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HTST puffing in order to produce crispy banana - The effect of the step-down treatment prior to air-drying

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Abstract

Banana snacks were produced by HTST puffing. Experiments were performed as follows: an initial pulse at 150 °C for 15 min + step-down treatment from 150 to 70 °C + air-drying at 70 °C. The aim of this work was to study the effect of this step-down treatment on banana snack attributes: crispness, shrinkage, color and structural morphology. Two variables were evaluated. The first was the magnitude of temperature reduction, named as *amplitude*. The second was the residence time at this temperature, named as *cycle time*. Results showed that an *amplitude* of 10 °C and *cycle time* of 7.5 or 10 min, lead to a gradual reduction of temperature. Banana snacks from these step-down treatments resulted in a highly porous structure, higher number of peaks in the force-deformation curve (an indicative parameter of crispness), less volume loss and, less color degradation. Thus, these treatments were shown to be an adequate alternative in relation to the conditions with the sudden reduction of temperature.

Keywords: Shrinkage, Crispness, Color, Explosion puffing.

1 Introduction

The banana has an important place in the production of agricultural crops in several countries, especially those located in the tropics. India is the top of the producers' list and in fifth place is Brazil (FAO, 2015). Despite the higher quantity of banana production in Brazil, the accumulation of loss in the production of bananas reaches 40% (EMBRAPA, 2015). The main causes of these losses are inadequate techniques for harvesting and post-harvesting; failures in the distribution and the difficulty in placing the product on the market. An alternative to reducing post-harvest loss is the production of dehydrated bananas. Among the many alternative processes, operational parameters or raw material physicochemical properties, crispy banana obtained by puffing technology is highly palatable as a consequence of crust formation (Monteiro et al., 2016). This kind of foodstuff has similar quality attributes to freeze-dried or deep-fried snacks. Nevertheless, the process presents advantages, such as low processing costs in comparison to freeze drying (Monteiro et al., 2016); lower oil content and longer shelf life (Bi et al., 2015) which may promise a bright future for fruits and vegetables dried under this technology. There are many methods to obtain puffing, including high temperature and a short time (HTST) drying pulse. The initial high temperature promotes the formation of an initial layer on the surface of the solid; this partially dry layer promotes the puffing (Varnalis et al., 2001). The puffing involves the release or expansion of vapour or gas within the product, either to create an internal structure; or to expand or rupture an existing one (Payne et al., 1989), resulting in crispy products with good rehydration capacity and faster drying (Hofsetz, 2007; Saca & Lozano, 1992).

After HTST puffing the product must be further dried to reduce the water activity (a_w), thus, reducing enzyme activity and the rate at which undesirable reactions occur (Barreiro et al., 1997; Saca & Lozano, 1992). Air-drying is commonly applied at 60 to 70 °C.

Previous research showed that HTST puffing at 150 °C for 15 min resulted in high quality crispy banana (Hofsetz & Lopes, 2005; Hofstez, 2007; Oliveira, 2007). However, according to the same studies, the reduction of temperature from 150 to 70 °C showed that it highly influences the crispness and the color in the quality of the final product. Further research on this stage of the process has not been reported yet. Therefore, in this work, the step-down treatment, which started after the HTST puffing (150 °C) and before the air-drying (70 °C)**,** was studied, in order to produce crispy banana.

2. Materials and methods

2.1 Raw material

Bananas (*Musa cavendishii*) of the Nanicão variety were purchased from a local market. The fruit was placed in a maturation chamber where they remained with a controlled temperature at 18 °C and relative humidity of 80 % until reaching 18.5 to 20.0 °Brix. Soluble solids were determined, in triplicate, by a refractometer (ATAGO, model, DR-A1, Japan) and corrected for acidity and temperature values (Zenebon et al., 2008). The bananas were peeled, cut into 0.01 m thick slices and into four equal parts. Banana pieces were placed in a drying tray in a single layer.

2.2 Air-drying process

A stainless steel vertical tray dryer previously described in Hofsetz & Lopes (2005) and Hofstez (2007) was used for the drying experiments. The air velocity throughout the process was fixed at 3.5 m/s. Air temperature inside the dryer column was measured by a "T" type thermocouple. Data was collected in intervals of 10 seconds and processed by the Field Chart 64C software (Novus, Inc., Brazil).

A diagram describing the experiments performed is displayed in Figure 1A. According to previous researches (Hofsetz & Lopes, 2005; Hofsetz, 2007; Oliveira, 2007) the best condition for the high temperature and short time is 150 °C for 15 minutes. After HTST puffing, a step-down treatment from 150 to 70 °C was conducted. As shown in Figure 1B, two variables were evaluated during this stage. The first was the magnitude of temperature reduction, referred to *amplitude*. The second variable studied was the residence time at this temperature, referred to *cycle time*. As a consequence of the different values of these variables, different step-down temperature profiles were obtained as well as different time for this stage. In Table 1 all the conditions studied are presented. Finally, banana pieces were submitted to air-drying at 70 °C. The experiments were conducted, in triplicate, until banana pieces reached water activity below 0.3, in order to guarantee the crispness (Hofsetz et al., 2007) and to prevent undesirable browning reactions (Moraga et al., 2011).

2.3 Crispy banana characterization

2.3.1 Water activity (a_w)

Water activity for banana snacks was determined using the Aqualab (DECAGON, model Series 3 TE, USA), in triplicate, at 25 °C as soon as drying process finished.

2.3.2 Instrumental texture

Dried banana snacks were analyzed immediately after the drying process in a Stable Microsystems Texture TAXT2i texture analyzer with a flat base of 3 mm diameter, at a strain rate of 1 mm/s and penetration until 50 % of their original height. Due to the low reproducibility of the test for this type of product, fifteen repetitions for each condition were performed. Two parameters indicative of crispness were determined from the curves of force-deformation: the number of peaks and the hardness of the piece of banana. The larger number of peaks are related to the larger void spaces in the food material, thus resulting in higher crispness (Raikham et al., 2013). Moreover, the presence of these air cells dropped the force after each fracture (Sothornvit, 2011), thus resulting in lower values of hardness. The counting of peaks was done based on a perception threshold of 0.3 N (Raikham et al., 2013).

2.3.3 Shrinkage

Bulk volume (V_b) was determined, in quintuplicate, by the liquid displacement method when immersed in n-heptane according to equation Eq. (1) (Yan et al., 2008; Zabalaga et al., 2016).

$$V_b = V_f - \frac{M_{t+s} - M_f - M}{\rho_s} \quad (1)$$

wherein: V_f is the volume of the glass pycnometer (m^3); M_{t+s} is the weight of the glass pycnometer + sample + solvent (kg); M_f is the weight of the glass pycnometer (kg); M is the weight of the sample (kg); ρ_s is the density of the n-heptane (kg/m^3).

Shrinkage was expressed as a ratio of the bulk volume of the dried piece at the end of the process, in relation to its initial bulk volume according to Eq. (2). (Hofstez et al., 2007; Yan et al., 2008).

$$S_b = \frac{V_b}{V_{bo}} \times 100 \qquad (2)$$

wherein: S_b is the shrinkage ratio (%); V_{bo} is the initial bulk volume of the piece (m^3) and V_b is the bulk volume of the dried piece (m^3).

2.3.4 Microstructural changes

Banana pieces at the end of the air-drying process were immediately photographed by an image capture system which consisted of a stereomicroscope (CARL ZEISS, model Citoval 2, Germany) and a digital color camera (KODAK EASY SHARE, model DX 4530, USA). Image processing was done using the software Image J.

2.4 Color

The color was determined on a spectrophotometer (HUNTER LAB, model ScanVis, USA) with CIELab scale (L^*, a^*, b^*). The color measurements were expressed in terms of L^* (L^* = 100 brightness and L^* = 0 darkness); a^* ($+a^*$ = redness and $-a^*$ = greenness) and b^* ($+b^*$ = yellowness and $-b^*$ = blueness). Nine determinations were performed per sample. The change of each of the parameters in relation to the raw material was calculated according to Eq. (3), (4) and (5).

$$\Delta L^* = L^* - L_0^* \qquad (3)$$

$$\Delta a^* = a^* - a_0^* \qquad (4)$$

$$\Delta b^* = b^* - b_0^* \qquad (5)$$

wherein: the subscripts 0 correspond to the raw material. The total color change (ΔE^*) was calculated according to Eq. (6) (Chua et al., 2001), Chroma (C) and Hue angle (H) were also calculated according Eq. (7) and Eq. (8), respectively (Francis, 1975; Maskan, 2001).

$$\Delta E^* = \left[\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2\right]^{1/2} \tag{6}$$

$$C = (a^2 + b^2)^{1/2} \tag{7}$$

$$H = \tan^{-1}\left(\frac{b}{a}\right) \tag{8}$$

2.5 Statistical analyses

Data was analyzed by analysis of variance (ANOVA) applying Tukey`s test at 95 % level of confidence as a post-hoc test through Statgraphics Centurion XV software (StatPoint, Inc., USA).

3 Results and Discussion

3.1 Drying process

Initially all the banana pieces were submitted to HTST puffing at 150 °C; after this process the pieces were submitted to different step-down treatments to reduce the temperature from 150 to 70 °C. The air temperature profiles during this stage are shown in Figure 2. It can be observed that the temperature instead of staying in the fixed value of *amplitude* and *cycle time* fluctuates around these values, however it is visible that each condition studied resulted in different profiles of temperature reduction, thus, different times to reduce the temperature from 150 to 70 °C were achieved, as can be seen in Table 2. The air-drying time, as well as the total drying time, were also different for each condition studied. Since, the process should be performed until banana a_w < 0.3 to guarantee crispness (Hofsetz et al., 2007; Moraga et al., 2011).

As shown in Table 2, pieces submitted to a sudden reduction of temperature from 150 to 70 °C with an *amplitude* of 80 °C and *cycle time* of 0 min achieved the air-drying temperature of 70 °C in around 9 min. However, 720 min in the air-drying was needed to achieve the desired water activity (a_w < 0.3). According to Hofsetz (2007), the abrupt reduction of temperature during this stage promoted the collapse of the porous structure, therefore resulting in longer air-drying times and increased shrinkage. On the other hand, pieces submitted to an *amplitude* of 5 °C and *cycle time* of 5 min reached the temperature of 70 °C in around 118 min, thus the air-drying lasted only 360 min. The drying kinetics and the total color change of banana dried under stepwise variation of air temperature from 35 to 20 °C was already studied (Chua et al., 2001). According to the authors, by employing stepwise variation of air-drying temperature with appropriate starting temperature and *cycle time*, it is possible to reduce the drying time significantly to reach the desired moisture content. As shown in Table 2, longer times of the step-down stage resulted in shorter times for the air-drying to achieve a_w < 0.3. Thus, shorter times for total drying time (the same behavior related by the authors).

3.2 Textural properties

Crispness is one of the most important characteristics of vegetables and fruit snacks produced by explosion puffing (Bi et al., 2015). A crispy texture is a result of a porous structure formed by air cavities surrounded by brittle structures (Scaman et al., 2014). Previous researchers investigated the textural attributes for snack foods through texture analyzers (Anton & Luciano, 2007) and showed that in a typical force-deformation curve, crispness is associated with the rapid propagation of fracture points (Hofsetz & Lopes, 2005), which represent the rupture of individual cell walls (Roudaut et al., 2002). Moreover, Pamies et al. (2000) applied the fractal analysis of a force-deformation curve and compared this analysis with sensory data showing that crispness is correlated with the number of spatial ruptures. Thus, a curve with many fracture points indicates a crispier structure (Tabtiang et al., 2011). The use of peak counting to describe crispness texture was satisfactorily reported in the literature for potato-soy (Nath & Chattopadhyay, 2007); pitaya (Yi et al., 2016) and banana (Raikham et al., 2013) snacks. Figure 3 shows the number of peaks in the force-deformation curve as a function of the step-down treatment for banana pieces.

An increase in the number of peaks due to the application of higher temperatures for longer times was observed in puffed potato (Nath & Chattopadhyay, 2008) and banana (Raikham et al., 2013). In this research, the entire banana pieces were submitted to the same puffing process (150 °C for 15 min). However, different step-down treatments were applied (Table 1). As shown in Table 2, the step-down with *amplitude* of 10 °C and *cycle time* of 10 min, which lasted approximately 96 min resulted in a higher number of peaks, around 18 (Figure 3). On the other hand, the condition with an *amplitude* of 80 °C and *cycle time* of 0 min resulted in a shorter time of step-down treatment (9 min) and also the less number of peaks, around eight (Figure 3). Thus, gradual reduction of temperature encourages the maintenance of the crispy structure in banana pieces, however, sudden reduction of temperature causes the loss of the crispness. ANOVA revealed no statistical difference between the other conditions studied.

Figure 4 shows the hardness for the curve force-deformation as a function of the step-down treatment. According to Sothornvit (2011), in the force-deformation curve, the compression force increases until the first set of cells fractured. The presence of air cells, in the crispy chip structure, dropped the force after each fracture. A lower value of hardness corresponds with a higher crispness (Sothornvit, 2011) due to the weakening of the cell wall, which may play an important role in cell rupture during the processing of snacks (Singthong & Thongkaew, 2009). The indirect relation between crispness (expressed in the number of peaks) and hardness was also reported in potato snacks (Nath & Chattopadhyay, 2008) and puffed banana (Raikham et al., 2013). For banana pieces submitted to different step-down treatments, ANOVA revealed no statistical difference for hardness, as shown in Figure 4, probably due to the low reproducibility of this test. Nevertheless, the values obtained were in the range of values already reported in the literature for crispy banana snacks (Raikham et al., 2013).

3.3 Shrinkage

Figure 5 shows the shrinkage ratio of dried banana pieces as a function of the step-down treatment. According to the literature, shrinkage is an anisotropic phenomena and predominant in certain regions of the sample (Hofsetz et al., 2007).

As shown in Figure 5, the gradual decrease in temperature resulting from the step-down treatment with an *amplitude* of 5 °C and *cycle time* of 5 min caused less volume loss, in relation to treatments with an *amplitude* of 80 or 10 °C and *cycle time* of 0 or 5 min, respectively. Thus, the sudden reduction in the temperature, during the step-down stage, caused the collapse of porous structure and increased the volume loss. Banana pieces submitted to air-drying at 70 °C shrank to 20% of original volume (Yan et al., 2008).

Comparing the results obtained in this work with those obtained from the authors, banana pieces from this study showed less volume loss, even in the most sudden reduction of temperature condition. Saca & Lozano (1992) compared the shrinkage in banana pieces dried under air-drying and HTST puffing + air-drying. Banana snacks resulted in 16 and 43 % of the original volume, respectively. Thus, HTST puffing is important for the product to gain a porous structure. Moreover, according to the results represented in Figure 5 the step-down treatment is important to maintain this structure. Banana snacks dried with an HTST puffing of 130 to 150 °C for 12 to 23 min + step-down lasting 25 min + air-drying at 70 °C shrank to 51-60 % of original volume depending on the HTST condition (Hofsetz et al., 2007). Banana pieces with an *amplitude* of 10 °C and *cycle time* of 7.5 or 10 min, which lasted 70 and 96 min, resulted in 68.39 and 66.50 % of the original volume, respectively. Therefore, a gradual reduction of temperature is important to maintain the crispy structure in banana snacks and reduce volume losses, as explained previously.

3.4 Color parameters

The change in color during thermal processing of foods takes place by various mechanisms, including the degradation of pigments, oxidation of ascorbic acid and the Maillard reaction (Barreiro et al., 1997; Chua et al., 2001). According to Chua et al., (2000) the surface moisture acts as a protective layer to minimize color degradations. Different temperature profiles produce different air-drying rates, thus, influencing the moisture migration to the surface. Color parameters (ΔL^*, Δa^* Δb^* and ΔE^*) of the CIELab scale for banana pieces submitted to different step-down treatments are shown in Table 3. ANOVA revealed that the *amplitude* and the *cycle time* influenced statistically the ΔL^* parameter. The treatment of an *amplitude* of 5 °C and *cycle time* of 5 min, which lasted 118 min to reduce the temperature from 150 to 70 °C resulted in greater losses of brightness. The reduced luminosity involved the destruction of thermo-labile pigments, and this consequently results in the formation of dark compounds (Barreiro et al., 1997). Thus, higher temperatures for longer times influenced the loss of brightness in the banana pieces. As stated by Chua et al., (2001) a gradual reduction of temperature reduces color degradation. Nevertheless, the temperatures used by the authors were 35 and 20 °C, much lower than the temperatures used in this work. The loss of brightness was already reported for air-dried (Baini & Langrish, 2009; Chua et al., 2001) and puffed (Saca & Lozano, 1992) banana.

No statistical difference between the step-down treatments for the redness/greenness (Δa^*) parameter was observed. For the yellowness/blueness (Δb^*) parameter it is possible to see that treatments with an *amplitude* of 80 and 10 °C and *cycle time* of 0 and 5 min, respectively, resulted statistically different from treatments of *amplitude* of 10, 10 or 5 °C and *cycle time* of 7.5, 10 or 5 min, respectively. According to Prachayawarakorn et al. (2008) for banana drying at high temperatures, the most sensitive color parameter during drying is ΔL^*. For the ΔE^* parameter ANOVA revealed that treatment of amplitude of 5 °C and cycle time of 5 min resulted statistically different for the other conditions studied. This treatment had more influence in the formation of darks compounds and loss in brightness, as discussed previously. Thus, the gradual reduction of temperature should last enough to promote crispness and reduce volume loss without affecting the final color in the snack. According to Chua et al., (2001) drying time and product quality are important considerations for any industrial drying process and step-down temperature profile drying offers a new dimension in transient drying to reduce color degradation without too much compromise in drying time. Treatments of *amplitude* of 10 °C and *cycle time* of 7.5 or 10 min promote the formation of crispy structure which resulted in a higher number of peaks (Figure 3). Although, dark compound and loss of brightness (ΔL^* parameter) were reported, the total color change parameter reported was ΔE^* = 19.30 to 22.20, respectively. These values are lower than the one obtained from the step-down treatment with an *amplitude* of 5 °C and *cycle time* of 5 min, which was ΔE^*= 29.04, showing that they are better options to produce puffed bananas.

The Chroma value (*C*) or saturation may be defined as the properties of chromatic content in the total color perception (Waliszewski et al., 1999). As shown in Table 3 ANOVA revealed no statistical difference for this parameter between banana pieces dried under different step-down treatments ($p > 0.05$), the same behavior was observed in banana slices dried at 50 to 70 °C (Waliszewski et al., 1999) and kiwifruits dried at 60 °C (Maskan, 2001). According to Waliszewski et al., (1999) Hue angle (*H*) > than 90° indicates more green and less yellow color, while values < than 90° indicate orange-red. In this work, all banana pieces dried under different step-down treatments resulted with H < 90°, however, these values decreased from 70.95 to 61.23, resulting in statistical differences ($p > 0.05$), as shown in Table 3. The treatment of an *amplitude* of 5 °C and *cycle time* of 5 min resulted in the lowest value attributable to the greater loss of brightness, as discussed previously.

3.5 Structural changes

Figure 6 presents photographs of dried banana snacks submitted to different step-down treatments. Figure 6A shows the structure of fresh banana, which is dense, pore-less and light colored. According to the literature, HTST puffing is important to promote the creation of porous structure and the outer layer (Hofstez et al., 2007; Zou et al., 2013). Figure 6B, shows the final structure of a banana piece with sudden reduction of temperature (*amplitude* of 80 °C and *cycle time* of 0 min). The structure obtained from the HTST puffing was lost; samples shrunk, but did not have much browning as compared with treatments with longer times at higher temperatures (Figure 6F). Volume loss and structural deformation after HTST puffing + air-dying was already observed in banana (Hofsetz et al., 2007b); mango snacks (Zou et al., 2013). Though the same volume loss was observed between treatments of an *amplitude* of 80 °C and *cycle time* of 0 min and *amplitude* of 10 °C and *cycle time* of 5 min, porous structure started to be evident for banana pieces submitted to this second treatment. (Figure 6C). The pore formation after explosion puffing is possible due to the evolution of the water vapor inside the samples. Such change, in turn, led to the development of the internal pressure and breakage of the sample tissue, which resulted in pore formation (Prachayawarakorn et al., 2008). These pores might affect not only the transport properties such as diffusivity, but also the crispy texture in the samples, which is essentially required for snack food (Prachayawarakorn et al., 2008). Figure 6D corresponds to treatment with *amplitude* of 10 °C and *cycle time* of 7.5 min; it is possible to see a highly porous structure in this piece, with many pores of different sizes, slightly shrunk. According to Prachayawarakorn et al., (2008) the large pores formed led to less volume loss and a highly porous structure in banana slices. Although the presence of a dark color is noted, this was evident in some of the outer areas. In Figure 6E from step-down treatment with *amplitude* of 10 °C and *cycle time* of 10 min, it is possible to see a porous structure and less volume loss. However, the presence of dark color was more evident than treatment with *amplitude* of 10 °C and *cycle time* of 7.5

min. In Figure 6F, thermal degradation and formation of browning compounds are shown that produced undesirable characteristics discussed previously (Table 3). For the treatment of *amplitude* of 5 °C and *cycle time* of 5 min, these characteristics are clearly visible in Figure 6E.

4 Conclusions

Crispy banana snacks were produced by HTST puffing. The pulse at 150 °C for 15 min was important to get a porous structure in the banana snacks. Nevertheless, the step-down treatment was important to maintain this structure. The time duration of this stage was different for each condition studied and was the variable defining the total air-drying time, so that banana pieces could reach a_w <0.30. Bananas with gradual reduction of temperature resulted in a higher number of peaks (an indicative parameter of crispness) and also less volume loss. However, much longer times at higher temperatures influenced the loss of brightness and formation of browning compounds. On the other hand, sudden reduction of temperature, in the step-down treatment, caused the loss of the porous structure, the final products were harder (less crispy) and resulted in a higher loss of volume. Therefore, a reduction of temperature from 150 to 70 °C should be gradual enough to maintain the porous structure without promoting undesirable characteristics in product color. Indeed, *amplitude* of 10 °C and *cycle time* of 7.5 or 10 min, which lasted 70 and 96 min respectively, showed to be adequate process options to maintain the crispy structure, less volume loss and less color degradation.

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Figure caption

Figure 1. Flow diagram of banana pieces air-drying experiments performed in a tray dryer **(A)**; step-down treatment profile: *amplitude* (°C) *versus cycle time* (min) **(B).**

Figure 2. Temperature profile (°C) for the step-down treatment *versus* time (min): *amplitude* of 80 °C *and cycle time of* 0 min; *amplitude* of 10 °C *and cycle time of* 5 min; *amplitude* of 10 °C *and cycle time of* 7.5 min; *amplitude* of 10 °C *and cycle time of* 10 min and *amplitude* of 5 °C *and cycle time of* 5 min.

Figure 3. Number of peaks for banana pieces submitted to different step-down treatments. Same letters in the same column are not significantly different (*p*>0.05).

Figure 4. Hardness (N) for banana pieces submitted to different step-down treatments. Same letters in the same column are not significantly different (*p*>0.05).

Figure 5. Shrinkage (%) for banana pieces submitted to different step-down treatments. Same letters in the same column are not significantly different (*p*>0.05).

Figure 6. Photographs of dried banana pieces submitted to different step-down treatments. Raw material **(A)**; *amplitude* of 80 °C and *cycle time* of 0 min **(B)**; *amplitude* of 10 °C and *cycle time* of 5 min **(C)**; *amplitude* of 10 °C and *cycle time* of 7.5 min **(D)**; *amplitude* of 10 °C and *cycle time* of 10 min **(E)**; *amplitude* of 5 °C and *cycle time* of 5 min **(F)**.