Effect of extrusion parameters on some properties of dietary fiber from lemon (*Citrus aurantifolia* Swingle) residues

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Approximately 50% of the original whole fruit mass, after citrus processing for juice, consist of the peel, membranes and seeds. Citrus residues consist mainly of insoluble fiber (celluloses) and a small proportion of soluble fiber (hemicelluloses and pectin). For this reason, citrus residues could be considered as a potential high fiber ingredient that is used for food industry. In this study, lemon residues were extruded to modify and increase their soluble fiber fraction. Surface response methodology with six central points and six axial points was used to evaluate the changes in dietary fiber fractions in lemon residues. The independent variables studied were extrusion temperature (from 59.77 to 110.63°C), moisture content of the sample (from 33.18 to 66.82%) and screw speed (from 3.18 to 36.82). The extrusion process increased the soluble fiber from 38.60% in unprocessed lemon residues to 40.00 to 50.01% in extruded samples. The highest content of soluble fiber was 50.00% when operating conditions were high in temperature (100°C), low in moisture content (40%) and low in screw speed (10 rpm). The results of this study indicate that extrusion is a process that has the capability to transform insoluble fiber to soluble fiber in lemon residues.

Key words: Lemon residues, extrusion, dietary fiber.

INTRODUCTION

Fruits and vegetables are good sources of vitamins, minerals, phytochemical compounds and fiber (Palafox-Carlos et al., 2011; Viuda-Martos et al., 2010). The Codex Alimentarius (ALINORM 09/32/26 2009) defines dietary fiber (DF) as carbohydrate polymers with 10 or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans. DFs decrease intestinal transit time, increase stool bulk, reduce total and low-density lipoprotein (LDL) cholesterol level in blood, decrease postprandial blood glucose and insulin level, and buffer excessive acid in the stomach. Also, DF consumption prevents some health problems such as diverticular disease, cardiovascular disease and colorectal cancer (Martínez-Flores et al., 2008). For this reason, DF becomes the 3rd most sought-after health information in supermarkets in countries like India, Australia, Western Europe and North America (Mehta, 2005). The importance of food fibers has led to the development of a large and potential market for fibre-rich products and ingredients, and nowadays there is a trend to find new sources of DF, such as agronomic by-products that have traditionally been undervalued (Rodríguez et al., 2006). Some sources of fibre have been studied like *Lentinus edodes*, mushroom known

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Abbreviations: DF, Dietary fiber; LDL, low-density lipoprotein; TDF, total dietary fiber; IDF, insoluble dietary fiber; SDF, soluble dietary fiber; CCD, central composite design.
commercially as Shiitake (Martinez-Flores et al., 2009), apple peel (Henríquez et al., 2010), white-grape by-product (Sánchez-Alonso et al., 2007), coconut fiber (Trinidad et al., 2006), carob fiber (Zunft et al., 2003), and extruded orange pulp (Larrea et al., 2005).

The extraction of juice from citrus fruits, such as oranges, grapefruit and lemons, provide citrus pulp as residue. According to Mirzaei-Aghsaghali and Maheri-Sis (2008), citrus pulp consists of 60 to 65% peels, 30 to 35% segment pulp and 0 to 10% seeds. On average, citrus pulp represents 60% of the fresh weight with a mean dry matter of 19.7%, but the residue can range between 49 and 69% of the initial weight. However, pressing reduces the moisture from 65 to 75%, after which the pulp is dried, but may also be dried without removing the pressed liquor. Dehydration of small particles of peel, pulp and seed, obtained by sieving the wet residue, provides dried citrus meal. In Michoacán, México, the production of this fruit is reported to be between 350 and 405 thousand tons per year. The by-product from the manufacture of lemon is generally used as livestock feed. Therefore, these by-products (lemon residues), mainly consisting of the peel, albedo, flavedo and juice vesicles are underutilized and could be a highly potential source for use as ingredient in food formulation. The application of the heat treatment with shear during the extrusion process of residues lime can cause a partial modification of the structure of insoluble fiber components such as cellulose to obtain compounds with characteristics of soluble fiber. For this reason, the objective of this study is to evaluate the effect of some extrusion parameters on the dietary fiber constituents of lemon by-products.

MATERIALS AND METHODS

Raw materials

Lemon residues of *Citrus aurantifolia* var. *Swingle* were collected from the Danisco Ingredients S.A. C.V. industry, located in Apatzingán, Michoacán, Mexico. The lemon residues were washed with clean water, drained and placed in a solar dehydrator at a temperature range of 45 to 55°C. The final moisture of dried samples was 8.70%. After seeds were removed manually from dried lemon residues, lemon residues were ground in a hammer mill (Pulvex model 200) and stored at 4°C for later analysis.

Chemical composition

The moisture, ash, protein and fat analysis in lemon residues were realized using the methods of the AACC (2000). Total dietary fiber (TDF), insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) were done with the methodology proposed by Prosky et al. (1998).

Extrusion process

Extrusion experiments were performed using a laboratory single extruder according to the experimental arrangement. The barrel had controlled electric heaters and a 1:1 screw compression ratio. A die with orifice of 6 mm in diameter was used. The extruded samples were dried in a forced-air oven at 60°C for 12 h, milled (0.420 mm) using a hammer (Pulvex model 200), and stored in polyethylene bags for further analysis.

Experimental arrangement

A central composite design (CCD) was used to evaluate the response of three independent variables: temperature ($X_1$), moisture ($X_2$) and screw speed ($X_3$), in the process of extruding lemon residues. The CCD used in this study was based on a 3k factorial treatment design with 3k additional combinations called axial points and n central points. The coordinates of the axial points of the coded factor were (+α, 0, 0,..., 0), (0, ±α, 0, 0,..., 0) and (0, 0, 0,..., ±α), and the central points were of the form (0, 0, 0,..., 0). Depending on the selection of α in the axial points, the CCD may have different properties, such as orthogonality, rotability and uniformity. The property of rotability applied in this case was achieved by setting $α = (2k)^{1/4}$. In this way, the value of α for a design with three factors was $α = 1.682$. The outline of the experimental design and their independent variables and variation levels are presented in Table 1. Table 2 shows the complete experimental arrangement that includes eight factorial points, six replicates at the central point, and six axial points. The dependent variables were SDF, IDF, TDF, L and color parameters. Treatments were performed randomly. Experimental results of the chemical composition and physicochemical properties values were presented as the mean ± of three measurements. However, all the processes were run in the statistical package Minitab 15.

Colour measurements

Color measurements were performed using a Hunterlab colorimeter (Model D-2.5M Hunter Associates Laboratory, Inc. Reston VA, USA). L (luminosity, dark [0] to bright [100]) and a (green [-] to red [+] ) coordinates were obtained using a D65 illuminant and 10° observer angle as a reference system.

RESULTS AND DISCUSSION

Chemical composition

The chemical analysis results of the lemon residues

| Table 1. Coded levels for independent variables. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Variable              | -α = (-1.682)       | -1              | 0               | +α = (+1.682)   |
| $X_1$ | 59.77          | 70              | 85              | 100             | 110.63         |
| $X_2$ | 33.18          | 40              | 50              | 60              | 66.82          |
| $X_3$ | 3.18           | 10              | 20              | 30              | 36.82          |

$X_1$ = Temperature (°C); $X_2$ = Moisture (%); $X_3$ = Screw speed (rpm).
Table 2. Description of the independent variables and results of the extruded treatments in samples of lemon residues.

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X<sub>1</sub> = Temperature (°C); X<sub>2</sub> = Moisture (%); X<sub>3</sub> = Screw speed (rpm); IDF = Insoluble dietary fiber; SDF = Soluble dietary fiber; TDF = Total dietary fiber. * = L color parameter, ** = a color parameter.

Effects of the extrusion variables on the composition of the dietary fiber of lemon residues

Table 2 and Figures 1 and 2 show the experimental results for the contents of IDF, SDF and TDF. In general, it was observed that IDF values decreased and SDF values increased when lemon residues were extruded. The value of IDF in unprocessed lemon residues was 57.01%. In samples extruded, the IDF decreased with higher temperatures and lower moisture contents, when the screw speed was 30 rpm (Figure 1). However, the lowest value of IDF (43.90%) was obtained in the individual treatment considering the following conditions: Temperature of 110.63°C, moisture of 50% and screw speed of 20. Probably, under these conditions, the residence time is adequate to assure the solubilization of the fibre components due to the effect of barrel temperature. The same behaviour was evidenced with lower moisture contents and lower screw speeds (10 rpm). These results are in agreement with those of Gourgue et al. (1994) who reported that with extruded lemon rinds, the IDF contents decreased from 47.94 to 33.66% for lemon. In this study, IDF of lemon residues decreased from 57.01 to 43.90-55.30%. Figure 2 shows the SDF as a function of the extrusion temperature, and the moisture content at a screw speed of 10 rpm. The value of SDF in unprocessed lemon residues was 38.60%. In the samples extruded, the highest value for SDF (50.00%) was obtained when the extrusion conditions of temperature were 100°C, the moisture content was 40% and the screw speed was 10 rpm. This was followed by the treatment of 110°C, moisture content of 50% and a screw speed of 20 rpm, when the SDF was 49.60%. This increment in SDF content would be caused by a partial solubilization of IDF as reported by Larrea et al. (2005a, b) that extrusion increased the values for SDF. Gourgue et al. (1994) reported that the SDF content of lemon rinds increased after the extrusion process, from 28.09 to 37.67%. In general, the TDF was maintained in extruded samples as compared to unprocessed lemon residues. However, a redistribution of IDF to SDF was appreciated.

Colour measurements

The L and a color parameters are shown in Table 2. The tendencies show that intensity of lightness of
unprocessed lemon residues decreased as compared to the extruded products from 69.6 to 50.92-58.88. The most intense changes were observed in treatments 4 (temperature of 100°C, moisture 60% and rpm 10) and 16 (temperature of 110.63°C, moisture 50% and rpm 20), having 50.92 and 51.49 \( L \) values, respectively. In treatment 16, we found the highest extrusion processing temperature, and in treatment 4 we found the second highest temperature of the experimental arrangement combined with the longer residence time (screw speed of 10 rpm). According to Martinez-Flores et al. (1998), the lightness reduction in extruded samples was probably due to the intensification of the Maillard reaction, which occurred between reducing sugars and proteins, causing the products to change from light brown colours to dark colours. Also, a change in a value was observed. The results showed that a value of unprocessed lemon residues increased as compared to the extruded products

Figure 1. Effects of extrusion temperature and moisture content on the insoluble dietary fiber of the lemon residues. The screw speed was 30 rpm.

Figure 2. Effects of extrusion temperature and moisture content on the soluble dietary fiber of the lemon residues. The screw speed was 30 rpm.
from 0.05 to 1.22-2.29. The most important change occurred in the same number 16 treatment which had the highest \( a \) value (2.29). It is important to note that the negative values of \( a \) parameter are related to green colour, while the positive values of \( a \) parameter are related to red colour. This means that extrusion process begins to change the green traditional colour of lemon residues.

**Conclusions**

The extrusion conditions increased soluble dietary fiber efficiently and decreased insoluble dietary fiber, particularly when the least temperature of 110°C and the lower screw speeds of 10 and 20 rpm were used to combine the moisture content samples of 40 and 50%.

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**REFERENCES**


