



Chemical profile, functional and antioxidant properties of tomato peel fiber

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ABSTRACT

Tomato processing residue is defined as a secondary raw material that can increase its value, being considered a potential source of dietary fiber and bioactive compounds. Commercial tomato peel fiber has been analyzed to ascertain the proximate and nutritional composition (moisture, fat, protein, dietary fiber, ash, and minerals), the fractions (insoluble, IDF, and soluble, and SDF) and sugar composition of dietary fiber, functional properties (water retention capacity, WRC, swelling capacity, SWC, fat absorption capacity, FAC, glucose diffusion retardation index, GDRI, and osmotic pressure), total antioxidant activity (AA), and the content of antioxidant bioactive compounds (phenolic compounds and lycopene). To extract phenolic compounds and dietary fiber, three methods were assayed in this study: enzyme hydrolysis, maceration, and ultrasonic assistance. The content of TDF was 84.16%, and the major fraction was the IDF (71.82%), formed mainly by hemicelluloses. Tomato peel fiber retained 6.76 g of water/g as WRC, and it was significantly correlated with the IDF content. In addition, the content of IDF determined the low FAC and SWC and the GDRI at 60 min (39.22%). The main phenolic compound was rutin, followed by naringenin, rutin derivatives, and chlorogenic acid derivatives. These were better extracted using ultrasonic assistance, whereas lycopene showed mean values between 3 and 4 mg/100 g. The AA of tomato peel fiber was low, since the phenolic compounds are mainly bound to the cell wall of plant, showing a low capacity for scavenging radicals. Due to its chemical profile and functional properties, tomato peel fiber can be used as a food supplement, improving the different physical, chemical, and nutritional properties of foods. However the color and flavor of this product must be considered in its applications to avoid a negative effect on the sensory characteristic of the foods to which it is added.

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1. Introduction

Tomato (*Lycopersicon esculentum*) is one of the most consumed vegetables in the world, either as a raw fruit or as a processed product. In fact, in Europe and the US, tomatoes are second only to potatoes in economic importance and consumption and are used in the foodstuff industry as raw material for the production of several products such as juices, sauces, purees, pastes, and canned tomatoes. In recent decades, the consumption of tomatoes has been associated with the prevention of several diseases (Sharoni & Levi, 2006; Wilcox, Catignani, & Lazarus, 2003) mainly due to the content of antioxidants, including carotenes (lycopene as well as β -carotene), ascorbic acid, tocopherol, and phenolic compounds (Martínez-Valverde, Periago, Provan, & Chesson, 2002; Periago et al., 2009). Lycopene has been shown to have strong

antioxidant activity; it exhibits the highest physical quenching rate constant with singlet oxygen; it induces cell-to-cell communication; and it modulates hormones, immune systems, and other metabolic pathways (Rao & Agarwal, 1999). Phenolic compounds exhibit a wide range of physiological properties, such as anti-allergenic, anti-atherogenic, anti-inflammatory, anti-microbial, antioxidant, anti-thrombotic, cardioprotective, and vasodilator effects (Balasundram, Sundram, & Samman, 2006). Whereas tocopherol and ascorbic acid are recognized as antioxidant vitamins and heat-labile compounds, lycopene and phenolic compounds are more resistant to thermal processing, being the main antioxidants in processed products.

Related to the distribution of both compounds in tomatoes, it is recognized that the peel of tomato is richer in lycopene and phenolic compounds than the pulp (George, Kaur, Khurdiya, & Kapoor, 2004). The peel of tomato is available in large quantities as a by-product, since more than 16 million metric tons of tomatoes were estimated to have been processed in the EU in 2005, leading to more than 200,000 tons of solid tomato residue (Anonymus, 2009). In Spain 2,300,000 tons of fresh tomatoes have been used in the industry in 2010, providing more than 30,000 tons of solid tomato residue (Anonymus, 2010). Tomato processing residue is defined as a secondary raw material, and it is possible to gain more benefits by applying several technological procedures to obtain bioactive compounds. One of them is tomato

Abbreviations: TDF, total dietary fiber; IDF, insoluble dietary fiber; SDF, soluble dietary fiber; AA, antioxidant activity; WRC, water retention capacity; SWC, swelling water capacity; FAC, fat adsorption capacity; GDRI, glucose diffusion retardation index; UAE, ultrasound-assisted extraction.

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dietary fiber. Therefore, tomato peels are drum dried, milled, and homogenized to facilitate the transport and storage of the bioactive residue, producing a product with around 75% total dietary fiber (FDT) (Anonymus, 2009). Tomato fiber also has a high content of antioxidants (phenolic compounds and lycopene). Thus, it could be considered an interesting ingredient to be used in the food industry, reducing the environmental pollution associated with the accumulation of tomato processing residue.

Total dietary fiber (TDF) is the part of plant that is resistant to intestinal digestion in human large intestine. The beneficial effects of TDF on human health and body function are well-documented; thus, a high consumption of TDF is associated with a reduced incidence of common disorders and diseases in developed societies such as chronic bowel disorders, obesity, diabetes, cardiovascular disease, and cancer (Bessesen, 2001; Johnson, 2004; Kris-Etherton et al., 2002). In addition, dietary fiber obtained from plant foods rich in phenolic compounds has been considered a dietary source of these antioxidants (Saura-Calixto, 1998).

By-products derived from the tomato industry not only have a potential application in the food industry; due to their content of bioactive compounds, but they are also attractive for the pharmaceutical or cosmetic industries. However, since phenolic compounds are bound to the cell wall and lycopene is inside the chromoplast, the quantification of these compounds requires applying extraction techniques to improve the characterization of the plant food by-products. Conventional extraction of polyphenols from cell walls is generally performed by maceration; however, this technique leads to a low recovery. Other processes have been described to improve extraction such as the use of enzymes and ultrasound. In recent years, enzymes have gradually been extended, because enzymes have high specificity, high catalytic efficiency, and no toxicity. Moreover, they are water soluble; biodegradable; and can be used under mild operational conditions of pH, temperature, pressure, and so on. Although the industrial applications of enzymes have been limited because most enzymes are relatively unstable, it is technically expensive to recover the active enzymes from the reaction mixture after completion of the catalytic process (Daoud, Kaddour, & Sadoun, 2010). Ultrasound-assisted extraction is now a well-established technique commonly used in laboratories and in the industry (Ma, Chen, Liu, & Ye, 2009). Furthermore, up-scaling ultrasonic devices is quite easy, and it is cheaper than other extraction techniques such as microwave-assisted extraction or supercritical fluid extraction.

Although plant food by-products are interesting from a nutritional point of view, only a few of them have been successfully developed from the vast quantities of plant residues produced by the food-processing industry. Tomato dietary fiber represents a potential material to be used as an ingredient in the food industry. It could be also used in the pharmaceutical sector as a nutritional supplement, due to the health-related properties of dietary fiber and associated bioactive compounds. To determine the applications of tomato fiber is crucial to characterizing it and evaluating possible applications according to its composition and functional properties. The objective of the present work has been to ascertain the nutritional composition, antioxidant compounds, and functional properties of tomato peel dietary fiber. To obtain more information about its phenolic composition and lycopene content, ultrasound, enzymatic, and maceration extraction methods have been assayed.

2. Material and methods

2.1. Samples

Tomato peel dietary fiber was provided by “Conservas Vegetales de Extremadura” (CONESA), Extremadura, Spain. Samples were obtained from tomato peel and were packaged in vacuum bags until

the samples were opened for the analysis. All analyses were carried out in triplicate.

2.2. Chemical composition

2.2.1. Nutritional composition

Moisture (method 964.22), crude protein content (method 955.04), lipid content (methods 920.39C), and ash (method 923.03) were estimated using AOAC (1990) official methods. The mineral determination (calcium, magnesium, sodium, potassium, iron, and zinc) was performed with an atomic absorption spectrophotometer (Perkin Elmer, model 3100, Norwalk, CT, USA).

2.2.2. Total, soluble, and insoluble dietary fiber

Total (TDF), soluble (SDF), and insoluble (IDF) dietary fiber were determined with the enzymatic and gravimetric methods described by Prosky, Asp, Scheweizer, Devries, and Furda (1988). The samples were digested to obtain the residue resistant to *in vitro* intestinal digestion and then filtered with a Fibertec System E 1023 (Höganäs, Sweden).

2.2.3. Neutral sugars and uronic acid

Neutral sugars were analyzed after acid hydrolysis of total dietary residues with sulphuric acid 12 M at 35 °C for 30 min. Individual sugars were chemically derivatized to form alditol acetate and were quantified by gas chromatography (Englyst, Quigley, & Hudson, 1994). An Agilent 7890A GLC (Mechelen, Germany) with a flame ionization detector and a capillary column DB-225 were used. Uronic acids were quantified spectrophotometrically in the hydrolysates following the method described by Englyst et al. (1994). The standards (rhamnose, fucose, arabinose, xylose, mannose, galactose, and glucose and galacturonic acids) were purchased from Sigma (St. Louis, EE.UU).

2.2.4. Total phenolic compounds

Total phenolics in the tomato dietary fiber were analyzed using Folin-Ciocalteu's colorimetric assay as described by Singleton and Rossi (1965). Samples were subjected to a procedure of extraction/hydrolysis, as described by Gahler, Otto, and Böhm (2003). One mL of 1 M HCl was added to 0.1 g of sample, vortexed for 1 min, and incubated at 37 °C for 30 min under constant shaking. Later, 1 mL of 2 M NaOH in 75% methanol was added, and the mixture was shaken for 1 min, incubated, and shaken at 37 °C for 30 min. Later, 1 mL of 0.75 M metaphosphoric acid was added, mixed for 1 min, and centrifuged at 2650 g for 10 min. The supernatant was transferred into a 10 mL volumetric flask, and 1 mL of a mixture of acetone:water (1:1, v/v) was added to the pellet, vortexed for 1 min, and centrifuged at 12,850 g for 5 min. The two supernatants were put together and the flask filled up to 10 mL with the mixture acetone:water. Finally, a 1 mL aliquot was taken, centrifuged at 12,850 g for 10 min, and assayed for total phenolics. For the colorimetric assay, 500 µL of 0.2 N Folin-Ciocalteu's phenol (Sigma, ST. Louis, EE. UU) reagent and 400 µL of a 2 M Na₂CO₃ solution were added to 100 µL of hydrolysate. After 2 h of incubation in darkness at room temperature, absorbance at 750 nm was measured. Gallic acid (Riedel-de Haën, Hannover, Germany) was used as the standard, and the total phenolic content in the samples was expressed as mg of gallic acid equivalents (GAE)/100 g.

2.3. Functional properties

2.3.1. Water retention capacity (WRC)

One gram of sample was hydrated with 30 mL of distiller water at room temperature (30 °C). After equilibration (for 18 h), the sample was centrifuged at 3000 g for 20 min; supernatant was then removed. The weight of residue was recorded both prior to drying (fresh weight) at 100 °C and after drying (dry weight) until a constant weight was obtained. WRC was calculated as the amount of water

retained by the sample (g/g dry weight) as follows (Robertson et al., 2000).

2.3.2. Swelling water capacity

Samples were accurately weighed (1 g) and transferred into a calibrated cylinder, and 10 mL of distilled water containing 0.02% sodium azide was added. After thoroughly mixing, cylinders were left to stand undisturbed for 18 h at room temperature. Then, the bed volume was recorded and expressed as volume/g original sample (Robertson et al., 2000).

2.3.3. Fat adsorption capacity (FAC)

Tomato peel fiber (4 g) was mixed with 24 mL sunflower oil for 30 min. Later, the sample was centrifuged at 1600 g for 25 min. The FAC was calculated as the amount of sunflower oil retained by tomato fiber expressed as g/g, following the method reported by Sosulsky and Cadden (1982).

2.3.4. Osmotic pressure

Osmotic pressure of tomato fiber was determined in a solution of 2% (w/v) in distilled water and 0.15 M ClNa, according to the method described by Rey and Labuza (1981) and using a Knauer osmometer (Berlin, Germany).

2.3.5. Determination of glucose diffusion retardation index (GDRI)

The tomato peel fiber samples were hydrated for 14 h before the dialysis with a sodium azide solution (1 g/l). Ten-centimeter lengths of dialysis bags (5–25/32, Medicell International, London) were soaked in 1 g sodium azide/l. The bags were filled with 6 mL of 1 g sodium azide/l and 36 mg glucose alone (as control) or with the addition of 0.2 g of the tomato fiber. Each bag was tied and suspended in 100 mL of 1 g sodium azide/l and placed in a stirred bath at 37 °C for 60 min. At 30 and 60 min, 10 µl of the dialysate was analyzed to determine the total glucose diffused from the bags (TGD) using a glucose assay kit (Chronolab System, S.L, Spain). The rate of diffusion of glucose was calculated according to the following equation:

$$GDRI = 100 - [(TGD \text{ containing fiber} \times 100)] / TGD \text{ from control sac.}$$

2.4. Individual phenolic compound

Individual phenolic compounds of tomato dietary fiber were identified by HPLC after their extraction with three different methods: enzyme hydrolysis, maceration, and ultrasound assistance. All samples were prepared and analyzed in triplicate.

2.4.1. Enzymatic extraction

Two different commercial enzymatic mixtures were used: Biocellulase W (Biocon Española, S.L, Cataluña, Spain) and Rapidase Vegetable Juice (DSM Food Specialties, MA Delft, The Netherlands). Fractions of 1.4 g tomato dietary fiber were put into a flask with 20 mL of citrate buffer pH 4.5, and 200 and 400 U/kg of enzyme were added and stirred to 120 rpm for 3 h at 50 °C. Then, the samples were centrifuged to collect citrate buffer, that was used to quantify the phenolic compounds in the aqueous phase. Twenty mL of 70% methanol was added to the pellet for the extraction of phenolic compounds. Samples were vortexed at room temperature. Then, 4.5 mL samples were taken and concentrated with a vacuum concentrator (Eppendorf model 5301, Hamburg, Germany) until they reached 1 mL. Both aqueous and 70% methanol extracts were quantified to determine the individual phenolic compounds.

2.4.2. Maceration

Tomato dietary fiber (1.4 g) and 20 mL of 70% methanol were put into a stirrer at 120 rpm over 15 h at room temperature, and an aliquot

of 4.5 mL was evaporated with a vacuum concentrator (Eppendorf model 5301, Hamburg, Germany) until it reached 1 mL to analyze the individual phenolic compounds by HPLC.

2.4.3. Ultrasound-assisted extraction (UAE)

Tomato dietary fiber (2.8 g) was weighed into a glass bottle with 40 mL 70% methanol. UAE (Branson Digital, model 250, Danbury, USA) was performed at amplitude 100% at 5, 10, and 15 min, and an aliquot of 4.5 mL was evaporated with a vacuum concentrator (Eppendorf model 5301, Hamburg, Germany) until it reached 1 mL and was used to quantify the individual phenolic compounds.

2.4.4. Chromatographic conditions

Phenolic compounds were analyzed by HPLC (Agilent 1200 Series, Mechelen, Belgium) with the following modules: quaternary pump Quat Pump G1311A, Degasser G1322A, Thermostated column support G 1316A and a DAD detector G1315D (scan range 240 to 400 nm and scan speed 10 nm/s). The phenolic compounds were separated with a RP C-18 column Lichrocart, 250×4 mm, 5 µm (Merck, Darmstadt, Germany) set at 15 °C. A gradient of water acidified (A) with 0.05% trifluoroacetic acid pH 2 and methanol (B) at a flow of 1 mL/min was applied with the following gradient: 0 min 80% A, 45 min 35% A, and 55 min 80% A. Runtime was 60 min. Identification and quantification of phenolic compounds in tomato peel samples were made by comparison of peak retention times, peak areas and spectra with those of external standards (Sigma, St. Louis, USA). UV-visible spectral measurements were made over the range of 210–400 nm. Chromatograms were recorded at 320 nm for hydroxycinnamic acids (chlorogenic acid, caffeic acid, *p*-coumaric acid, and ferulic acid), 360 nm for flavonols (rutin, myricetin, quercetin, and kaempferol) and flavone (luteolin), and 280 for naringenin.

2.5. Analysis of lycopene

Lycopene was quantified spectrophotometrically following the method described by Sharma and Le Maguer (1996). Lycopene extraction also assayed the three extraction methods mentioned above. To 1 g tomato peel dietary fiber, 50 mL of hexane:ethanol:acetone (50:25:25) was added, and the mix was introduced to a bath with UAE (100% amplitude at 5, 10, and 15 min). In addition, the mix was also macerated for 15 h at room temperature to test the effect of maceration in lycopene extraction. Distilled water (15 mL) was added to the sample to separate phases, collecting the hexane. For enzymatic extraction, the following were used: Biocellulase W (Biocon Española, S.L, Cataluña, Spain) and Rapidase Vegetable Juice (DSM Food Specialties, MA Delft, The Netherlands). Fractions of 1 g tomato dietary fiber were put into a flask with 20 mL of citrate buffer pH 4.5. Then, 200 and 400 UI/kg of enzyme were added and stirred at 120 rpm for 3 h at 50 °C. Samples were centrifuged to dispose of citrate buffer. Then, 50 mL of hexane:ethanol:acetone (50:25:25) was added. For the extraction of lycopene, samples were mixed for 30 min at room temperature. After that, 15 mL of distilled water was added, and the upper phase containing hexane and lycopene was collected to quantify the lycopene. All steps were performed in the dark.

2.6. Antioxidant activity of tomato fiber

Antioxidant activity (AA) of both hydrophilic and lipophilic extracts was measured by the Trolox Equivalent Antioxidant Capacity (TEAC) assay (Miller, Sampson, Candelas, Bramley, & Rice-Evans, 1996). The assay is based on the reduction of the radical cation of ABTS that is generated by filtering an ABTS solution through manganese dioxide powder. Trolox (Sigma, St. Louis, USA) was used as the standard, and results were expressed as µmol Trolox equivalents/kg. To obtain the hydrophilic extracts, 0.5 g of sample was diluted in 10 mL of water, vortexed for 1 min, and centrifuged at 12,850 g for

10 min. The supernatant was assayed for TAA. The lipophilic extracts were obtained by homogenizing 0.2 g of sample in 20 mL of a mixture hexane:acetone:methanol (2:1:1, v/v/v) for 30 min protected from light. After that, 15 mL of water was added, and the mixture was centrifuged at 2650 g for 5 min (Shi et al., 2007). The upper layer containing the lipophilic fraction was transferred into a 10 mL volumetric flask and filled up to 10 mL with hexane. Finally, a 1 mL aliquot of the lipophilic fraction was dried under a nitrogen stream and then reconstituted into 0.5 mL 2-propanol before being analyzed for AA.

2.7. Statistical analysis

Data were analyzed by the Statistical Package SPSS 15.0 version for Windows. An analysis of variance was included in the data treatment to study the variation in the analyzed compounds as a function of the extraction methods. Relationships between variables were examined using Pearson correlation coefficients. *P* values < 0.05 were considered statistically significant.

3. Results and discussion

3.1. Composition of tomato peel fiber

Table 1 summarizes the proximate composition, dietary fiber, and mineral content of the sample. It was found that tomato peel dietary fiber has a low content of crude protein (13.3%), lipid (6%), and ash (3%), being the main compounds the complex carbohydrates represented by dietary fiber. The content of TDF was 84.16 g/100 g with the following distribution: IDF 71.82 g/100 g and SDF 14.33 g/100 g. The TDF content of tomato peel fiber was found to be higher than those reported in other vegetables; for example, red grape peels (64.6 g/100 g) (Saura-Calixto, 1998), carrot peels (45.5 g/100 g) (Chantaro, Devahastin, & Chiewchan, 2008), and fiber-rich cocoa product (60.5 g/100 g) (Lecumberri et al., 2007). The ratio of IDF:SDF was 5:1, since the peels of vegetables are usually rich in cellulose and hemicelluloses that make the IDF. In fact, the neutral sugar composition and uronic acids of dietary fiber (Fig. 1) showed that the main sugars of tomato peel fiber are mannose (38.56%), galactose (16.17%), xylose (15.38%), arabinose (15.16%), and glucose (14.64%), which indicates that hemicelluloses are the predominant polysaccharide of this fiber. However, the content of uronic acids, associated with pectin and SDF, was very low. A high proportion of IDF in the tomato fiber could be considered an advantage, because IDF can be used in the food industry as an ingredient to increase the indigestible insoluble compounds. It can also be processed by different approaches (chemical treatments, fermentation, and enzymatic treatment with endo-hydrolases) to convert IDF into SDF (Vitaglione, Napolitano, & Fogliano, 2008). To get a better fiber profile, tomato fiber can be mixed

with another dietary fiber to increase the soluble fraction; for example, with dietary fiber from fruit peels.

The mineral composition of tomato fiber (Table 1) shows that the major elements are K, Mg, Ca, and Na. These results show that tomato fiber could be considered a good source of K, Mg, and Ca, and it is low in Na. On the contrary, the content of Fe and Zn is considered very low. From a nutritional point of view the low Na/K ratio in tomato peel dietary fiber is interesting. This is due to the low content of sodium that it is present in the tomato fruit, which has been suggested as a protective factor against cardiovascular diseases. In addition, this property is interesting from a nutritional point of view, because tomato fiber could be used as a food supplement, and it does not increase the mineral content of food significantly, providing low levels of Na.

3.2. Functional properties of tomato peel fiber

The use of specific fibers in food products is largely determined by their functionality, which depends on physicochemical properties and by food processing, however their impact on sensory characteristics of food must be considered (Tosh & Yada, 2010). Table 2 shows the functional, antioxidant, and physiological properties of tomato peel fiber. To ascertain the functional properties, WRC, SWC, and FAC were evaluated as hydration properties. To determine the antioxidant properties, hydrophilic and lipophilic antioxidant activities and total phenolic compounds were quantified. To determine the physiological properties, the osmolarity and the GDRI were evaluated.

Hydration properties of dietary fiber refer to its ability to retain water within its matrix. Fiber with strong hydration properties could increase stool weight and potentially slow the rate of nutrient absorption from the intestine, and it can enhance the viscosity of the added food. The WRC of the peel of the tomato sample was 6.76 g/g; however, this product showed a very low SWC. The WRC value was similar to those found in other dietary fiber sources like artichoke (Lopez et al., 1996), soybean (Espinosa-Martos & Rupérez, 2009), and seaweeds (Gómez-Ordoñez, Jiménez-Escrig, & Rupérez, 2010). It was significantly higher than those reported for fiber from citrus peels and apple pomace (Figueroa, Hurtado, Estévez, Chiffelle, & Asenjo, 2005). However, the low SWC is related to the amount of IDF and the low content of SDF, especially pectin. It is known that the structural characteristics and chemical composition of the fiber play an important role in the kinetics of water uptake (Figueroa et al., 2005; Lopez et al., 1996). Moreover, it is also known that cellulose and insoluble hemicelluloses, the main compounds of our sample, do not swell when mixed with water (Lecumberri et al., 2007). These results are in agreement with those reported for the carob pod fiber, which is a product rich in IDF (70%) (Bravo, Grados, & Saura-Calixto, 1994). According to the hydration proportion in a water system and from a technological point of view, tomato peel fiber can contribute to stabilizing food systems, improving product density and minimizing shrinkage, since IDF is used as a texturizing agent that contributes to mouthfeel and reduces lipid content. From a nutritional point of view, tomato fiber increases the daily intake of indigestible compounds with a beneficial effect on intestinal function.

The ability of fiber to adsorb fat or oil can be important in food applications; for example, in preventing fat loss upon cooking and in nutrition where the ability to absorb or bind bile acids and increase their excretion is associated with plasma reduction (Schneeman, 1999). According to Lopez et al. (1996) and Femenia, Lefebvre, Thebaudin, Robertson, and Bourgeois (1997), FAC depends on the surface properties of fiber, overall charge density, thickness, and the hydrophobic nature of the fiber particle. The FAC of tomato peel fiber was 1.46 g oil/g, which is similar to fibers from other fruits, vegetables, and seaweeds (≤ 2 g/g) (Femenia et al., 1997; Figueroa et al., 2005; Gómez-Ordoñez et al., 2010; Lopez et al., 1996) and lower than cereal fibers (2–4 g/g) (Femenia et al., 1997). Sosulsky and Cadden (1982)

Table 1
Proximate and nutritional composition of tomato peel fiber.^a

Parameters	Amount
Protein (%)	13.30 ± 0.04
Lipid (%)	6.01 ± 0.13
Moisture (%)	5.71 ± 0.18
Total dietary fiber (% TDF)	86.15 ± 0.63
Insoluble dietary fiber (% IDF)	71.82 ± 0.75
Soluble dietary fiber (% SDF)	14.33 ± 0.40
Ash (%)	3.01 ± 0.02
Calcium (mg/100 g)	140.50 ± 27.20
Magnesium (mg/100 g)	157.33 ± 20.13
Sodium (mg/100 g)	78.33 ± 2.75
Potassium (mg/100 g)	1125 ± 93.67
Iron (mg/100 g)	1.68 ± 2.79
Zinc (mg/100 g)	0.53 ± 0.33

^a Data are mean values of triplicate determination ± standard deviation.

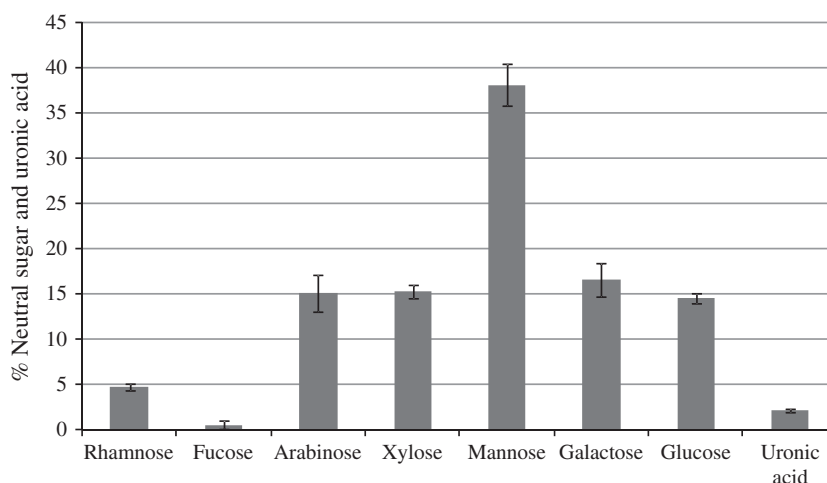


Fig. 1. Percentage of neutral sugars and uronic acid of tomato peel fiber residue.

found that fibers with high lignin contents have a higher FAC. Therefore, the low values of FAC found in tomato peel fiber may be due to the absence or limited presence of lignin in tomato peels (Fraga, Villamide, & Carabaño, 1995).

The osmotic pressure of a tomato peel fiber solution was measured as an indicator of potential problems associated with diarrhea after the intake of the fiber. Data measured in water was very low, whereas the osmolarity of the sample in a physiological solution of ClNa was 313 mosM/kg. This is similar to the internal physiological values (302 mosM/kg), showing a significant correlation with the WRC ($r = 0.99$, $p = 0.043$). For this reason, we can assume that tomato fiber has WRC water but cannot capture water from the internal environment of the organism by itself, avoiding diarrhea problems (López, 1995).

The GDRI is considered a useful *in vitro* index to predict the effect of the fiber on the delay of glucose absorption in the gastrointestinal tract. At 30 min, the GDRI was zero (data not shown), since the glucose diffusion in the sample was the same as that in the control. However, the GDRI of the tomato peel fiber at 60 min was 39.2% (Table 2), increasing the GDRI with time. Some authors have indicated that fiber GDRI is influenced by viscosity, and it could also be due to the physical obstacle presented by insoluble fiber particles toward glucose molecules and the entrapment of glucose within the network formed by fiber (Chau, Chen, & Lin, 2004; Lopez et al., 1996). Our results suggest that tomato peel fiber can reduce the absorption of glucose during intestinal digestion mainly due to the entrapment of molecules of glucose in the network formed by the IDF components. This property is interesting from a nutritional point of view, because it

could reduce postprandial glucose after the intake of foods to which tomato peel fiber is added.

3.3. Antioxidant activity (AA) and phenolic content of tomato peel fiber

Many epidemiological studies have focused on the physiological effects of consuming a diet rich in fiber. In all cases, attention has mainly focused on the polysaccharides, while the bioactive compounds associated with dietary fiber and its potential antioxidant role have been less considered. AA and the content of total phenolic compounds of tomato peel are shown in Table 2. The content of total phenolic compounds of tomato peel fiber was 158.1 mg GAE/100 g, showing a higher content than those reported in other fibers; for example, orange (*C. aurantium* cv. *Canoneta*) (0.51 mg GAE/100 g) (Garau, Simal, Roselló, & Femenia, 2007), orange (*C. sinensis* cv. *Valencia*) (0.16 mg GAE/100 g), and lime (*C. aurantifolia* cv. *Persa*) (0.35 mg GAE/100 g) (Larrauri, Rupérez, Bravo, & Saura-Calixto, 1996). However, total phenolic compounds were considerably low compared with other fibers from cocoa (Lecumberri et al., 2007) and carrot peels (Chantaro et al., 2008).

AA of tomato peel fiber was 3.90 μ mol TEAC/g for hydrophilic extract and 0.044 μ mol TEAC/g for lipophilic extract (Table 2). Hydrophilic AA is related to the total phenolic compound content of tomato fiber, since these compounds are the main antioxidants of tomato when vitamin C has been hydrolyzed (García-Alonso et al., 2009; Periago et al., 2009). Hydrophilic AA was lower than expected; it is noteworthy that the AA of the phenolic compounds in food is usually attributed to the soluble fraction. As a consequence of the high content of IDF, which entrapped the main phenolic compounds bounded to the cell wall of the plant, the AA of the hydrophilic extracts of tomato peels was also relatively low. Lipophilic AA is attributed to the content of lipophilic antioxidants like lycopene. However, lipophilic AA is usually low in tomatoes and tomato products when it is analyzed using the ABTS method (García-Alonso et al., 2009). Despite the relatively low AA of this by-product, it is important to emphasize remarkable attributes of this product, especially in comparison with other sources of dietary fiber like cellulose, wheat bran, etc., commonly used in the food industry, which lack intrinsic AA. Therefore, this quality of tomato peel enhances its possibility as an alternative source of dietary fiber.

3.4. Extraction and quantification of phenolic compounds and lycopene

To identify the main antioxidants (phenolic compounds and lycopene) bound to tomato peel fiber, an appropriate extraction is

Table 2

Functional properties, total phenolic compounds, and antioxidant activity of tomato peel fiber.^a

Parameters ^b	Tomato peel fiber
WRC (g water/g)	6.76 $\pm$ 0.21
SWC (mL water/g)	0.11 $\pm$ 0.01
FAC (g oil/g)	1.46 $\pm$ 0.06
Osmotic pressure (mosM/kg ClNa)	313.10 $\pm$ 1.02
Osmotic pressure (mosM/kg water)	22.07 $\pm$ 0.88
% GDRI (60 min)	39.22 $\pm$ 4.24
Total phenolic compounds (GAE mg/100) g	158.10 $\pm$ 7.70
AA (μ mol TEAC/g)	
Hydrophilic extract	3.90 $\pm$ 0.46
Lipophilic extract	0.044 $\pm$ 0.092

^a Data are mean values of triplicate determination $\pm$ standard deviation.

^b WRC: water retention capacity; SWC: swelling water capacity; FAC: fat adsorption capacity; GDRI: glucose diffusion retardation index; AA: antioxidant activity.

Table 3

Content of individual phenolic compounds (expressed in mg/kg) in tomato peel fiber extracted with three different methods: enzyme hydrolysis, maceration, and ultrasound assistance.^a

	Biocellulase		Rapidase		Maceration	Sonication		
	200 U/kg	400 U/kg	200 U/kg	400 U/kg	15 h	5 min	10 min	15 min
Chlorogenic	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Chlorogenic der	38.00 ± 0.43 ^b	38.4 ± 2.20 ^b	33.00 ± 1.12 ^b	36.5 ± 2.03 ^b	108.64 ± 3.53	116.60 ± 7.73	141.10 ± 20.15	136.88 ± 36.22
p-Coumaric	7.38 ± 2.23	8.85 ± 0.77	8.62 ± 0.40	7.70 ± 0.93	18.62 ± 0.41	24.76 ± 1.29	26.58 ± 1.75	26.13 ± 1.66
p-Coumaric der	17.00 ± 5.13	21.60 ± 3.93	18.70 ± 1.05	16.70 ± 2.60	33.44 ± 2.03	101.34 ± 4.30	101.99 ± 1.17	98.65 ± 3.25
Quercetin	6.36 ± 1.19	7.30 ± 0.26	5.53 ± 0.23	5.04 ± 0.75	9.45 ± 0.24	13.03 ± 1.16	13.68 ± 0.76	13.02 ± 1.48
Rutin	107.06 ± 21.56	148.00 ± 13.56	140.40 ± 3.78	127.29 ± 8.14	314.28 ± 8.98	371.44 ± 30.06	410.13 ± 24.78	387.33 ± 34.58
Rutin der	36.00 ± 8.66	46.50 ± 4.88	44.92 ± 0.80	40.51 ± 5.37	75.53 ± 2.10	85.92 ± 18.95	106.54 ± 9.11	109.75 ± 16.25
Naringenin	79.40 ± 1.43 ^b	82.50 ± 5.14 ^b	73.52 ± 1.97 ^b	74.10 ± 6.32 ^b	189.88 ± 4.06	272.69 ± 21.34	287.62 ± 15.61	281.42 ± 36.91
Total	291.14 ± 11.1	353.15 ± 19.6	324.25 ± 1.35	307.54 ± 2	749.84 ± 15.55	985.78 ± 112.93	1087.64 ± 87.7	1056.18 ± 67.9

Chlorogenic der: Chlorogenic acid derivatives; p-Coumaric der: p-Coumaric acid derivatives; Rutin der: Rutin derivatives.

^a Data are mean values of triplicate determination ± standard deviation, Nd: not detected.

^b Significant differences for $p \leq 0.05$.

necessary to avoid underestimation. Table 3 shows the individual phenolic compounds of tomato fiber obtained following different extraction methods: enzymatic treatment with Rapidase and Biocellulase at two enzyme concentrations (200 U/kg and 400 U/kg), maceration and ultrasound assistance (UAE). In general, UAE is the method that provides a better extraction of phenolic compounds from tomato peel fiber, followed by maceration and enzymatic treatment. The analysis of variance showed that the content of individual phenolic compounds depends on the extraction method, since statistically significant differences ($p \leq 0.05$, data not shown) were observed among the three procedures. These results suggest that UAE is more efficient, reducing the extraction time and increasing yield. The fact that enzyme extraction is less efficient than UAE or maceration might be due to the fact that during enzymatic hydrolysis, proteins are released from the cell wall. This is known to form a complex with the phenolic compound, therefore reducing the yield (Li, Smith, & Hossain, 2006). Both maceration and sonication were used by directly mixing the sample with methanol 70%, which has the ability to denature proteins and provide a better extraction.

If we observe the results in each of the extraction methods, no significant differences were observed in the enzymatic procedure according to the amount of the enzyme. Regarding the two types of enzymes used, only Biocellulase gave a significant increased recovery ($p \leq 0.05$) of total derivatives of chlorogenic compared with Rapidase. This difference could be due to the different enzymatic activities of the Commercial products. Specifically, Biocellulase contains xylanase, which hydrolyses the hemicellulosic polysaccharides of the cell walls

of plants (Beg, Kapoor, Mahajan, & Hoondal, 2001). Therefore, the enzymatic degradation of the cell wall facilitates the extraction of the phenolic compounds, taking into consideration that hemicelluloses are the predominant polysaccharides of tomato peel fiber.

The yield of all phenolic compounds using the UAE was significantly higher ($p \leq 0.05$) than those obtained using maceration and extraction. However, the content of phenolic compounds in tomato peel fiber obtained after different sonication periods (5, 10, and 15 min) did not vary with time. Hence, sonication for 5 min is recommended as enough time to obtain a good extraction of phenolic compounds bound to fiber polysaccharides.

Although the three extraction methods provided different total amounts of phenolic compounds, the profiles obtained were the same in all the assays, rutin being the main compound, followed by naringenin, rutin derivatives, and derivatives of chlorogenic acids (Table 3). These results suggest that tomato peel fiber has several flavonoids with beneficial effects for human health. For example, rutin has been associated with markedly decreased hepatic and cardiac levels of triglycerides (Fernandez et al., 2010), and it has been suggested that it has anti-inflammatory properties (Guardia, Rotelli, Juarez, & Pelzer, 2001). Naringenin has been suggested as an antioxidant, an anti-inflammatory, and a regulator of fat metabolism and sex hormone metabolism. Finally, quercetin has been reported to exhibit antioxidative, anticarcinogenic, anti-inflammatory, anti-aggregation, and vasodilating effects (Erlund, 2004).

The content of lycopene in tomato peel fiber extracted following the three procedures and quantified spectrophotometrically is shown

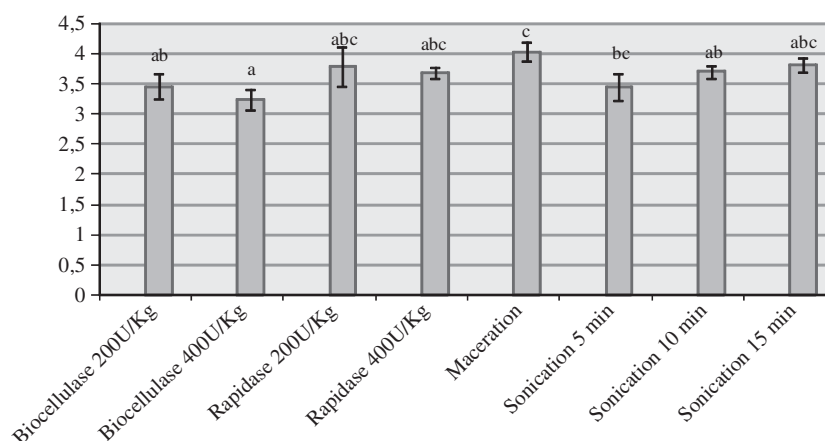


Fig. 2. Lycopene content of tomato peel fiber (expressed as mg/100 g) extracted with three different methods: ultrasound assistance (UAE), maceration, and enzyme hydrolysis (different letters show significant differences for $p \leq 0.05$).

in Fig. 2. The content of lycopene in tomato peel fiber ranged between 3 and 4 mg/100 g. With maceration, a slightly higher but significant extraction of this carotenoid was obtained. However, with all extraction methods, a residual content of lycopene remained in the sample, because the tomato fiber continued to exhibit a red color after the extraction with hexane. These results suggest that to improve the extraction of lycopene from tomato peels, stronger treatment is required, such as supercritical fluid extraction (Rozzi, Singh, Vierling, & Warkins, 2002) or supercritical carbon dioxide (Topal, Sasaki, Goto, & Hayakawa, 2006).

4. Conclusion

This study revealed that tomato peel fiber is rich in insoluble fiber and could potentially be used as a food supplement to improve different physical, chemical, and nutritional properties of the foods to which it is added. Tomato peel fiber can be considered a source of insoluble hemicelluloses and antioxidant bioactive compounds, such as lycopene, rutin, and chlorogenic acids. Due to its properties, tomato fiber could be used as a functional ingredient in many potential applications: as a volume replacer, thickening, or texturizing agent in the development of foods with low-fat content; as a rich dietary fiber source; and as an antioxidant enhancer. However, color and flavor must be considered in its applications to avoid a negative effect on sensory characteristics of food to which it is added.

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