Development of an Ingredient Containing Apple Peel, as a Source of Polyphenols and Dietary Fiber

Carolina Henríquez, Hernán Speisky, Italo Chiffelle, Tania Valenzuela, Manuel Araya, Ricardo Simpson, and Sergio Almonacid

Abstract: Apple peel is a waste product from dried apple manufacture. The content of phenolic compounds, dietary fiber, and mineral are higher in apple peel, compared to other edible parts of this fruits. The objective of this study was to develop an ingredient from Granny Smith apple peel, using a pilot scale double drum-dryer, as drying technology. The control of all steps to maximize the retention of phenolic compounds and dietary fiber was considered. Operational conditions, such as drying temperature and time were determined, as well as important preprocessing steps like grinding and PPO inhibition. In addition, the physical–chemical characteristics, mineral and sugar content, and technological functional properties such as water retention capacity, solubility index, and dispersability among others, were analyzed. A simple, economical, and suitable pilot scale process, to produce a powder ingredient from apple peel by-product, was obtained. The drying process includes the application of ascorbic acid at 0.5% in the fresh apple peel slurry, drum-dryer operational conditions were 110 °C, 0.15 rpm and 0.2 mm drum clearance. The ingredient developed could be considered as a source of phenolic compounds (38.6 mg gallic acid equivalent/g dry base) and dietary fiber (39.7% dry base) in the formulation of foods.

Keywords: apple peel, dietary fiber, drum-dryer, ingredient, phenolic compounds

Practical Application: A method to develop an ingredient from Granny Smith apple peel using a pilot scale double drum-dryer as drying technology was developed. The method is simple, economical, feasible, and suitable and maximizes the retention of phenolic compounds and dietary fiber present in the raw matter. The ingredient could be used in the formulation of foods.

Introduction

Apples are a significant part of the human diet. In addition, they have been identified as one of the main dietary sources of antioxidants, mainly phenolic compounds, such as flavonoids and phenolic acid; and they also possess high antioxidant capacity (Wolfe and others 2003; Khanizadeh and others 2008). In Chile, apple trees are one of the most important fruit trees, and commercial apple production has reached 1.3 million ton/y (ODEPA 2009). Around 60% of this production is destined for exports, mainly as fresh produce, while the rest is processed to juice concentrates, frozen, and dried products. The dried-apple processing generates apple peel as waste product. Industrially, apples are peeled mechanically, and the peels are typically used as compost or in the production of juice. It is estimated that approximately 9000 metrics tons of peels are generated annually, as a result of apple processing.

Several researches have determined that the antioxidant concentration and antioxidant capacity of the apple peel is higher than that of the pulp fractions or the whole fruit, these components are known to have health-promoting properties (Wolfe and others 2003; Łata and Tomala 2007; Drogoudi and others 2008; Khanizadeh and others 2008). In addition, several researches have reported that the dietary fiber and the mineral content are higher in apple peel as compared to other edible parts of the fruit (Gorinstein and others 2001; Leontowicz and others 2003). If apple peel shows potential in improving general health when consumed, the development of an apple peel ingredient represents an attractive way to add value to this by-product but, it needs to be processed to a stabilized form.

Fruit drying is a very ancient practice; it extends shelf life, and minimizes handling/distribution of raw materials with high moisture content. However, drying causes physical, chemical, and biological changes, especially to natural nutrients because most of the bioactive compounds are relatively unstable to heat (Chantaro and others 2008; Chan and others 2009). On the other hand, recent studies have shown that thermally processed foods, especially fruits and vegetables, have higher biological activity due to their various chemical changes during heat treatment, when compared to the food at the fresh state (Chang and others 2006; Mrkìc and others 2006). Three scientific reports have shown the development of a powder product from apple peel (Bomben and others 1971; Wolfe and Liu 2003; Rupasinghe and others 2008). Bomben and others (1971), developed an ingredient to enhance flavor in apple pie, but they did not focus on antioxidant components. Wolfe

MS 20091033 Submitted 10/16/2009, Accepted 4/16/2010. *Author Henríquez is with the doctorate program, Univ. de Chile, Santiago, Chile. Authors Henríquez, Simpson, and Almonacid are with Centro Regional de Estudios en Alimentos Saludables, Valparaíso, Chile. Author Speisky is with Inst. de Nutrición y Tecnología de los Alimentos, Univ. de Chile, Santiago, Chile. Authors Chiffelle and Valenzuela are with Dept. de Agroindustrias y Enología, Facultad de Ciencias Agronómicas, Univ. de Chile, Santiago, Chile. Author Araya is with Centro de Investigación Agrícola y Ambiental, Univ. de Viña del Mar, Viña del Mar, Chile. Authors Simpson and Almonacid are with Dept. de Ingeniería Química y Ambiental, Univ. Técnica Federico Santa María, Valparaíso, Chile. Direct inquiries to author Henríquez (E-mail: carolinahenriquez@creas.cl; sergio.almonacid@usm.cl).*

doi: 10.1111/j.1750-3841.2010.01700.x

Journal of Food Science A Publication of the Institute of Food Technologists

and Liu (2003) used 3 systems to carry out the drying process of apple peel; oven, convective air, and freeze driers, they focused on the polyphenol retention after drying. As expected, freeze drier resulted in the higher polyphenols retention, 92% wet base. The process in the oven system was carried out at 40, 60, and 80 °C, each of them up to equilibrium, and polyphenols retention were in the range 69% to 78% wet base. Finally, the convective air system retention was 92% wet base; however, drying temperature and final moisture were not reported. Rupasinghe and others (2008) used an oven system at 60 °C to dry the apple peel and incorporated it to an apple muffin. They did not specify the drying operation. In general, these data are difficult to be compared. Systematic studies to analyze the process that stabilizes this by-product have not been reported in the literature.

The drum dryer is a common and economical industrial practice for the production of a variety of foodstuffs, such as milk, precooked cereals, applesauce, fruit purees, baby foods, dry soup mixture, and so on (Kostoglou and Karapantasios 2003; Pua and others 2007). It is one of the cheapest methods of drying with 60% to 90% energy efficiency, higher production rates, and fewer operating labor requirements (Tang and others 2003). In addition, this type of drying is suited to many heated sensitive products since exposure to high temperature is limited to a few seconds (Pua and others 2007). Temperature, drying time, and other important processing variables should be determined to maximize the retention of important bioactive compounds, that is, phenolics and dietary fiber of apple peel. Another factor that needs to be controlled during the preprocessing step of apple peel drying is the level of polyphenoloxidase (PPO) activity; apples are highly susceptible to enzymatic browning and the waiting time before drying could have a significant impact on antioxidant components.

The general objective of this study was to develop a product/process to obtain an apple peel powder ingredient, by utilizing a double drum dryer system to stabilize the product. While the specific objectives were (1) to develop the preprocessing (grinding) steps to drum drying apple peel; (2) to evaluate the retention of phenolic compounds and the dietary fiber, after drying apple peels; (3) to evaluate 4 PPO inhibitors; ascorbic acid, citric acid, commercial mix, and blanching, applied before drum drying, during the grinding step; and (4) to characterize the physical, chemical, antioxidant, and functional quality of the powder product.

Materials and Methods

The methodology consisted of 3 main steps; raw material characterization and conditioning, drum dryer operation, and inhibition of PPO activity and product (ingredient) characterization.

Granny smith apple peels were used as raw material, since it is often used to produce dried apples. Peel was collected from a local commercial manufacturer, SURFRUT Co., in 2008. Immediately after mechanically peeling, the peels were packed into polyethylene bags, frozen at −20 °C, then transported to the Univ. Federico Santa María, and stored in a freezer chamber at −20 °C until used.

The double drum dryer used in this study consists of 2 hollow cylinders of equal diameters rotating very close together in opposite directions, while heated internally by saturated steam (Model ADD by Food and Chemical Equip. Inc., Buffalo, N.Y., U.S.A.). In general, the material to be dried is fed into the wedge shaped space between the drums, then it divides into 2 films (one on each drum), and after a residence time in contact with the heated surface, the dried material is removed by scraper blade, spanning the whole width of the each drum (Kostoglou and Karapantasios 2003; Pua and others 2007). Figure 1 shows a diagrammatic scheme of the methodology

Raw material characterization (Step [1] in Figure 1)

Proximate composition: It was determined by AOAC reference methods (AOAC 2006).

Color: It was measured from 6 randomly selected samples of frozen apple peel. The parameters CIELab: L^*, a^*, and b^* were measured in a Minolta (Osaka, Japan) CR-200b tristimulus reflectance colorimeter. Numerical values of a^* and b^* were converted into Hue angle ($H° = \tan^{-1}(b^*/a^*)$) and Chroma ($C = (a^{*2} + b^{*2})^{1/2}$) (McGuire 1992).

pH, titratable acidity, and soluble solids content: Samples of frozen apple peel were homogenized for 1 min in 200 mL of boiled water in a blender. The homogenate was filtered in a vacuum condition and the filtrate apple juice was used for the analysis. The pH was measured using a digital pH-meter (Microprocessor pH Meter 537 WTW, Weilheim, Germany). The titratable acidity was determined, by the titration with 0.1 M NaOH to pH 8.1. The results were expressed as percentage of malic acid (% of malic acid) (AOAC 2006). The soluble solids content was determined using a hand-refractometer (model Master T, VWR International, West Chester, U.K.) at 20 °C. Ten milliliters of the filtrate were centrifuged at 1600 × *g* for 10 min in a centrifuge

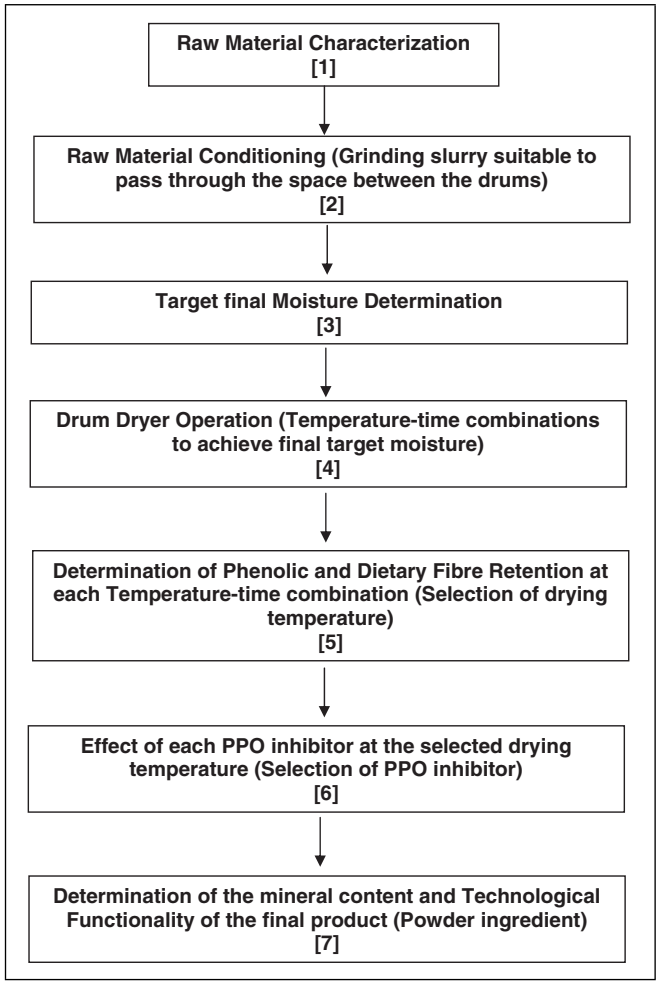

Figure 1–Diagrammatic scheme of the methodology.

(HERMLE Z200A, Wehingen, Germany) and the soluble solid content (°Brix) was determined in the resultant supernatant.

Total and reducing sugar contents: These were determined by the Munson and Walker method (AOAC 2006).

Dietary fiber: It was determined by the enzymatic-gravimetric methods according to Lee and others (1992).

Total phenolic content: It was determined using a modified colorimetric method proposed by Singleton and Rossi (1965). A total of 10 g of apple peel were mixed with 90 mL of solvent extraction (70 : 30 acetone : water). Then, this mixture was homogenized for 1 min in an Ultra Turrax homogenizer (OMNI Intl., GLH-02, Kennesaw, Ga., U.S.A.); and then the extracts were mixed in an orbital shaker at 170 rpm for 60 min. Subsequently, three samples (1.5 mL) were centrifuged at 2500 × *g* for 15 min, and the supernatants were analyzed. Then, 0.50 mL of this extract was mixed with 3.0 mL of distilled water and 0.25 mL of Folin–Ciocalteu reagent (Sigma Chemical Co., St. Louis, Mo., U.S.A.). Immediately, 0.75 mL of sodium carbonated (20%) and 0.95 mL of distilled water were added. Finally, the mixture was incubated for 30 min at 37 °C, and the absorbance was read at 765 nm using a UV-Vis spectrophotometer (Jenway 6505, Felsted, U.K.). The measurement was compared to a standard curve prepared with gallic acid (Sigma Chemical Co.) solution. The total phenolic content was expressed as milligrams of equivalents of gallic acid per gram of dry weight (mg EGA/g DW). The analyses were run in triplicate.

Mineral composition: The minerals analyzed in this study were: nitrogen, phosphorus, potassium, calcium, magnesium, and sodium; and trace elements: copper, iron, manganese and zinc. The preparation and the analyses of the samples was developed using the protocol experimental proposed by Sadzawka and others (2007). Working standard solutions of N, P, K, Mg, Na, Ca, Fe, Cu, Mn, and Zn were prepared from the stock standard solutions containing 1000 mg/L of element in distilled water. In each analytical batch, at least 5 reagent blanks and 3 international reference materials were included to assess precision and accuracy for chemical analysis. Calibration and measurement of all the above-mentioned elements (except N and P) were done on Atomic Absorption Spectrometer (Varian AA 240, Palo Alto, Calif., U.S.A.), using the flame spectrophotometric method with air and acetylene. The N and P contents were estimated with a molecular absorption spectroscopic method. The absorbance was measured using a UV-Vis spectrophotometer (Jenway 6505), at 650 nm for N and 466 nm for P. The measurement was compared to a standard curve prepared with standards of N-NH_4 and P-PO_4 solutions, respectively. Nutrient concentration of the main mineral was expressed as a percentage (%) and the trace elements were expressed as milligrams per hundred grams of fresh weight (mg/100 g FW). All analyses were run in triplicate.

Preprocessing conditioning (Step [2] in Figure 1)

The raw material consists of peel pieces around 5 × 5 mm, with some attached pulp. It was necessary to add water to appropriately ground the raw material into a suitable slurry for drum drying. Different proportions of solid/water were tried until the best possible slurry (minimum water addition) was obtained. For this purpose, a Waring blender (51 BL 32, Torrington, Conn., U.S.A.) with variable speed was used.

Target moisture of the final product (Step [3] in Figure 1)

To determine the corresponding moisture, prepared slurry was drum dried to different final moisture, and a_w was measured at 25 °C, with a water activity meter (HygroLab2 HW4, Rotronic Instruments Corp. Huntington, N.Y., U.S.A.).

Pilot scale drum-dryer operation (Step [4] and [5] in Figure 1)

Four typical processing temperatures were selected: 110, 120, 130, and 140 °C, and the corresponding drying times (drum speed) to achieve the target moisture of the final product were determined in a 1st experimental step, for which the clearance between the 2 drums was set at 0.2 mm. After time–temperature combinations for the selected final moisture were determined, a 2nd experimental step was carried out to evaluate the processing effect on the nutritional components (phenolics and dietary fiber) and functional properties (water retention capacity [WRC], swelling capacity [SWC], solubility index [SI], dispersability, and fat adsorption capacity [FAC]).

Effectiveness of the inhibition of PPO activity (Step [5] in Figure 1)

The treatments evaluated to inactivate the PPO were: (1) application of chemical solutions at 0.2 and 0.5%; ascorbic acid, citric acid, and SURFRUT preparation (commercial mix, private information of supplier company SURFRUT, mix of ascorbic acid, and citric acid). In these treatments, chemical solutions were applied to the grinding process, in the concentration indicated previously, before the drying operation; (2) Blanching: Frozen apple peels were dipped in boiling water for 10 s; then drained and cooled in a water bath of distilled water. After this, the fresh apple peel slurry was prepared. These assays aimed to evaluate the best condition to inactivate PPO and hence to avoid the polyphenols oxidation while waiting for drying. To evaluate the effect of these pretreatments, the pastes were kept at 20 °C for 120 min (time enough to simulate any waiting time before drying). The corresponding chemical analyses were: PPO activity and total phenolic content. The extraction of PPO was developed following a modified protocol reported by Rocha and de Morais (2001). Twenty grams of fresh apple peel slurry were homogenized using an Ultra-Turrax homogenizer (OMNI Intl., GLH-02, Kennesaw, Ga., U.S.A.) for 1 min with 40 mL of 0.05 M pH 6.5 sodium phosphate buffer, 2% of insoluble polyvinilpirrolidone (PVP, Sigma Chemical Co.) and 0.25% of Triton X100 (Sigma Chemical Co.). The homogenates were centrifuged (HERMLE Z200A) at 4 °C for 20 min at 2300 × *g*. Then, the supernatants were filtered and used for the analysis. Three replicates were assayed for each determination. The protein content was determined in the extract prepared by the colorimetric method described by Bradford (1976).

The PPO activity was evaluated using a modified method reported previously by Almeida and Nogueira (1995) and Rocha and de Morais (2001). The PPO activity was assayed by determining the rate of increase in absorbance at 420 nm in a UV-Vis spectrophotometer (Jenway 6505). The reaction mixture contained 2.6 mL of 0.05 M pH 6.5 sodium buffer phosphate, 0.3 mL of 0.6 M catechol (Sigma Chemical Co.) substrate, freshly prepared in the same buffer and 0.1 mL of enzyme preparation. The reference cuvette contained only the buffer and the catechol substrate solution. The reaction mixture was incubated for 60 min at 30 °C in a water-bath, previously to be mixed with the enzyme extract. Absorbance values were recorded at 1 min intervals. The linear section of the activity curve as a function of time was used to determine PPO activity (Units of PPO/mg of soluble protein/min). The unit for the PPO activity was defined as a change of 0.001 in absorbance in the conditions of the assay. Determinations were

performed in duplicate for each of the 3 replicates of each experiment.

The total phenolic content was determined, using the method described previously. However, to avoid the interference between the ascorbic acid and the Folin–Ciocalteau reagent that contributes to the absorbed measurement in the assay (Wolfe and Liu 2003), was prepared an extract ascorbate free of sample of fresh apple peel slurry with ascorbic acid. In this case, 100 μL of the fresh extract, prepared with the methods described previously, were mixed with 300 μL of 4 mM pH 6.5 sodium buffer phosphate and 15 μL of ascorbate oxidase (Sigma Chemical Co.) (43.2 U/mL) and incubated at ambient temperature for 60 min. After this, the total phenolic content was evaluated with the methods described previously. Determinations were performed in triplicate for each of the 3 replicates of each experiment.

Product (ingredient) characterization (Step [6] in Figure 1)

Proximate composition, color, pH, acidity, solid soluble content, total and reducing sugar, dietary fiber, and total phenolic content: were determined with the methods described previously.

Functional properties: To evaluate possible modifications affecting the structural arrangement of cell wall polysaccharides from apple peel samples, hydration-related properties, SWC and WRC; dispersability, SI and FAC were measured. WRC, SWC, and SI were evaluated following the method reported by Femenia and others (1997). Dispersability was evaluated with the method proposed by Gamel and others (2006). These 4 evaluations were done at 2 different water temperatures (20 and 100 °C). FAC was measured at ambient temperature (20 °C), according the method reported by Femenia and others (1997).

Statistical analysis

All results were expressed as mean ± SE of 3 samples taken of each condition evaluated. All processing tests were made in duplicate, and samples were analyzed in triplicate. These evaluations were performed by one-way analysis of variance and statistical significance by Student's *t* test. All statistical analysis and correlations were performed using SAS software (SAS Inst. Inc., Cary, N.C., U.S.A.). Differences at $P < 0.05$ were considered to be significant.

Results and Discussion

Raw material characterization

The physicochemical parameters and the content of total phenolic, sugar, mineral, and dietary fiber of Granny Smith apple peel are shown in Table 1.

Moisture represented about 86% of the total fresh weight of the apple peel. This value is similar to the value reported by Łata (2007). The Granny Smith apple peel had a low content of ash, lipids, and protein, but a high content of crude fiber. The nitrogen-free extract confirmed the high content of carbohydrates.

In general, most foods have pH values in the range of between 4 and 7 (Fennema 1985). The pH of Granny Smith apple peel was 4.1. The acidity was 2.3% of malic acid and the solids soluble content was 40.8 °Brix. The color parameters of Granny Smith apple peels, indicated that the peel was lighter, green (a^* parameter was negative), and the coordinate b^* indicates a slight yellow colour. The Hue angle and the Chroma values obtained were 116 and 44, respectively. Similar L^*, a^*, and b^* values were reported by Drogoudi and others (2008).

The results of main mineral and trace elements content of Granny Smith apple showed that the samples evaluated contained high amounts of potassium, followed by nitrogen, phosphorus, calcium, magnesium, and sodium, which were the most abundant elements. In relation of the trace elements, it can be seen that iron has the highest concentration, followed by manganese, zinc, and copper. These microelements are involved in many biochemical processes supporting life.

Dietary fiber plays an important role in human health (Figuerola and others 2005). Apple peel is a good source of total dietary fiber (TDF), with a well-balanced proportion between the soluble and insoluble fraction. Our results indicated that TDF represented about 47.8% of the dry weight of Granny Smith apple peel. This value is 17-fold higher than the values reported by Gorinstein and others (2002) and Leontowicz and others (2003). This difference could be attributed to different cultivars evaluated and different fruit growing conditions. Most of the TDF content of apple peels corresponds to insoluble dietary fiber (IDF) (42.1%) in comparison to the content of soluble dietary fiber (SDF) (5.8%). In disagreement with our results, Gorinstein and others (2002) and Leontowicz and others (2003), reported that the proportion of IDF and SDF was 2.3-fold higher and 2-fold lower, than the values reported by these researches, respectively. The IDF/SDF

Table 1–Characterization of Granny Smith apple peel and apple peel ingredient.[a]

Parameters	Granny Smith apple peel	Apple peel ingredient
Proximal composition		
Moisture (%)	86.2 ± 1.9	2.2 ± 0.4
Ash (%)	2.4 ± 0.1	2.3 ± 0.03
Lipids (%)	2.7 ± 0.1	2.1 ± 0.2
Crude fiber (%)	19.6 ± 0.6	18.6 ± 1.5
Protein (%)	2.7 ± 0.5	2.3 ± 0.2
Nitrogen free extract (%)	72.7 ± 0.1	74.7 ± 1.3
Acidity (% of málic acid)	2.3 ± 0.1	2.9 ± 0.2
PH	4.1 ± 0.02	4.2 ± 0.01
Solubles solids (° Brix)	40.8 ± 2.2	63.5 ± 2.7
Water activity		0.2 ± 0.01
Colour parameters		
L^*	63.8 ± 0.8	51.3 ± 4.1
a^*	–19.1 ± 0.3	3.9 ± 0.4
b^*	39.9 ± 0.7	27.2 ± 0.6
Hue	115.6 ± 0.3	81.8 ± 1.7
Croma	44.3 ± 0.73	27.5 ± 0.3
Sugar		
Total	48.9 ± 1.6	55.4 ± 1.9
Reducing	36.9 ± 3.0	43.0 ± 0.6
Mineral composition		
Nitrogen (%)	0.37 ± 0.07	0.37 ± 0.03
Phosphorus (%)	0.11 ± 0.02	0.11 ± 0.00
Potassium (%)	1.06 ± 0.20	0.78 ± 0.02
Calcium (%)	0.08 ± 0.01	0.12 ± 0.00
Magnesium (%)	0.06 ± 0.01	0.07 ± 0.00
Sodium (%)	0.06 ± 0.02	0.04 ± 0.00
Iron (mg/kg)	149.41 ± 1.94	194.59 ± 19.53
Manganese (mg/kg)	10.26 ± 0.73	11.90 ± 0.71
Zinc (mg/kg)	5.41 ± 0.06	5.05 ± 0.32
Cupper (mg/kg)	4.07 ± 0.59	20.13 ± 3.23
Dietary fiber		
Total (%) (TDF)	47.8 ± 1.8	39.7 ± 0.5
Soluble (%) (SDF)	5.8 ± 2.4	11.9 ± 1.2
Insoluble (%) (IDF)	42.1 ± 4.2	27.8 ± 1.1
Total phenolic content (mg EGA/g DW)	28.3 ± 1.1 41.2 ± 2.0 (Slurry)	38.6 ± 1.4

[a]Values represent mean of 3 replications ± SE.

ratio was 7.3/1, which is different to the proportion of 1.7/1 obtained by Gorinstein and others (2002) and Leontowicz and others (2003). In addition, this ratio is not considered a well-balanced proportion for physiological purposes because a 70% to 50% of insoluble and 30% to 50% of soluble dietary fiber, is required to complement each other (Gorinstein and others 2001). The SDF/IDF ratio is important for both, dietary and functional properties. It is generally accepted that, sources that are suitable as a food ingredient, should have a soluble–insoluble ratio of approximately 1/2 (Figuerola and others 2005). Our results indicate that the SDF/IDF ratio of apple peel is 1/13.7.

The total phenolic content of Granny Smith apple peels, was 28.3 mg GAE/g DW. This value is 3-fold higher than the values reported by Łata (2007) and Drogoudi and others (2008), but it is 3- and 5-fold lower than the data obtained by Łata and Tomala (2007). These differences may be due to the complexity of these groups of compounds, different fruit growing conditions, and the methods of extraction and analysis used in the samples evaluated.

Preprocessing conditioning

The selected rate solid/water was 100 g frozen apple peel with 60 mL of distilled water.

Target moisture of the final product

Product final water activity is a key factor for powder ingredients, normally for these types of products, an a_w value of 0.2, at storage temperature of 25 °C, is recommended (Fennema 1985; Pua and others 2007). The prepared slurry was drum dried to different moisture contents, and the moisture content corresponding to a a_w of 0.2 was determined to be between 2% and 3%.

Pilot scale drum-dryer operation

The drying kinetic of apple peel slurry, dried in the pilot scale drum-dryer is shown in Figure 2, for all four processing temperatures evaluated. These kinetics allowed to estimate the processing times to achieve 2% moisture at each temperature (Table 2). It can be observed, that drying temperature had an important influence on the drying rate. As expected, longer drying periods were required at lower temperatures. Additionally, drying kinetics showed a biphasic behavior, a rapid sharp decrease in the moisture content followed by a slow elongated decrease to a stable level.

The total phenolic content in the raw matter and respective apple peel dried samples, are shown in Figure 3A. It varied between 25.8 and 14.1 mg GAE/g DW. Our results indicate significant reduction ($P < 0.05$) of phenolic compounds during the drying process. In effect, Wolfe and Liu (2003) reported reduction of total phenolic contents when drying apple peel in different systems such as oven, air, and freeze drying. Other researchers have determined that the drying process applied to different products, resulted in significant declines in total phenolic content (Larrauri and others 1997; Kwok and others 2004; Chan and others 2009). This effect could be a result of polyphenols enzymatic oxidation, especially during the preprocessing operations, and due to the thermal instability of these molecules (Kwok and others 2004; Kyi and others 2005).

Additionally, Figure 2 shows that higher temperature treatments such as 130 and 140 °C (shorter residence times), resulted in lower retention of total phenolic compounds, 57% and 55% dry base, respectively. While the process carried out at the lowest temperature of 110 °C (longest residence time) showed the highest phenolic retention, approximately 70% dry base. This indicates that the severity of the treatment is a function of temperature, moisture, and time (Kwok and others 2004; Mrkìc and others 2006). In agreement with this study, Larrauri and others (1997) and Kyi and others (2005) determined that the polyphenol degradation rate increases with increasing drying temperature for different vegetable tissue.

The thermal process changes the properties of dietary fiber in many ways. In Figure 3B, the content of TDF, IDF, and SDF, for the raw matter and the 4 temperatures studied are shown. Our results indicate that TDF decreases as drying temperature increases; however, this difference was not significant ($P > 0.05$). TDF was retained between 85% and 95% dry base being the highest retention at 110 °C. In relation to IDF and SDF, all the temperatures modified the proportion of IDF/SDF from 1/13 in the raw

Table 2–Drying kinetic of apple peel.

Drying temperature (°C)	Drum speed (rpm)–drying time (s)
110	0.15–400
120	0.50–153
130	1.25–85
140	2.0–55

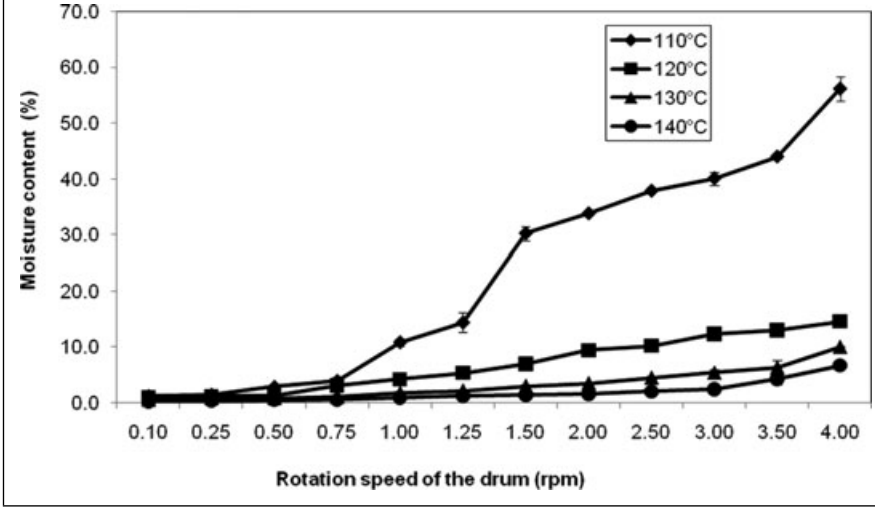

Figure 2–Drying kinetics at 110, 120, 130, and 140 °C.
[1] Values represent mean of 3 replications ± SE.

material to the same value of 1/3 in the final product, just within the recommended range of close to 1/2, suitable as a food ingredient (Figuerola and others 2005). This may be due to the exposure to high temperatures of vegetable tissue, which could release fiber components from the insoluble cell wall matrix, increasing the soluble fiber content. In effect, the mechanical disruption of cells during processing might have resulted in better extraction of fiber components (Puupponen-Pimiä and others 2003).

The values obtained in this study for TDF were 1.1- to 1.4-fold higher than those reported by Rupasinghe and others (2008), for apple peel from Idared and Northern Spy cultivars, which were dried at 60 °C for 48 h in an oven system. In agreement with the result of this study, the proportion of IDF/SDF obtained by Rupasinghe and others (2008), was between 1/3 and 1/4, for Idared and Northern Spy, respectively. On the other hand, these study's values of TDF and IDF were 1.3- and 1.5-fold lower than those reported by Figuerola and others (2005), for concentrates of Granny Smith apple pomace, dried at 60 °C during 30 min in an air tunnel drier.

The functional properties of samples of apple peel dried and evaluated at 20 and 100 °C are shown in Table 3. Drying treatments did not significantly affect the functional properties ($P > 0.05$).

Dispersibility is an indication of the suspensibility of particles in water, which is a useful functional parameter in formulations of various food products (Gamel and others 2006). Dispersability ranged between 44.8% and 52.2% (at 20 °C) and from 52.9% and 56.9% (at 100 °C).

Swelling capacity (SWC) of the apple peel varied between 8.6 and 10.0 mL water/g DW (at 20 °C) and from 8.1 to 9.6 mL water/g DW (at 100 °C). In disagreement with us, the values reported by Figuerola and others (2005) are 1.3-fold lower than the values obtained in this study. This difference could be related to the structural characteristics and the chemical composition of the components (water affinity), which play important roles in the

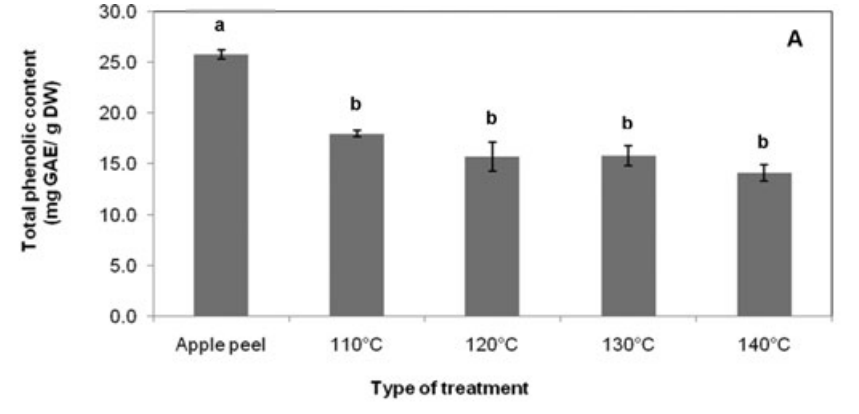

Figure 3–Total phenolic content (2A) and total, insoluble, and soluble dietary fiber (2B) in the apple peel (raw matter) and in the dried apple at 110, 120, 130, and 140 °C. [1,2,3]
[1] TDF = total dietary fiber; IDF = insoluble dietary fiber. SDF = soluble dietary fiber.
[2] Values represent mean of 3 replications ± SE.
[3] Different letters in the same treatment denote significant differences ($P < 0.05$); values bearing the same superscript are not significant.

Table 3–Functional properties in the apple peel dried at 110, 120, 130, and 140 °C.[A,B]

	Temperature of evaluation (°C)							
	20 °C				100 °C			
Functional properties	**110 °C**	**120 °C**	**130 °C**	**140 °C**	**110 °C**	**120 °C**	**130 °C**	**140 °C**
Dispersability (%)	44.8 ± 2.3[a]	47.3 ± 0.5[a]	48.1 ± 0.7[a]	52.2 ± 2.3[a]	52.9 ± 2.3[a]	54.8 ± 0.0[a]	56.9 ± 1.9[a]	55.5 ± 3.0[a]
SWC (mL water/ g DW)	9.7 ± 0.2[a]	10.0 ± 0.[a]	9.6 ± 0.0[a]	8.6 ± 0.0[a]	9.6 ± 0.3[a]	8.9 ± 0.1[a]	9.0 ± 0.5[a]	8.1 ± 0.4[a]
SI (%)	38.7 ± 0.9[a]	36.5 ± 0.7[a]	37.3 ± 0.3[a]	38.1 ± 0.6[a]	35.9 ± 0.6[a]	34.6 ± 0.8[a]	35.7 ± 0.7[a]	37.5 ± 0.6[a]
WRC (g water/ g DW)	1.7 ± 0.1[a]	1.9 ± 0.2[a]	1.7 ± 0.1[a]	1.8 ± 0.1[a]	2.0 ± 0.1[a]	1.9 ± 0.2[a]	2.0 ± 0.1[a]	1.7 ± 0.1[a]
FAC (g oil/g DW)	5.6 ± 0.0[a]	5.7 ± 0.2[a]	6.0 ± 0.1[a]	5.5 ± 0.2[a]				

SWC = swelling capacity; SI = solubility index; WRC = water retention capacity; FAC = fat absorption capacity.
[A]Values represent mean of 3 replications ± SE.
[B]Means in the same type of functional properties and temperature of evaluation followed by the same superscript small letter in a row are not significantly different ($P < 0.05$).

kinetics of water uptake (Figuerola and others 2005). According to these researchers, water could be held in capillary structures of the components as a result of surface tension strength, and also water could interact with molecular components, through hydrogen bonding or dipole forms.

Solubility index (SI) is another property relevant to the consumption characteristics of ingredients as it affects sensory attributes such as taste perception (Shittu and Lawal 2007). The date obtained in this study indicate that SI ranged from 36.5% to 38.7% (at 20 °C) and from 34.6% to 37.5% (at 100 °C). The most important factor that is expected to affect solubility is the sugar and fat content, since sugar is the major soluble component of the products (Shittu and Lawal 2007).

The enhanced ability of a food ingredient to absorb and retain water and oil, may help to improve binding structure, enhance flavor retention, improve mouth feel and reduce moisture and fat losses (Gamel and others 2006). The results of this study indicated that water retention capacity (WRC) of the dried apple peel varied from 1.7 to 1.9 g of water/g DW (at 20 °C) and from 1.7 to 2.0 g of water/g DW (at 100 °C). A similar value of WRC was reported by Figuerola and others (2005).

The fat adsorption capacity (FAC) depends on surface properties, overall charge density, thickness, and hydrophobic nature of the components (Figuerola and others 2005). The values showed by the dried apple peel varied between 5.5 and 6.0 g of oil/g DW. These results are 4-fold higher than the values obtained by Figuerola and others (2005).

The results obtained in this study indicate that, the drying temperature and the drum speed, which maximize the retention of phenolic compounds and dietary fiber; and did not affect the functional properties, were 110 °C and 0.15 rpm, respectively.

Effectiveness of the inhibition of PPO activity

Enzymatic browning causes deterioration of sensory and nutritional quality, due to phenolic compound degradation, and affects appearance and organoleptic properties, such as color and flavor. Several methods have been used to control the PPO activities, such as the use of blanching or the utilization of antibrowning agents (Almeida and Nogueira 1995).

The changes in PPO activity over the period of time (120 min at ambient temperature), after the application of antibrowning agents such as citric acid, ascorbic acid and SURFRUT preparation, at 0.2% and 0.5%, plus the blanching, are shown in Figure 4. It can be seen that the PPO activity was significantly different depending on the type of treatment used ($P < 0.05$). All the treatments decrease significantly the PPO activity, in comparison with the control ($P < 0.05$). In addition, in all of them, we observed that PPO activity increased over the period of time; however only in the case of the blanching and ascorbic acid at 0.2%, we determined that this difference was significant after being exposed for 120 min at 20 °C. In agreement with this study, Rocha and de Morais (2005) reported that in apple cubes stored at 4 °C, the PPO activity increased after 7 d of storage.

The most efficient compound in decreasing the PPO activity was ascorbic acid at 0.5%. These results are in agreement with the data obtained by Rocha and de Morais (2005) who have determined that among the inhibitors used, ascorbic acid was the most effective. The other concentration of antibrowning agent evaluated in this study (0.2%), decreased the PPO activity, but the reduction was significantly lower (39.7%). This could indicate that the inhibition of PPO is dependent on the concentration of the chemical agent used. In effect, Almeida and Nogueira (1995) reported that, 0.5% of ascorbic acid was sufficient for complete inhibition of enzyme from apples. The blanching significantly reduced the PPO activity, but in comparison with the control, at the beginning, around 33% of PPO activity remained; however, this increased to 54%, at the end of the evaluation. Similar results were reported by Akissoe and others (2005), and they hypothesized that in the case of yam (*Dioscorea spp.*), the structure and/or other components stabilized the PPO during blanching, preventing its inactivation. In our case, the condition of the samples and the time of exposure could not be adequate for PPO inactivation.

Drying of the apple peel at 110 °C, completely inactivated the PPO activity (date not shown).

Figure 5 shows the total phenolic content of the fresh apple peel slurry. Our results indicate that the phenolic content varied significantly between the treatments applied ($P < 0.05$). However, when we considered the exposure at 20 °C, the differences observed were significantly ($P < 0.05$) in the control and the citric acid treatments at 0.2% and 0.5%. In effect, our values showed that in the control treatment, the total phenolic content decreased significantly 29% after the exposure at 20 °C during 120 min.

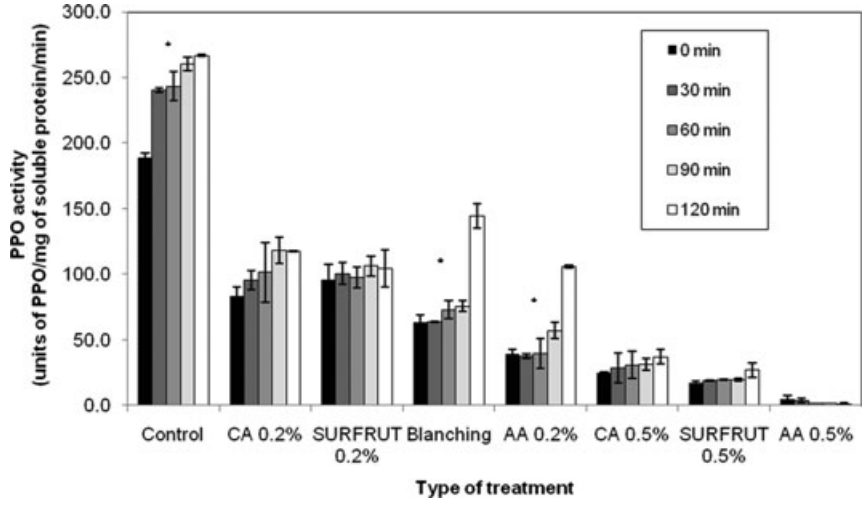

Figure 4–PPO activities in the fresh apple peel slurry, after the application of the antibrowning treatment, and exposed at ambient temperature during 120 min.[1,2,3]
[1] CA 0.2% = citric acid at 0.2%; SURFRUT 0.2% = SURFRUT preparation 0.2%; AA 0.2% = ascorbic acid at 0.2%; CA 0.5% = citric acid at 0.5%; SURFRUT 0.5% = SURFRUT preparation 0.5%; AA 0.5% = ascorbic acid at 0.5%.
[2] Values represent mean of three replications ± SE.
[3] * Significant difference ($P < 0.05$) of treatment over time.

The data obtained indicated that the utilization of antibrowning agents reduced the loss of phenolic compounds during the preprocessing and significantly retained the highest proportion of these compounds, in comparison with the control. However, independently of the type and concentration of antibrowning agent, the phenolic compounds decreased at the end of the evaluation.

The blanching reduced the total phenolic content, in comparison to the control. In effect, in comparison with the control, the loss varied between 23% and 6%, at the start and the end of the exposition at 20 °C, respectively. This was probably due to leaching in the water or to enzymatic oxidative degradation of the phenols catalyzed by PPO (Wolfe and Liu 2003; Akissoe and others 2005; Mrkìc and others 2006). In agreement with us, similar results were reported by Puupponen-Pimiä and others (2003), Akissoe and others (2005), and Chantaro and others (2008). However, Wolfe and Liu (2003) determined that apple peels blanched for 10 s had the highest total phenolic content, than those that were untreated or subjected to citric acid or vitamin C dips. These differences could be attributed to different apple cultivars, drying processes and applications of the pretreatment methods.

On the other hand, in all the treatments evaluated, no correlation was observed when PPO activity was plotted against total phenolic content (date not shown). Similar results were reported by Rocha and de Morais (2005) in apple cubes treated with ascorbic acid.

We determined the effect of antibrowning agent on fresh apple peel slurry and evaluated the effect of the best treatments over the total phenolic content of the apple peel dried at 110 °C. The treatment choices were (1) citric acid at 0.2% and 0.5%; (2) SURFRUT preparation at 0.2% and 0.5%; and (3) ascorbic acid at 0.2% and 0.5%. The results obtained are shown in Figure 6. It can be see that the treatments with ascorbic acid at 0.5% have the highest significant total phenolic content in the fresh apple peel slurry and in the dried apple peel.

The results obtained show that, to obtain an ingredient with a higher content of phenolic compounds, one of the most important factors that need to be controlled during the processing is the PPO activity; due to the drying process only reduced the phenolic compounds to around 12%.

Product (ingredient) characterization

The physical and chemical parameters and the content of sugar, total phenolic, and dietary fiber of the apple peel ingredient are shown in Table 1.

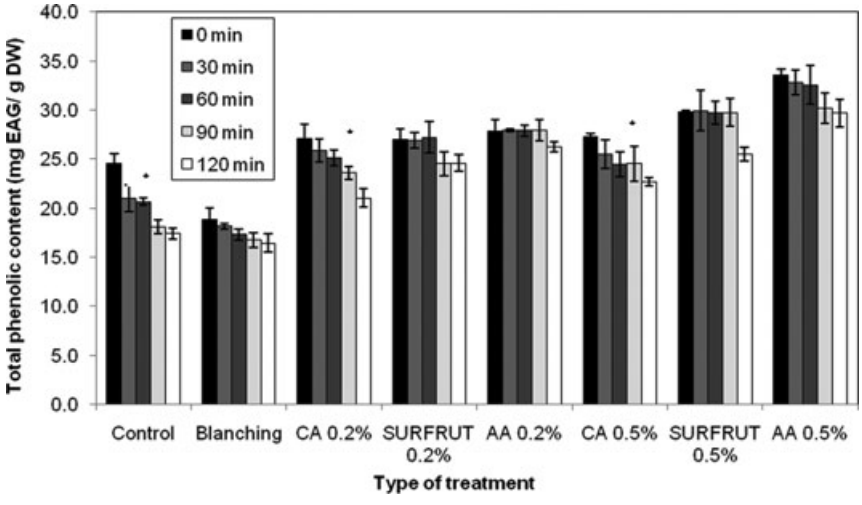

Figure 5–Total phenolic content in the fresh apple peel slurry, after the application of the antibrowning treatment, and exposed at ambient temperature during 120 min.[1,2,3]
[1] CA 0.2% = citric acid at 0.2%; SURFRUT 0.2% = SURFRUT preparation 0.2%; valign="442pt" AA 0.2% = ascorbic acid at 0.2%; CA 0.5% = citric acid at 0.5%; SURFRUT 0.5% = SURFRUT preparation 0.5%; AA 0.5% = ascorbic acid at 0.5%.
[2] Values represent mean of three replications ± SE.
[3] * Significant difference ($P < 0.05$) of treatment over time.

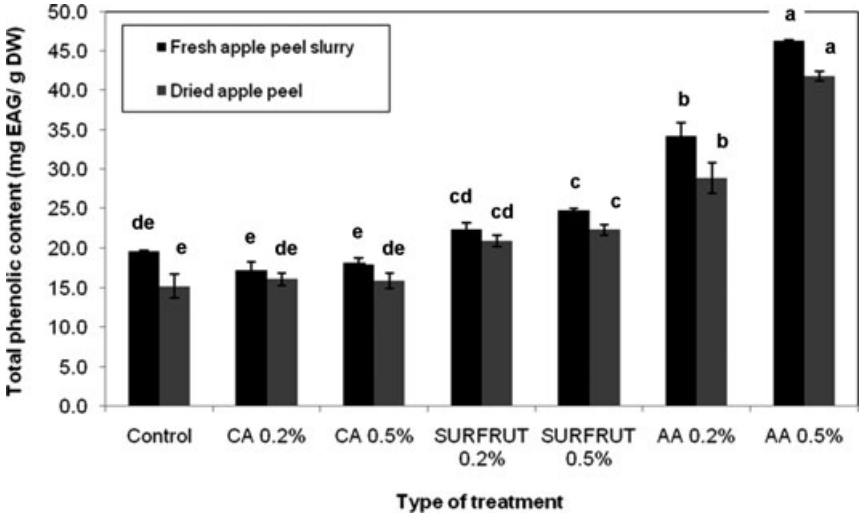

Figure 6–Total phenolic content in the fresh apple peel slurry and in the dried apple, after the application of different treatments antibrowning.[1,2,3]
[1] CA 0.2% = citric acid at 0.2%; SURFRUT 0.2% = SURFRUT preparation 0.2%; AA 0.2% = ascorbic acid at 0.2%; CA 0.5% = citric acid at 0.5%; SURFRUT 0.5% = SURFRUT preparation 0.5%; AA 0.5% = ascorbic acid at 0.5%.
[2] Values represent mean of three replications ± SE.
[3] Different letters in the same treatment denote significant differences ($P < 0.05$); values bearing the same superscript are not significant.

Moisture was 2%. The ingredient had a low content of ash, lipids, and protein, but a high content of crude fiber. The values of ash and lipids are 2- and 5-fold lower, respectively, than the data reported by Rupasinghe and others (2008). These differences could be related to the utilization of different apple cultivars and drying methods. The high value of nitrogen free extract confirmed the high content of carbohydrates.

The pH of the ingredient was 4.2; this was in the range of most foods (Fennema 1985). The a_w was 0.2; this was in the range that different researches have established for this type of ingredient. However, it is 1.3-fold higher than the data obtained by Wolfe and Liu (2003) for freeze-dried apple peel. Color parameters indicated that in comparison to the raw matter, the drying of the apple peel, decreased the parameters L^* and b^*, but increased a^* value. This implies that the color of the ingredient was lighter, slight yellow color, and dull. In agreement with our dates, Rababah and others (2005) reported similar L^*, a^*, and b^* values for dried apple puree, with the presence of ascorbic acid at 0.1%.

The content of reducing and total sugar was 43% and 55%, respectively. The value of total sugar is 1.5-fold higher than the value reported by Wang and Thomas (1989) for dried apple pomace using a pilot scale drum-dryer.

The main mineral and trace elements content of apple peel ingredient showed that the samples evaluated contained high amounts of potassium, followed by nitrogen, phosphorus, calcium, magnesium, and sodium, which were the most abundant elements. In addition, it can be seen, that among the trace elements, iron has the highest concentration, followed by copper, manganese, and zinc.

TDF, IDF, and SDF represented about 39.7%, 27.8%, and 11.8%, respectively. These values are 1.3-fold lower than the values obtained previously in the samples dried at 110 °C. These differences could be related to the storage time of the apples used to produce the ingredient, because these samples were stored for 9 mo, in comparison to the samples used before (3 mo). In effect, during storage, the cell structure is softened depending on the activation of protopectinase, resulting in a degradation and loss of viscosity of the cell wall polysaccharides; any degradation of pectic substances may influence the digestion and absorption rate of carbohydrates in apples, as well as the bulking capacity of the pectin per se (Suni and others 2000). Additionally, the TDF obtained for us was 1.2-fold higher than the value reported by Wang and Thomas (1989) for dried apple pomace using a pilot scale drum-dryer. The proportion of IDF and SDF were 70% and 30%, respectively. This ratio is considered proportionally well balanced for physiological purposes. In addition, the SDF/IDF ratio of dried apple peel is 1/2, being a suitable source for a food ingredient. These results indicate that the drying of the apple peel improve the dietary and functional properties of dietary fiber present in fresh apple peel, and this implies that this ingredient could be considered a good source of fiber. Our results of IDF and SDF are similar to the values reported by Rupasinghe and others (2008).

The total phenolic content of this ingredient was 38.6 mg EAG/g DW. This value is 8- and 2-fold higher, respectively, than the data reported by Rupasinghe and others (2008) and Wolfe and Liu (2003) for oven-dried apple peel at 60 and 80 °C, respectively. These differences could be attributed to different cultivars and drying process. On other hand, our process lost a 15% of phenolic compounds, in comparison with the lost obtained by Wolfe and Liu (2003) for air-dried and freeze-dried blanched peels (8%).

Table 4–Functional properties of apple peel ingredient.[A,B]

	Temperature of evaluation (°C)	
Functional properties	**20 °C**	**100 °C**
Dispersability (%)	40.2 ± 2.0[b]	51.2 ± 2.7[a]
SWC (mL water/g DW)	8.7 ± 0.2[a]	9.3 ± 0.3[a]
SI (%)	45.9 ± 1.3[a]	44.3 ±1.5[a]
WRC (g water/g DW)	2.9 ± 0.1[a]	3.0 ± 0.2[a]
FAC (mL oil/g DW)	4.2 ± 0.4	

SWC = swelling capacity; SI = solubility index; WRC = water retention capacity; FAC = fat absorption capacity.
[A]Values represent mean of 3 replications ± SE.
[B]Means in the same functional properties followed by the same superscript small letter in a row do not differ significantly ($P < 0.05$).

Functional properties of the ingredient are shown in Table 4. In general, all of these properties did not change significantly when the water temperature was changed.

Conclusions

In this study, a simple, rapid, feasible, economical, and suitable pilot scale process to produce an ingredient with apple peel by-product was developed. The results obtained indicate that drying technology did not affect significantly the nutritional quality of apple peel; in effect, the loss of phenolic compounds and dietary fiber, in comparison with the raw matter, was only 15% and 17% dry base, respectively. This indicates that this by-product has a high potential to be used as ingredient in the formulation of foods, with higher levels of antioxidants and dietary fiber. Apart from the basic nutritional elements, it also adds economical value to secondary products from the apple processing business. Additionally, the use of this solid waste could reduce environmental impact due to the liberation of a huge amount of residues.

Acknowledgments

The authors wish to acknowledge CONICYT (Comisión Nac de Investigación Científica y Tecnológica) for doctorate scholarship to C. Henríquez and SURFRUT Co. for the apple peel samples.

References

Akissoe N, Mestres C, Hounhouigan J, Nago M. 2005. Biochemical origin of browning during the processing of fresh yam (*Dioscorea* spp.) into dried product. J Agric Food Chem 53:2552–7.
Almeida M, Nogueira J. 1995. The control of polyphenol oxidase activity in fruits and vegetables: a study of the interactions between the chemical compounds used and heat treatments. Plant Foods Hum Nutr 47:245–56.
[AOAC] Assn. Official Analytical Chemist. 2006. Official methods of analysis. 18th ed. Gaithersburg, Md.: AOAC Intl. 2000 p.
Bomben JL, Guadagni DC, Harris JG. 1971. Apple-flavored thickener from apple peel: converting an uneconomical byproduct into a useful product. Food Technol 25:1108–17.
Bradford MM. 1976. A rapid and sensitive method for the quantification of microgram quantities of protein utilizing the principle of protein binding. Anal Biochem 72:248–54.
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 113:166–72.
Chang C, Lin H, Chang C, Liu Y. 2006. Comparisons on the antioxidant properties of fresh, freeze-dried and hot-air-dried tomatoes. J Food Engr 77:478–85.
Chantaro P, Devahastin S, Chiewchan N. 2008. Production of antioxidant high dietary fiber powder from carrot peels. LWT 41:1987–94.
Drogoudi P, Michailidis Z, Pantelidis G. 2008. Peel and flesh antioxidant content and harvest quality characteristics of seven apple cultivars. Sci Hortic 115:149–53.
Femenia A, Lefebvre AC, Thebaudin JY, Robertson JA, Bourgeois CM. 1997. Physical and sensory properties of model foods supplemented with cauliflower fiber. J Food Sci 62:635–9.
Fennema, O. 1985. Food chemistry. 2nd ed. New York: Marcel Dekker, Inc. 991 p.
Figuerola F, Hurtado ML, Estévez AM, Chiffelle I, Asenjo F. 2005. Fibre concentrates from apple pomace and citrus peel as potential fibre source for food enrichment. Food Chem 91:395–401.
Gamel T, Linssen J, Mesallam A, Damir A, Shekib L. 2006. Seed treatments affect functional and antinutritional properties of amaranth flours. J Sci Food Agric 86:1095–102.
Gorinstein S, Zachwieja Z, Folta M, Barton H, Piotrowicz J, Zemser M, Weisz M, Trakhtenberg S, Màrtín-Belloso O. 2001. Comparative contents of dietary fiber, total phenolics, and minerals in persimmons and apples. J Agric Food Chem 49:952–7.

Gorinstein S, Màrtín-Belloso O, Lojek A, Číž M, Soliva-Fortuny R, Park Y, Caspi A, Libman I, Trakhtenberg S. 2002. Comparative content of some phytochemicals in Spanish apples, peaches and pears. J Sci Food Agric 82:1166–70.
Khanizadeh S, Tsao R, Rekika D, Yang R, Charles MT, Rupasinghe HP. 2008. Polyphenol composition and total antioxidant capacity of selected apple genotypes for processing. J Food Comp Anal 21:396–401.
Kostoglou M, Karapantasios TD. 2003. On the thermal inertia of the wall of a drum dryer under a cyclic steady state operation. J Food Engr 60:453–62.
Kwok BHL, Hu C, Durance T, Kitts DD. 2004. Dehydration techniques affect phytochemical contents and free radical scavenging activities of Saskatoon berries (*Amelanchier alnifolia* Nutt). J Food Sci 69:122–5.
Kyi T, Daud W, Mohammad A, Samsudin M, Kadhum A, Talib M. 2005. The kinetics of polyphenol degradation during the drying of Malaysian cocoa beans. Int J Food Sci Technol 40:323–31.
Larrauri J, Rupérez P, Saura-Calixto F. 1997. Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. J Agric Food Chem 45:1390–93.
Łata B. 2007. Relationship between apple peel and the whole fruit antioxidant content: year and cultivar variation. J Agric Food Chem 55:663–71.
Łata B, Tomala K. 2007. Apple peel as a contributor to whole fruit quantity of potentially healthful bioactive compounds cultivar and year implication. J Agric Food Chem 55:10795–802.
Lee S, Proxy L, De Vries J. 1992. Determination of total, soluble and insoluble fiber foods. Enzimatic- gravimetric methods, mes-tris buffer. Collaborative study. J Assoc Offic Anal Chem 75:395–416.
Leontowicz M, Gorinstein S, Leontowicz H, Krzeminski R, Lojek A, Katrich E, Číž M, Màrtín-Belloso O, Soliva-Fortuny R, Haruenkit R, Trakhtenberg S. 2003. Apple and pear peel and pulp and their influence on plasma lipids and antioxidant potentials in rats fed cholesterol-containing diets. J Agric Food Chem 51:5780–5.
McGuire R. 1992. Reporting of objective color measurements. HortScience 27:1254–5.
Mrkìc V, Cocci E, Dalla Rosa M, Sacchetti G. 2006. Effect of drying conditions on bioactive compounds and antioxidant activity of broccoli (*Brassica oleracea* L.). J Sci Food Agric 86:1559–66.
ODEPA (Oficina de Estudios y Políticas Agrarias). 2009. Bases de Datos Productivas. Available from: http://www.odepa.cl. Accessed Oct 10, 2009.
Pua CK, Hamid NSA, Rusul G, Rahman RA. 2007. Production of drum-dried jackfruit (*Artocarpus heterophyllus*) powder with different concentration of soy lecithin and gum arabic. J Food Engr 78:630–6.
Puupponen-Pimiä R, Häkkinen S, Aarni M, Suortti T, Lampi A, Eurola M, Piironen V, Nuutila A, Oksman-Caldentey K. 2003. Blanching and long-term freezing affect various bioactive compounds of vegetables in different ways. J Sci Food Agric 83:1389–402.
Rababah T, Ereifej K, Howard L. 2005. Effect of ascorbic acid and dehydration on concentrations of total phenolics, antioxidants capacity, anthocyanins, and color in fruits. J Agric Food Chem 53:4444–7.
Rocha A, de Morais A. 2001. Characterization of polyphenoloxidase (PPO) extracted from "Jonagored" apple. Food Control 12:85–90.
Rocha A, de Morais A. 2005. Polyphenoloxidase activity of minimally processed 'Jonagored' apples (*Malus domestica)*. J. Food Process Pres 29:8–19.
Rupasinghe HV, Wang L, Huber G, Nancy L, Pitts N. 2008. Effect of baking on dietary fibre and phenolics of muffins incorporated with apple skin powder. Food Chem 107:1217–24.
Sadzawka A, Carrasco MA, Demanet R, Flores H, Grez R, Mora ML, Neaman A. 2007. Métodos de análisis de tejidos vegetales. 2nd ed. Santiago, Chile: Series Actas Instituto Nacional de Investigación Agropecuaria N° 40. 140 p.
Shittu TA, Lawal MO. 2007. Factors affecting instant properties of powdered cocoa beverages. Food Chem 100:91–8.
Singleton V, Rossi J. 1965. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. Am J Enol Vitic 16:144–58.
Suni M, Nyman M, Eriksson N, Björk L, Björck I. 2000. Carbohydrate composition and content of organic acids in fresh and stored apples. J Sci Food Agric 80:1538–44.
Tang J, Feng H, Shen GQ. 2003. Drum drying. Encyclopedia of agricultural, food, and biological engineering. New York: Marcel Dekker Inc. p 21–4.
Wang HJ, Thomas RL. 1989. Direct use of apple pomace in bakery products. J Food Sci 54:618–20.
Wolfe K, Liu RH. 2003. Apple peels as a value-added food ingredient. J Agric Food Chem 51:1676–83.
Wolfe K, Wu X, Liu RH. 2003. Antioxidant activity of apple peels. J Agric Food Chem 51:609–14.