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Research Article

Fruit By-Product Processing and Bioactive Compounds

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Total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant potential (FRAP), and diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity of avocado peel, avocado seeds, kiwi fruit, orange peel, pineapple peel, and pomegranate skin by-products during processing (i.e., dried, blanched, freezed, and fresh) were determined. It was hypothesized that fruit by-products would add a significant value to the food products. Heat treatments resulted in increasing TPC and TFC and reducing power of fruit by-products with avocado peels TFC of 136.9 and 63.1 mg/100 g of dried and blanched treatments, respectively, compared to 14.4 mg/100 g of fresh and 20.6 mg/100 g of freezed treatments. Orange peels TFC increased from 54.4 mg/100 g of fresh to 194.4 and 380.0 mg/100 g for blanched and dried treatments, respectively. Fresh treatments had the lowest DPPH (%) (IC_{50}), indicating a significant effect of blanching and drying on fruit by-product antioxidant activity with some exceptions. IC_{50} increased from 20.0 of fresh to 39.8% of dried pineapple peel and from 6.5 to 15.0% for pomegranate skin of fresh and dried treatments, respectively. The use of fruit by-products regardless to its processing as supplements to flours would significantly increase flour's bioactive availability.

1. Introduction

The consumptions of synthetic additives such as antioxidants in foods are increasingly limited due to concerns of potential adverse effects on human health [1]. Natural antioxidants are of vital importance as a health concern of potential risks of synthetic antioxidants in the food industry. The beneficial health attributes of the natural bioactive compounds include having antibacterial, antitumor, antiviral, antimutagenic, and cardioprotective activities [2].

Fresh fruits and vegetables intake in the human diet is increasing in both domestic and international levels due to growing recognition of its health-promoting benefits [3, 4]. Fresh fruits and vegetables are rich sources of the natural antioxidants such as phenolic compounds. For instance, mango and pomegranates were reported to have a radical scavenging activity comparable to that of butylated hydroxyanisole (BHA) [5]. El-Barotyet al. [6] on the same manner studied the probiotic and antioxidant activities of pineapple and reported a 0.3–1.4 log cycle increases in probiotic and a significant increase in antioxidant activities as a result of pineapple powder supplementation in yoghurt. Hui et al. [7] reported that peanut skins in addition of 2.5% to cookies resulted in 30% increase in polyphenolic content.

In the plant kingdom, phenolic compounds are the most widely distributed secondary metabolites that contribute to both plant and human health. Polyphenols such as flavonoids play numerous molecular and biochemical roles in plant, such as signaling, plant defense, mediating auxin transport, antioxidant activity, and free radical scavenging [8, 9] Fruits are typically consumed in fresh or in a processed form, and the peel of the fruit is discarded as waste of little value. Since these fruits' residues are inexpensive and easily available, it is usually used as fertilizers [10]. However, studies indicated that significant amounts of bioactive compounds and essential nutrients are present in the seeds, peels, and skins of the fruits [11]. Therefore, its antioxidants activity and bioactive molecules content limited focus has

been shifted to such residues as valuable constituents in the food, cosmetics, and pharmaceutical industries [4].

Fruit by-products are considered a rich source of dietary fibers, organic acids, minerals, pigments, and phenolic compounds [4]. Avocado (*Persea americana)* seeds, for example, contain more than 70% of the amino acids of the fruit and possess significant amounts of antioxidant activity [12]. Kiwifruit (*Actinidia deliciosa*) and pomegranate (*Punica granatum* L.) skins also considered a significant source of antioxidants [12]. Despite its bioactive compound contents, fruit by-products are prone to either spoilage or producing objectionable flavor and taste due to the greater microbial content and organic content [13]. Therefore, fruit by-products are required to be processed before use in food applications.

Although processing can impart foods with its distinctive characteristics including texture, flavor, and aroma; it also can cause a reduction in their bioactive compounds, nutrient contents, and antioxidant capacity [14, 15]. Due to the lack of information regarding the effects processing on the bioactive compounds of fruits by-products, this study was undertaken to assess the effects of blanching, freezing, and drying on TFC and TPC and antioxidant activities on fruits by-products.

2. Materials and Methods

2.1. Materials. Avocado (*Persea americana*) (i.e., seed and skin), kiwifruit (*Actinidia deliciosa*) (i.e., skin), pineapple (*Ananas comosus*) (i.e., peel) pomegranate (*Punica granatum* L.) (i.e., skin), and orange peel (*Citrus sinensis*) were acquired from a local fruit and salad manufacturer in Amman, Jordan. The study was conducted in 2019, and all fruit by-products were collected using fresh (i.e., grown and harvested in Jordan) or imported fruits.

Folin–Ciocalteu reagent was acquired from AppliChem, GmbH (Darmstadt, Germany). 2-Chloro-p-nitrophenyl-α-D-maltotrioside, quercetin, gallic acid, ascorbic acid, and aluminum trichloride were from Sigma-Aldrich (Steinheim, Germany), 2, 2-Diphenyl-1-picrylhydrazyl was obtained from ICN, Biomedical Inc., USA. Sodium carbonate was purchased from Merck (Darmstadt, Germany). All solvents used were of HPLC grade.

2.2. Treatments and Extraction. Fruit by-product samples were kept cold (i.e., 8°C) until transferred to the laboratories of the Department of Nutrition and Food Technology, the University of Jordan. Samples were freshly prepared, as arrived to the department's laboratories, and were sliced divided into four sections separated by treatments (i.e., fresh, blanched, frozen, and dried). Complete randomized design (CRD) was followed in conducting the study. Fresh samples were not treated. Blanched samples were immured in 80°C water for 4 min after which the blanching water was evaporated, and the residues were added to the treated fruit by-products. For freezing treatment, samples were kept at −18°C for 14 days before samples were prepared for extraction and measurements, and for drying treatment, sliced samples were dried using a conventional oven at 45°C for up to 48 hours. Blanched, fresh, frozen, and dried treatments moisture contents were adjusted to 12% moisture content before extraction in order to eliminate the effect of water extraction solution polarity as affected by moisture content of the samples. Treated fruit by-products were then grinded separately into flour to pass through a 100 μm sieve.

For extractions, 40 ml of ethanol was added to 10 g of samples, vortexed for 30 minutes before filtered three times. The filtrate from the first, second, and third extracts were combined and kept at refrigerated temperature (i.e., 7°C) until use.

2.3. Total Flavonoids Content (TFC) Determination. TFC of the fruit by-product extracts were determined by according to the method reported by Phjimulyani et al. [16]. In brief, 0.5 ml of each extract as well as the standard (quercetin) was mixed with 1 ml of 2% aluminum trichloride/ethanol solution. The volume of the mixture was then completed to 25 ml with water in a volumetric flask and allowed to stand for 40 min at 23.2°C. Absorbance of the sample was then measured at 415 nm using the spectrophotometer (Labomed spectrophotometer, model UVD-2900, Labomed, USA). Results were expressed in mg of quercetin equivalent per 100 g dry weight plant material. Figure 1 shows the standard curve of quercetin equivalent that was used to calculate TFC of fruit by-products.

2.4. Total Phenolic Content (TPC) Determination. TPC of the fruit by-product extracts was determined by the Folin–Ciocalteu reagent (FCR) according to Miliauskas et al. [17]. In summary, 0.1 ml ethanol extracts and standard solution (gallic acid) were separately mixed with 0.5 ml of Folin–Ciocalteu reagent. After exactly 3 min, 2 ml of 10% (w/v) sodium carbonate solution was added before the final mixture was vortex for 20 seconds and then incubated in dark for 1 h at 23.2°C. Absorbance was then measured at 650 nm using the spectrophotometer (Labomed spectrophotometer, model UVD-2900, Labomed, USA). Results were expressed in mg gallic acid equivalents per 100 g dry weight plant material. Figure 1 shows the standard curve of gallic acid equivalent that was used to calculate TPC of fruit by-products.

2.5. Ferric Reducing Antioxidant Potential (FRAP) Determination. Reducing antioxidant potential of fruit by-products was determined using the following method that was described by Benzie and Strain [18]. In brief, FRAP reagent was prepared from 300 mmoL/L acetate buffer, pH 3.6, 20 mmoL/L ferric chloride, and 10 mmoL/L TPTZ made up in 40 mmoL/L hydrochloric acid. The solutions were mixed together in the ratio 10 : 1 : 1 (v : v : v), respectively. 3 mL of FRAP reagent was then mixed with 50 μL of fruit by-products extract, and the contents were mixed thoroughly. After 30 minutes incubation at 23.2°C, absorbance of the samples was measured 593 nm at 30 s intervals for 4 minutes. Result was expressed as ascorbic acid equivalent (0.1 g of dry sample material/100 ml distilled water). Figure 1 presents

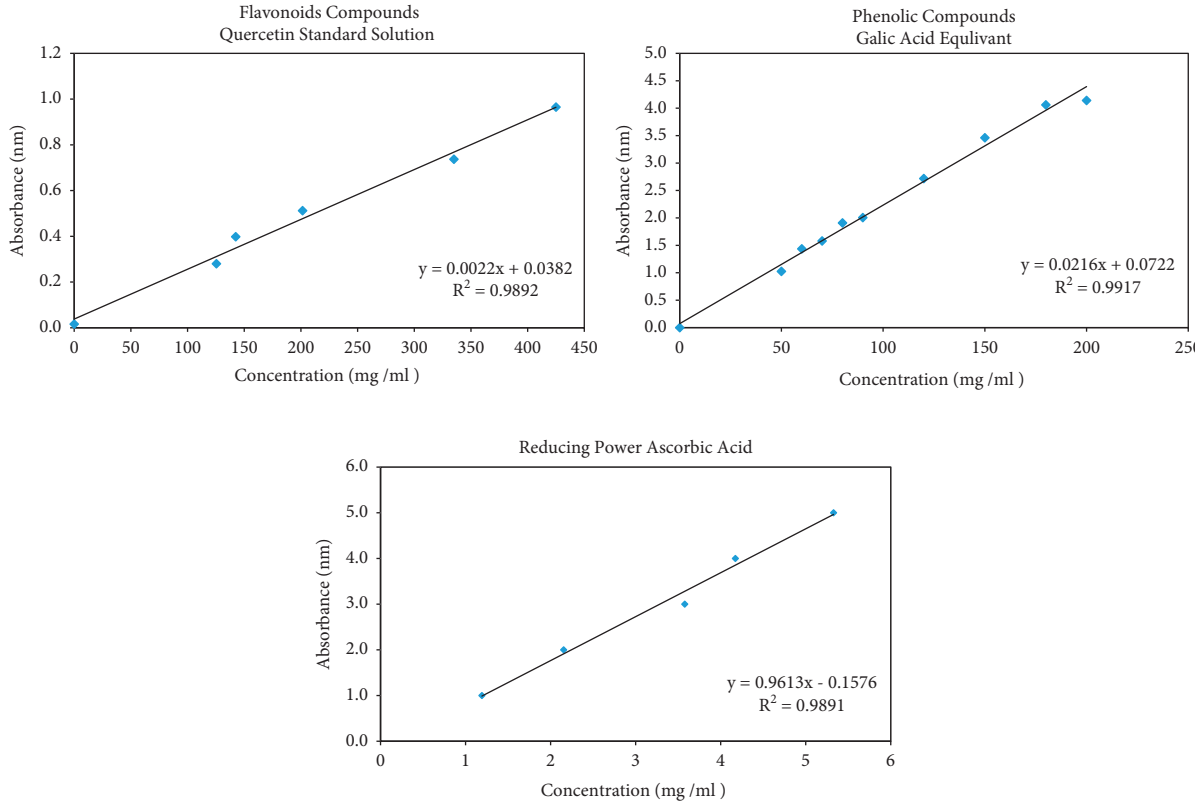

FIGURE 1: Standars curves used to calculate flavonoids, phenolic contents, and reducing power of dried, blanched, freezed, and fresh fruit by-products.

the standard curve of ascorbic acid equivalent that was used to calculate reducing activity of fruit by-products.

2.6. Diphenyl-1-picrryylhydazyl (DPPH) Free Radical Scavenging Activity Determination. DPPH radical scavenging effect was determined according to the method of Miliauskas et al. [17]. In brief, 0.2 ml of ethanol solution of DPPH (2, 2-diphenyl-1- picrylhydrazyl) (50 mg/100 ml) was mixed in selected levels of fruit by-product extract solutions. The mixture was then brought to a total volume of 4.0 ml with ethanol. After mixing thoroughly, the mixture was allowed to stand for 45 min in a dark place. Absorbance was then measured at 515 nm, and the radical scavenging activity of the tested samples was expressed as % inhibition according to the following formula [19].

$$\text{Inhibition}\,(\%) = \left[\frac{(\text{Abs. control} - \text{Abs. sample})}{\text{Abs. control}}\right] \times 100. \quad (1)$$

IC_{50} was calculated as the concentration of each extract (mg/ml) needed to scavenge 50% of the DPPH radicals with a lower IC50 indicating a higher antioxidant activity of a compound (Figure 2).

2.7. Statistical Analysis. Flavonoids (mg/100 g), phenolics (mg/100 g), reducing power (%), and DPPH inhibition measurements of processed avocado peel, avocado seeds, kiwi fruit, orange peel, pineapple peel, and pomegranate skin by-products were averaged and regarded as a replicate. Analysis of variance (ANOVA) of the complete randomized design (CRD) was performed to determine the significance of differences using JMP (release 10.0, SAS Institute, Cary, NC). Least significant differences (LSDs) at the 5% level of probability were used to separate differences in TFC, TPC, reducing power (0.1 g/100 ml), and DPPH inhibition (%) between treatments of the same fruit by-products as well as to separate these differences of the same treatment between fruit by-products.

3. Results and Discussion

Table 1 provides the average TFC (mg/100 g), TPC (mg/100 g), reducing power (0.1 g/100 ml), and DPPH inhibition (%) of avocado peel, avocado seeds, kiwi fruit, orange peel, pineapple peel, and pomegranate skin by-products during processing. The ANOVA indicated a significant difference ($P < 0.05$) between various processing methods of TFC and TPC measurements of fruit by-products (data not shown). More specifically, the results illustrated an increase in TFC and TPC of dried and blanched fruit by-products in comparison with fresh and freezed treatments. Dried treatments had the greatest TFC and TPC. For example, avocado peels TFC increased from 14.4 mg/100 g of fresh to 20.6, 63.1, and 136.9 mg/100 g for freezed, blanched, and dried, respectively. Similarly, orange peels TFC increased from 54.4 mg/100 g of fresh to 56.9, 194.4, and 380.0 mg/100 g for frozen, blanched,

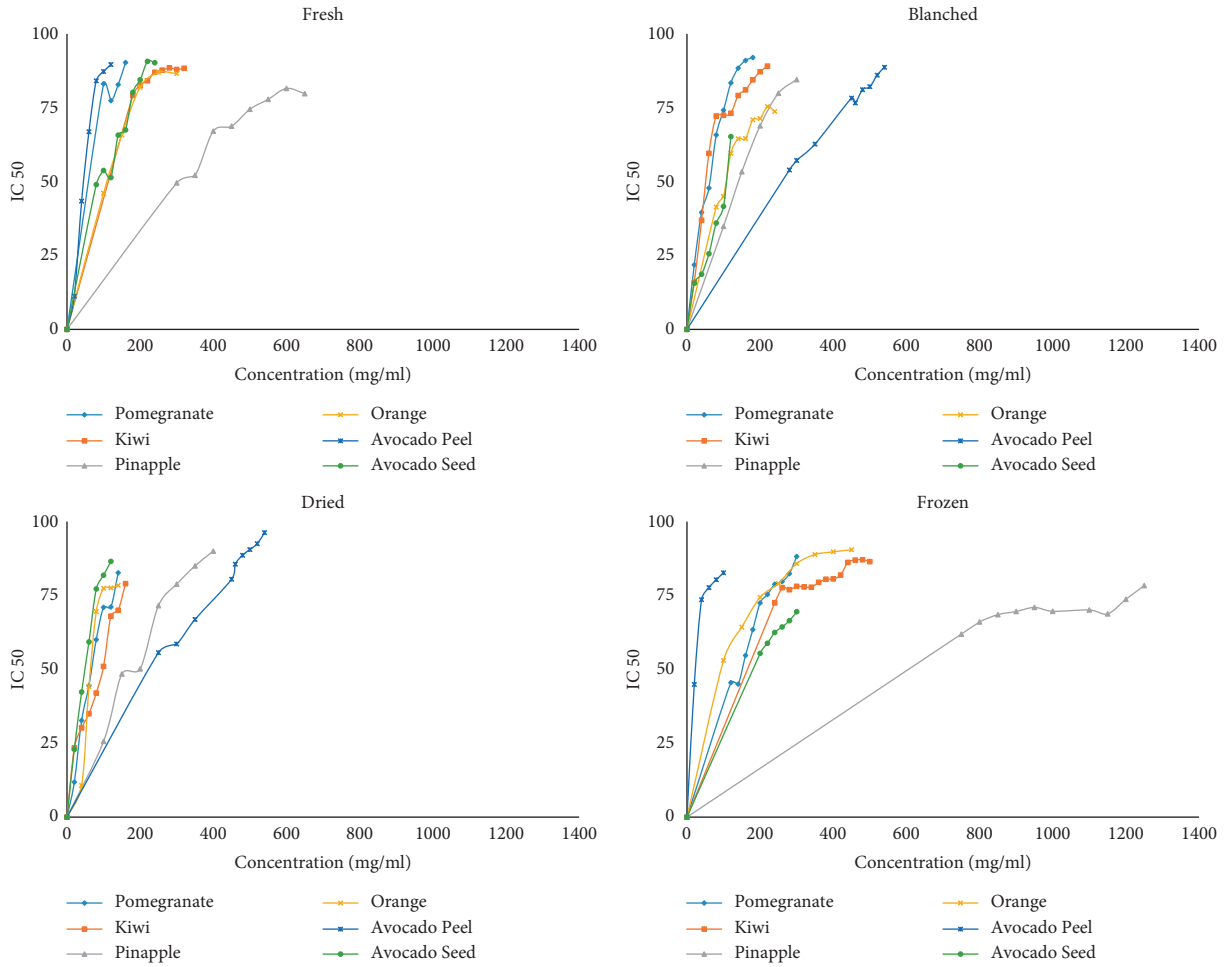

Figure 2: Diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity of dried, blanched, freezed, and fresh fruit by-products.

Table 1: Means of total flavonoid content (TFC, mg/100 g), total phenolic content (TPC, mg/100 g), reducing power (FRAP <0.1 g/100 ml), and DPPH inhibition (IC50, %) of avocado peel, avocado seeds, kiwi fruit, orange peel, pineapple peel, and pomegranate skin during processing.

Fruit by-product	TRT	TFC (mg/100 g)[1]	TPC (mg/100 g)	FRAP (0.1 mg/100 ml)	IC_{50} (%)
Avocado peel	Dried	136.9[a]	1,017.2[b]	93.6[d]	14.5[c]
	Blanched	63.1[b]	359.1[d]	169.0[a]	11.1[d]
	Frozen	20.6[c]	1,000.5[c]	128.3[c]	55.6[b]
	Fresh	14.4[d]	2,466.8[a]	149.2[b]	76.6[a]
Avocado seed	Dried	54.1[a]	5,973.0[a]	152.2[a]	52.5[a]
	Blanched	45.4[b]	4,958.6[b]	147.9[b]	21.6[c]
	Frozen	33.8[d]	1,268.6[d]	128.2[d]	28.2[b]
	Fresh	39.8[c]	2,036.6[c]	142.7[c]	17.8[d]
Kiwi fruit	Dried	10.6[a]	4,571.9[a]	59.9[b]	32.1[b]
	Blanched	1.3[b]	852.6[b]	93.6[a]	43.2[a]
	Frozen	0.0[c]	324.2[c]	32.1[c]	30.0[c]
	Fresh	1.3[b]	331.8[c]	28.5[d]	20.2[d]
Orange peel	Dried	380.0[a]	4,232.3[a]	177.7[a]	27.7[b]
	Blanched	194.4[b]	2,445.5[b]	133.9[b]	38.8[a]
	Frozen	56.9[c]	828.5[c]	49.3[c]	26.1[b]
	Fresh	54.4[c]	756.5[c]	47.7[d]	26.2[b]

Table 1: Continued.

Fruit by-product	TRT	TFC (mg/100 g)[1]	TPC (mg/100 g)	FRAP (0.1 mg/100 ml)	IC_{50} (%)
Pineapple peel	Dried	18.8[a]	1,342.8	42.6[a]	15.0[b]
	Blanched	13.1[b]	733.4[b]	32.3[b]	19.8[a]
	Frozen	1.3[c]	152.4[c]	6.5[c]	9.9[c]
	Fresh	18.8[a]	95.0[d]	0.6[d]	6.5[d]
Pomegranate skin	Dried	862.5[a]	6,138.2[c]	93.6[d]	39.8[c]
	Blanched	405.6[d]	5,346.8[d]	106.3[c]	45.3[b]
	Frozen	478.8[c]	6,454.4[b]	173.5[a]	47.8[a]
	Fresh	504.4[b]	6,909.8[a]	166.6[b]	20.0[d]

[1]Flavonoids content ((quercetin equivalents (mg/100 g)), phenolic compounds (gallic acid equivalents (mg/100 g)), FRAP (ascorbic acid equivalent (0.1 g/100 ml)), and IC_{50} (i.e., concentration of extract (mg/ml) needed to scavenge 50% of the DPPH radicals (mg/ml)) within the same fruit by-product and different treatment having different letters are significantly ($P < 0.05$) different according to the LSD.

and dried, respectively. The trend of reducing power of fruit by-products, however, was not consistent for avocado and pomegranate where fresh and freezed treatments had higher reducing powers than either the blanched or dried treatments. Pomegranate fruits are recognized for their high anthocyanin content accumulation in the skin and arils [20, 21]. Our results agree with Brand-Williams et al. [22] who reported high levels of bioactive compounds in avocado husk and with seed showing high levels of these compounds.

TFC and TPC after blanching were greater than that of the fresh and freezed treatments, which may be ralted to the efficient release of bioactive compounds from the fruit by-product's matrix by softening the cells. Furthermore, the bioaccessibility of phenolic compounds may also be increased due to heat treatment releasing the bound phenolic compounds. Thermal processing (i.e., blanching, boiling, and/or steaming) was reported to an increase in TPC of vegetables and fruits after heat treatments; a result related to the breaking down of bioactive compounds results in increased TFC and TPC [23]. On the same manner, blanching was reported to increase total phenolic and carotenoid contents of the carrots [24]. Al-Dabbas et al. [25] reported an increase in TFC and TPC and antioxidant activity of sweet and chilli pepper with heat treatment. The authors attributed the increase of bioactive compounds during heating to the dehydration of food matrix that led to the improvement in extractability of phenolics. Shaimaa et al. [26], on the other hand, related cooling to the inhibition of polyphenolics degradation as a result of inactivating polyphenol oxidase enzyme during heating.

Reducing power and DPPH inhibition of fruit by-products treatments are also presented in Table 1. Reducing power (%) of orange peel had the greatest value to 177.7 (%). Results also indicated that blanched and dried treatments had the greatest reducing power among fruit by-product treatments except pomegranate skin. Freezed pomegranate skin had a reducing power of 173.5% compared to 166.6, 106.3, and 93.6% of fresh, blanched, and dried treatments, respectively. The increased antioxidant activity of the fruit by-products extracts probably due to the polarity of the extract solution. The increased antioxidant activity of the fruit by-products extracts indicated an increased capacity of these extracts to reduce the Fe^{+3}-TPTZ to Fe^{+2} complexes. Moreover, TPC is highly correlated ($r = 0.59$) with the antioxidant activity. Results also indicated a significant impact of heat treatment on the kinetics of antioxidant activity. Fresh samples, for instance, had a correlation coefficient of 0.81 while drying and blanched resulted in a decrease in correlation coefficient between TPC and antioxidant activity to 0.44 and 0.22, respectively. In this regard, Chuah et al. [27] correlated the high total antioxidant capacity in walnut skin to its high levels of phenolic acids and tannins. On the same manner, due to the heat treatment, Açar et al. [28] indicated that the inactivation of prooxidant enzyme resulted in decreasing the antioxidant activity of cashew nut extracts.

DPPH (%) of fresh treatment had the lowest IC_{50} indicating a significant effect of processing, namely, blanching and drying on the DPPH inhibition with the exception of avocado and orange peel. For instance, avocado seeds IC_{50} increased from 17.8% of fresh to 28.2, 21.6, and 52.5 for freezed, blanched, and dried treatments, respectively. Similarly, IC_{50} increased from 20.0 of fresh to 39.8% of dried pineapple peel and from 6.5 to 15.0% for pomegranate skin of fresh and dried treatments, respectively. Processing of fruit by-products seems to be the detrimental preservation technique. Processing and cooking of fruit by-products may have affected the proanthocyanidin content suggesting proanthocyanidins degradation during the drying process. Moreover, heat treatment may have resulted in the formation of highly polymerised compounds and thus affected the extraction of bioactive compounds [29]. Freezing, on the contrary seemed to be the least harmful having DPPH retention values. It is worth indicating here that DPPH inhibition of avocado peel results in an increase in DPPH with the heat treatment, while heat treatment had no impacts on the DPPH of orange peel. Our results are in agreement with Barth et al. [14] who indicate that boiling, pressure, and microwave cooking, baking, and frying at several time-temperature combinations were reported to reduce the radical scavenging activities of vegetables. On the same manner, Randhir et al. [24] reported that blanching significantly reduced DPPH inhibition activity in carrots. However, the authors reported a limited effect of blanching on the reducing power activity.

Table 2 presents a comparison of the average bioactive compounds and antioxidant activity of fruit by-products as affected by processing. The ANOVA indicated a significant

Table 2: Average flavonoid content (mg/100 g), phenolic content (mg/100 g), reducing power (0.1 g/100 ml), and DPPH inhibition (%) of dried, blanched, freezed, and fresh avocado peel, avocado seeds, kiwi fruit, orange peel, pineapple peel, and pomegranate skin.

Status	Fruit	TFC (mg/100 g)[1]	TPC (mg/100 g)	FRAP (0.1 mg/100 ml)	IC_{50} (%)
Dried	Avocado peel	136.9^{c}	1,017.2^{e}	93.6^{c}	14.5^{d}
	Avocado seed	54.1^{d}	5,973.0^{b}	152.2^{b}	52.5^{a}
	Kiwi fruit	10.6^{f}	4,571.9^{c}	59.9^{d}	32.1^{c}
	Orange peel	380.0^{b}	4,232.3^{c}	177.7^{a}	27.7^{c}
	Pineapple peel	18.8^{e}	1,342.8^{d}	42.6^{e}	15.0^{d}
	Pomegranate skin	862.5^{a}	6,138.2^{a}	93.6^{c}	39.8^{b}
Blanched	Avocado peel	63.1^{c}	359.1^{f}	169.0^{a}	11.1^{f}
	Avocado seed	45.4^{d}	4,958.6^{b}	147.9^{b}	21.6^{d}
	Kiwi fruit	1.3^{f}	852.6^{d}	93.6^{e}	43.2^{b}
	Orange peel	194.4^{b}	2,445.5^{c}	133.9^{c}	38.8^{c}
	Pineapple peel	13.1^{e}	733.4^{e}	32.3^{f}	19.8^{e}
	Pomegranate skin	405.6^{a}	5,346.8^{a}	106.3^{d}	45.3^{a}
Freezed	Avocado peel	20.6^{d}	1,000.5^{c}	128.3^{b}	76.6^{a}
	Avocado seed	33.8^{c}	1,268.6^{b}	128.2^{b}	17.8^{d}
	Kiwi fruit	0.0^{e}	324.2^{e}	32.1^{d}	20.2^{c}
	Orange peel	56.9^{b}	828.5^{d}	49.3^{c}	26.2^{b}
	Pineapple peel	1.3^{e}	152.4^{f}	6.5^{e}	6.5^{e}
	Pomegranate skin	478.8^{a}	6,454.4^{a}	173.5^{a}	20.0^{c}
Fresh	Avocado peel	14.4^{d}	2,466.8^{b}	149.2^{b}	55.6^{a}
	Avocado seed	39.8^{c}	2,036.6^{c}	142.7^{c}	28.2^{d}
	Kiwi fruit	1.3^{e}	331.8^{e}	28.5^{e}	30.0^{c}
	Orange peel	54.4^{b}	756.5^{d}	47.7^{d}	26.1^{e}
	Pineapple peel	18.8^{d}	95.0^{f}	0.6^{f}	9.9^{f}
	Pomegranate skin	504.4^{a}	6,909.8^{a}	166.6^{a}	47.8^{b}

[1]Flavonoids content (quercetin equivalents (mg/100 g)), phenolic compounds (gallic acid equivalents (mg/100 g)), FRAP (ascorbic acid equivalent (0.1 g/100 ml)), and IC_{50} (i.e., concentration of extract (mg/ml) needed to scavenge 50% of the DPPH radicals (mg/ml)) within the same treatments (blanched, dried, freeze, and fresh) of different fruit by-products having different letters are significantly ($P < 0.05$) different according to the LSD.

difference ($P < 0.05$) between various processing methods on TPC, FRAP, TFC, and IC_{50} measurements of fruit by-products (Table 3). Flavonoid content ranged from 10.6 to 862.5, from 1.3 to 405.6, from 0.0 to 478.8, and from 1.3 to 504.4 mg/100 g, while TPC ranged from 1017.2 to 6138.2, from 359.1 to 5346.8, from 152.4 to 6454.4, and from 95.0 to 6909.8 mg/100 g of dried, blanched, freezed, and fresh fruit by-products, respectively. Results showed that pomegranate skin had the greatest ($P < 0.05$) TFC and TPC regardless of processing, while kiwifruit skin had the lowest TFC. Avocado peel had the lowest ($P < 0.05$) TPC of dried and blanched, while pineapple peel had the lowest ($P < 0.05$) TPC of freezed and fresh treatments.

According to their structure, phenolics (i.e., compounds that contain one or more phenol unit in their molecules) are classified into several phenolic acids, coumarins, flavonoids, stilbenes, lignans, lignins, and tannins [30]. More specifically, condensed tannins that are also known as proanthocyanidins are found in abundance in fruits and fruit products [31]. Koleckar et al. [32] reported a high level of tannin punicalagin in pomegranate juice (1500–1900 mg/L) and suggested greater levels in pomegranate peels. The authors have also detected and quantified the presence of anthocyanins, ellagic acid derivatives, and hydrolyzable tannins. Several authors have also linked proanthocyanidins to antioxidant properties including free radical scavengers and chelators of transition metals and have an inhibitory power of prooxidative enzymes [29, 33]. More specifically, Landete et al. [34] reported the presence of punicalagin in pomegranate husk that was comparable to that in pomegranate juice with punicalagin showing significant ferrous chelating activity and reducing power ability.

Our results are in agreement with Aloqbi et al. [35] who reported that avocado pulp is rich in flavonoids (21.9 ± 1.0 mg/100 g), phenolic compounds (410.2 ± 69.0 mg/100 g) and carotenoids (0.815 ± 0.201 mg/100 g). The authors also indicate that avocado skin was reported of being superior to the pulp with 44.3 ± 3.1 mg/100 g of flavonoids, 679.0 ± 117.0 mg/100 g of total phenolics, and 2.585 ± 0.117 mg/100 g of carotenoids, in addition to its TPC (704.0 ± 130.0 mg/100 g), that is, mainly catechins, hydroxybenzoic acids, hydroxycinnamic acids, procyanidins, and flavanols (47.97 ± 2.69 mg/100 g); avocado seeds were reported to contain a high level of α-tocopherol (5.36 ± 1.77 mg/100 g) and α-tocotrienol, lutein, and β-carotene exhibiting its higher antioxidant activity [35, 36]. As for pineapple peels, polyphenolic compounds were reported to be mainly catechin (58.51 mg/100 g dry extracts), epicatechin (50.00 mg/100 g), gallic acid (31.76 mg/100 g), and ferulic acid (19.50 mg/100 g) [2]. These polyphenolic compounds exhibit the antioxidant activity of the pineapple peels.

Our results also indicated significant variation ($P < 0.05$) between various bioactive compounds composition and antioxidant activity of fruits by-products. TFC and TPC variation between various fruits by-products was related to

Table 3: Analysis of variance (ANOVA) of the total phenolic content (TPC), FRAP, total flavonoid content (TFC), and IC50 of fruit by-products during blanching, drying, fresh, and freezing.

Source of variation	DF		Sum of squares	Mean square	*F* ratio		Sum of squares	Mean square	*F* ratio
				TPC (mg/100g)					
Model	5		54402892	10880578	17662.06		52229606	10445921	19353.98
Error	6	Blanching	3696	616.0425		Drying	3238	539.73	
C. total	11		54406589				52232844		
Model	5		56644119	11328824	88131.41		64447734	12889547	107250.9
Error	6	Freezing	771	128.54468		Fresh	721	120.1812	
C. total	11		56644890				64448455		
				FRAP (0.1 mg/100 ml)					
Model	5		30167.021	6033.4	6786.532		17516.363	3503.27	10426.87
Error	6	Blanching	5.334	0.89		Drying	2.016	0.34	
C. total	11		30172.355				17518.379		
Model	5		43594.666	8718.93	65797.14		51424.725	10284.9	139105.7
Error	6	Freezing	0.795	0.13		Fresh	0.444	0.073936	
C. total	11		43595.461				51425.168		
				TFC (mg/100 g)					
Model	5		355163.56	71032.7	28558.26		1063844.1	212769	143843.7
Error	6	Blanching	14.92	2.5		Drying	8.9	1.479167	
C. total	11		355178.49				1063852.9		
Model	5		351479.17	70295.8	12854.1		385470.96	77094.2	19001.39
Error	6	Freezing	32.81	5.5		Fresh	24.34	4.1	
C. total	11		351511.98				385495.31		
				IC50 (%)					
Model	5		1853.01	370.602	1822.633		2252.3367	450.467	1001.039
Error	6	Blanching	1.22	0.203		Drying	2.7	0.45	
C. total	11		1854.23				2255.0367		
Model	5		6112.4967	1222.5	3526.44		2685.1075	537.022	1682.574
Error	6	Freezing	2.08	0.35		Fresh	1.915	0.319	
C. total	11		6114.5767				2687.0225		

Significance at $P < 0.05$. Prob > $F = 0.0001$ for all treatments.

the chemical composition and structure variations of plants. For instance, the plant shell was indicated to accumulate the higher concentration of these compounds as the protection mechanism against ultraviolet radiation and/or a defense against pathogens and predators [37].

Table 2 also presents the reducing power and DPHH of fruit by-products during processing. Results showed that pomegranate skin had the greatest ($P < 0.05$) reducing power of fresh and freezed samples, while avocado seed and orange peel had the greatest ($P < 0.05$) power of the dried and blanched samples, respectively. Avocado peel had the lowest IC_{50} of heat-treated samples, while it had the greatest ($P < 0.05$) of fresh and freezed samples. These results indicated that due to the differences in bioactive compound types of various fruit by-products, it was expected that these compounds are influenced by processing conditions differently.

4. Conclusion

Fruit by-products flours were characterized in relation to the effect of processing on its bioactive compounds. Fruit by-products have significant amount of flavonoids and phenolic compounds and poses high reducing power and antioxidant activity. Drying, blanching, and freezing have significant impacts on bioactive compounds and antioxidant activity. Results suggest the possible utilization of the nonedible parts of avocado seed and skin, kiwifruit skin, pineapple peel, pomegranate skin, and orange peel as an inexpensive source of bioactive compounds. Nutritional value and antinutritional factors of fruits by-products are believed to be a fruitful research area with the use of fruits by-products produced expected to influence foods nutritional aspects.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Ethical Approval

Human testing was not involved in this study.

Consent

Written informed consent was obtained from all study participants.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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