Journal of Medicinal Plants Research Vol. 6(1), pp. 161-167, 9 January, 2012
Available online at http://www.academicjournals.org/JMPR
DOI: 10.5897/JMPR11.916
ISSN 1996-0875 ©2012 Academic Journals

Full Length Research Paper

Effect of drying techniques on the total phenolic contents and antioxidant activity of selected fruits

Bushra Sultana[1], Farooq Anwar[2,4]*, Muhammad Ashraf[2,3] and Nazamid Saari[4]

[1]Department of Chemistry and Biochemistry, University of Agriculture, Faisalabad-38040, Pakistan.
[2]Department of Botany, University of Agriculture Faisalabad-38040, Pakistan.
[3]Department of Botany and Microbiology, King Saud University, Riyadh, Saudi Arabia.
[4]Faculty of Food Science and Technology, Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Accepted 10 October, 2011

The effect of drying techniques (ambient-drying and oven-drying) on the total phenolic contents and antioxidant activity of selected fruits (apple (*Malus pumila*, var. skysuper), plum (*Prunus salicina,* var. Fezele manani), apricot (*Prunus armeniaca* L, var. Nuri), strawberry (*Fragaria ananassa* var. Corona) and mulberry (*Morus alba* L, var. serrata) were studied. The antioxidant attributes of the fruits were evaluated following different colorimetric assays, while the composition of phenolic acids of the fresh fruits was analyzed by the reverse phase high performance liquid chromatography (RP-HPLC). The amounts of total phenolics (TP) were higher in mulberry samples followed by strawberry, plum, apple and apricot. The tested fruits exhibited appreciable radical scavenging capacity ranging from 58.7 to 82.2% and inhibition of linoleic acid peroxidation activity ranging from 61.8 to 86.1%. The RP-HPLC analysis of the fresh fruits revealed the presence of vanillic- (16.9), syringic- (12.7), *p*-coumaric- (2.30 to 47.5), ferulic- (0.9 to 32.9), sinapic- (3.10 to23.3), caffeic- (6.70-32.8), and gallic- (2.60 to 5.60) acids mg/kg of fresh fruit; *p*-coumaric acid being the most prominent component detected. The results of this study revealed that the amounts of TP and antioxidant activity of all the tested fruits, except those of apricot, decreased after drying treatment; relatively more pronounced decline was observed for the ambient-dried samples as against oven-drying. Therefore, it could be suggested that oven-drying at optimum temperature is comparatively a better means to dry and preserve fruits retaining maximum amounts of antioxidant compounds.

Key words: Fruits, drying, DPPH scavenging, inhibition of per oxidation, phenolic acids, high performance liquid chromatography (HPLC).

INTRODUCTION

It is now well recognized that consumption of selected fruits and vegetables is strongly linked with the reduced risk of chronic diseases such as cancer, inflammation, neurological and cardiovascular disorders and other degenerative diseases (Choi et al., 2007). Antioxidant nutrients including vitamins, carotenoids and polyphenolics with multiple biological activities are mainly responsible for the beneficial health effects of fruits and vegetables (Spada et al., 2008). Phenolic antioxidants are gaining continuing attention due to their efficacy in counteracting free radicals, linked with various diseases. Plants phenolics are considered comparatively more stable and are available as active phytochemicals for uses in different food products to protect them from oxidation and enhancing shelf-life. On the other hand, carotenoids and vitamin C being heat sensitive are quite unstable and their applications in processed foods have been restricted because of their more susceptibility to deterioration (Kuljarachanan et al., 2009). Currently, there is a continuing demand of fresh or minimally

*Corresponding author. E-mail: fqanwar@yahoo.com.

Abbreviations: **RP-HPLC,** Reverse phase high performance liquid chromatography; **TP,** total phenolics; DPPH, 2,-diphenyl-1-picrylhydrazyl radical; **UV,** ultraviolet; **BHT,** butylated hydroxytoluene; **GAE,** gallic acid equivalents; **TPC,** total phenolic content; **AA,** antioxidant activity.

processed foods to getting more nutritive components through diet. Fruits and vegetables are available in fresh form for very short periods and therefore, they are preferably stored at low temperatures, sometimes dried and processed into different items like juices, canned foods and jams, etc. under best suitable conditions for retaining maximum nutrient value. It is well accepted that the conditions of storage and processing exhibit notable effect on the concentration of inherited phytochemicals, especially, carotenoids, phenolic antioxidants and vitamin C of fruits and vegetables (Gebezynski, and Kmiecik, 2007). Drying/dehydration have become comparatively efficient way to minimize nutritional losses and microbial growth, thus leading to enhancing shelf-life of fruits (Di Scala and Crapiste, 2008). Effect of drying on fruit quality is not fully understood, however, major changes in fruits occur when they are exposed to drying at elevated temperature or at low temperature for longer periods.

It is generally considered that besides the chemical and nutritional changes, various physiological and pharmacological alterations in fruit cell-wall polysaccharides can also affect other quality attributes including texture and color of the fruits (Di Scala and Crapiste, 2008; Femenia, 2007). Several drying techniques are being used to dry fruits, some of which are very costly and time-consuming. Vacuum belt drying is a newly introduced technique with many advantages, however, comparatively expensive and rarely accessible (Vashisth et al., 2011). Some fruits are dried under the sun or by using an artificial dryer for the purposes of long term uses (Asgar et al., 2003). Some literature reports show promising effects of ultraviolet (UV) irradiation on the quality of the fruits as compared to other non-thermal fruit preserving techniques (Lopez-Rubira et al., 2005; Alothman et al., 2009). It was found that sun-drying may increase the antioxidant activity and total phenolic contents of some fruits (Al-Farsi et al., 2005). Air-drying and oven-drying are also in practice as an effective and cheap means to dry the fruits (Vega-Galvez et al., 2009). However, drying temperature may affect the quality of fruits. For example, according to a recent study, fruits dried at high temperature have higher concentrations of antioxidant compounds like phenolic acids, anthocyanins, etc. (Shin et al., 2008), while, low drying temperature (freeze-drying) resulted in loss of fruit quality (Cordenunsi et al., 2005); moreover, it is a costly and somewhat lengthy procedure (Vashisth et al., 2011). As drying conditions and postharvest regimes may affect the composition of fruits, so the present research work was planned to appraise the effects of two common drying practices (ambient-drying and oven-drying) on the antioxidant activity and phenolic acids profile of the selected fruits (apple, plum, apricot, strawberry and mulberry).

MATERIALS AND METHODS

Five commercially grown fruits: apple (*M. pumila*, var. skysuper), plum (*P. salicina,* var. Fezele manani), apricot (*P. armeniaca* L, var. Nuri), strawberry (*Fragaria anan(a)ssa* var. Corona) and mulberry (*Morus alba* L, var. serrata), were procured from the main fruit market of Faisalabad city, Pakistan. The fruit specimens were authenticated by Dr. Mansoor Hameed, taxonomist, Department of Botany, University of Agriculture, Faisalabad, Pakistan. Three random samples for each fruit species (consisting of 1000 g each) were taken packed in polythene bags and transported to the laboratory of the Department of Chemistry and Biochemistry, University of Agriculture Faisalabad, Pakistan. Analytical grade chemicals and reagents were used throughout the experimental work. 2, 2,-diphenyl-1-picrylhydrazyl radical (DPPH; 90.0%), linoleic acid, food grade synthetic antioxidant butylated hydroxytoluene (BHT; 99.0%), Folin-Ciocalteu reagent (2 *N*), and standards of phenolic acids (vanillic, syringic, *p*-coumaric, ferulic, sinapic, caffeic and gallic acid) were purchased from the Sigma Aldrich Company (St, Louis, MO, USA). All other chemicals also of analytical grade that is, ferrous chloride, ammonium thiocyanate, potassium dihydrogen phosphate, dipotassium hydrogen phosphate and sodium bicarbonate used in this study were procured from Merck (Darmstadt, Germany).

Sample preparation and drying procedure

The fruit samples were separated into two groups; one for the evaluation of antioxidant activity, on the day of collection (fresh fruit basis), and the other portion subjected to drying under two different conditions described below: Fruit samples of each of apple, strawberry, mulberry, plum and apricot were washed with tap water and then dried with a paper towel. Edible parts of the fruits were cut into small pieces of about 2 mm × 1 cm size. Each sample was independently subjected to ambient-drying (average temperature 30°C, up to 7 days) and oven-drying (using an electric vacuum oven (VOC-300 SD; EYELA, Tokyo, Japan) at 80°C up to 2 days) until constant weight achieved.

Sample extraction for antioxidant activity evaluation

The fresh (homogenized) and dried (ground, 80 mesh) fruit samples (20 g each) were extracted individually with 200 ml methanol solution (methanol: water, 80:20 v/v) for 6 h at room temperature in an orbital shaker (Gallenkamp, UK). The extracts were separated from the residues by filtering through Whatman No. 1 filter paper. The residues were re-extracted two times with the same extracting solvent and the extracts obtained were combined. The combined extracts were concentrated and freed of solvent under reduced pressure at 45°C, using a rotary evaporator (EYELA, S B-651, Rikakikai Company Limited. Tokyo, Japan). The extracts were weighed and stored in a refrigerator (9188 D, Dawlance, Busan , Korea) at -4°C , until further analyses.

Determination of total phenolics (TP)

The amount of TP was appraised using the Folin-Ciocalteu reagent following a previously described method (Chaovanalikit and Wrolstad, 2004). Briefly, 50 mg of the crude extract was mixed with 0.5 ml of Folin-Ciocalteu reagent and 7.5 ml deionized water. The mixture was kept at room temperature for 10 min. After adding 1.5 ml of 20% sodium carbonate solution (w/v), the mixture was incubated in a water bath at 40°C for 20 min followe d by cooling in an ice bath; the absorbance was recorded at 755 nm using a spectrophotometer (model U-2001, Hitachi Instruments Inc., Tokyo, Japan). The amount of TP was calculated using a gallic acid standards calibration curve (concentration range 10-100 mg/L, R^2 = 0.9986). The results were expressed as gallic acid equivalents (GAE) g/100 g of dry fruit. All samples were analyzed thrice and the results averaged.

Determination of 2, 2'–diphenyl–1-picrylhydrazyl radical scavenging activity

DPPH free radical scavenging activity of the fruit extracts was appraised using previously described method (Iqbal et al., 2005). Briefly, to 1.0 ml of extract containing 25 µg/ml of dry extract in methanol, 5.0 ml of freshly prepared solution of DPPH (0.025 g/L) were added. The progress of reaction was indicated with a change in the color from purple to yellow. Finally the absorbance of the reaction mixture was recorded at 515 nm using a spectrophotometer and DPPH radical scavenging activity was calculated. Absorbance measured at 5 min was used for the comparison of radical scavenging activity of the extracts.

Inhibition of lipid peroxidation

We also evaluated the antioxidant potential of the fruit extracts by monitoring their ability to inhibit linoleic acid peroxidation (Iqbal et al., 2005). Each fruit extract (5 mg) was independently added to a linoleic acid solution (0.13 ml), 99.8% ethanol (10 ml) and 10 ml of 0.2 *M* sodium phosphate buffer (pH 7). The volume of the mixture was raised to 25 ml with distilled water and incubated at 40°C for 360 h (15 days).

The degree of oxidation was measured by the peroxide value following the thiocyanate method (Yen et al., 2000). Briefly, 10 ml of ethanol (75% v/v), 0.2 ml of aqueous solution of ammonium thiocyanate (30% w/v), 0.2 ml of sample solution and 0.2 ml of ferrous chloride ($FeCl_2$) solution (20 mM in 3.5% HCl; v/v) were added serially. After 3 min of consistent stirring, the absorption of the reaction mixture was read at 500 nm using a spectrophotometer. A control contained all the reagents, except sample extracts. Synthetic antioxidant BHT was used as a positive control. Percent inhibition of linoleic acid oxidation was calculated with the following equation: 100 – [(Abs. increase of sample at 360 h / Abs. increase of control at 360 h) × 100], to express antioxidant activity.

Sample extraction for the analysis of phenolic acids by HPLC

Extraction/hydrolysis of phenolic acids was carried out following the method of Tokusoglu et al. (2003). Briefly, 25 ml of acidified methanol (1% (v/v) HCl) containing 0.5 mg tertiary butyl hydroquinone (TBHQ) were added to 5 g of each fruit sample and the mixture was refluxed at 90°C for 2 h to obtain free phenolic acids. The extract was cooled to room temperature and centrifuged at (980 × *g*) for 10 min. The upper layer was taken and sonicated for 5 min so as to remove any traces of air.

HPLC analysis of phenolic acids

Acid-hydrolyzed fresh fruit extracts were filtered through a 0.45 µm (Millipore) membrane filter, prior to analysis by reverse phase-HPLC (LC-10A, Shimadzu, Kyoto, Japan), that was the following accessories: binary LC-10 AS pumps, SCL-10A system control unit, Rheodyne injector, CTO-10A column oven, SPD-10A UV–Vis detector, and data acquisition class LC-10 software. A filtered sample of 20 µl was injected into an analytical Supelco (Supelco Inc., Supelco Park, Bellefonte, PA, USA) ODS reverse phase (C18) column (250 × 4.6 mm; 5 µm particle size). The mobile phase consisted of two solvent systems A: H_2O containing 0.02% triflouroaceticacid, B: MeOH containing 0.02% triflouroacetic acid (v/v). The mobile phase was sonicated and filtered under vacuum through a 0.45 µm membrane before use. The phenolic acids were separated by isocratic elution of the mobile phase (mixture of solvent A and B, 50:50 v/v) at a flow rate of 0.50 ml min^{-1} at 30°C and identified at a wavelength of 280 nm. Identification of different types of phenolic acids such as vanillic, syringic, *p*-coumaric, ferulic, sinapic, caffeic and gallic acid was done by comparing their retention times with those of authentic standards (Sigma Chemicals Company, St Louis, MO, USA). Quantitatification of all compounds was done using calibration curves of appropriate standards.

Dry matter determination

Due to varying amount of water in different fruits, all calculations were made on dry mass basis. For the determination of dry matter, each sample (5 to 6 g of each fresh fruit) was dried in an electric vacuum drying oven (VOC- 300 SD, EYELA, Tokyo, Japan) at 70°C, until a constant weight is achieved (This indicates complete removal of water).

Statistical analysis

Three different samples for each fruit were assayed. Each sample was analyzed individually in triplicate and data were reported as mean (n = 3 x 3) ± SD (n = 3 x 3). Analysis of variance of data for each attribute was worked out using the Minitab 2000 Version 13.2 statistical software (Minitab Inc. Pennsylvania, USA). Significant differences (P<0.05) among means were determined by Duncan's multiple range test. A probability value of $P \leq 0.05$ was considered to denote a statistically significant difference between the mean values.

RESULTS AND DISCUSSION

Total phenolic contents (TPC)

Phenolics, a well known group of plant secondary metabolites, are prominent free radical scavengers and also responsible for exhibiting multiple medicinal and physiological functions in animals as well as in plants (Manach et al., 2005). Total phenolic content (TPC) of the fresh and ambient-dried and oven-dried fruits is shown in Table 1. The results showed a significant variation (P<0.05) for TPC among the analyzed fruit species. Among freshly analyzed fruits, higher amount of TP (g/100g of dry matter) was found in mulberry cv. Serrata (3.66), followed by strawberry cv. Corona (2.98), plum cv. Fezele manani (2.59), apple cv. Skysuper (1.65), and apricot cv. Nuri (0.59). The influence of drying method on TPC, was non-significant (P<0.05). Non-significant effects of drying on the total phenolic contents of date fruits has also been reported recently (Borchani et al., 2011). Percent loss in TP contents as affected by ambient-drying ranged from 14.75 to 30.50%. Interestingly among fruits, higher loss was noted for the apricot fruit.

This loss in TP might be ascribed to greater enzymatic degradation as ambient-drying took comparatively longer time for drying leading to additional enzymatic reactions (Garau et al., 2007; Chan et al., 2009; Vega-Galvez et al., 2009). On the other hand, TP contents of all oven dried fruits except that of apricot fruit, relative to fresh samples, also decreased (a decline of 10.8 to 33.9%).

Table 1. Total phenolic contents (GAE g/100 g of dry matter) of the fruits as affected by drying techniques.

Fruit	TPC (GAE g/100 g of dry matter)		
	Fresh[a]	Air-dried (average temperature 30℃) [a]	Oven-dried (temperature 80℃) [a]
Strawberry[B]	2.98 ± 0.13	2.47 ± 0.08	2.19 ± 0.07
Mulberry[A]	3.66 ± 0.14	3.12 ± 0.06	3.17 ± 0.14
Plum[B]	2.59 ± 0.08	2.18 ± 0.09	2.31 ± 0.06
Apple[C]	1.65 ± 0.06	1.32 ± 0.04	1.09 ± 0.05
Apricot[D]	0.59 ± 0.07	0.41 ± 0.02	0.72 ± 0.03

Values (mean ± SD) are average of three samples of each fruit, analyzed individually in triplicate (n = 3 × 3), (P < 0.05). Different capital alphabets in superscript indicate significant differences among fruits while small alphabets in superscript indicate non-significant differences among processing techniques.

Table 2. Inhibition of linoleic acid peroxidation activity (%) of the fruits as affected by drying techniques.

Fruit	Inhibition of linoleic acid peroxidation activity (%)		
	Fresh[a]	Air-dried (average temperature 30℃) [a]	Oven-dried (temperature 80℃) [a]
Strawberry[B]	80.6 ± 1.9	76.8 ± 2.3	78.9 ± 2.2
Mulberry[A]	86.1 ± 2.5	82.1 ± 1.8	83.6 ± 1.7
Plum[B]	79.2 ± 2.8	75.3 ± 2.2	76.8 ± 2.3
Apple[C]	72.5 ± 2.9	69.8 ± 2.7	68.1 ± 2.8
Apricot[D]	61.8 ± 2.5	58.9 ± 1.7	63.7 ± 1.9

Values (mean ± SD) are average of three samples of each fruit, analyzed individually in triplicate (n = 3 x 3), (P < 0.05). Different capital alphabets in superscript indicate significant differences among fruits while small alphabets in superscript indicate non-significant differences among processing techniques.

This decrease in the phenolic contents, though of lesser extent than ambient-drying, might be due to thermal decomposition of antioxidant components (Senevirathne et al., 2009). Nonetheless, an increase in the TP contents of oven-dried apricot fruit might be ascribed to the formation of Maillard reaction products leading to formation of new phenolic compounds from their precursor at high temperature (Que et al., 2008; Yu et al., 2005). Moreover, it can be presumed that bound phenolics with larger molecular weight, in apricort might have been liberated into simple free forms by heat treatment leading to enhancing over all total phenolic contents of the samples. Heat treatment is found to be very effective for increasing the TPC in different foods such as dry beans (Boateng et al., 2008), carob powder (Hilal et al., 2009) vegetables (Sultana et al., 2008), grape seeds (Kim et al., 2006) and peanuts (Davis et al., 2010).

Percent inhibition of linoleic acid peroxidation

Antioxidant activity (AA) of different fruit extracts was assessed by measuring their ability to inhibit oxidation of linoleic acid using the thiocyanate method (Yen et al., 2000). A significant (P < 0.05) variation in the inhibition of lipid peroxidation potential, exhibited by different fruit species, was observed (Table 2). Levels of inhibition of lipid peroxidation offered by fresh fruit extracts (61.8 to 86.1%) were higher than those determined in ambient-dried (58.9 to 82.1%) and oven-dried (63.7 to 83.6%) fruits extracts. Mulberry cv. Serrata exhibited the highest level (86.1%) while the apricot cv. Nuri sample showed the lowest extent of linoleic acid (61.8%). Strawberry cv. Corona, plum cv. Fezele manani and apple cv. Skysuper also inhibited oxidation of linoleic acid at high levels that is, 80.6, 79.2 and 61.8%, respectively. As a result of drying under either of the conditions, inhibition of linoleic acid peroxidation of all fruit extracts, except apricot, decreased indicating non-significant (P>0.05) effects of the methods. As expected, a larger percent decrease in inhibition was noted for ambient-dried fruits. The decrease of antioxidant activity of the fruits after drying might be due to the loss of polyphenol compounds of the fruits (Suvarnakuta et al., 2011).

DPPH free radical scavenging capacity

The effectiveness of the tested fruit extracts for scavenging $DPPH^{\cdot}$ radical showed the similar trends as observed for inhibition of linoleic acid peoxidation activity (Table 3). Among fresh fruits, maximum $DPPH^{\cdot}$ scavenging activity was exposed by mulberry cv. Serrata (82.2%) followed by strawberry cv. Corona (80.1%), plum

Table 3. DPPH free radical scavenging capacity (%) of the fruits as affected by drying techniques.

Fruit	DPPH scavenging capacity (%)		
	Fresh[a]	Air-dried (average temperature 30℃) [a]	Oven-dried (temperature 80℃) [a]
Strawberry[B]	80.1 ± 1.6	78.4± 1.7	79.3 ± 1.6
Mulberry[A]	82.2 ± 1.1	81.1 ± 1.2	80.8 ± 2.8
Plum[B]	79.2 ± 2.1	78.3 ± 2.3	77.4 ± 1.5
Apple[C]	70.3 ± 1.9	68.8 ± 1.9	66.1 ± 2.7
Apricot[D]	58.7 ± 1.7	56.8 ± 2.2	60.8 ± 1.8

Values (mean ± SD) are average of three samples of each fruit, analyzed individually in triplicate (n = 3 x 3), (P < 0.05). Different capital alphabets in superscript indicate significant differences among fruits while small alphabets in superscript indicate non-significant differences among drying technique.

Table 4. Comparison between different antioxidant assays as furnished by calculating correlation coefficient (r) (n = 15).

Variable	Total phenolics	Inhibition of oxidation	DPPH· scavenging
Total phenolics	----------	0.985	0.957
Inhibition of oxidation	0.985	----------	0.977
DPPH· scavenging	0.957	0.977	----------

cv. Fezele manani (79.2%), apple cv. Skysuper (70.3%), and apricot cv. Nuri (58.7%). Comparatively greater decline in DPPH radical scavenging activity was observed for ambient-dried fruit samples as compared to that for oven- dried. This decrease in antioxidant activity of dried fruits might be due to change in the chemical composition or loss of antioxidant constituents of the fruits (Li et al., 2006). However, in our study drying at 80℃ increased the antioxidant activity of apricot. Overall, the results of the present investigation showed considerable variation in the total phenolic contents and antioxidant activity among different fruits. The antioxidant properties were some what superior for fresh fruits followed by those dried at 80℃, whereas the lowest activities were recorded for ambient-dried samples.

Correlation analysis

The results of the colorimetric tests depicting the antioxidant activity of the fruits extract were compared and correlated with each other (Table 4). In the present analysis, we observed a good correlation between the results of TP and radical scavenging activity (r = 0.957). Furthermore, correlation coefficient (r) values for amounts of TP versus inhibition of oxidation and DPPH scavenging activity versus inhibition of oxidation were found to be 0.985 and 0.977, respectively predicting good positive relationships. Overall, correlation analysis data revealed that DPPH· scavenging activity and inhibition of lipid peroxidation of the fruits antioxidant extracts are strongly dependent on the TP contents.

Phenolic acids profile in fruits

The concentrations of phenolic acids determined by HPLC in different fresh fruits are presented in Table 5. Contents of phenolic acids varied significantly (P < 0.05) among types of fruit species as well as nature of phenolic acid. However, drying showed non-significant (P<0.05) effects on the phenolic acid profile of the tested fruits. All the investigated fruits primarily contained *p*-coumaric, ferulic and caffeic acids. Among fruits, strawberry was found to be a rich source of phenolic compounds (104.4 g/kg of dry fruit), *p*-coumaric acid being the principal component with contribution of 47.5 mg/ kg of dry matter, followed by sinapic (23.3), ferulic (14.9), caffeic (13.6), and gallic (13.6) acids. Conversely, ferulic acid was the major phenolic acid of mulberry (32.9 mg/kg), followed by *p*-coumaric (22.4), vanillic (16.9), syringic (12.7), and caffeic (11.9) acids. Plum and apple also contained caffeic acid as the major phenolic compound at levels of 32.8 and 26.1 mg/kg, respectively.

However, concentration of caffeic acid (26.1) determined in the present analysis of apple was found to be higher than that reported by Dragovic-Uzelac et al. (2005) that is, 13.2 mg/kg and Suarez et al. (2010) that is, 22 mg/kg of dry pomace. Such variations in of data might be attributed to differences in the varieties of the fruit used, analytical method adopted as well as due to agroclimatic factors of the harvest place. *P*-coumaric acid (23.6 mg/kg) was determined to be the main phenolic acid in apricot. The amounts of ferulic, caffeic, and gallic acids determined were 13.9, 6.7 and 4.54 mg/ kg, respectively. Dragovic-Uzelac et al. (2007) reported

Table 5. Contents of phenolic acids (mg/kg of dry matter) of selected fresh fruits quantified by HPLC

Fruit	Vanillic acid	*p*-coumaric acid	Ferulic acid	Caffeic acid	Sinapic acid	Syringic acid	Gallic acid	Total phenolics
Strawberry	ND	$47.5^{Aa} \pm 0.8$	$14.9^{Bc} \pm 0.5$	$13.6^{Cc} \pm 0.5$	$23.3^{Ab} \pm 0.8$	ND	$5.60^{Ad} \pm 0.1$	104.9
Mulberry	$16.9^{Ac} \pm 0.4$	$22.4^{Bb} \pm 0.4$	$32.9^{Aa} \pm 0.6$	$11.9^{Cd} \pm 0.3$	ND	$12.7^{Ad} \pm 0.5$	ND	79.9
Plum	ND	$2.30^{Dc} \pm 0.2$	$13.6^{Bb} \pm 0.3$	$32.8^{Aa} \pm 0.7$	ND	ND	$2.60^{Bc} \pm 0.2$	35.4
Apple	ND	$10.2^{Cb} \pm 0.2$	$0.9^{Dd} \pm 0.3$	$26.1^{Ba} \pm 0.5$	$3.10^{Bc} \pm 0.2$	ND	ND	40.3
Apricot	ND	$23.6^{Ba} \pm 0.4$	$13.9^{Bb} \pm 0.5$	$6.70^{Dc} \pm 0.7$	ND	ND	$4.54^{Ac} \pm 0.1$	48.7

Values (mean ± SD) are average of three different samples of each fruit, analyzed individually in triplicate ($n = 3 \times 3$), ($P < 0.05$), ND = not detected. Different capital alphabets in superscript indicate significant differences among fruits while different small alphabets in superscript indicate significant differences among phenolic acids.

somewhat lower levels of ferulic (5.09 to 10.81 mg/kg), caffeic (2.39 to 7.83 mg/kg), and gallic (2.35 to 3.47 mg/ kg) acids in apricot than our present results.

Conclusion

This study indicated that extracts of the fresh fruits possessed greater amounts of TP and thus exhibited higher antioxidant activities than the dried fruit samples. Data on the effects of drying methods showed that greater reduction in the amount of TP and also in antioxidant activity occured when samples were subjected to ambient- drying as compared with oven-drying. Therefore, on the basis of the present results it could be suggested that oven-drying at optimum temperature is a comparatively better means to preserve fruits retaining maximum antioxidant nutrients. Overall, the antioxidant potential of the tested fruits might be attributed to the presence of considerable amounts of various phenolic acids as detected in the present study.

AKNOWLEDGEMENT

Authors express their gratitude to the Higher Education Commission, Islamabad, Pakistan for providing financial aid to conduct this research work.

REFERENCES

Al-Farsi M, Alasalvar C, Morris A, Baron M, Shahidi F (2005). Comparison of antioxidant activity, anthocyanins, carotenoids, and phenolics of three native fresh and sun-dried date (*Phoenix dactylifera* L.) varieties grown in Oman. J. Agric. Food Chem., 53: 7592-7599.

Alothman M, Bhat R, Karim AA (2009). UV radiation-induced changes of antioxidant capacity of fresh-cut tropical fruits. Innov. Food Sci. Emerg. Technol., 10: 512-516.

Asgar M, Yamauchi R, Kato K (2003). Structural features of pectins from fresh and sun dried Japanese persimmon fruit. Food Chem., 87: 247-251.

Borchani C, Besbes S, Masmoudi M, Blecker C, Paquot M, Attia H (2011). Effect of drying methods on physico-chemical and antioxidant properties of date fibre concentrates. Food Chem., 125: 1194-1201.

Boateng J, Verghese M, Walker LT, Ogutu S (2008). Effect of processing on antioxidant contents in selected dry beans (*Phaseolus vulgaris* L.). LWT - Food Sci. Technol., 41: 1541-1547.

Chan EWC, Lim YY, Wong SK, Lim KK, Tan SP, Lianto FS, Yong MY (2009). Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. Food Chem., 113: 166-172.

Chaovanalikit A, Wrolstad RE (2004). Total anthocyanins and total phenolics of fresh and processed cherries and their antioxidant properties. J. Food Sci., 69: 67-72.

Choi YH, Jeong S, Lee J (2007). Antioxidant activity of methanolic extracts from some grains consumed in Korea. Food Chem., 103: 130-138.

Cordenunsi BR, Genovese MI, Aseimento JRON, Hassimotto RJ, Santos NMA, Lajolo FM (2005). Effects of temperature on the chemical composition and antioxidant activity of three strawberry cultivars. Food Chem., 91: 113-121.

Davis JP, Dean LL, Price KM, Sander TH (2010). Roasted effects on the hydrophilic and lipophilic antioxidant capacities of peanut flours, blanched peanut seeds and peanut skins. Food Chem., 119: 359-547.

Di Scala KC, Crapiste GH (2008). Drying kinetics and quality changes during drying of red pepper, LWT: Food Sci. Technol., 41: 789-795.

Dragovic-Uzelac V, Pospisil J, Levaj B, Delonga K (2005). The study of phenolic profiles of raw apricots and apples and their purees by HPLC for the evaluation of apricot nectars and jams authenticity. Food Chem., 91: 373-383.

Dragovic-Uzelac V, Levaj B, Mrkic V, Bursac D, Boras M (2007). The contents of polyphenols and carotenoids in three apricots cultivars depending on stage of maturity and geographical region. Food Chem., 102: 966-975.

Femenia A (2007). High-value co-products from plants: cosmetics and pharmaceuticals. In: Waste management and co product recovery in food processing; K. W. Waldron (Ed.); Wood head Publishing Limited: Cambridge.

Garau MC, Simal S, Roselle C, Femenia A (2007). Effect of air-drying temperature on physico-chemical properties of dietary fiber and antioxidant capacity of oranges (*Citrus aurantium* v. Canoneta) by-products. Food Chem., 117: 647-653.

Gebezynski P, Kmiecik W (2007). Effects of traditional and modified technology, in the production of frozen cauliflower, on the contents of selected antioxidant compounds. Food Chem., 101: 229-235.

Hilal Ş, Ayhan T, Monika PF (2009). Effect of roasting process

on phenolic, antioxidant and browning properties of carob powder. Euro. Food Res. Technol., 230: 155-161.
Iqbal S, Bhanger MI, Anwar F (2005). Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. Food Chem., 93: 265-272.
Kim SY, Jeong SM, Park WP, Nam KC, Ahn DU, Lee SC (2006). Effect of heating conditions of grape seeds on the antioxidant activity of grape seed extracts. Food Chem., 97: 472-479.
Kuljarachanan T, Devahastin S, Chiewchan N (2009). Evolution of antioxidant compounds in lime residues during drying. Food Chem., 113: 944-949.
Li BB, Smith B, Hossain MDM (2006). Extraction of phenolics from citurs peels. I. Solvent extraction method. Sep. Puri. Technol., 48: 182-188.
Lopez-Rubira V, Conesa A, Allende A, Artes F (2005). Shelf life and overall quality of minimally processed pomegranate arils modified atmosphere packaged and treated with UV-C. Post. Biol. Technol., 37: 174-185.
Manach C, Mazur A, Scalbert A (2005). Polyphenols and prevention of cardiovascular diseases. Curr. Opin. Lipid, 16: 77-84.
Que F, Mao L, Fang X, Wu T (2008). Comparison of hot air drying and freez drying on the physicochemical properties and antioxidant activities of pumpkin (*Cucurbita moschata* Duch.) flours. Inter. J. Food Sci. Technol., 43: 1195-1201.
Senevirathne M, Jeon YJ, Ha JH, Kim SH (2009). Effective drying of citrus by-product by high speed drying: A novel drying technique and their antioxidant activity. J. Food Eng., 92: 157-163.
Shin YB, Ryuc JA, Liua RH, Nockc JF, Watkinsc CB (2008). Harvest maturity, storage temperature and relative humidity affect fruit quality, antioxidant contents and activity, and inhibition of cell proliferation of strawberry fruit. Post. Biol. Technol., 49: 201-209.
Spada PDS, de Souza GGN, Bortolini GV, Henriques JAP, Salvador M (2008). Antioxidant, mutagenic, and antimutagenic activity of frozen fruits. J. Med. Food, 11: 144-151.
Suarez B, Alvarez AL, Garcia YD, Barrio GD, Lobo AP, Parra F (2010). Phenolic profiles, antioxidant activity and *in vitro* antiviral properties of apple pomace. Food Chem., 120: 339-342.
Sultana B, Anwar F, Iqbal S (2008). Effect of different cooking methods on the antioxidant activity of some vegetables from Pakistan. Int. J. Food Sci. Technol., 43: 560-567.
Suvarnakuta P, Chaweerungrat C, Devahastin S (2011). Effects of drying methods on assay and antioxidant activity of xanthones in mangosteen rind. Food Chem., 125: 240-247.
Tokusoglu O, Unal MK, Yildirum Z (2003). HPLC-UV and GC-MS characterization of the flavonol aglycons quercetin, kaempferol and myrecetin in tomato and tomato pastes and other tomato-based products. Acta Chromatogr., 13: 196-207 .
Vashisth T, Singh RK, Pegg RB (2011). Effects of drying on the phenolics content and antioxidant activityof muscadine pomace. LWT - Food Sci. Technol., 44: 1649-1657.
Vega-Galvez A, Di Scala K, Rodriguez K, Lemus-Mondaca R, Miranda M, Lopez J, Perez-Won M (2009). Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian). Food Chem., 117: 647-653.
Yen GC, Duh PD Chuang DY (2000). Antioxidant activity of anthraquinones and anthrone. Food Chem., 70: 307-315.
Yu J, Ahmedna M, Goktepe I (2005). Effects of processing methods and extraction solvents on concentration and antioxidant activity of peanut skin phenolics. Food Chem., 90: 199-206.