Impact of freeze-drying conditions on the sensory perception of a freeze-dried orange snack

Running Title: Sensory perception of an orange snack as affected by freeze-drying conditions

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Abstract

BACKGROUND: The health benefits provided by fruit mean that there is continuous interest in offering consumers new products to stimulate its consumption. To this end, dehydrated fruit snacks may be an interesting option. In this study, the impact of the freezing rate (slow and high), shelf temperature (40 and 50 ºC) and working pressure (5 and 100 Pa) on the perception and acceptability of a freeze-dried orange snack obtained from an orange puree was evaluated. RESULTS: Of the different freeze-drying conditions studied, the working pressure was the variable with the greatest effect. The lowest working pressure (5 Pa) leads to samples being obtained with a slightly lower water content, which are perceived with higher citrus flavor and crispiest. The highest pressure (100 Pa) leads to samples with a greater water content, perceived with a more yellow intense color. Nevertheless, there is no significant consumer preference for any of the different processed samples. The number of force peaks, which is positively correlated with the crispness, shows a significant and negative correlation (r=-0.91) with the water content of the sample. CONCLUSION: The study revealed that considerations other than the sensory can determine the best conditions of the freeze-drying process with which to obtain an orange snack. The number of force peaks obtained from a penetration test may be proposed as an instrumental analysis of the snack's crispness tool which supplies information that closely resembles customer perception of this attribute.

Keywords: free choice profile, hedonic comparison, texture, freeze-drying pressure, freeze-drying shelf temperature.

1. Introduction

In the last few years, an interest in following a healthy diet has led to people consuming greater amounts of fruit, since it seems to contribute to human well-being. This contribution is related to the fruit's bioactive compounds, mainly related to antioxidant capacity, which can help in preventing some pathologies (WHO, 2004). Citrus fruit is one of the most important commercial crops in a large number of countries. The global production of oranges in 2018/19, for example, reached 54.3 million tons (USDA, 2020), such a high figure due to their sensory and nutritional attributes.

Oranges are composed mainly of fibres, simple sugars, and a wide variety of bioactive compounds that possess antioxidant properties and have a positive impact on health. Vitamin C, phenolic compounds such as the flavanones hesperidin and narirutin, and carotenoids are some of the characteristic compounds of this fruit, which are related to the suppression of oxidative stress (Chanet et al., 2012; Du et al., 2012; Zou et al., 2016) and prevention and/or protection against cancer, cardiovascular disease, heart disease, and macular degeneration, among other illnesses (Meléndez-Martínez et al., 2007; Nowak et al., 2018; Roohbakhsh et al., 2015).

From a commercial point of view, oranges are widely consumed fresh or in processed forms, such as juice or jam, which are responsible for its economic importance. However, consumers are continually demanding new products and formats which can satisfy their needs, including ease of handling. Snacks are widely consumed between the main meals. The growth trend of the snacks is expected to increase over the years, which offers the opportunity of formulating new food products (AINIA, 2018). Nowadays, the promotion of a healthier lifestyle has made the population aware of the food they eat. Despite an increasing snack frequency has been associated with unhealthier dietary behaviour, in recent years 50% of the consumers declare to take healthy snacks (AINIA, 2018; Hartmann et al., 2012). In this scenario, snacks obtained from dehydrated fruit puree may offer a market opportunity.

Currently, the market offers dehydrated fruit products, with apples being the most common dehydrated fruit found in many supermarkets, but pineapple, strawberry, kiwi, mango, and banana are also available. One of the most common and classical dehydration technics for getting this kind of products is air drying, osmotic dehydration, or freeze-drying. The air dryers use hot air that circulates around the food pieces. In general, air dryers are simple and versatile in comparison to other types of dryers, and food pieces of any shape and size can be handled (Mujumdar, 2014). However, they are not recommended to be used for drying thermolabile compounds due to the high temperature applied during the process. The osmotic dehydration requires low temperature and energy, and it leads to good quality final product, however, besides the fact that it can vary its characteristic taste, it does not allow to obtain very dry products.

Freeze-drying is a dehydration technique based on the sublimation of the water present in a product using low temperatures and pressure, which presents advantages and disadvantages. On the one hand, it permits the preservation of thermolabile compounds and contributes to the obtaining of a higher quality product as compared with other dehydration techniques (Karam et al., 2016). On the other hand, the characteristics of the freeze-drying process and the long process time involved make freeze-drying an expensive process. One way to shorten the process time and, therefore, reduce the cost, is the adequate fit of the conditions of the freezing and drying steps. However, the variables involved may affect the quality of the obtained product (Ceballos et al., 2012; Egas-Astudillo et al., 2018; Genin & René, 1996; Hammami & René, 1997; Martínez-Navarrete et al., 2019; Silva-Espinoza et al., 2020a).

With the above considerations, offering a high added value orange snack obtained from freeze-dried orange puree may not only be an interesting option for consumption by the general public, but also for those special groups with special needs, such as children, athletes, the elderly, etc. A prior study, recently carried out on freeze-dried orange puree obtained under different conditions (freezing rate, shelf temperature and, working pressure), concluded that the colour and texture of the obtained products, measured by instrumental analysis, were affected by these process conditions. Bioactive compound preservation, however, was not significantly affected, retaining more than 80% of the content of vitamin C, total phenols, and antioxidant activity after freeze-drying (Silva-Espinoza et al., 2020a). However, it is also important to know the consumer perception of this product, its global acceptability, and the role the process conditions can play in consumer opinion. One important factor contributing to the choice of a snack is that its consumption should be a pleasure from the sensory point of view. The sensory attributes of a food item tend to be perceived in the following order: appearance, odour/aroma, consistency/texture, and flavour (Meilgaard et al., 1999). As regards snacks, despite 44% of the consumers looking for aspects related to nutrition and well-being, flavour is the most important general attribute for 71% of the consumers (AINIA, 2018).

In addition, the texture of a snack is another factor to consider, since the crunchiness/crispness of a snack is considered a very good indicator of its consumer acceptance (Luyten et al., 2004; Martínez-Navarrete et al., 2019). A consensus meaning for crisp would be “desirably firm and brittle and easily crumbled” and for crunch “chew with a crushing noise” (Tunick et al., 2013). However, different definitions of crunchy and crispy have been reported, even the differences between them are not so clear because they vary between different studies, countries, and languages (Luyten et al., 2004; Tunick et al., 2013) and some researchers consider the terms interchangeable (Chen et al., 2005). Nevertheless, Alonzo-Macías et al. (2014) analysed different studies and compiled practical examples of crunchy/crispy foods, indicating raw carrot and apple or, pickled ginger as crunchy food, and breakfast cereals, biscuits, and freeze-dried and swell-dried products as crispy food. According to this classification, the orange snacks evaluated in this study would be in the crispy food group.

In this study, the impact of the freezing rate, shelf temperature, and working pressure throughout freeze-drying on the sensory perception of an orange snack was evaluated. The objective was to identify if any of the samples was preferred by consumers as a snack type food, with a view to a better selection of the process conditions in order to obtain a rounded product. Complementary to this aim, some instrumental textural properties were measured in order to evaluate the crispness of the samples.

2. Material and Methods

2.1. Raw material and formulation

The oranges (Citrus x sinensis cultivar Navelina) used in this study were purchased in October 2019 from a local supermarket in the city of Valencia (Spain). They were selected after a visual inspection based on a similar weight and size, colour homogeneity, and good physical integrity. The carriers used to obtain a stable dehydrated orange puree were gum Arabic (GA, Scharlab, Sentmenat, Spain) and bamboo fibre (BF, VITACEL®, Rosenberg, Germany). The orange puree was triturated and mixed with GA and BF using a bench top electrical food processor (Thermomix TM 21, Vorwerk, Spain) under the speed and time conditions described by Silva-Espinoza et al. (2020a).

2.2. Freeze-drying conditions

Samples were frozen in a conventional freezer (S, Liebherr Mediline LGT 2325, Liebherr, Baden-Wurtemberg, Germany) for 48 h, at a supposed slow freezing rate (S) and dried at two different pressures, 5 and 100 Pa (P_5 and P_{100}, respectively) in the chamber and two different shelf temperatures (T), 40 and 50 ºC (Telstar Lyo Quest-55-, Telstar, Terrassa, Spain). In addition to these four conditions, another one including a faster freezing-rate (F) was considered in the study. This sample was frozen in a blast freezer (Hiber RDM051S, Hiber, Cernusco sul Naviglio, Italy) and dried at P5 and 50 ºC. The shelf temperature conditioned the drying time, this being 7 h at 40 °C and 6 h at 50 °C. This time was selected based on preliminary experiments as being enough to achieve a water content lower than 5 %; this is the critical water content for the glass transition of this product at the usual handling temperature, thus ensuring a crispy product (Silva-Espinoza et al., 2020b). In this way, five different conditions were studied, and the obtained samples were coded as $S\_40\_P_5$, $S\_40\_P_{100}$, $S\_50\_P_5$, $S\_50\_P_{100}$ and $F\_50\_P_5$.

2.3. Water content

The water content of the freeze-dried samples was measured with an automatic Karl Fisher titrator (Mettler Toledo, Compact Coulometric Titrator C10S, Worthington, OH, USA). Three replicates were made for each sample.

2.4. Sensory analysis

2.4.1. Free choice profile

The Free Choice Profile (FCP) methodology (Williams & Langron, 1984) was used to describe the sensory profile of the orange snack obtained under the five different freeze-drying conditions. A total of 20 untrained assessors (80% women, 20% men), of ages ranging from 23 to 50 years old, participated in the study. The FCP consisted of two sessions. Portions of 20 x 20 x 5 mm of each freeze-dried orange puree were tested. In the first session, the assessors were given an explanation about the procedure and asked to evaluate the similarities and differences as regards the appearance, taste, aroma, and texture of the two most different samples. They were instructed to describe the samples using their own terms to point to the intensity of the attributes, avoiding the use of hedonic terms to specify their acceptability. Of the five samples obtained when applying the different freeze-drying conditions, the results of Silva-Espinoza et al. (2020a) were considered to select the two most different ones as regards the water content and the instrumental colour and texture, these being S_40_P_{100} and F_50_P_5. In the second session, the assessors were asked to rate their own list of descriptors for each of the five samples using a 10 cm unstructured line scale with the anchors "Not perceived" and "Very intense". In both sessions, the samples were presented with random three-digit codes for each one and were served at room temperature. Bottled water was provided to cleanse the palate between samples.

2.4.2. Hedonic pair comparison

A hedonic pair comparison test was carried out with a total of 60 consumers aged between 20 and 60 years old. Considering the results of FCP, the pair of samples S_50_P_5 and S_50_P_{100} was selected for evaluation. Each sample was identified by a random three-digit code and presented to consumers randomly in a standardized test room with separate booths (ISO, 1998). Each panel member evaluated the pair of samples and was asked to identify the sample that they preferred. The results were analysed using the corresponding table following a bilateral hypothesis (Roessler et al., 1978).

2.5. Textural properties

A penetration test (Texture analyzer TA-XT2i, Stable Micro Systems, Godalming, UK) was carried out to evaluate some instrumental textural properties of each freeze-dried orange puree. Portions of 20 x 20 x 5 mm of each orange snack were compressed using a cylindrical probe of 10 mm diameter, applying a strain of 80% at a test speed of 1 mms^{-1}. Five replicates were performed per sample. The force-distance curve was registered and the total number of force peaks (force threshold 0.05 N), the maximum force (F_{max}, N), and the slope of the first part of the curve up to 2 mm (N/mm), related to the rigidity or resistance of the sample to be deformed, were selected as the parameters to characterize the instrumental texture.

2.6. Statistical analysis

A Generalized Procrustes Analysis (GPA) was applied to the FCP data using XLSTAT statistical software 2010.5.02 (Addinsoft, Barcelona, Spain). An analysis of variance (ANOVA) using Tukey's HSD test was performed to establish the significant differences of the textural properties among the studied samples, which were considered when $p<0.05$. The Pearson correlation coefficient values (r) were obtained using Statgraphics Centurion XVI.II.

3. Results and Discussion

Despite the fact that the water content of all the snacks was around the expected value, the samples that were freeze-dried at a lower pressure had a lower water content (3.63±0.15 g water/100 g sample, $p<0.05$) than that of samples S_50_P_{100} (4.70±0.14 g water/100 g sample, $p<0.05$) and S_40_P_{100} (5.300±0.001 g water/100 g sample, $p<0.05$). These results confirm the impact of both the shelf temperature and also the working pressure on the duration of the freeze-drying process (Silva-Espinoza et al., 2020a). However, it is important to emphasize at this point the difficulty of obtaining an exact water content in a freeze-dried product, especially in the low-moisture zone (Genin et al., 1996; Tang & Pikal, 2004).

3.1. Free choice profile

The FCP is a quantitative descriptive analysis which was developed for the purposes of finding out the perception of the consumers using their own terminology, avoiding a technical description of the products (Murray et al., 2001a). This analysis was selected to determine the attributes that describe the orange snacks. The consumers generated different terms, grouped by appearance, taste, aroma, and textural attributes. The results from the FCP analysis are shown in Fig. 1, which shows the two dimensions of the GPA graph. In this figure, the most commonly-mentioned attributes and their frequency of mention are summarized. The total amount of variance explained by the two dimensions was 72.93%: 48.63% accounted for by dimension 1 and 24.30% by dimension 2. On the left-hand side of the plot, the attributes related to texture and flavour, such as light texture, acid taste, and citrus flavour, were placed; these characterized orange snacks dried at P_5. On the right hand-side of the plot, the terms related to appearance (bright and yellow intensity) were related to orange snacks dried at P_{100}. As regards dimension 2, with the exception of sample F_50_P_5 which is related to the crispy texture, this does not explain the variability of the rest of the samples.

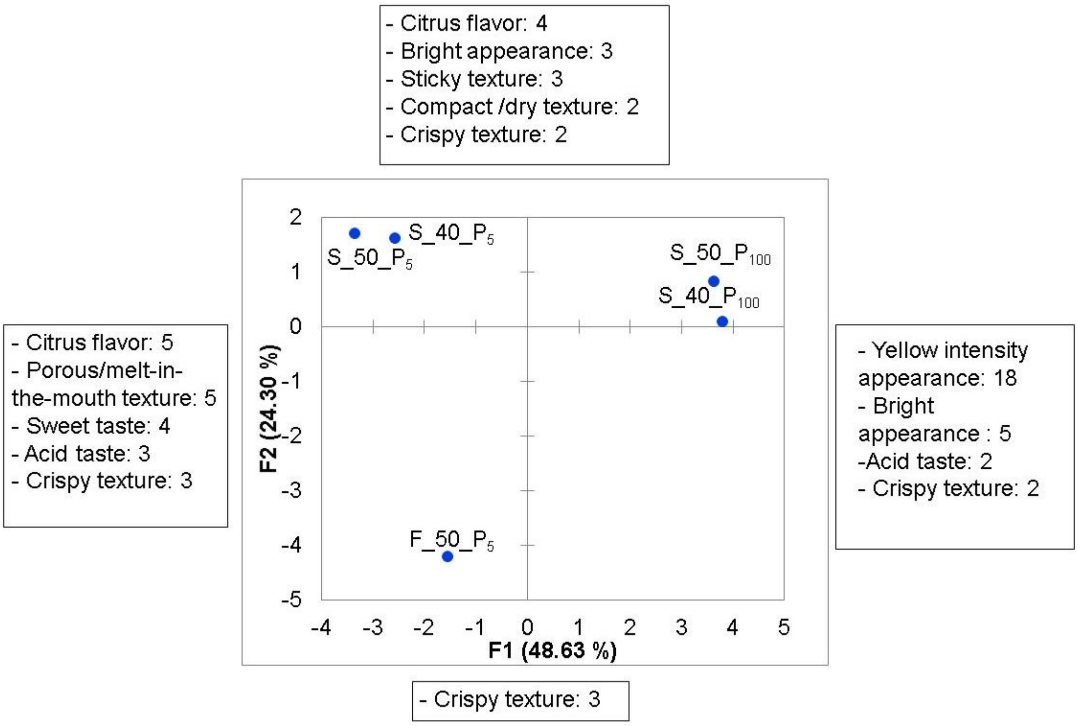

Figure 1. Two dimension Generalized Procrustes Analysis plot of the differences among snacks freeze-dried under different process conditions. The main descriptors correlated with the first two dimensions are listed together on the boxes with the times that the descriptor was mentioned.

As can be observed in Fig. 1, the crispy texture attribute appears on all 4 sides of the graph, which means that although the assessors perceived the samples as difficult to deform, they break relatively easily producing a sharp sound (Luyten et al., 2004). However, the assessors also perceived another textural aspect. The orange snacks freeze-dried at P_5, were related with a crispy product after the first bit, although with a porosity that causes it to melt in the mouth when it comes into contact with saliva. This sensation was defined by the assessors as porous/melt-in-the-mouth texture. Another aspect to be pointed out is the water content of the samples, which can be related to the perception of the textural attributes. In fact, some studies have obtained a negative relationship (r2>-0.9) between the sensory score for crispness in crackers, extruded snacks, bread crust and potato chips, and their water content (Katz & Labuza, 1981; Primo-Martín et al., 2006; Srisawas & Jindal, 2003). Although the water content difference between the samples freeze-dried at P_5 and P_{100} was small (~1.5%), it seems that the lower water content of those samples freeze-dried at P_5 was what leads the assessors to qualify the texture of these samples also as porous/melt-in-the-mouth.

With respect to the appearance, the samples that were freeze-dried at P_{100} were widely perceived as samples of a more intense yellow (Fig. 1). This relationship was also obtained by Silva-Espinoza et al. (2020a) using an instrumental analysis, where the samples freeze-dried at P100 showed a higher chroma, which is directly related to the intensity of the colour. As regards the flavour properties, the samples freeze-dried at P5 were perceived as sweet, acid, and with citrus notes. Therefore, it can be suggested that the non-volatile and volatile compounds that characterize the orange flavour are better preserved at lower working pressures during freeze-drying. A study about the effect of different freeze-drying conditions on the retention of the principal mushroom aroma (1-octen 3-ol) showed its better retention when working at a lower pressure (5 Pa) (Kompany & René, 1993). This pressure effect has been related to the freeze-drying phenomenon known as “collapse” or shrinkage, promoted at higher pressures. The shrinkage leads to a decrease in the retention of volatile compounds and a loss of flavour due to changes in the structure of the freeze-dried matrix (Petersen & Lorentzen, 1973). However, we must also bear in mind that the samples freeze-dried at P_5 were also those with a lower water content. The higher concentration of compounds responsible for the aroma and flavour in this case could also contribute to this effect. Therefore, despite the FCP analysis showing the working pressure as being the only process variable with a significant effect on the different sensory perceived attributes, whether it is indeed the working pressure or the water content of the samples should be confirmed by further studies.

3.2. Hedonic pair comparison

A hedonic pair comparison was carried out so as to identify the sample preferred by consumers as a snack type product. The results of FCP indicate the main differences among samples as being due to the working pressure during the freeze-drying process. As no differences were found between either studied temperature at the same pressure, a shelf temperature of 50 ºC was selected due to the shorter freeze-drying time. In addition, Silva-Espinoza et al. (2020a) found that the bioactive compounds were slightly better preserved when freeze-dried at 50 ºC vs. 40 or 30 ºC due to the shorter process time. Therefore, the samples selected for the hedonic par comparison were $S\_50\_P_5$ and $S\_50\_P_{100}$.

From the 60 responses, sample S_50_P_5 was preferred by 34, while S_50_P_{100} was selected by 26. The tabulated (60, 0.05) value points to 39 as being the critical minimum number of times a sample must be preferred in a Two-Sided Directional Difference test in order to consider significant differences among samples (Meilgaard et al., 1999). As this value is higher than the 34 obtained in our experiment, this means that consumers do not significantly prefer one sample over another.

3.3. Textural properties

As an example, Figure 2 shows one of the replicates of the force versus distance curves, obtained from the penetration test, for each of the samples freeze-dried under the different process conditions. The number of peaks and the Fmax obtained from the curves are shown in Figure 3. These parameters are useful mechanical indicators to evaluate the level of crunchiness/crispness of a solid food.

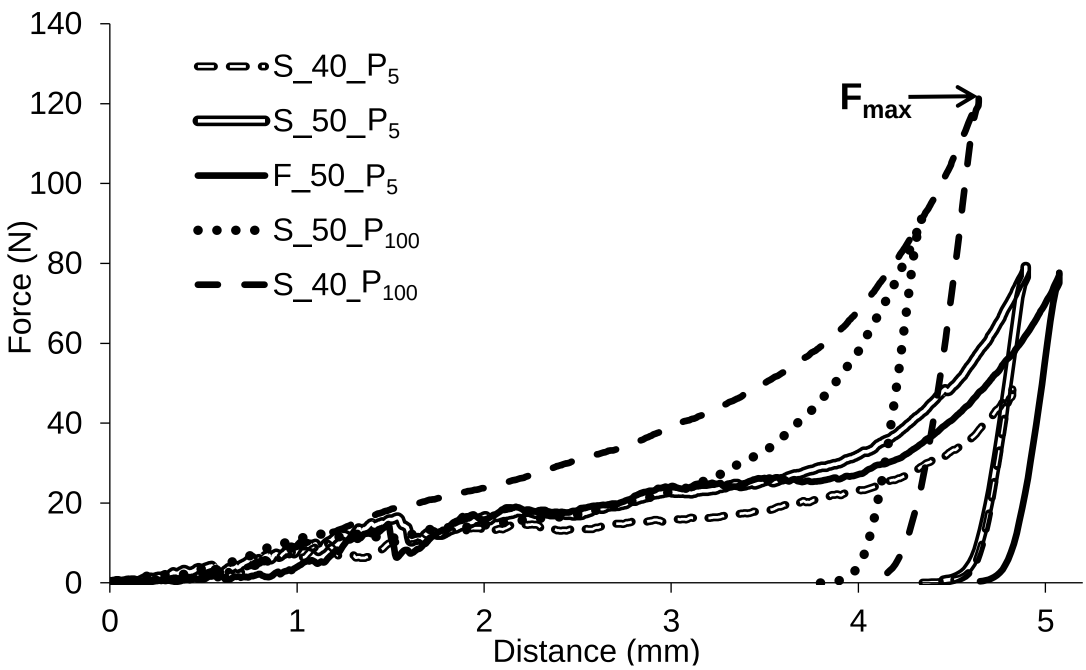

Figure 2. Examples of force–distance curves obtained from the freeze-dried purees frozen at slow (S) and fast (F) freezing rate, freeze-dried at 5 Pa (P_5) and 100 Pa (P_{100}) with 50 ºC and 40 ºC as shelf temperatures.

The crispness, an indicator of the firmness and the freshness of a snack, is positively related with the number of force peaks (Alonzo-Macías et al., 2014). In this study, the number of force peaks of the five samples allowed three different significant groups to be obtained (Fig. 3). Samples that were freeze-dried at the lowest pressure (P_5) exhibited a higher number of peaks ($p<0.05$) and so a crispier texture. The lower number of force peaks shown by the samples freeze-dried at P_{100}, even more marked at the lowest temperature (Fig. 3), is related to their less crispy nature ($p<0.05$). Nevertheless, a significant negative correlation (r= -0.9125) was obtained between the water content and the number of force peaks, which indicates that the higher the water content, the less crispy the product. As in this case the samples obtained at P_{100} had higher water content than those at P_5, the differences observed in texture could be the result of either different pressure or different water content. It means, the different pressure could lead to a different structure development, for instance more or less porous, that affects the textural perception of the snack. Or maybe the structure is the same and the differences are simply a consequence of the different water content of the samples. In the latter case, the texture of two samples with the same water content obtained under different pressure should no show differences in texture. To confirm this statement, another set of samples was freeze-dried under the different process conditions in an attempt to obtain freeze-dried products with no significant differences in the water content ($p>0.05$). This was finally achieved in 3 cases: $S\_50\_P_{100}$ (2.9±0.09 g water/100 g sample), $S\_40\_P_5$ (2.8±0.6 g water/100 g sample) and $S\_50\_P_5$ (2.2±0.3 g water/100 g sample). The crispness of these samples was evaluated through the number of force peaks and the obtained results (44±5, 46±6, and 50±6, respectively) showed no significant differences ($p>0.05$). These results permit the confirmation that it was the water content and not the different working pressure during freeze-drying that affected the texture of the samples, as was also observed by other authors (Hammami et al., 2001). Another important fact that has been observed is the impact that small differences in the water content of the snack, such as those obtained in this study (between 3.63 and 5.30 %), have on its crispy texture.

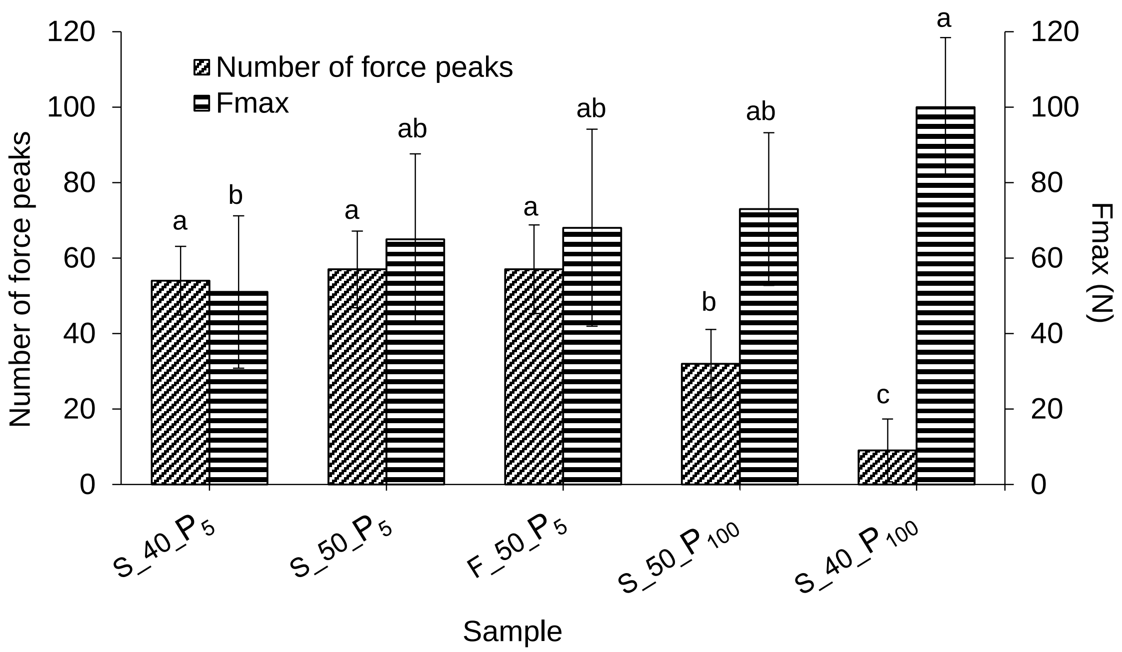

Figure 3. Textural parameters obtained from the mechanical penetration test. Mean values and Tukey's HSD of number of peaks in the left axis and F_{max} in the right axis of each of the freeze-dried orange purees frozen at slow (S) and fast (F) freezing rates, freeze-dried at 5 Pa (P_5) and 100 Pa (P_{100}) with 50 ºC and 40 ºC as shelf temperatures. Different letters for each parameter indicate different homogeneous groups ($p<0.05$).

As regards Fmax, this parameter was shown to be insufficiently sensitive to differentiate between samples, as only sample $S\_40\_P_5$ presented a significantly lower value than S_40_P_{100} ($p<0.05$, Fig. 3). However, a significant negative correlation (r= -0.7109) between the number of peaks and Fmax was observed. This correlation indicates a trend in which a snack with a greater number of force peaks, meaning a crispier product that breaks more easily when eaten, shows a lower Fmax value. As for the rigidity of the samples, a steeper slope indicates more resistance to deformation which means greater rigidity. The values of slope of the different samples obtained were between 8±4 and 11±4 (N/mm), with no significant differences ($p>0.05$). Therefore, it does not seem to be a suitable parameter for assessing the different texture of these samples either.

On the basis of the results of the textural properties measured instrumentally and those perceived by consumers (section 3.1), the crispness of the snacks correlates well with the number of force peaks. However, when the number of peaks is high, the consumers perceive a crispy texture that was loosed when the snack is exposed to saliva and “melt in the mouth”. This is characteristic of crispy products based on dry foams (Lillford, 2017), extruded snack samples (Murray et al., 2001b) or, in our case, to highly porous products. Thus, the suggestion exists that there is a relationship between the perception of the samples as porous/melt-in-the-mouth and the fact that they are crispier, which may be due to their greater brittleness before they melt.

4. Conclusion

The consumers perceived and highlighted different attributes for the freeze-dried orange puree offered as an orange snack, related to their flavour, texture, and colour. Crispness was closely related to the water content, which must be precisely defined and controlled. Of the different freeze-drying conditions studied, the working pressure was the variable that most affected the different perceived quality attributes of the samples. A lower working pressure during freeze-drying leads to samples being obtained with a lower water content, which were perceived with higher citrus notes (citrus flavour, acid taste, and sweet taste) and as the crispiest. A higher working pressure leads to samples perceived with a more intense yellow colour. Consumers do not significantly prefer any sample in particular. Considering these results, aspects other than the sensory may be managed to select the best freeze-drying conditions under which to obtain a consumer-popular orange snack. As regards the instrumental analysis of crispness, the number of force peaks obtained from a penetration test may be proposed as an adequate tool with which to obtain results that closely resemble the texture perceived by the consumers.

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Conflict of interest: none.

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