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# Physical properties of french fries made with quinoa and opuntia-peel flours

Propiedades físicas de papas fritas elaboradas con harinas de quinua y cáscara de tuna

Propriedades físicas de batatas fritas feitas com farinhas de quinoa e de casca de opuntia

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## Food technology

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## Abstract

A large part of the world population consumes fast food on a regular basis. Most of these menus are accompanied by french fries. Their consumption does not represent a major nutritional contribution, and the frying process incorporates a considerable amount of oil into the french fries, increasing the risks of diseases such as obesity. The objective of the present work was to evaluate the physical and textural properties of a potato chip substitute made by extrusion technology with the incorporation of flours of a nutritious cereal such as quinoa and prickly pear peel in its formulation. Color and porosity were evaluated by image analysis. Texture by mechanical compression tests with an Instron universal testing machine and oil absorption rate by a modified compression method. Sticks of a potato substitute were obtained and fried by immersion in oil at 180 °C in the same way as a commercial pre-fried product. The firmness of the sticks (4.5 N) is 30 % higher than the commercial product, while the oil absorption rate (6.25 %) of the products obtained is three times lower. This phenomenon could be due to the fiber content present in the prickly pear peel flour and protein content in the quinoa flour. It is concluded that is possible to elaborate products similar to traditional and commercial potato chips, so that, without altering the consumption habits of the population, it can allow the intake of healthier foods.

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## Resumen

Gran parte de la población mundial consume habitualmente comida rápida. La mayoría de estos menús tienen como acompañante a las papas fritas. Su consumo no representa mayor aporte nutricional, además, el proceso de fritura incorpora una cantidad considerable de aceite a las papas fritas incrementando los riesgos de enfermedades como la obesidad. El objetivo del presente trabajo fue evaluar las propiedades físicas y texturales de un sucedáneo de papas fritas elaborado mediante tecnología de extrusión con la incorporación de harinas de un cereal nutritivo como la quinua y de cáscara de tuna en su formulación. El color y la porosidad se evaluaron mediante análisis de imágenes. La textura mediante pruebas de compresión mecánica con una máquina universal de ensayos Instron y el índice de absorción de aceite mediante un método de compresión modificado. Se obtuvieron bastoncillos de un sucedáneo de papas que fueron freídos por inmersión en aceite a 180 °C al igual que un producto prefrito comercial. La firmeza de los bastoncillos (4,5 N) es 30 % superior al producto comercial, mientras que el índice de absorción de aceite (6,25 %) de los productos obtenidos es tres veces inferior. Este fenómeno pudiera ser debido al contenido de fibra presente en la harina de cáscara de tuna y de proteína en la harina de quinua. Se concluye que, es posible elaborar productos similares a las papas fritas tradicionales y comerciales, de modo que, sin alterar los hábitos de consumo de la población, pueda permitir la ingesta de alimentos más saludables.


**Palabras clave:** sucedáneo de papas fritas, fritura, harina de quinua, cáscara de tuna, extrusión


## Resumo

Grande parte da população mundial tem o hábito de consumir regularmente fast-food. A maioria dos menus de fast-food tem as batatas fritas como acompanhamento essencial. O seu consumo não representa um maior aporte nutricional, além disso o processo de fritura incorpora uma quantidade considerável de óleo às batatas fritas, aumentando os riscos de doenças como a obesidade. O objetivo deste trabalho de pesquisa foi avaliar as propriedades físicas e texturais de um substituto da batata frita, elaborado por tecnologia de extrusão com a incorporação de farinha de um cereal nutritivo como a quinoa e farinha da casca de Opuntia em sua formulação. Os resultados indicam que é possível obter zaragatoas de um substituto da batata que podem ser fritas por imersão em óleo a 180 °C, tal como um produto comercial pré-frito. A firmeza dos substitutos da batata frita é 30 % maior do que a do produto comercial, enquanto a sua taxa de absorção de óleo é três vezes menor do que esta (6.25 %). Provavelmente a fibra presente na farinha de casca de Opuntia e a proteína presente na farinha de quinoa podem causar este fenómeno. Conclui-se que, é possível fabricar produtos semelhantes à batata frita tradicional e comercial, de modo que, sem alterar os hábitos de consumo da população, possa permitir-lhes uma alimentação mais saudável.


**Palavras-chave:** substituto de batatas fritas, fritura, farinha de quinoa, casca de Opuntia, extrusão

## Introduction

Potato is the fourth most consumed food in the world, after rice, wheat and maize (Hu *et al*., 2024), with french fries being the main form of consumption, providing a high amount of energy, but low percentage (2.8 %) of protein (Beals, 2019); furthermore, that the high concentration of oil (46.29 %) in french fries (Mohamed Latif *et al*., 2020), could generate health problems in consumers (Salehi *et al*., 2024). Frying is the process of cooking food by immersing it in oil or edible fats at high temperatures. The frying process results in the gelatinisation of starch, denaturation of proteins and evaporation of water, in addition, it gives foods desirable attributes such as bright colour, crispness and pleasant taste (Wang *et al*., 2024). It is a unique process because it provides the final products with special sensory characteristics such as taste and texture (Dehghannya and Ngadi, 2023; Farkas *et al*., 1996).

Among the main frying methods for potatoes currently employed are: deep-fat frying, in which potato samples are immersed in oil at temperatures between 180 and 190 °C for time periods of 3.5 to 6 min, (Ramadan and Mörsel, 2003) (Ghaderi *et al*., 2018; Rahimi *et al*., 2017); vacuum frying, potato samples are processed at 108 °C for approximately 9 min, at 13,49 KPa (Esan *et al*., 2015), hot air frying, whose temperature ranges are between 150 to 185 °C in time lapses of 12 to 30 min, (Abd Rahman *et al*., 2017; Heredia *et al*., 2014; Teruel *et al*., 2015; Tian *et al*., 2017), Non-fat frying (Non-fat frying) process in which temperatures of 185 °C for two min are used, (Al-Khusaibi *et al*., 2015) and microwave frying with temperature ranges from 177 to 193 °C with times of 1 to 2 min, (Parikh and Takhar, 2016).

Oil absorption levels during the frying process could be reduced by incorporating flour from fruit peels such as prickly pear, which contains dietary fibre, protein and antioxidant compounds that make it an interesting ingredient for human consumption (Bouazizi *et al*., 2020; Daniloski *et al*., 2022).

The food needs and nutritional requirements of consumers mean that food technologists are constantly on the lookout to design and create new food structures that are nutritious, healthy and palatable. One of the most important technologies used in the generation of new foods is pre-cooking by extrusion, which allows the use of different formulations and the generation of products of different sizes and shapes, such as crisps (Alam *et al*., 2016).

The extrusion process involves forcing a mixture of ingredients to flow under a variety of controlled temperature and humidity conditions along the length of a cylinder and out through a slot-shaped orifice or at a predetermined rate. The process has several advantages, such as high continuous production rates, greater versatility in product shape, and easier control of product density (Alam *et al*., 2016; Guy, 2001). The programmed extrusion parameters determine the new structure and properties of the final product (Sakonidou *et al*., 2003). Cereals and products with high starch content are the main raw material for extrusion-processed formulations (Sandoval *et al*., 2009).

Consequently, and in view of the fact that potato crisps are an accompaniment to fast food or conventional food, traditionally consumed by the world population, and that their nutritional contribution is minimal, the aim of this study was to evaluate the physical and textural properties of a crisp substitute made by extrusion technology, incorporating flour from a nutritious cereal such as quinoa and prickly pear peel flour in its formulation.

## Materials and methods

### Ingredients used

The materials used to obtain the crisp substitute were quinoa flour, prickly pear peel, potato and starch. The white prickly pear, quinoa and potato flours were purchased at the local market in the city of Puno, Peru. The starch was Universal brand ( Productos Extragel y Universal S.A.C. Company). The prickly pear flour was obtained from white prickly pear shells, washed and disinfected with a solution of sodium hypochlorite (0.1 $mL.L^{-1}$) for three (3) min. Subsequently, they were cut into 1 cm² pieces and dried at a temperature of 28 ± 2 °C in an oven (Ovens Medic, Elas-50 Lts, Peru) for seven (7) days. Finally, the dried peels were ground in a pulveriser mill (Fritsch, AS 200, Germany) and sieved through a 200 µm mesh. As a comparison sample, Bell's pre-fried potatoes purchased in a local supermarket in the city of Puno were used.

### Formulation of crispy substitute

Table 1 shows the proportions of the ingredients used in the formulation of the crispy substitute, as well as the final moisture conditions and screw speeds during the extrusion process. The ingredients were mixed and the moistures were conditioned at 50 and 55 %.

**Table 1. Formulation codes, ingredients, moistures and screw speeds used in the formulation of crispy substitutes in the form of sticks.**

| Formulation code | Ingredients | Percentage (%) | Final moisture (b.h.) | Screw speed (rpm) |
|---|---|---|---|---|
| P1-1 | PF | 45 | 50 | 100 |
| | S | 35 | | |
| P1-2 | QF | 15 | 55 | 100 |
| | TSF | 5 | | |
| P2-1 | PF | 42,5 | 50 | 100 |
| | S | 32,5 | | |
| P2-2 | QF | 15 | 55 | 100 |
| | TSF | 10 | | |

PF (Potato flour); S (Starch); QF (Quinoa flour); TSF (Prickly pear shell flour).

### Extrusion conditions

The extrusion tests were carried out on a Brabender twin-screw laboratory extruder (TwinLab-F 20/40, Germany). The screw diameter is 20 mm with a length of 795 mm. The cylinder is 80 cm long and divided into four zones with independent temperature control (40, 50, 55 and 60 °C). From the feed hopper to the inlet of the texturising system, the screws were arranged as follows: five SE/30/30, four SE/20/20, two SE/30/30 screw conveyors, one KP45/5/20 block mixer, one SE/30/30 screw conveyor, four SE/20/20, four SE/30/30, five SE/20/20, three SE/30/30 and three SE/20/20 screw conveyors, which facilitate the homogenisation and mixing of the ingredients, allowing their continuous flow at 2 $kg.h^{-1}$. A 25 × 7 mm segmented, cooled texturising head (Brabender GmbH & Co. KG, 628470, 1935902, Duisburg, Germany), consisting of three nozzles with a total length of 358 mm and an outlet of 126 × 112 mm, was installed in the final part. The cooler was Julabo GmbH (600F, 10429787, Germany) and operated at a temperature of 20 °C (figure 1).

After the extrusion and texturising process, product strips of 25 mm wide, 7 mm high and 100 mm long were obtained. With the help of a scalpel, they were cut to obtain sticks of 8 × 7 × 100 mm in width, height and length respectively.

### Frying of the sticks

The obtained sticks and the commercial potato samples were placed in a stainless steel basket and fried by immersion in a pot with two litres of Cocinero vegetable oil (Alicorp S.A.A.) at a temperature of 180 °C on an induction cooker. Frying was carried out for ~18 s for P1, ~40 s for P2 and ~115 s for the commercial sample, during which time the surface colour of the potato sticks was golden brown and then drained for one minute to remove excess surface oil, as shown in the diagram in figure 2.

### Colour evaluation

The evaluation of the colour of the obtained potato sticks and the commercial sample was carried out by image analysis.

### Image acquisition

Digital imaging of the extruded sticks and commercial potato samples was performed using a CCD colour camera (Zeiss, Axiocam 105 colour, Jena, Germany) attached to a stereomicroscope (Carl Zeiss, Stemi 508, Jena, Germany) with a resolution of 2560 × 1920 pixels. The samples were 1 cm² in area and 7 mm thick. A ring light

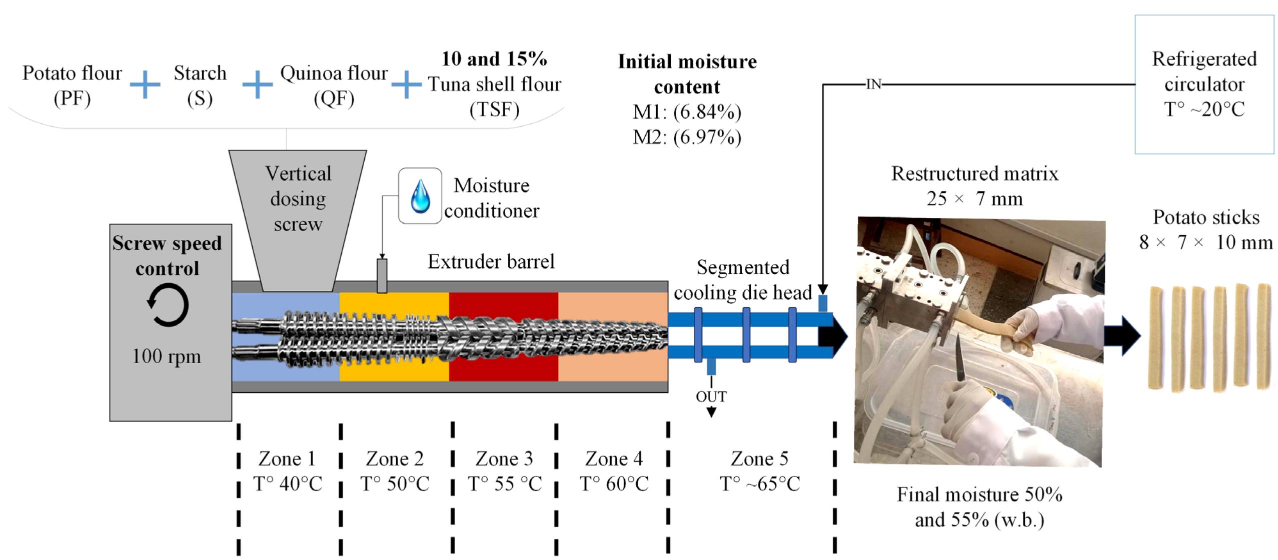


**Figure 1. General scheme of the extrusion process of potato substitutes in the form of sticks, with potato, quinoa and prickly pear peel flours in their formulation.**

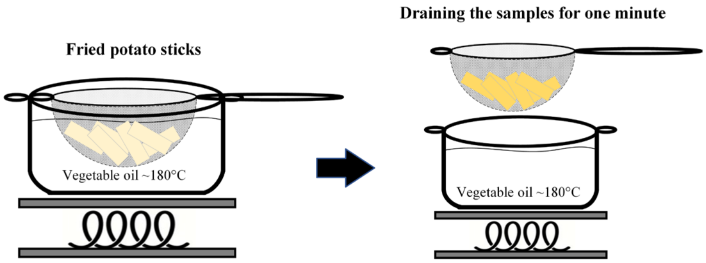


**Figure 2. Frying scheme of potato sticks and commercial sample.**

(Prolink, LSH-1200, China), placed around the main lens of the stereoscope, was used as an illumination source. The whole system was mounted inside a dark chamber to minimise the effect of ambient light. The images were captured in five repetitions for each sample. The images were obtained in JPG format.

**Colour analysis**

The colour analysis was performed only in surface view, because in lateral position the thickness of the rods disturbed the uniform light distribution. Images were acquired in red (R), green (G) and blue (B) format and converted to the hue (H), saturation (S) and lightness (L) model (Equation 1), for its better approach to human perception (Medina *et al*., 2010; Yan *et al*., 2021), using a routine programmed in Matlab (Mathworks, Inc., Natick, MA, USA.).

$$= \begin{cases} Arctan\dfrac{\frac{\sqrt{3}}{2}(G-B)}{R-0.5(G+B} \; if\; R-\dfrac{G+B}{2}>0 \\ \pi + \text{Arctan}\dfrac{\frac{\sqrt{3}}{2}\;(G-B)}{R-0.5(G+B)} \; in\; another\; way \end{cases}$$

$$S = 1 - min\left(\frac{R,G,B}{L}\right) \qquad (1)$$

$$L = \frac{R+G+B}{3}$$

**Texture profile analysis**

Texture profile analysis of the potato sticks and the commercial potato sample was performed using an Instron universal testing machine (model 3365, Norwood, Massachusetts, USA) with a puncture probe within 10 minutes after frying to avoid moisture absorption from the surrounding air and moisture loss below the crust, which would cause the fries to become soggy and mushy. The tests were carried out at a crosshead speed of 4 $mm.s^{-1}$, using a load cell with a capacity of 500 N. The number of swabs subjected to the tests was determined by the number of swabs in the test. The number of swabs subjected to pressure was five units for each formulation and commercial sample, until a deformation percentage of 60 % of the initial height of the sample was reached.

The data obtained were analysed in Bluehill Universal Test Method Devolopment Training software (Instron, Norwood, Massachusetts, USA).

**Determination of oil absorption rate (OAR)**

The compression method proposed by Bhuiyan and Ngadi (2024) with some modifications was used to determine the OAR of both the sticks and the commercial crisps during the frying process. For this, five swabs were weighed for each treatment and absorbent paper (Scott®, Kimberly-Clark Peru S.R.L.) of 5 × 20 cm was cut, then the swabs were wrapped with the absorbent paper imitating a sandwich system. A constant pressure of 450 N was exerted on the prepared sample for 12 s using the Instron S21889 probe. After compression, the swabs were reweighed (confirming that no part of the absorbent paper was adhered to the surface of the crust). The calculation of the OAR was performed with the following formula:

$$OAR = \frac{Initial\ weight\ -\ Final\ weight}{Initial\ weight} \times 100 \qquad (2)$$

**Determination of porosity**

The cross-sectional porosity of the fried products, both of the sticks (P1-1, P1-2, P2-1, P2-2) and of the commercial potato samples, was determined by image analysis (Medina *et al*., 2011). A stereomicroscope (ZEISS, Stemi 508, Germany) with 1.25 × magnification and 0.63 × objective was used to acquire the respective images. The colour images were converted from RGB to black and white format. The ratio between the total area of the air cells and the cross-sectional area was defined as the cross-sectional porosity (Ps) (equation 3).

$$OAR = \frac{Initial\ weight\ -\ Final\ weight}{Initial\ weight} \times 100 \qquad (3)$$

**Statistical analysis**

An analysis of variance (ANOVA) and a significant difference limit test (LSD) at a 95 % confidence level ($P < 0.05$) were performed to determine the existence of significant differences in all analyses performed. Statgraphics 19 software (Statistical Graphics Corp., Herndon, Va., USA) was used.

## Results and discussion

**Colour analysis**

Figures 3a and 3b present the three components of the HSL colour model for the two stick formulations, extruded potato, commercial potato after frying.

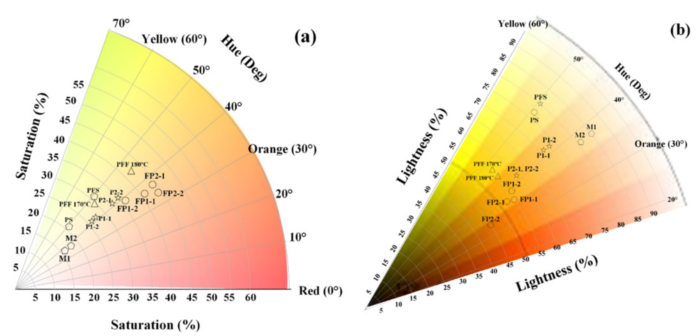


**Figure 3. Colour parameters for formulations, sticks and commercial potato.** (a) Saturation (%) versus hue (°); (b) Brightness versus hue (°). M1 and M2 (flour blends), PS-PFS (raw and fried commercial sample), PFF (pre-fried fried potato), P1-P2 (stick formulations), FP1-FP2 (fried sticks).

Colour data from pre-fried potato samples fried at 170 and 180 °C were also considered for comparison (Adedeji and Ngadi, 2018). All samples analysed had a shade between 30 and 50°, with the sticks having the lowest shade compared to conventional and commercial potatoes. The incorporation of quinoa and starch in the extrusion of potato sticks decreases their colour tone compared to conventional products, due to chemical reactions that occur during the process and affect the brightness and intensity of the colour (Martin *et al*., 2021).

**Texture analysis**

The sticks with the lowest firmness were the formulations P1-2, P2-1 and the commercial sample. Moisture content probably influenced the firmness of the potato sticks, since according to Grahl *et al*. (2018) high moisture in the extrusion process causes a decrease in the shear energy and firmness of the product. In this context, it is observed that the higher the moisture content, the lower the maximum strength. On the other hand, the higher the addition of prickly pear peel flour, the higher the maximum strength increases slightly, probably due to the presence of fibre. Table 2 presents the results of the texture analysis of the raw and fried sticks as well as the commercial sample.

**Oil absorption**

Figure 4 shows the oil absorption rate of the swabs and of the commercial crisp sample.

It can be observed that all the sticks (P1-1, P1-2, P2-1 and P2-2) have a lower oil absorption rate, being the P2-2 formulation (with 10 % prickly pear peel flour and 55 % moisture) the one with the lowest rate (4.68 %). This may be due to the fact that the presence of fibre in prickly pear husk (Ochoa-Velasco *et al*., 2022), reduces fat absorption in the chips of the sticks. In this regard, Gutiérrez-Silva *et al*. (2023) indicate that the fibre in the formulations reduces the rate of oil absorption, providing a barrier effect that prevents its penetration during frying. In addition, it contributes to maintaining the texture and colour of the final product, which could justify the relationship between a higher presence of fibre and a lower rate of oil absorption.

On the other hand, according to Wang *et al*. (2024), the addition of protein to the food matrix can reduce oil absorption in the frying process, due to the presence of quinoa flour in the sticks formulation.

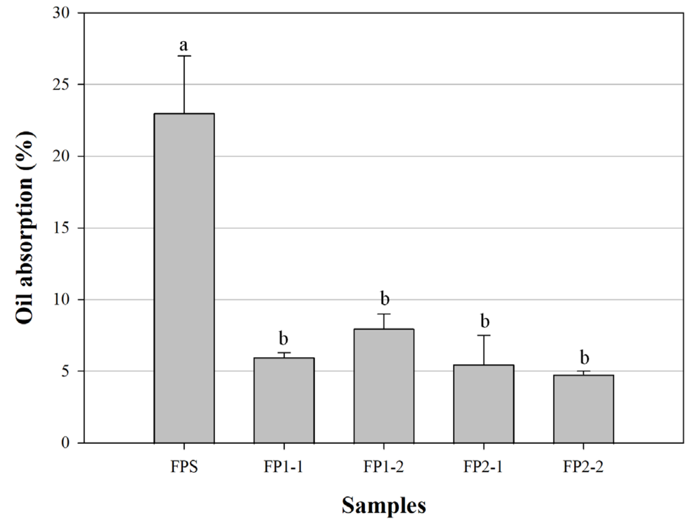


**Figure 4. Oil absorption rate during the frying process of commercial potato sample (FPS) and of the sticks samples obtained by extrusion.**

Potato frying times are an important factor in the oil absorption process; however, in the formulations used in the sticks, they were reduced by up to 80 % compared to the time used in frying commercial potato samples.

**Porosity**

Figure 5 presents the results of the porosity determination of the cross-section of the sticks and the commercial sample.

**Table 2. Texture analysis results of the commercial potato sample and of the raw and fried sticks.**

| Sample code | Commercial sample / Sticks | | Fried samples: commercial product and sticks | | | |
|---|---|---|---|---|---|---|
| | Maximum strength (N) | Energy (mJ) | Maximum strength (N) | Energy (mJ) | Cross-sectional view | Surface view |
| PS | 0.97 ± 0.6[a] | 2.54 ± 1.26[a] | 0.80 ± 0.24[a] | 1.08 ± 0.23[a] |  |  |
| P1-1 | 2.7 ± 0.13[c] | 8.26 ± 2.51[b] | 5.60 ± 1.48[c] | 9.90 ± 2.50[c] |  |  |
| P1-2 | 1.69 ± 0.06[b] | 4.69 ± 1.24[a] | 3.13 ± 0.21[b] | 5.74 ± 0.54[b] |  |  |
| P2-1 | 4.46 ± 0.20[d] | 1.42 ± 0.93[c] | 5.78 ± 1.21[c] | 10.41 ± 2.60[b] |  |  |
| P2-2 | 3.18 ± 0.10[c] | 9.91 ± 3.74[b] | 3.55 ± 0.33[c] | 5.05 ± 0.84[c] |  |  |

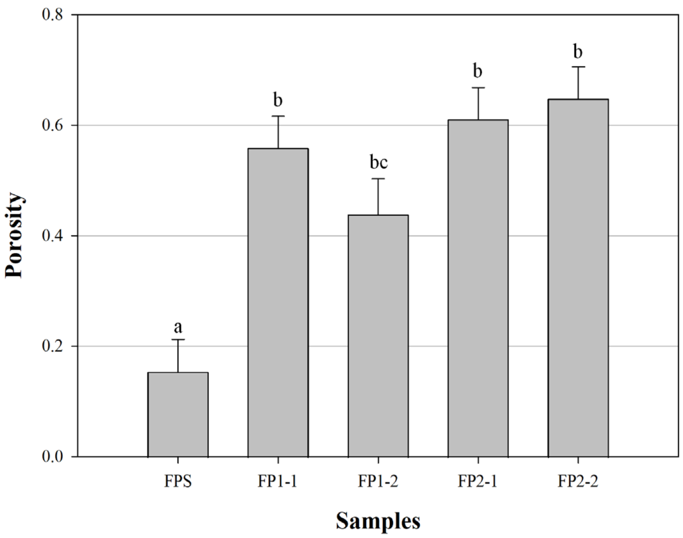


**Figure 5. Porosity of the cross-sections of the commercial potato sample (FPS) and of the sticks with quinoa and prickly pear flour included in their formulation.**

As can be seen, the porosity of the commercial crisps is much lower than the porosity of the cross-section of the substitute samples. This is probably due to the fact that the extrusion process, using high pressure and temperature, generates an aerated and expanded structure in the products obtained (Almendares *et al*., 2021).

## Conclusions

It is possible to obtain crisp substitutes through extrusion technology, incorporating quinoa flour and prickly pear shell flour into the potato flour in the initial formulation, which allows low oil absorption rates during frying, opening up the possibility of not drastically changing the consumption habits of the population, offering them a healthier product.

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