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Effects of processing conditions on the quality of vacuum fried cassava chips (*Manihot esculenta* Crantz)

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ABSTRACT

The preoccupation by the nutritional quality of the chips grows due to the consumption increase, which motivates the research and development of new appetizer products that contribute to less calories and fats intake in the diet with good flavor and facility of consumption. The objective of this work was to study the behavior of chips of cassava blanched or un-blanched and processed under atmospheric and vacuum frying conditions to determine the influence of these treatments on the mechanical and acoustic parameters, optical properties and the oil absorption. For it, vacuum frying trials to 120, 130 and 140 ºC were realized, and they were compared with the realized ones under atmospheric pressure (165 ºC). The obtained results shown that the blanching pretreatment implies a considerable improvement in the color of the samples vacuum treated and less oil absorption. Vacuum frying of cassava chips with previous blanching may be an alternative to the atmospheric frying since it improves the color of the samples, reduces the oil gain and maintains his crispness, being the treatment at 130 ºC under vacuum conditions with blanching the one that better results contributed.

Key words: cassava, vacuum frying, atmospheric frying, blanching, oil absorption.

1. Introduction

Cassava *(Manihot esculenta* Crantz) is an extensively cultivated tuber crop and its consumption was classified as a cultural component in developing countries. Cassava is a staple food for millions of people in the tropical regions of Africa, Latin America and Asia (Nambisan, 2011). A major factor limiting the food value of cassava is the presence of cyanogenic glucosides (linamarin and lotaustralin) which liberate acetonecyanohydrin and hydrogen cyanide upon hydrolysis by the endogenous enzyme, linamarase (Conn, 1979). The presence of these toxic compounds in cassava and its food products has been a cause of concern because of their possible effects on health. It is therefore necessary to eliminate/reduce their levels in tubers to a minimum in order to make cassava safe for consumption. Major research efforts to eliminate/reduce cyanoglucosides have focused on development of acyanogenic cassava varieties by breeding, controlling its metabolism and processing to remove cyanogens. Many called varieties “sweet” have very low levels of these cyanogenic glucosides and can be consumed of safe way, after a thermal process. Traditional methods used for processing include boiling, blanching, drying, parboiling and drying, baking, steaming, frying and preparation of flour. These processes result in cyanide losses ranging from 25% to 98% (Nambisan, 2011). To remove cyanogens from cassava and to valorize this culture and open new markets, new uses for cassava were sought, once of which was cassava fried chips.

Numerous studies have revealed that excess consumption of fat, a main component in deep-fat fried food, is a key dietary contributor to coronary heart disease and perhaps cancer of the breast, colon, and prostate (Browner, Westenhouse, & Tice, 1991). In recent years, consumer preference for low-fat and fat-free products has been the driving force of snack food industry to produce lower oil content products that still retain the desirable texture and flavor (Garayo & Moreira, 2002). Several processes have been developed in order to allow companies to manufacture reduced-fat products that posses the desired quality attributes of deep fat fried food whilst preserving their nutritional properties. These include alternative technologies such as extrusion, drying, and baking, which may be applied to raw food or formulated products. Unfortunately, none of them has been as successful as expected because they are still unable to impart the desired quality attributes of deep fat fried food, such as flavour, texture, appearance, and mouthfeel (Dueik, Robert, & Bouchon, 2010). In this sense, vacuum frying may be an option for production of fruits, vegetables and another product with low oil content and the desired texture and flavor characteristics. Vacuum frying is defined as the frying process that is carried out under pressures well below atmospheric levels, preferably below 50 Torr (6.65 kPa). Due to the pressure lowering, the boiling points both of the oil and the moisture in the foods are lowered. Vacuum frying possess some advantages that include: (1) can reduce oil content in the fried product, (2) can preserve natural color and flavours of the product due to the low temperature and oxygen control during the process, (3) has less adverse effects on oil quality (Shyu, Hau, & Hwang, 1998), (4) decreased acrylamide content (Granda, Moreira, & Tichy, 2004), and (5) preservation of nutritional compounds (Da Silva & Moreira, 2008). Vacuum frying studies have been developed for various types of food such as potatoes (Garayo & Moreira, 2002), banana (Jackson, Bourne, & Barnard, 1996), breadfruit (Bates, Graham, Matthews, & Clos, 1991), carrots (Dueik et al., 2010), pineapple (Pérez-Tinoco, Perez, Salgado-Cervantes, Reynes, & Vaillant, 2008) or vegetables chips (Da Silva & Moreira, 2008). However, no mention was found in the literature on using cassava to produce vacuum-fried chips for human consumption.

Blanching is a process of food preparation where the food is plunged into boiling water or steam used for enzyme activity reduction. It is one of the most widely used methods to prevent browning (Liu-Ping, Min-Zhang, & Mujumdar, 2005; Shyu, & Hwang, 2001; Shyu, Hau, & Hwang, 2005) and to leach soluble sugars (Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001). Califano & Calvelo (1987) reported that blanched step previous to frying in potato chip processing improves the color and texture, and reduces, in some cases, the oil by gelatinization of the surface starch. Troncoso, Pedreschi & Zúñiga (2009) suggest that blanching and blanching combined with air drying affect significantly instrumental parameters such as color (L^*,a^* and ΔE) and flavour as well as overall quality of potato chips, but the best flavour was obtained for potato chips without pre-treatment vacuum frying.

The objective of this study was to develop high-quality cassava chips using a blanching pre-treatment and vacuum frying as process treatments and to study changes in color, mechanical and acoustic parameters, oil content and moisture, in order to identify the potential of vacuum frying for producing novel cassava snacks following new health trends.

2. Materials and methods

2.1. Sample preparation

Fresh cassava (*Manihot esculenta* Crantz) from Costa Rica was purchased from a local market in Valencia (Spain). It was verified that the pieces were whole, healthy (free of mould, rottenness or deterioration) and free of any strange scent. Whole cassava was stored at room temperature prior to use. Peeled cassavas were cut into 1.5-1.8 mm thick slices with a slicer (Siemens MS70001, Siemens, Spain). The cassava slices were divided in two groups. One of them was cassava slices with a blanching pre-treatment before being fried (B) and the other group was fried without pre-treatment (UB).

2.2. Blanching treatment

Blanching treatment was carried out in a thermostated water bath (Precisterm S-386, Selecta, Barcelona, Spain) at 70 °C during 10 minutes (Taiwo & Baik, 2007). After treatment, excess water on product surface was removed by gently blotting with tissue paper (Krokida et al., 2001).

2.3. Frying treatments

Two frying treatments, atmospheric frying and vacuum frying, were considered. For frying treatments sunflower oil (Hacendado, España S.A., Sevilla, Spain) was used. The ratio frying oil/cassava was 20:1 w/w in all treatments. Atmospheric frying (AF) was carried out at 165°C since this is within the range of temperatures normally used for frying (between 150 °C and 180 °C) (Choe & Min, 2007). For the atmospheric frying experiments, a commercial deep fat fryer was used (Movilfrit, Barcelona, Spain). Vaccum frying was made using a vacuum fryer (Gastrovac, International Cooking Concepts, Barcelona, Spain). Three levels of oil temperature for vacuum frying (120, 130 and 140 °C) were considered in this study. After frying treatment, before vacuum rupture, cassava chips were removed from oil and centrifuged for 2 min to avoid oil impregnation (Da Silva & Moreira, 2008). The amounts of time studied were from 1 to 10 minutes (one minute intervals) for atmospheric and vacuum treatments. After frying, the cassava chips were cooled at room temperature and packed in polyethylene pouches (Cryovac® HT3050, Cryovac Sealed Air Corporation, Barcelone, Spain) and stored at 25ºC before analysis.

2.4. Proximate composition

Moisture content of cassava chips was measured in a vacuum oven by drying at 70 ºC. Ground samples (5 g) were dried to constant weight. Moisture content was calculated from the weight difference between the original and dried samples and expressed as dry base. Tree samples were used for each time and temperature.

The total fat content of dried samples of cassava chips (5 g) was extracted with petroleum ether (BP 40-60 ºC) for four hours in a Soxtec System 2055 Tecator extracting unit (FOSS, Hillerød, Denmark) and gravimetrically determined. Tree samples were used for each time and temperature.

2.5. Characteristics of the fried product

Weight loss determination was calculated as the percentage weight difference between the raw and fried samples relative to the weight of the raw cassava slices. The samples were dried with an absorbent paper before being weighed in order to remove the superficial water in the fresh cassava slices and the oil in the fried ones. The weight of the samples was measured with an analytical balance Mettler Toledo model PB 303-S (Mettler Toledo GmbH, Greinfensee, Switzerland). Tree samples were used for each time and temperature.

A TA-XT2 texture analyser (Stable Micro Systems Co Ltd, Godalming, Surrey, UK) with the program of data analysis Texture Expert version 4.0.13.0 (2009) and one spherical probe P/0.5S of ½ inch of diameter (Micro Stable System) was used to determine breaking force, area under the curve and number of peaks. The samples were placed on a platform HDP/CFS ("Crips Fracture Support Rig") the parameters of the test were: speed of test 1mm/s, force of activation 5g, distance of sounding 3 mm. All numerical results were expressed in grams. For the study of the crispy character a surrounding sound detector with a microphone Bruel and Kjaer (8-mm diameter) incorporated was used (Chen, karlsson, & Povey, 2005; Varela, Chen, Fiszman, & Povey, 2006). The microphone was put to 4 cm of distance in an angle of 45° with respect to the center of the sample. The environmental acoustics and the noise were filtered using a filter of high step of 1 kHz. The data acquisition rate was 500 points per second for both force and acoustic signals. All tests were performed in a laboratory with no special soundproof facilities at room temperature. Twenty replications were performed for each kind of cassava chip. Force/displacement and SPL/displacement curves were simultaneously plotted. From the force curve the following parameters were extracted: area below the force curve (N·s), higher value of force (N) and number of force peaks (drop in force higher than 0.049 N). From the sound curves, the number of sound peaks (drop in sound pressure level higher than 10dB) and the sound pressure level (dB) (average of the ten higher peaks, SPLmax10).

The surface color of cassava chips was measured with a spectrocolorimeter Minolta cm-3600-d (Minolta, Osaka, Japan) using a color data analysis software (SpectraMagic™ NX, Minolta, Osaka, Japan). Measures were realized using a diaphragm SAV (0.4-0.7 mm) and with basic white and black plate having in account that the samples were translucent. Results were expressed in CIELab system referred to the illuminant D65 and observer 10°. Theory of Kubelka-Munk of multiple scattering was applied to the obtained reflection spectra in order to evaluate the translucence degree (Hutchings, 1999). Taking into account the translucence from the samples ten measurements by each treatment became of frying with white bottom, ten measurements with black bottom and in addition the measurement to the percentage of reflectance of the used white plate.

2.6. Statistical analysis

The effect of blanching, temperature and vacuum pressure on the drying curve, the oil content, weight loss, color and texture of cassava chips was evaluated using a factorial design with two levels for blanching treatment, four levels for temperature and six levels for frying time. Multifactor analysis of variance (ANOVA) was performed on the instrumental parameters to evaluate differences among the cassava chip samples. The statistical analysis of the data was performed using statistical package Statsgraphics Centurion XVI ver. 16.2.04 (StatPoint Technologies Inc., Virginia, USA). Statistical significance was expressed at the $p<0.05$ level.

3. Results and discussion

3.1. Blanching treatment

The initial weight of samples before blanching was 3.2±0.7 g, after blanching the average weight was 3.5±0.6 g. Blanching implies a significant increase ($p<0.05$) of weight (6.9%) of samples. This weight gain can be explained by the water absorption that occurs during blanching process by immersion in hot water that implies changes in product structure. According to Zivanovic & Buescher (2004) blanching disrupts the hydrogen and other non-covalent bonds between cell wall polymers. Pectins are degraded and solubilized from the cell wall and the middle lamella between adjacent cell walls. This leads to a loss of adhesion between cells and turgor pressure which ultimately destroys the membrane integrity (Ma & Barrett., 2002; Xin, Zhang, Xu, Adhikari, & Sun, 2015) that facilitates water exchange.

3.2. Weight loss during frying

Fig. 1 shows the effect of frying time and pre-treatment on weight loss for vacuum and atmospheric fried cassava chips. Effect of pre-treatment was significant ($p<0.05$) for vacuum and atmospheric fried samples during all stages of frying. At the end of the process (10 min) the weight loss of blanched samples (B), including all temperatures, was 57±2% while that for unblanched samples (UB) was 49±2%. If we consider the weight gain due to the blanching process the final weight of samples was similar ($p \geq 0.05$), 1.7±0.4 g for unblanched samples and 1.4±0.3 for blanched samples. Related to the effect of temperature no differences were found ($p \geq 0.05$) between treatments at the end of the process (10 min), the weight variation experienced by the samples fried under atmospheric conditions (165ºC) was around 53±5 % with respect to initial weight while the mass variation experienced by cassava chips under vacuum conditions was 54±5 % at 120 ºC, 50±4 % at 130 ºC and 55±3 % at 140 ºC.

3.3. Moisture content

Fig. 2 shows moisture loss for each frying time during vacuum and atmospheric frying and the effect of pre-treatment methods on the moisture of fried cassava chips. Moisture content of the fried cassava chips was found to be influenced by the blanching pretreatment. The loss of moisture during vacuum and atmospheric frying presented a classical drying profile. There was an initial rapid decrease in water content, which was mainly due to the loss of surface and unbound inner water, followed by a gradually decreasing gradient due to crust formation. All samples were dried to the same final moisture content (0.013±0.015 g water/g dry solid). No differences were found in moisture ($p \geq 0.05$) after 10 min of treatment between treatments. When moisture data (g water/g dry solid) were fitted to an empirical model as an exponential function of time, $X_w = a \cdot e^{-b \cdot t}$, (Bauman & Escher, 1995), the moisture data fitted ($R^2 > 0.98$) this model properly and reflected the faster water loss in atmospheric fried samples (Table 1). The frying temperature significantly affected the rate of moisture loss and the time required to achieve the desired level of dehydration (Fig. 2) in the first stage of the frying process. In this stage, water loss increase (higher values of “b” parameter) with temperature and blanching for vacuum treatments (Table 1). Treatments under vacuum condition at 140 ºC showed higher “b” values that carried out at 165 ºC at atmospheric pressure. The differences are thought to be mainly associated with micro-structural changes. Samples fried under vacuum conditions are exposed to lower temperatures. As a result, micro-structural changes/damage are impaired (this is one of the main advantages of vacuum technology). Also, during the initial depressurization step of vacuum frying, micro-structural surface changes may occur, which may prevent water from escaping. Furthermore, even though dehydration is mainly limited by heat transfer, diffusion may play a role (Dueik et al., 2010). Diffusion slows down at lower temperatures, a factor that may preclude moisture loss. Similar results were found by Mariscal & Bouchon (2008) when frying apple slices and Dueik et al. (2010) with carrots crisps. After 5 min of treatment there are not differences in moisture content of samples due to blanching treatment or temperature of frying ($p<0.05$). At this point the mean value for moisture was 0.025±0.027 g water/g dry solid or 2.3±2.4 %, other authors as García-Armenta et al. (2016) in studies of multifractal breakage pattern of tortilla chips associated a moisture content around 1-4 % with quality foodstuffs.

3.4. Oil content

Oil content of the fried cassava chips decreased with blanching (Fig. 3). The mean value of oil content for blanched samples (B) was 0.036±0.019 and 0.050±0.034 for unblanched samples (UB). When cassava slices were blanched, water would be removed from the cells of the cassava slices by diffusion. In addition, water would also be vaporised during vacuum frying and might leave behind pores in the cassava slices. By the other hand vacuum treatment implies a significant reduction in oil content ($p<0.05$). The mean value for oil content in samples fried at atmospheric pressure (165 ºC) was 0.085±0.027 while samples treated under vacuum conditions showed lesser oil content values, 0.027±0.004 at 120 ºC, 0.034±0.014 at 130 ºC and 0.027±0.008 at 140 ºC. The time of treatment was not significant for oil absorption ($p \geq 0.05$). Oil absorption is a complex mechanism, which is still not clearly understood under vacuum conditions (Garayo & Moreira, 2002). There are many factors that make this a complex phenomenon, such as the initial product structure, the various interchanges between the product and the heating medium, product variation and oil properties, chemical reactions, food moisture content, the cooling phase, the frying time, the temperature, the drainage time or pressurization time (Velasco, Marmesat, & Dobarganes, 2008). Several studies (Dana & Saguy, 2006; Moreira, Castell-Pérez, & Barrufet, 1999) demonstrated that most of the oil does not penetrate the product during frying but during the cooling period, when the product is removed from the fryer and the product starts to cool, leading to water vapor condensation and a subsequent decrease in internal pressure. Oil adhering to the food surface is sucked in due to the consequent 'vacuum effect'. Therefore, oil uptake is a surface phenomenon, involving equilibrium between adhesion and drainage as the food is removed from the oil bath (Moreira & Barrufet, 1998; Moreira, Sun, & Chen, 1997). Mariscal & Bouchon (2008) concluded that permeability was of great importance because oil absorption is essentially a surface-related phenomenon resulting from the competition between drainage and suction into the porous crust once the food is removed from the oil bath and begins to cool. These results indicated that blanching combined with vacuum frying can be an alternative to reduce oil content in cassava chips.

3.5. Color

Color is considered as the most representative quality index in a chip. It is affected by chemical composition of raw material and determines processing capability (Lisinska & Leszczynski, 1989). The golden color is characteristic and a very significant attribute of fried products and determinant in acceptance from consumers (Krokida et al., 2001). Table 2 shows instrumental parameters of color (L*, a*, b*, h^*_{ab} and C^*_{ab}) in function of pretreatment and frying conditions for samples fried during 5 min. Blanching pre-treatment affected significantly ($p<0.05$) the instrumental parameters of color. Blanching increase L* and h^*_{ab} and diminishes a*, b* and C^*_{ab}, providing samples with a lower extent of browning and a more golden-yellow color in comparison with unblanched samples. L* is a critical parameter in the frying industry, and is usually used as a quality control factor, therefore its adequate control is of great importance. Blanching is a common method to avoid browning before frying in vacuum (Liu-Ping et al., 2005; Shyu et al., 2005; Shyu & Hwang, 2001) or atmospheric conditions. Blanching contribute to lixiviate soluble sugars (Krokida et al., 2001), also the heating of samples at a temperature higher to gelatinization point of starch allows a decrease of reducing sugars that are implied in Maillard reaction.

Vacuum frying was a significant effect over the instrumental parameters of color (Table 2). Vacuum frying reduces significantly ($p<0.05$) a*, b* and C^*_{ab} values and increase h^*_{ab} values. Cassava chips fried under vacuum had L* values similar than the values corresponding to the slices fried under atmospheric conditions. As mentioned before analyzing the effect of pre-treatment, a higher a* and b* values indicates a “darker” color, which is desirable in these products (Fig. 4). High h^*_{ab} values are mainly associated to non-enzymatic browning reactions (Mariscal & Bouchon, 2008). The redness (a*) values increased significantly ($p<0.05$) with frying temperature (Table 2). Baik & Mittal (2003), Pedreschi, Hernández, Figueroa, & Moyano (2005) and Ngadi, Li, & Oluka (2007) also reported that redness increased gradually with traditional frying time, finding that the higher the frying temperature, the darker the resulting potato slices. This suggests that the Maillard reaction was limited by temperature and not by the pressure conditions. Analysis of variance showed temperature had a significant effect ($p<0.05$) on yellowness (b*) in cassava chips. The high level of vacuum frying temperature (140 ºC) decreased L* and h^*_{ab}. Color coordinates showed that cassava chips vacuum fried at 140 ºC were ‘‘darker’’ than those fried at 120 ºC or 130 ºC. Several studies have shown that during frying, under atmospheric or vacuum conditions, higher temperatures increase the extent of browning (Garayo & Moreira, 2002; Krokida et al., 2001; Pedreschi et al., 2005; Shyu & Hwang, 2001; Shyu et al., 2005; Troncoso et al., 2009), supporting the results observed in this work. Then, combination of blanching pretreatment with vaccuum frying at moderate temperature can be a good procedure to improve color in cassava chips.

3.6. Texture and sound

Recent methods simultaneously measured both the compression force and the sound pressure when a solid food was being fractured (Castro-Prada, Luyten, Lichtendonk, Hamer, & Van Vliet, 2007; Chaunier, Courcoux, Della Valle, & Lourdin, 2005; Chen et al., 2005; Salvador, Varela, Sanz, & Fiszman, 2009). These methods are more objective, in that they avoid the dependence on panelists. Chen et al. (2005) showed that acoustic events and force drops occurred almost correspondingly. Representative profiles of the force and the simultaneously recorded sound during the probe displacement in the cassava chips are shown in Fig. 5. The force–displacement curves show a jagged appearance with several fracture events, typical of crispy food (Chen et al., 2005; Salvador et al., 2009; Taniwaki & Kohyama, 2012; Taniwaki, Sakurai, & Kato, 2010; Varela et al., 2006; Vincent, 1998). In order to compare objectively the behavior of the different cassava chips, specific parameters were extracted from the force and sound curves. The parameters evaluated were: 1) the area under the force versus displacement curve; 2) the number of total force peaks, which are an index of the jaggedness of the curve; 3) the maximum force peak, which are related with hardness of the product; 4) the number of total sound peaks, and 5) the sound pressure level (average of the ten higher peaks, SPLmax10). Fig. 6 shows the parameters obtained for force and sound curves for samples fried during 5 min. Blanching implies an increase of the area and a reduction in the maximum force peaks ($p<0.05$) and had no effect on the rest of measured parameters ($p\geq0.05$). Vacuum treatment increase the number of force peaks ($p<0.05$) (Fig. 6b). In vacuum fried samples an increase of temperature implies a decrease of area under force versus displacement curve and force maxima (Fig. 6a and 6c). With respect to sound parameters, samples fried under vacuum conditions at 130 ºC and 140 ºC showed high number of sound peaks ($p<0.05$) (Fig. 6d). The sound pressure level (SPLmax10) ranged between 95.04 dB and 98.48 for all treatment been samples treated at 130 ºC under vacuum conditions and samples fried at 165 ºC under atmospheric conditions those that showed a higher level of SPL.

In general sensory crispness is positively related to the number of fracture and acoustic events, to SPLmax10, and to the area below the force curve (Salvador et al., 2009). In addition, certain degree of sensory hardness is necessary for crispness perception. On the other hand, a low number of force and acoustic events normally are taken as an index of low crispness (Salvador et al., 2009). The increase of temperature in vacuum fried samples implies a reduction of the area. Segnini, Dejmek, & Öste (1999a, 1999b) and Pedreschi, Segnini, & Dejmek (2004) used the maximum force of break as an indication of crispness. A high number of force and sound peaks have been associated to a high sensory crispness (Chen et al., 2005; Varela et al., 2006). In cassava chips samples fried at 130 ºC under vacuum conditions seems to present a good combination of force and sound parameters that can be related with samples with adequate crispness profile.

4. Conclusions

The obtained results shown that the blanching pretreatment implies a considerable improvement in the color of the samples vacuum treated and less oil absorption. Vacuum frying of cassava chips with previous blanching may be an alternative to the atmospheric frying since it improves the color of the samples, reduces the oil gain and maintains his crispness, being the treatment at 130 ºC under vacuum conditions with blanching the one that better results contributed.

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