidant properties

Antioxidant activity was measured by three methods: i) The 2,2'-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity was determined following the method of Viuda-Martos[14]; the amount of sample necessary to decrease the absorbance of DPPH (IC_{50}) by 50% was calculated graphically, ii) The ferric reducing power (FRAP) was determined by using the potassium ferricyanide-ferric chloride method [17] and estimated in terms of Trolox equivalent antioxidant capacity (TEAC) in mmol/L Trolox; iii) The ferrous ion-chelating (FIC) assay was carried out according to the method of Singh[18]; to determine the concentration needed to obtain 50% chelating effect (EC_{50}), the percentage of chelating effect was plotted against sample concentration.

2.5. Statistical analysis

Data was analyzed by one-way ANOVA test (SPSS statistical software, version 20.0, Chicago, IL, USA), using Tukey's pairwise comparisons post-hoc test with a significance level of 0.05. Three independent batches of 2 kg of dates were processed for each date cultivar. All determinations were run in triplicate, except fiber determinations that were duplicated.

3. Results and discussion

3.1. Physicochemical properties

3.1.1. Proximate composition

Table 1 presents the average composition of date pastes and blanching water. Regarding pH values, MP and MBW presented a pH close to neutrality making them suitable for incorporating into many foods. CP and CBW with a lower pH could modify food acidity when added, which needs to be taken into account for potential uses. Date paste has a great tendency to retain water [19] and so CP presented very high moisture. Also, MP presented high moisture, surely increased compared to data from fresh "tamr" Medjoul fruit (34.73 ± 1.16 g/100 g). Furthermore, it was demonstrated that blanched date fruits captured a plus of water [19]. Results for pH and moisture were in accordance to those obtained from Martín-Sánchez[20] in a similar Confitera date paste.

Date pastes were characterized by a high sugar content, and MP had the highest total soluble solids (TSS) values ($p<0.05$) as a consequence of fruit maturity. MP presented higher content of protein, ash, TDF, IDF and SDF ($p<0.05$) than CP. TDF in dried dates has been found between 8.1-12.3% dry matter (DM) [21]. Thus, both date pastes analyzed in the present study could be considered high in TDF. It is interesting to note that Martín-Sánchez[19] reported that blanching improves some technological properties of dates. In blanched dates the water holding capacity and the emulsion stability are increased, which are very important properties to obtain a desirable texture in some products [19]. On the other hand MBW showed higher TSS, protein and ash ($p<0.05$) than CBW. The relatively high TSS content of the MBW makes it an interesting source of sugars.

3.1.2. Sugars

Sugars are the major chemical constituent of date pastes being this content higher ($p<0.05$) in MP (33.02%) than in CP (22.53%) due to variety and maturation stage, indeed total sugar contents in dates increase from the early stage (Kimri) to the last stage of maturity (Tamr). Date pastes were mainly composed by glucose and fructose; these two types of reducing sugars have approximately equal concentration in both cultivars (Figure 1) as the ratio Glu/Fru informed. CBW had the lowest sugar content (1.28%) and sucrose was the predominant sugar, representing nearly the 75% of the total sugar content. MBW contained about 15 times more glucose and fructose than CBW, as reported in previous studies [10], which is explained by the stage of ripening of date fruits.

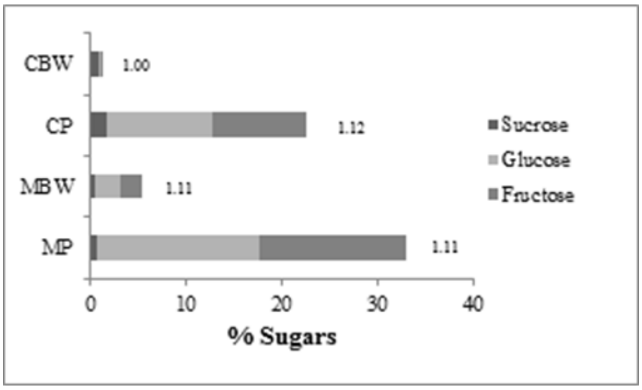

Figure 1. Sugar profile of the date pastes and blanching water (g/100 g, mean values). The numbers at the end of each bar represent the ratio Glu/Fru

Table 1. pH, total soluble solids (ºBrix), moisture, protein, fat, ash, total dietary fibre (TDF), insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) of Medjoul and Confitera date pastes and blanching water (mean values ± error standard)

	MP	MBW	CP	CBW
pH	6.98 ± 0.01^b	6.25 ± 0.03^B	5.80 ± 0.00^a	5.70 ± 0.00^A
ºBrix	39.8 ± 0.58^b	8.00 ± 0.10^B	29.73 ± 0.07^a	2.17 ± 0.05^A
Moisture (g/100 g)	60.2 ± 0.47^a	93.86 ± 0.12^A	70.27 ± 0.27^b	97.97 ± 0.17^B
Protein* (g/100 g)	3.51 ± 0.10^b	0.71 ± 0.09^B	2.62 ± 0.11^a	0.19 ± 0.07^A
Fat* (g/100 g)	0.17 ± 0.04^b	---	0.13 ± 0.05^a	---
Ash* (g/100 g)	3.32 ± 0.12^b	0.67 ± 0.07^B	2.48 ± 0.10^a	0.18 ± 0.02^A
TDF* (g/100 g)	12.43 ± 0.18^b	n.d.	9.29 ± 0.08^a	n.d.
IDF* (g/100 g)	10.22 ± 0.46^b	n.d.	7.63 ± 0.22^a	n.d.
SDF* (g/100 g)	2.21 ± 0.14^b	n.d.	1.64 ± 0.05^a	n.d.

*Values are given on dry matter (DM).

Abbreviations: MP, Medjoul paste; MBW, Medjoul blanching water; CP, Confitera paste; CBW, Confitera blanching water; n.d.: not determined.

Values with different small superscript letters within the same line significantly differ ($p<0.05$) between pastes.

Values with different capital superscript letters within the same line significantly differ ($p<0.05$) between blanching water.

Table 2. Organic acid (mg/100 g) profile of date pastes and blanching water (mean values ± error standard)

	MP	MBW	CP	CBW
Oxalic acid	53.29 ± 2.51^{b}	0.22 ± 0.03^{A}	41.41 ± 2.94^{a}	4.29 ± 0.11^{B}
Citric acid	155.43 ± 3.97	9.72 ± 0.83^{A}	159.93 ± 12.46	70.27 ± 2.06^{B}
Malic acid	764.58 ± 0.38^{b}	15.78 ± 0.76^{A}	579.01 ± 43.07^{a}	22.22 ± 0.21^{B}
Ascorbic acid	12.64 ± 1.54	N.d.	11.14 ± 1.09	N.d.
Succinic acid	507.79 ± 9.19^{a}	142.28 ± 21.61^{A}	640.19 ± 53.07^{b}	276.00 ± 17.20^{B}
Formic acid	111.68 ± 21.55	5.71 ± 0.18^{A}	129.31 ± 19.83	52.40 ± 2.31^{B}
Acetic acid	179.15 ± 25.54	33.50 ± 5.01^{A}	244.08 ± 37.14	198.74 ± 1.76^{B}
Fumaric acid	187.45 ± 0.33^{b}	9.18 ± 1.32^{A}	61.33 ± 5.85^{a}	52.44 ± 3.07^{B}
TOTAL ACIDITY (%)	1.97 ± 0.05	0.22 ± 0.03^{A}	1.87 ± 0.18	0.68 ± 0.04^{B}

Abbreviations: MP, Medjoul paste; MBW, Medjoul blanching water; CP, Confitera paste; CBW, Confitera blanching water; N. d., not detected.
Values with different small superscript letters within the same line significantly differ (p<0.05) between pastes.
Values with different capital superscript letters within the same line significantly differ (p<0.05) between blanching water

3.1.3. Organic acids

Table 2 shows the organic acid profile of date pastes and blanching water. In MP malic acid was the predominant organic acid, as other authors pointed out [22,23]. From a technological point of view being malic acid the predominant acid it is a positive trait since it acts as a flavour enhancer [19]. In CP, CBW and MBW succinic acid was the major organic acid, succinic is also a tasty organic acid. In pastes other organic acids were presents at lower concentrations such as acetic, fumaric and citric acids. Ascorbic acid was only present in pastes, may be due to thermal inactivation of this acid during blanching. The inner parts of the fruit (origin of pastes) retained some ascorbic acid content whereas the blanching water reached boiling temperatures for longer times and so ascorbic was completely inactivated. In CBW a relative high concentration of formic acid was found, which has previously demonstrated to stimulate the growth of lactobacilli [24]. Both pastes had similar total acidity ($p>0.05$) but among blanching water CBW had higher total acidity content ($p<0.05$) than MBW, so the blanching process highly affects Confitera dates as a largeramount of the organic acids are solubilized and leaked into the water.

3.1.4. TPC and TFC

Factors such as variety, growing condition and maturity among others, might be responsible for the observed differences in TPC and TFC values (Figure 2) [25]. Indeed, natural drying occurred during dates ripening is regarded as unfavorable for antioxidants, due to the possibility of inducing oxidative decomposition either enzymatically by polyphenol oxidase and glycosidase or by thermal degradation of phenolic compounds [26]. Confitera was the date variety which presented the highest TPC and TFC ($p<0.05$), both in paste and blanching water (Figure 2), although such phenolic content could reach values of 14.500 mg GAE/L for the same cultivar in the same maturation stage [20]. Besides, CBW appears as a source of phenolics as its content is similar to that of date pastes. Different results have been found by other authors in date fruits. Amorós[22] reported values up to 4000 mg of GAE/L in the early Khalal maturation stage whereas Mansouri[27] found that TPC ranged from 24.9 to 83.6 mg of GAE/L in ripe date fruits.

Flavonoids possess diverse health benefits, which include antioxidant and radical scavenging activities, among others [3]. However, the composition of flavonoids and other antioxidant phenolics in fruit changes dramatically during ripening [28]. The highest TFC was found in CP, followed by CBW. Chaira[29] reported the highest content of flavonoids in the Korkobbi variety (54.46 quercetin equivalents/100 g) which supposedly was responsible for the highest antiradical efficiency of this cultivar.

In relation to individual phenolic compounds significant differences were found in the literature regarding date cultivar and origin, as well as the maturation stage in which date fruits were found. Normally hydroxycinnamic acids (HCAs), including chlorogenic, caffeic, ferulic, *p*-, *m*-, *o*-coumaric and cinnamic acids are the most predominant group of phenolic acids. Hydroxybenzoic acids (HBAs),including gallic, protocatechuic, syringic, isovanillic and 3-hydroxybenzoic acids are found at lesser amounts [27,30,31]. However, other authors found higher levels of HBAs in their date fruit samples [32]. Also, Amira et al.[31] identified and quantified two other phenolic acids, hydroxyphenylacetic and phenylacetic acids. Regarding the ripening stage, HBAs are found with an appreciate amount until maturation of date fruit [31]. On this basis Confitera dates are expected to present higher amounts of HBAs than Medjoul dates. Flavonoids namely catechin, apinegin, isoquercetin, rutin, quercetrin, quercetin and luteolin were identified in the literature [30,31,32]. Furthermore Hong et al[33] identified several procyanidin oligomers and flavonoid glycosides of lutein, quercetin and apinegin in Deglet Nour cultivar. The beneficial effects derived from individual phenolic compounds have been attributed to their antioxidant activity [34] and several studies have proven the contribution of dietary polyphenols to human health [35,36,37].

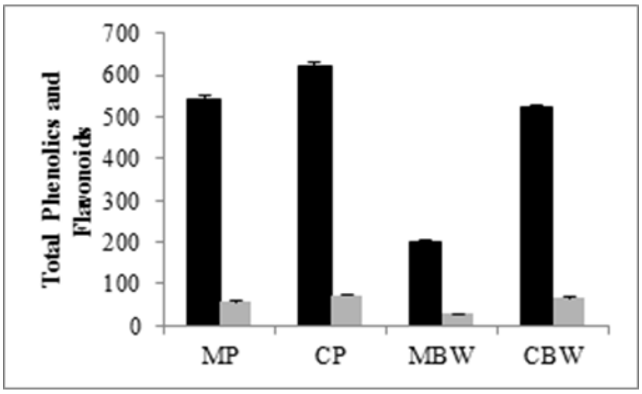

Figure 2. Total phenol content (TPC; mg GAE/L) and total flavonoid content (TFC; mg RE/100 g) of Medjoul and Confitera pastes (MP, CP) and blanching water (MBW, CBW) (■ TPC, ■ TFC).

3.2. Antioxidant Properties

Due to the antioxidant activity (AA) measured by an individual assay reflects only the chemical reactivity under the specific conditions applied in that assay a mixture of methods should be used when assessing AA *in vitro* to cover all the aspects of antioxidant efficacy [38]. Three assays based on spectrophotometry methods of antioxidant capacity were used in this study.

Regarding the DPPH assay (Table 3) CBW showed the highest ($p<0.05$) ability to inhibit DPPH radical at 10 g/100 g. The DPPH scavenging data suggest that the extract is capable of scavenging free radicals, hence preventing the initiation and propagation of free-radical-mediated chain reactions [39]. The higher antioxidant activity, the lower IC_{50} value; in this sense the order of AA was: CP<MBW<CBW<MP.

Analysis of the reducing properties showed (Table 4) that pastes had a low antioxidant action. CBW showed the highest values ($p<0.05$) of TEAC over all samples analyzed and did so in a concentration-dependent manner.

Table 3. Antioxidant activity of date pastes and blanching water at different concentrations (A = 2.5 %, B = 5 %, C = 7.5 %, D = 10 %), measured by the DPPH method.

Type of material	DPPH Inhibition (%)				
	A	B	C	D	$^{1}IC_{50}$
Medjoul paste	1.93 (0.15)	1.25^{A} (0.69)	2.24^{A} (0.46)	3.99 (0.99)	34.71
Confitera paste	3.69 (0.39)	3.69^{B} (0.08)	4.22^{B} (0.31)	4.91 (1.15)	69.28
Medjoul BW	5.60^{X} (0.47)	6.71^{X} (0.53)	6.66^{X} (0.16)	7.77^{X} (0.22)	41.51
Confitera BW	9.60^{xY} (0.32)	15.16^{yY} (0.59)	17.37^{zY} (0.16)	17.18^{zY} (0.27)	37.70

[1]IC_{50}, concentration (%) for a 50% inhibition. BW blanching water.

Values with different small superscript letters within the same line significantly differ ($p<0.05$).

Values with different capital superscript letters within the same column significantly differ ($p<0.05$).

*Values in parentheses denote standard error.

Analysis of the metal ion-chelating properties showed (Table 5) that both blanching water were capable of chelating iron (II) in a concentration dependent manner. However, pastes showed no ion-chelating activities at any of the tested concentrations. CBW presented the highest values of metal chelation ($p<0.05$) at all concentrations tested, which is reflected in a lower EC_{50}. Chelating ability is of great interest in the food industry due to the transition of metal ions contributes to lipid oxidation, which is the main source of degradation of food products [14].

Taking into consideration the results obtained from the different methods used, CBW showed the strongest antioxidant capacity. Several studies have pointed to the antioxidant activity of the phenolic and flavonoid compounds in dates [27,40]. Viuda-Martos[41] proved that 4 mL of orange juice waste water showed an equivalent activity to that provided by 0.1 g ascorbic acid or 0.1 g BHT measured by the DPPH method. They also attributed the antioxidant activity of the citrus waste to the phenolic compounds and flavonoids they contained.

Table 4. Antioxidant activity of date pastes and blanching water at different concentrations (A = 2.5 %, B = 5 %, C = 7.5 %, D = 10 %), measured by the FRAP method.

Type of material	FRAP TEAC[1] (mM Trolox/L)			
	A	B	C	D
Medjoul paste	0.02^{aA} (0.00)	$0.04^{a,bA}$ (0.00)	$0.05^{b,c}$ (0.00)	0.07^{c} (0.00)
Confitera paste	0.04^{aB} (0.00)	$0.05^{a,bB}$ (0.00)	0.06^{b} (0.00)	0.08^{c} (0.00)
Medjoul BW	0.09 (0.02)	0.09^{X} (0.00)	0.14^{X} (0.00)	0.22^{X} (0.05)
Confitera BW	0.28^{w} (0.01)	0.47^{xY} (0.03)	0.66^{yY} (0.02)	0.93^{zY} (0.02)

[1]TEAC, Trolox equivalent antioxidant capacity. BW blanching water.

Values with different small superscript letters within the same line significantly differ ($p<0.05$).

Values with different capital superscript letters within the same column significantly differ ($p<0.05$).

*Values in parentheses denote standard error.

In general, BW presented higher antioxidant activities than pastes, that maybe due to the effect of the matrix, much more complex in pastes than in BW. In pastes, the availability or action of substances with antioxidant activity may be hindered. This is also due to the complex mechanisms that lead to the antioxidant activity in which other compounds different from phenolics maybe taking part in the antioxidant mechanism.

Table 5. Antioxidant activity of date pastes and blanching water at different concentrations (A = 2.5 %, B = 5 %, C = 7.5 %, D = 10 %), measured by the FIC method

Type of material	FIC Chelating effect (%)				
	A	B	C	D	$^1EC_{50}$
Medjoul paste	N.e	N.e	N.e	N.e	---
Confitera paste	N.e	N.e	N.e	N.e	---
Medjoul BW	1.67^{wX} (0.04)	4.19^{xX} (0.02)	5.12^{yX} (0.05)	11.19^{zX} (0.05)	14.84
Confitera BW	20.49^{wY} (0.12)	30.74^{xY} (0.05)	37.74^{yY} (0.05)	54.26^{zY} (0.06)	9.15

$^1EC_{50}$, concentration (%) for a 50% chelating effect. BW blanching water.

Values with different small superscript letters within the same line significantly differ (p<0.05).

Values with different capital superscript letters within the same column significantly differ (p<0.05).

*Values in parentheses denote standard error.

N.e., Not effect.

4. Conclusions

Pastes and blanching water from the date industry could provide an optimal mix of dietary fiber, natural antioxidants and other bioactive compounds to be used as ingredients for food products. Medjoul paste and blanching water have demonstrated to be a good source of sugars, especially reducing sugars, with a nearly neutral pH, that make them suitable to be used by food industries like the bakery, confectionery or dairy industries. Confitera paste and blanching water have an important content in phenols and flavonoids, which in particular confers antioxidant properties to Confitera blanching water, making them good candidates for applications in the meat industry. Therefore, the possibility to successfully incorporate these new functional ingredients from non-commercial dates into the food chain would help the date industry on waste management and valorization.

Blanching process especially affects Confitera cultivar since a huge amount of organic acids, phenolics and flavonoids are solubilized or leaked during date processing. In the scope of the valorization of date fruit by-products and wastes, this fact would made blanching water from Confitera dates an ideal substrate for deriving a range of value added products in food and nutraceutical industries by employing bioprocessing technologies [42].

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