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# EFFECT OF DIFFERENT SOLVENTS AND DRYING CONDITIONS ON THE EXTRACTION OF PHYTOCHEMICAL BIOACTIVES FROM ORANGE PEEL

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## ABSTRACT

Oranges (*Citrus sinensis* L.) are one of the most cultivated citrus fruits worldwide. Citrus peel is the main residue left after processing. The disposal of this agro-waste represents a problem for citrus industries, where the implementation of strategies for its valorization is essential. This study compared the effects of two different drying methods for leftover orange peel (*C. sinensis* var. Valencia) on extract yield, its chemical composition, and antioxidant capacity using two extraction solvents. The experimental design was completely randomized in a 3 × 2 factorial arrangement, including three types of peel: dehydrated peel at 60 °C pilot level (C60), dehydrated peel at 204 °C industrial level (CI), and fresh peel (CF), and two extraction solvents: 70 % ethanol and methanol. The extraction yield was higher ($p < 0.05$) using CF with 70 % ethanol. The content of total phenols (TPC), total flavonoids (TFC), and antioxidant capacity in orange peel was higher ($p < 0.05$) using CF with 70 % ethanol or methanol. The concentration of hesperidin was similar in all types of peel using methanol, and CF presented a higher amount of naringin than peels dehydrated using 70 % ethanol or methanol. The use of CF with 70 % ethanol or methanol as extraction solvents allowed a higher extraction yield (46 and 38 %), higher concentrations of TPC (12.31 and 14.03 mg GAE $g^{-1}$ DW), TFC (9.5 and 8.74 mg QE $g^{-1}$ DW), antioxidant capacity (273.9 and 272.69 μM TE $g^{-1}$ DW), and naringin (13.6 mg $g^{-1}$ DW) compared to dried orange peels.

**Keywords**: *Citrus sinensis* var. Valencia, flavonoids, antioxidant capacity, hesperidin, naringin.

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## INTRODUCTION

Orange (*Citrus sinensis* L.) is one of the most cultivated fruit species worldwide. Mexico ranked fourth in global orange production, after Brazil, India, and China, with an annual total of 4800 Gg (FAO, 2022). According to García-Salazar *et al*. (2021), of the total orange production in Mexico, 56 % is consumed fresh, 34 % is used for industrial juice extraction, and 10 % is lost post-harvest. In the course of citrus fruit juice preparation, 30–34 % of peel is obtained as the main residue (Rafiq *et al*., 2018). Harnessing citrus peels for the revalorization of bioactive compounds can potentially improve the economic viability of citrus cultivation in a circular economy framework that promotes sustainable agriculture (Wang *et al*., 2022).

There is scientific evidence that citrus peel contains bioactive substances such as flavonoids (Afifi *et al*., 2023), pectins (Hosseini *et al*., 2016), carotenoids (Suri *et al*., 2021), essential oils (Boukroufa *et al*., 2015), and sugars (Choi *et al*., 2013) that are potential ingredients for food (antimicrobials, additives, prebiotics), pharmaceuticals (anti-inflammatory, anticancer), and cosmetics industries (Panwar *et al*., 2021; Suri *et al*., 2022). The main citrus flavonoids are flavones, flavanones, and their polymethoxy derivatives, distinguishing between glycosides and aglycones (Ammar *et al*., 2022). In them, naringenin and hesperitin occur under the aglycone forms, and naringin, neohesperidin, hesperidin, narirutin, and didimin are found under the glycoside forms (Kumar *et al*., 2022). Hesperidin has been shown to possess antioxidant, anti-inflammatory, hypoglycemic, anticancer, and antiviral capabilities (Zheng *et al*., 2021). Due to the polarity of flavonoids, organic solvents such as methanol are efficient for their extraction. Non-toxic and biodegradable alternatives such as ethanol are used in extraction methods to reduce the impact of organic solvents on the environment while providing similar performance (Fu *et al*., 2020). Flavonoid-enriched compounds obtained by solvent extraction frequently contain other soluble components, and are thus called crude extracts. The crude extract is suitable for flavonoid detection, but additional separation and purification are required to obtain citrus flavonoid monomers (Zhu *et al*., 2023).

In this study, the effects of two drying methods for *C. sinensis* var. Valencia peel were evaluated: a) dehydrated peel at 60 °C pilot level (C60), b) dehydrated peel at 204 °C industrial level (CI), and c) fresh peel (CF) on the extraction yield, chemical composition, and antioxidant capacity of the peel, using two extraction solvents, 70 % ethanol and methanol. The chemical composition analysis included the content of total phenols, total flavonoids, and two individual flavonoids, hesperidin and naringin. Two antioxidant assays, the free radical 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)-diammonium salt (ABTS) and the free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH), were used for antioxidant capacity tests.

## MATERIALS AND METHODS

### Reagents

Methanol and ethanol were purchased from Meyer Chemicals. Quercetin, hesperidin, and naringin grade high-performance liquid chromatography (HPLC, ≥ 95 %), 2,2-diphenyl-1-picryhydrazyl (DPPH, ≥ 97 %), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)-diammonium salt (ABTS, ≥ 98 %), 6-hydroxy-

2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox), potassium persulfate (≥ 99 %), aluminum chloride (99 %), gallic acid, and Folin-Ciocalteu's reagent (2 M) were purchased from Sigma-Aldrich.

### Raw Material

Valencia orange peel was provided by an agroindustry located in Veracruz, Mexico. The peel was obtained after the juice and oil extraction process and consisted of the flavedo (exocarp), albedo, and endocarp membranes. To dehydrate the peel at 60 °C, a convection oven with six racks and 66.04 × 45.72 cm trays was used until the weight of the peel was constant. The industrially dehydrated peel was provided by an agroindustry and contained 6.16 ± 0.02 % moisture; this peel was dehydrated in a rotary industrial oven at an initial temperature of 204 °C. The dehydrated shells were then ground (Micron pulverizer mill, model K20A, Mexico) and sieved to obtain a flour (particle size < 250 μm).

The moisture percentage in fresh peel was calculated using NMX-F-083-1986 (DOF, 1986). The total ash content was determined according to the NMX-F-607-NORMEX-2020 guidelines (DOF, 2020). The fat content of the ethereal extract was determined using NOM-086-SSA1-1994 (normative appendix C, numeral 1) (DOF, 1994). The crude protein content (N × 6.25) was calculated using NMX-F-608-NORMEX-2011, and crude fiber with NMX-F-613-NORMEX-2017 (DOF, 2017). Total carbohydrates were calculated using the proximate analysis difference, while dietary fiber, soluble dietary fiber, and insoluble dietary fiber were determined using the NMX-F-622-NORMEX-2008 (DOF, 2008) method.

### Experimental design

The experiment was completely randomized in a factorial arrangement (3 × 2), resulting in three types of peel: dehydrated peel at 60 °C pilot level (C60), dehydrated peel at 204 °C industrial level (CI), and fresh peel (CF), and two extraction solvents: 70 % ethanol and methanol. Each treatment was done in triplicate.

### Polyphenol extraction

Polyphenol extraction was performed according to the methodology described by Perlatti *et al*. (2016) for both solvents. Samples (1 g) of dried peel (C60 and CI) and fresh peel were placed in 50 mL Falcon tubes (Corning, NY, USA) containing 20 mL of solvent. The samples were placed in an ultrasonic bath (Branson model 2800, Danbury, CT, USA) at 40 kHz for 30 min, pausing every 5 min for 3 min to avoid heating the samples. The temperature of the water bath was 30 ± 2 °C. The tubes were then centrifuged (Heraeus Megafuge model 16R, Germany) for 30 min at 4 °C and 20 800 ×g. The supernatant was recovered and the precipitate was re-extracted with 10 mL of solvent and ultra-sonication for 15 min. Both supernatants were combined for each sample and the solvent was removed in a rotary evaporator (Buchi model R-215, Flawil, Switzerland) at 40 °C. Finally, the extract was resuspended in 5 ml of HPLC-grade methanol and stored at -20 °C until analysis. Experiments were performed in triplicate for each sample. The extraction yield was expressed as grams of extract per 100 grams of orange peel on a dry basis (g 100 $g^{-1}$ DW).

### Total phenol determination

The total phenol content (TPC) was determined according to the methodology described by Waterhouse (2002) with some modifications. The extracts were diluted (1:10), and 500 μL of diluted extract were mixed with 3 mL of deionized water, adding 250 μL of Folin-Ciocalteu 1 N reagent (1:1 (v/v). After 5 min, 750 μL of a 20 % (w/v) sodium carbonate solution and 950 μL of deionized water were added. The mixture was vortexed and kept in the dark for 30 min at room temperature. Then, the absorbance was measured at 765 nm using a spectrophotometer (Shimadzu UV-1800 Kyoto, Japan). Gallic acid with concentrations from 10 to 80 μg $mL^{-1}$ was used as a standard for calibration ($y = 0.01024\ x + 0.0100942$; $R^2 = 0.9986$). Results were expressed as milligrams of gallic acid equivalents per gram of orange peel on a dry basis (mg GAE $g^{-1}$ DW).

### Total flavonoid determination

Total flavonoid content (TFC) was determined using the colorimetric method with aluminum chloride (Chang *et al*., 2002). Quercetin was used to calculate the calibration curve ($y = 0.00766959\ x - 0.0137669$; $R^2 = 0.99799$). Ten milligrams of quercetin were dissolved in 10 mL of 80 % methanol and diluted to 5, 10, 25, 50, 70, and 100 μg $mL^{-1}$. The diluted standard solutions (0.5 mL) were mixed separately with 1.5 mL of 80 % methanol, 0.1 mL of 10 % aluminum chloride, 0.1 mL of 1 M potassium acetate, and 2.8 mL of deionized water. After incubation at room temperature for 30 min, the absorbance of the reaction mixture was measured at 415 nm with a spectrophotometer (Shimadzu UV-1800, Kyoto, Japan). Similarly, for the diluted orange peel extracts, 0.5 mL were reacted with aluminum chloride to determine flavonoid content as described above. The results were expressed as milligrams of quercetin equivalents per gram of orange peel on a dry basis (mg QE $g^{-1}$ DW).

### HPLC analysis

High-performance liquid chromatography (HPLC) was used to determine the hesperidin and naringin content of orange peel extracts. The concentration of the extracts was 10 mg $mL^{-1}$. Each sample was filtered through a 0.45 μm syringe filter. The flavonoids in the extract were analyzed using an HPLC system and a diode array detector (PDA) at a 280 nm detection wavelength. The injection volume was 1 μL with a flow rate of 1 mL $min^{-1}$. Identification of hesperidin and naringin in the extract was achieved by comparing the retention time and UV absorption pattern with those of the standard compound. The calibration equation was used to quantify the amount of each flavonoid, the result being expressed as milligrams of flavonoid per gram of orange peel on a dry basis (mg $g^{-1}$ DW). Each measurement was conducted in triplicate.

## Determination of antioxidant capacity by means of spectrophotometric assays

### DPPH method

Determination of DPPH antioxidant capacity was carried out according to Brand-Williams *et al*. (1995). Diluted extract samples (100 μL) were mixed with 3.9 mL of a 6 × $10^{-5}$ mol $L^{-1}$ DPPH solution in HPLC-grade methanol. The reaction mixture was incubated in the dark for 60 min, and the absorbance was determined at 515 nm using a spectrophotometer (Shimadzu UV-1800, Kyoto, Japan). Trolox standard concentrations from 160 to 1200 μM were used for calibration ($y = - 2.17922\ x + 0.695740$; $R^2 = 0.9988$). Results were expressed as equivalent micromoles of Trolox per gram of orange peel on a dry basis (μM TE $g^{-1}$ DW). Each sample was analyzed in triplicate.

### ABTS method

The ability of orange peel extracts to inhibit the ABTS radical was determined as described by Re *et al*. (1999). A stock solution was prepared with a 7 mM ABTS-+ solution containing 140 mM potassium persulfate; this solution was kept in the dark at room temperature for 12 to 16 h. The ABTS-+ working solution was prepared by diluting the ABTS-+ stock solution with 0.15 M phosphate buffer saline (PBS), pH = 7.4, so that the absorbance of the total mixture was 0.70 ± 0.02 at 734 nm. A 2970 μL of ABTS-+ working solution was added to 30 μL of the diluted shell extracts, and the mixture was shaken, allowed to stand in the dark for 30 min and the absorbance at 734 nm was read using a spectrophotometer (Shimadzu UV-1800, Kyoto, Japan).

A calibration curve ($y = - 0.0002106\ x + 0.674245$; $R^2 = 0.9951$) was prepared using Trolox standard (125 to 3000 μM). Each sample was analyzed in triplicate. Results were expressed as equivalent micromoles of Trolox per gram of orange peel on a dry basis (μM TE $g^{-1}$ DW).

## Statistical analysis

All treatments were performed in triplicate, and the data obtained were expressed as the mean value ± standard deviation. The data obtained were subjected to analysis of variance and comparison of treatments using Tukey's test ($p < 0.05$) with SAS 9.00 statistical software (NC, USA).

# RESULTS AND DISCUSSION

## Proximal analysis

Residual orange peel had a high content of total carbohydrates and soluble and insoluble dietary fiber (Table 1), which was similar to the amounts reported by other authors (de Moraes *et al*., 2013; Batool *et al*., 2020). The dietary fiber of citrus fruits is of higher quality than that of alternative sources such as cereals because citrus has a higher proportion of soluble dietary fiber (de Moraes *et al*., 2013).

**Table 1.** Proximal analysis and fiber content in residual peel of Valencia orange (*Citrus sinensis* L.)

| Determination | Percentage (%) |
|---|---|
| Moisture | 74.25 |
| Ash | 0.62 |
| Fats (ethereal extract) | 0.56 |
| Crude protein | 1.37 |
| Crude fiber | 2.86 |
| Total carbohydrates | 23.20 |
| Dietary fiber | 18.00 |
| Soluble dietary fiber | 8.72 |
| Insoluble dietary fiber | 10.28 |

## Extraction yield

The extraction yield was high ($p < 0.05$) using CF with 70 % ethanol or methanol. The lowest yield was obtained when CI was used, and an intermediate yield was obtained with C60, approximately 30 % (Figure 1). In this regard, Chakroun *et al.* (2023) reported that Thomson Navel orange peel, which had been dehydrated at 50 °C for 9 h and macerated with methanol for 72 h, obtained a 35 % extract yield, similar to the peel dehydrated at 60 °C. On the other hand, Lai *et al.* (2024) obtained an extraction yield of 33.36 ± 5.19 % using ground Newhall orange peel dehydrated at 50 °C for 12 h and subjected to ultrasound extraction for 30 min with a frequency of 45 kHz and a temperature of 35 °C.

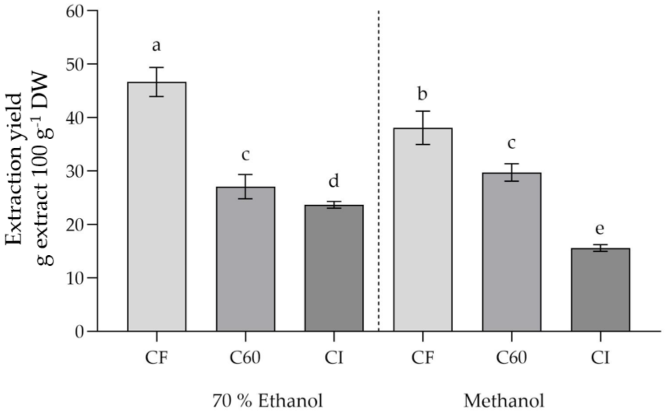

**Figure 1**. Extraction yield (grams of extract per 100 grams of orange (*Citrus sinensis* L.) peel on a dry basis, g 100 $g^{-1}$ DW) using 70 % ethanol or methanol with ultrasonication. CF: fresh peel; C60: dehydrated peel at 60 °C, pilot level; CI: dehydrated peel at 204 °C, industrial level. Data are mean values ± standard deviation. Different letters indicate significant differences between orange peel samples (Tukey, $p < 0.05$).

### Total phenol and flavonoid content

TPC was higher ($p < 0.05$) using fresh peel and 70 % ethanol or fresh peel and methanol compared to dry peels C60 and CI (Table 2). Covarrubias-Cárdenas *et al*. (2018) reported that dried sour orange peels presented the lowest phenolic content (22.7 ± 0.94 mg GAE $g^{-1}$ DW), while the highest total phenol content was observed in fresh peels (40.9 ± 3.44 mg GAE $g^{-1}$ DW); both peel samples were subjected to ultrasound-assisted extraction (20 kHz, 130 W) for 12.5 min at 80 % radiation, indicating that drying the peel could influence yield as cell membranes and organelles adhere, preventing the extraction of phenols. On the other hand, Barrales *et al*. (2018) measured the phenol content in orange peels that were dehydrated in an air circulation oven at 50 °C for 24 h, ground in a blade mill, and subjected to ultrasound-assisted extraction with 50 % (v/v) ethanol in an ultrasonic bath at 30 °C for 15 min. The value of total phenol content obtained by these authors was 5.5 ± 0.1 mg GAE $g^{-1}$ DW, which is similar to that obtained in this study when dehydrated peels (C60 and CI) were used.

**Table 2.** Total phenols and flavonoids content in residual orange (*Citrus sinensis* L.) peel.

| Solvent | Peel | TPC (mg GAE $g^{-1}$ DW)* | TFC (mg QE $g^{-1}$ DW)** |
|---|---|---|---|
| Ethanol (70 %) | CF | 12.31 ± 1.39 a | 9.50 ± 1.47 a |
| | C60 | 5.96 ± 0.27 b | 3.07 ± 0.60 b |
| | CI | 4.94 ± 0.32 b | 2.67 ± 0.35 b |
| Methanol | CF | 14.03 ± 0.76 a | 8.74 ± 1.08 a |
| | C60 | 5.98 ± 0.87 b | 2.61 ± 0.25 b |
| | CI | 4.55 ± 0.17 b | 2.01 ± 0.20 b |

The data are mean values ± standard deviation. Different letters in the same column indicate significant difference between orange peels (Tukey, $p < 0.05$). TPC: Total phenol content; TFC: total flavonoid content; CF: fresh peel; C60: dehydrated peel at 60 °C, pilot level; CI: dehydrated peel at 204 °C, industrial level. *Milligrams of gallic acid equivalents per gram of orange peel on a dry basis; **milligrams of quercetin equivalents per gram of orange peel on a dry basis.

On the other hand, fresh orange peel presented higher TFC ($p < 0.05$) using 70 % ethanol or methanol, with 9.50 ± 1.47 and 8.74 ± 1.08 mg QE $g^{-1}$ DW, respectively. Meanwhile, de Miera *et al*. (2023) mentioned that the content of total phenols and flavonoids was higher when using 80 % ethanol and orange peel dehydrated at 40 °C for 24 h, compared to water and ethyl acetate as solvents by means of an ultrasound-assisted extraction at 60 °C for 30 min.

### Individual flavonoid content

Hesperidin and naringin content in orange peels was quantified by HPLC. There was no difference ($p \geq 0.05$) in the hesperidin content in fresh and dehydrated peels when methanol was used as an extraction solvent (Table 3). This coincides with the study by Lai *et al*. (2024), who obtained a higher amount of hesperidin in navel orange peel extracts obtained by ultrasound extraction with methanol (129.77 ± 19.65 mg $g^{-1}$) than in extracts obtained with 70 % ethanol (48.89 ± 7.36 mg $g^{-1}$). In addition, the solubility of hesperidin is limited in water (< 20 mg $L^{-1}$) (Londoño *et al*., 2007), which could have affected during extraction with 70 % ethanol. In turn, naringin was found in greater amounts in fresh peels than in dehydrated peels, regardless of the solvent used during extraction (Table 3). Unlike hesperidin, naringin is water soluble but is generally found in lower amounts than hesperidin in orange peel (Zuin *et al*., 2021; Baglioni *et al*., 2024).

**Table 3**. High-performance liquid chromatography (HPLC) quantification analysis of hesperidin and naringin in residual orange (*Citrus sinensis* L.) peel.

| Solvent | Peel | Hesperidin (mg $g^{-1}$ DW)* | Naringin (mg $g^{-1}$ DW)* |
|---|---|---|---|
| Ethanol (70 %) | CF | 14.75 ± 5.66 bc | 13.37 ± 0.56 a |
| | C60 | 4.97 ± 0.43 c | 7.67 ± 0.36 c |
| | CI | 7.07 ± 1.81 c | 7.09 ± 0.34 c |
| Methanol | CF | 44.80 ± 9.26 a | 13.62 ± 0.25 a |
| | C60 | 33.03 ± 14.13 ab | 9.77 ± 0.82 b |
| | CI | 34.53 ± 3.12 ab | 5.77 ± 0.20 d |

Data are mean values ± standard deviation. Different letters in the same column indicate significant differences between orange peel samples (Tukey, $p < 0.05$). CF: fresh peel; C60: dehydrated peel at 60 °C, pilot level; CI: dehydrated peel at 204 °C, industrial level. *Milligrams of flavonoid per gram of orange peel on a dry basis.

### Antioxidant capacity

Antioxidant capacity was evaluated by DPPH and ABTS assays as mean values of three replicates. ABTS values were higher ($p < 0.05$) in extracts using fresh peel and 70 % ethanol or methanol compared to dehydrated C60 and CI peels (Table 4). In this regard, Mehmood *et al*. (2017) reported 9.16 ± 0.29 μmol TE $g^{-1}$ of sample using methanolic extracts (50 % v/v) of orange waste (peel and bagasse) that were dehydrated at 60 °C for 6–8 hours. Furthermore, when the same authors used ethanolic extracts (50 % v/v), they quantified ABTS values of 8.94 ± 0.29 μmol TE $g^{-1}$ of sample, suggesting that when using ethanol (50 % v/v) or methanol (50 % v/v), similar ABTS values were obtained.

DPPH values were higher ($p < 0.05$) when using dehydrated peels (C60 and CI) and 70 % ethanol and when fresh peels were used with methanol (Table 4). Covarrubias-

**Table 4**. Antioxidant capacity in residual orange (*Citrus sinensis* L.) peel extracts determined by 2,2-diphenyl-1-picryhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) methods.

| Solvent | Peel | ABTS ($\mu$M TE $g^{-1}$ DW)* | DPPH ($\mu$M TE $g^{-1}$ DW)* |
|---|---|---|---|
| 70 % Ethanol | CF | 273.90 ± 24.05 a | 6.31 ± 0.57 c |
| | C60 | 144.29 ± 14.14 b | 15.57 ± 0.57 a |
| | CI | 119.87 ± 9.05 b | 15.80 ± 1.37 a |
| Methanol | CF | 272.69 ± 37.67 a | 16.04 ± 0.66 a |
| | C60 | 133.34 ± 15.59 b | 11.96 ± 0.38 b |
| | CI | 93.99 ± 4.66 b | 6.67 ± 0.28 c |

Data are mean values ± standard deviation. Different letters in the same column indicate significant difference between orange peel samples (Tukey $p < 0.05$). CF: fresh peel; C60: dehydrated peel at 60 °C, pilot level; CI: dehydrated peel at 204 °C, industrial level. *Micromoles of Trolox per gram of orange peel on a dry basis.

Cárdenas *et al.* (2018) reported higher antioxidant capacity (DPPH) in dried sour orange peels and lower antioxidant capacity for fresh orange peel extracts. This suggests that some phytochemical compounds react during the drying process, forming other antioxidant compounds by the formation of phenol complexes with proteins (Martín-Cabrejas *et al*., 2009).

Barrales *et al*. (2018) reported a similar DPPH value (17 μM TE $g^{-1}$ dried peel) to that obtained in this work (16 μM TE $g^{-1}$ DW) using the dried peels and ethanol as an extraction solvent. These authors measured the antioxidant capacity in orange peel dehydrated in an air circulation oven at 50 °C for 24 h, ground, and subjected to ultrasound-assisted extraction with 50 % (v/v) ethanol in an ultrasonic bath at 30 °C for 15 min. On the other hand, in this study, the ABTS radical scavenging capacity was higher than the DPPH radical scavenging capacity (Table 4), which is in agreement with the study by Kim and Lim (2020) on ethanol, methanol, and acetone extracts of immature Satsuma mandarin peel, in which ABTS radical scavenging capacity was four times higher than the DPPH radical scavenging capacity in an ethanol extract, indicating that its radical scavenging capacity works better in a hydrophilic system. The DPPH assays use radicals dissolved in organic solvents, which is applicable to the hydrophobic system, but the ABTS assay is applicable to both hydrophilic and lipophilic systems (Floegel *et al*., 2011).

## CONCLUSIONS

The drying conditions affected the yields of orange peel phytochemical bioactives when using both extraction solvents. The highest extract yield was obtained in fresh residual peel, with 46 and 38 % using 70 % ethanol and pure methanol, respectively.

Similarly, the highest concentration for total phenol content (14.03 mg GAE $g^{-1}$ DW), total flavonoid content (9.5 mg QE $g^{-1}$ DW), antioxidant capacity (273.90 μM TE $g^{-1}$ DW), and naringin (13.62 mg $g^{-1}$ DW) was found in fresh residual peel. In the case of hesperidin content, methanol extraction obtained better yields (44.80 mg $g^{-1}$ DW) and no differences were found in the content of both types of peels (fresh and dry). The use of fresh or dehydrated orange peel is an option for the orange fruit processing company within the revaluation alternatives as a source of flavonoids, particularly hesperidin and naringin.

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