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3D printed food system development based on Nanoencapsulated and micro powder nutritious ingredients

Desarrollo de un sistema de alimentos impresos 3D a partir de ingredientes nutritivos en polvo micro y nanoencapsulados

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Abstract The products developed are mainly based on the mixture of powdered food ingredients obtained through the spry dry technology that together with a liquid ingredient form a homogeneous mixture reaching a fluidity behavior inside the printer cartridge during the extrusion process, the deposited or extruded material must present a good balance between fluidity and rigidity to support the load of the deposited layers, thus presenting a structurally stable print. Subsequently, production cost studies of the products were carried out and sensory and rheological analyses were performed.

Key words: 3D printing; powder food; food matrix; microencapsulation; nanoencapsulation.

Resumen Los productos alimenticios desarrollados se basan principalmente en la mezcla de ingredientes en polvo obtenidos mediante la tecnología de spry dry que junto con un ingrediente líquido forman una mezcla homogénea alcanzando un comportamiento de fluidez dentro del cartucho de la impresora durante el proceso de extrusión, el material depositado o extruido debe presentar un buen balance entre fluidez y rigidez para soportar la carga de las capas depositadas presentando de esta manera una impresión estructuralmente estable. Posteriormente se realizaron estudios de costos de producción de los productos y se realizaron análisis sensoriales y reológicos.

Palabras clave: Impresión 3D; Alimentos en polvo; matrices alimentarias; microencapsulación; nanoencapsulación..

Introduction

3D printing is an automated manufacturing process by adding or depositing layer by layer, where a three-dimensional object is created by overlapping successive layers of material (Piyush; Kumar; Kumar, 2020). 3D printing is also known as additive manufacturing and is one of the most accurate manufacturing techniques with application potential in almost all industrial, commercial, and even domestic fields. Its use in the food area is currently being studied, as it has become a novel topic of interest in the scientific community due to the increase in publications during recent years, which have had a favourable impact on the food sector due to its great potential to manufacture 3D structures with complex geometries, elaborate textures, potentially improved nutritional contents, and a new presentation of food.

The first 3D printer in operation was developed in the 1980s and used photopolymer and plastic as input or printing material (Horvath, 2014). As its development and application potential progressed, there was also innovation in the types of materials that could be printed, such as metals and ceramics according to the needs that arose, but it was not possible to use this type of apparatus to print food, so the first 3D food printer was developed during 2009, with a syringe-based extruder to deposit food pastes on a platform (Cohen *et al.*, 2009; Zhu; Stieger; van der Goot; Schutyser, 2019).

The technology of 3D food printing is very recent, so it remains a challenge to obtain foods that present easy printability and guarantee the quality of printed products in terms of structural stability.

Nonetheless, there has been successful attempts to obtain stable structures through the printing processes with different classes of food, where it is sometimes necessary to use additives such as gums and starches (Pérez; Nykvist; Brøgger; Larsen; Falkeborg, 2019) that allow to achieve an adequate consistency that provides greater stability.

A suitable food material for the 3D printing process will depend on its physicochemical and rheological properties, so criteria have been established to evaluate the suitability of the material. According to Godoi, Prakash and Bhandari (2016), the established printability criteria are the ease of depositing layer by layer and the ability to maintain the stable structure after the printing process, and even after a post-processing, if necessary (baking) (Godoi *et al.*, 2016).

A wide variety of food printers can be found in today's market, such as the ChefJet, designed to create chocolate and sugar structures. The italian company Berrilla didn't want to be left behind, developing a 3D printer for fresh pasta in 2016, however, the American company 3D Systems innovated with chocolate printing, naming its device CocoJet, and finally the design studio of Dovetailed developed a 3D printer for fruits, which is based on the combination of fruit juice and sodium alginate powder (Bitfab, 2019). Therefore, the Foodini is the most popular printer on the market because it integrates the functionality and application of the beforementioned printers.

3D printing is undoubtedly one of the most important revolutions in recent years, where we have not yet seen its true technological and application potential, which is why its relevance in the scientific and industrial community grows exponentially.

Experimental details

Spray drying

The Blackberry-Açai powder products (açaí pulp, blackberry pulp and maltodextrin), cheese powder (fresh cheese, maltodextrin) and biscuit (vegetable fat, wheat flour, salt, egg powder and minerals) were microencapsulated by dry spray by the company ALSEC S. A. S.

Design and formulation of premix products

After the spray drying processes, the designs of the powder mixture were made so that they met the nutritional requirements such as carbohydrates, fat, protein, and micronutrients, in addition to the functional requirements that met the texture characteristics, so they are printed and contribute to a sensorially acceptable final product.

3D printer

Initially, the powder products were hydrated with water and mixed until a homogeneous mass was obtained. The extrusion of the material was carried out manually with a syringe, making sure that there were no air bubbles left to make a suitable deposit of the food by means of the layer-by-layer technique, and thus simulating the operation of the printer to choose the appropriate mixture and subsequently use the Foodini 3D printer.

For 3D prints, a Foodini food printer was used, created by Natural Machines, the cartridges or capsules are made of stainless steel, which prevents the retention of odors and flavors, in addition to facilitating cleaning and disinfection to be reused. Two (2) nozzles with 1,5 mm and 4,0 mm diameters were used for printing the products; the first nozzle was used for mora-açaí and cheese, while the second was used for the biscuit, since said product, due to its consistency, hindered the extrusion process in the 1,5 mm diameter nozzle

Rheological tests

Rheological analyses were carried out using a rheometer of the brand Medingen GmbH, series RHEOTEST RN, to determine the viscoelastic zones. The methods used were frequency-sweeping oscillation and amplitude-sweeping oscillation.

Bromatological and nutritional analyses

The methods used for the bromatological and nutritional analyses of the powdered products (biscuit, cheese and mora-açaí) are shown in Table 1.

Sensory analysis

An analysis was carried out from an affective* test to evaluate the different products. For this purpose, different aspects were considered, such as flavor, shape, color, aroma, texture when touching it, sensation in the mouth and quality of the product in general; the above was evaluated with final consumers with an age range of 16-70 years. The test consisted of giving each person a sample of the food to consume, and they were subsequently instructed to record in a format that contained the hedonic scale, the level of liking according to their perception. As seen in Figure 1, participants were not allowed to share information with another person about sensory assessment to avoid bias in the results. The total sampling per product was 50 people.

Results and discusión

The studies carried out on the 3 products with potential application for food 3D printing technology

Table 1

Methods used for bromatological and nutritional analyses of powder samples

Sample	Parameters analyzed	Method/technique
Powdered biscuit	Moisture (in flour, cereals and bakery wares) g/100g	AOAC 925.10. Ed 21:2019. (Gravimetry, Stove Drying) Certified
Powdered cheese and powdered mo-ra-açaí	Moisture g/100g	P-LF-008 Version 3 (Gravimetry-Oven Drying at 105°C)
Biscuit powder, cheese powder and mora-açaí powder	Total solids g/100g	P-LF-008 Versión 3 (Gravimetría - calculo por diferencia)
	Total protein g/100g	ISO 1871:2009 (Kjeldahl) (Alimentos para consumo humano y animal) Acreditado
Powdered biscuit	Total fat g/100g	AOAC 920.85. Ed. 21:2019 (Extracción etérea, Soxhlet)
Powdered cheese and powdered mo-ra-açaí	Total fat g/100g	AOAC 922.06. Ed. 21:2019 (Hidrólisis ácida)
Biscuit powder, cheese powder and mora-açaí powder	Crude fiber g/100g	AOAC 962.09. Ed 21:2019 (Hidrólisis ácida, alcalina y calcinación)
	Total dietary fiber g/100g	AOAC 985.29. Ed. 21:2019 (Enzimático - Gravimétrico).
Powdered biscuit	Moisture (in flour, cereals and bakery wares) g/100g	AOAC 923.03. Ed.21:2019 (Gravimetría, Calcinación 550°C) Acre-ditado. Acreditado
Queso en polvo y mora-açaí en polvo	Ash g/100g	P-LF-001 Versión 5 (Gravimetría - calcinación a 600°C)
	Total Carbohydrates g/100g	AOAC 986.25 (E).Ed.21:2019 (Determinación
		por diferencia)
	Available Carbohydrates g/100g	Food composition data de H. Greenfield y
		D.A.T. Southgate Food and Agriculture
		Organization of the United Nations Rome 2012.
	Total sugars g/100g	AOAC 923.09. Ed 21:2019 (Lane-Eynon)
	Calories mg/100g	Indirect Determination of Atwater Factor
	Iron (Fe) mg/100g	AOAC 985.35. Ed. 21:2019 (Spectrophotometry
	Calcium (Ca) mg/100g	of atomic absorption). Certified
	Sodium (Na) mg/100g	
Biscuit powder, cheese powder and mora-açaí powder	Vitamina A IU/100g	P-LF-043 Version 4 (High Efficiency Liquid Chromatography, HPLC)
	Vitamina C (Ascorbic Acid) mg/100g	P-LF-042 Version 5 (High Efficiency Liquid Chromatography, HPLC)
	Saturated fat g/100g	
	Monounsaturated fat g/100g	
	Polyunsaturated fat g/100g	
	Total grasa unsaturated g/100g	P-LF-106 Version 1 (GC-FID Gas Chromatography)
	Cis fat g/100g	
	Trans fats g/100g	
	Content of Omega 3 g/100g	
	Content of Omega 6 g/100g	
	Content of Omega 9 g/100g	
	Cholesterol mg/100g	P-LF-108 Version 1 (GC-FID Gas Chromatography)
	Zinc (Zn) mg/100g	AOAC 985.35. Ed. 21:2019 (Atomic Absorption Spectrophotome-try).

Source: Own elaboration.

System I. Cheese

Easy extrusion and a texture that allows maintaining a 3D structure formed layer by layer are important factors for the printability of the material. Thus, several tests were carried out with 10 g of powdered cheese, and the amounts of water were varied to obtain a homogeneous mixture where the variables were verified by manual extrusion of a syringe, simulating the printing process. Subsequently, and based on the results obtained, a sample was chosen that presented the best balance between fluidity and firmness or structural stability.

Figure 1 shows how the texture and stiffness of the layers of food material improve with the decrease in the amount of water in the powder cheese mixture.

The quantities of water that showed the best behavior in its texture were 3,5 and 4 g of water, so each mixture is prepared and introduced into the printer cartridge for subsequent printing. The food material with 3,5 g water was not sufficiently fluid, which prevented extrusion, and therefore the correct printing on nozzle # 15 (the diameter is approximately 1,5 mm). On the other hand, the reconstitution of the cheese powders with 4 g of water presented the appropriate texture and fluidity in the printing, since a solid and firm geometry was obtained between layers, as seen in Figure 2, which makes it promising as a printing material.

Figure 3 shows a skull-shaped impression, where all the details of the figure are appreciated, thus it can be concluded that the printing parameters and the texture of the material are suitable for the product.

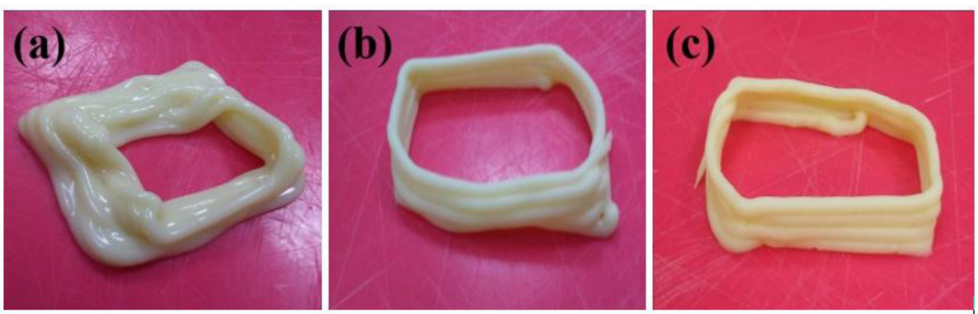

Figure 1

Mixture of 10 g cheese powder with (a) 5 gr, (b) 4 g and (c) 3,5 g water. Source: Own elaboration.

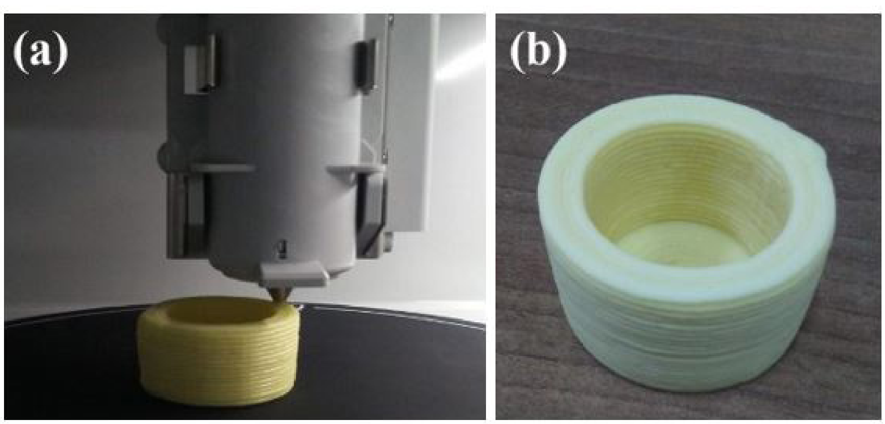

Figure 2

Cheese cylinder printed on the Foodini 3D printer (a) during the printing process and (b) after printing is finished. Source: Own elaboration

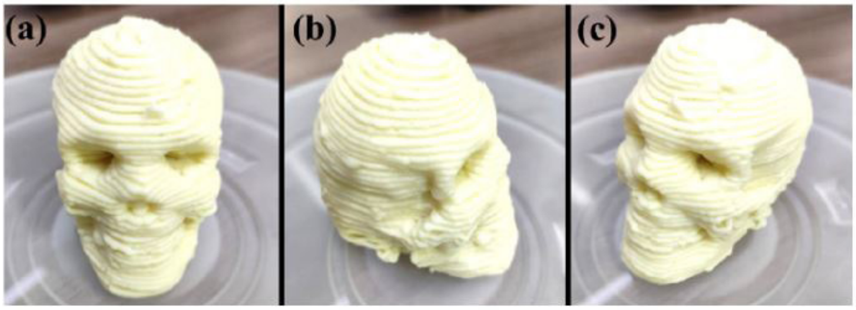

Figure 3

3D cheese skull with different views (a) front, (b) right side and (c) left side. Source: Own elaboration.

Rheological tests

To determine the behavior of the material within the viscoelastic region, a strain sweep between 0,2 and 11 % is performed, as shown in Figure 4, which presents breakage of the structure at a deformation strain percentage of approximately 0,17 %, since it is the maximum point that the graph reaches. The loss modulus (G´´) is below the storage modulus (G´), which indicates that, when performing a deformation strain on the sample, the behavior tends to be elastic, which manifests a solid nature of the sample.

Figure 5 shows the frequency sweep from 10 s-1 to 1 s-1, for the test a constant variable was set to a stress of 0,15 %. It is observed that the sample has an elastic behavior because the storage module (G´) is above the loss module (G´´), with a constant phase angle of approximately 20°, which does not present a significant change throughout the frequency scan, indicating that the material shows a solid behavior, both in high and low frequencies.

Nutritional Analysis

Table 2 presents the nutritional composition of the cheese for 3D applications, a low fat and high protein product can be observed, where approximate values of 20 % were obtained, similar to the protein values also reported by Tarazona-Díaz (2018). It is important to note that the presented proteins are mainly caseins of high biological and nutritional value (O'Brien; O'Connor; O'Callaghan: Dobson, 2004).

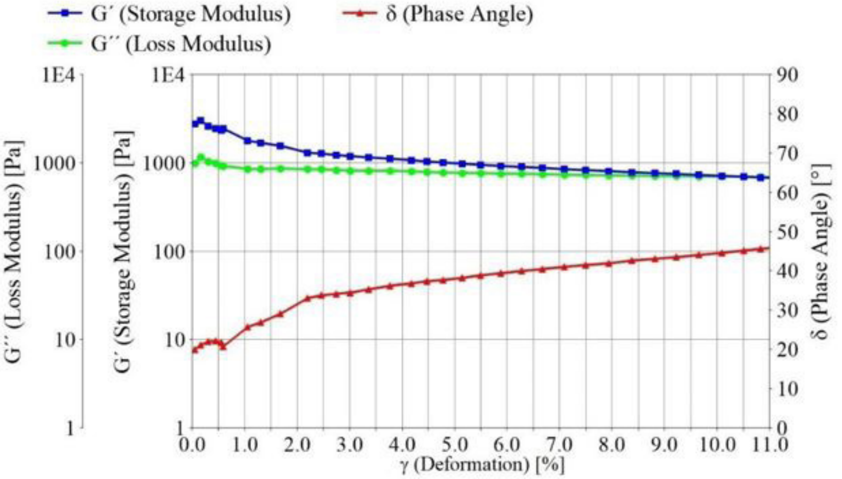

Figure 4

Amplitude sweeps or deformation strain of the blackberry with açaí CD Mode, τ 0,2-11 %, f 1 s-1, T:25 °C y 40 Points with an activation time of 10 seconds. Source: Own elaboration.

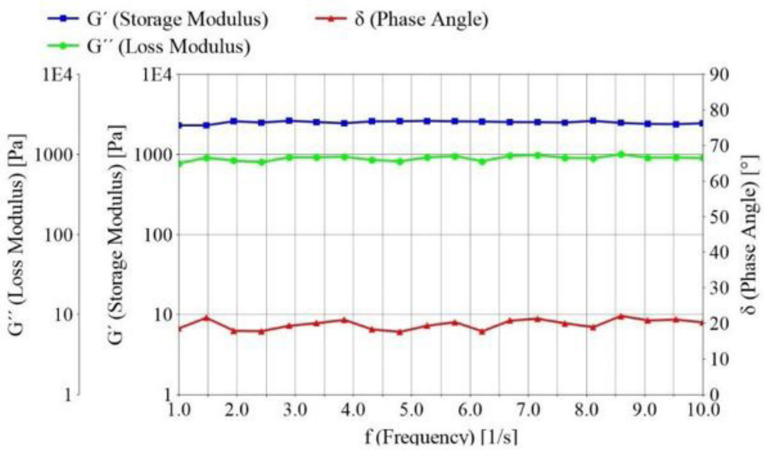

Figure 5

Frequency sweep in the viscoelastic area of the cheese. CD Mode, frequency range of 10 s-1-1 s-1, fixed deformation parameter 0,15 %, T:25 °C and 20 points with an activation time of 10 seconds. Source: Own elaboration.

Table 2

Composition of cheese for 3D printing

Nutrition Facts/Información Nutricional

Size for portion/Tamaño de la Porción: 4 cucharaditas (20g)
Portions per Container/Porciones por envase 10

Amount Per Serving/Cantidades por Porción			
Calories/Calorías 70		Calories from Fat/Calorías de la Grasa 0	
		% Daily Value*/% Valor Diario*	
Total Fat/Grasa Total 0g			**0 %**
Satured Fat/Grasa Saturada 0g			**0 %**
Trans Fat/Grasa Trans 0g			
Cholesterol/Colesterol 15mg			**5 %**
Sodium/Sodio 520mg			**22 %**
Total Carbohydrate/Carbohidrato Total 13g			**4 %**
Dietary Fiber/Fibra Dietaria 0g			**0 %**
Sugars/Azúcares 3g			
Protein/Proteína 4g			**8 %**
Vitamin A/Vitamina A 2%			Vitamin C/Vitamina C 0%
Calcium/Calcio 15%			Iron/Hierro 0%

*Percent Daily Values are based on a 2000 calorie diet./Your daily values may be higher or lower depending on your calorie needs:
*Los porcentajes de Valores Diarios están basados en una dieta de 2000 calorías.Sus Valores Diarios pueden ser mayores o menores dependiendo de sus necesidades calóricas:

	Calories/Calorías	2000	2500
Fat Total/Grasa Total	Less then/Menos de	65 g	80 g
Sat. Fat/Grasa Saturada	Less then/Menos de	20 g	25 g
Cholesterol/Colesterol	Less then/Menos de	300 mg	300 mg
Sodium/Sodio	Less then/Menos de	2400 mg	2400 mg
Total Carbohydrate/Carbohidrato Total		300 g	375 g
Dietary Fiber/Fibra Dietaria		25 g	30 g

Calories per gram/Calorías por gramo:
Fat/Grasa 9 Carbohydrate/Carbohidrato 4 Protein/Proteína 4

Source: Own elaboration

System II. Blackberry-açaí

A blackberry mixture with 5 % açaí was prepared, with the aim of giving an added value to the use of açaí as an innovative food because of its antioxidant properties and how it strengthens the immune system.

To assess the texture of the product, 10 g of the mixture were hydrated with 4 g of water, where a low structural strength was observed when performing the extrusion process with the syringe, as seen in Figure 6.

Figure 6

Blackberry structure with açaí, made by extrusion with a syringe filled with a homogeneous mixture of 10 g of the powder product hydrated with 4g of water. Source: Own elaboration

When a desired consistency is not obtained, 20 % starch ALM MOD BS25 UTEX SR starch is added to the mixture, to improve the strength of the material, and it is hydrated with 7 g of water. Figure 7 shows how the structural strength of the food material increases favorably when being extruded by the syringe.

Figure 7

20 % starch ALM MOD BS2fl UTEX SR in the berry with açaí mix and hydrated with 7 g of H2O. Source: Own elaboration.

Subsequently, the printability of the mixture is evaluated by preparing 40 g of the product and loading it into the Foodini printer's cartridge. Figure 8 clearly shows how to obtain a structure with a well-defined height and with very good stability to support the load exerted on the first printed layers, in addition to not showing a deformation in the printed structure.

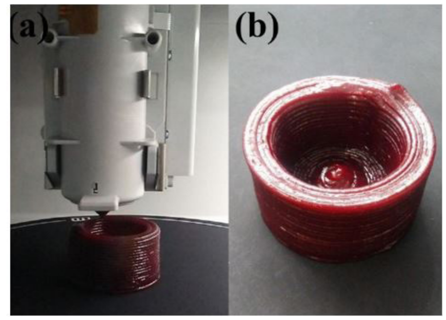

Figure 8

3D printing of the berry with açaí (a) during the printing process and (b) after the printing is finished. Source: Own elaboration.

Rheological tests

Figure 9 depicts the records obtained during the amplitude scanning test for the blackberry sample with açaí. This was carried out by performing an initial deformation strain of 0,2 % until reaching a strain of 20 %, where a frequency of 1 s^{-1} was established as a fixed variable with an activation time of 10 seconds; the test was carried out at room temperature with a record of 40 points. It is observed that the storage module (G´) is located above the loss module (G´´), which means that, when performing a strain stress on the sample, the behavior tends to be viscous, manifesting a solid nature of the sample. The food material is destroyed when subjected to a deformation of approximately 1,043 %. From this point on, the modules begin to descend in their magnitude, while the angle in said deformation increases, thus confirming the breakage of the structure.

Figure 10 shows the frequency sweep from 10 s^{-1} to 1 s^{-1}, for the test a deformation strain of 0,9 % was established as a constant variable with 20 record points and 10 seconds sample activation. The following results have been noted: that it exhibits an elastic behavior because the storage module (G´) is above the loss module (G´´). The angle less than 40° of phase does not present a significant change throughout the sweep of frequency, indicating that the material exhibits solid behavior at both high and low frequencies.

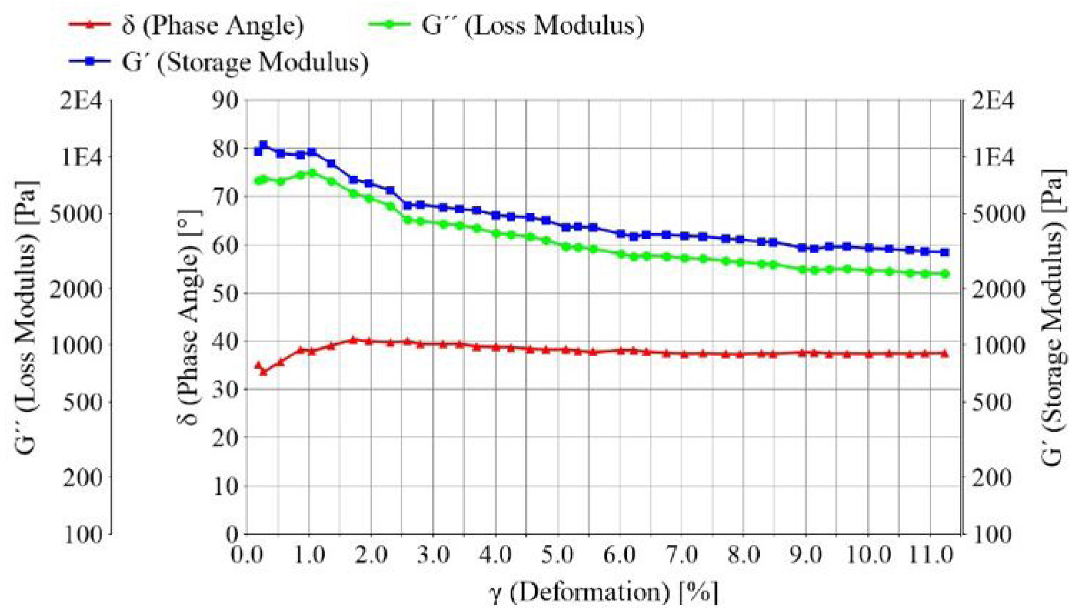

Figure 9

Amplitude sweeps or deformation strain of the blackberry with açaí. CD Mode, τ 0, 2 -11 %, f 1 s⁻¹, T:25 °C and 40 points with an activation time of 10 seconds. Source: Own elaboration.

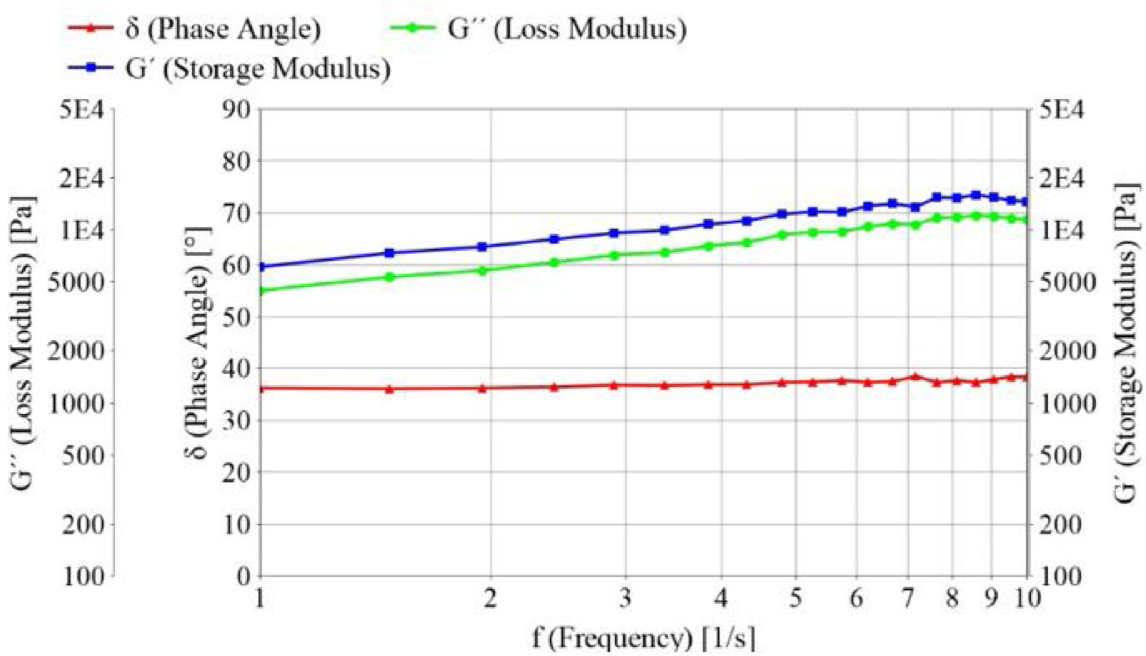

Figure 10

Frequency sweep in the viscoelastic zone of the blackberry with açaí. CD Mode, frequency range 10 s−1–1 s−1, fixed deformation parameter 0,9 % T:25 °C and 20 points with an activation time of 10 seconds. Source: Own elaboration

Nutritional Analysis

Table 3 presents the nutritional composition of the blackberry with 5 % açaí for 3D applications, which has a considerable contribution of vitamin C, where values of 15 % of the recommended daily portion were obtained.

System III. Cookie

To obtain a nutritious cookie, it was necessary to develop a formulation of the product as shown in Table 4.

Subsequently, the sweetener pastry was developed and formulated from erythritol, maltodextrin, stevia and tricalcium phosphate to be included in the cookie formulation.

For the sweetness level of the pastry sweetener to be similar to the commercial sweetener, it was necessary to evaluate the formulation with different percentages of stevia, from 0,01 % to 1 % until reaching the required sweetness level by sensory analysis performed by diluting 10 % of the product in water.

When adjusting the sweetness level in the sweetening pastry formulation, the texture of the material is evaluated with different amounts of water. 10 g of the cookie formulation were prepared and homogeneously mixed with 5 g of water; when performing the extrusion process with the syringe, it is observed that the layers deposited on each other are not very well defined due to the semi-liquid texture, so the material does not have sufficient structural strength, as shown in Figure 11 (a), therefore the amount of water is reduced to 3 g. When performing the same extrusion process with the syringe, a much more solid and stable structure can be seen in Figure 11 (b).

Figure 12 shows the biscuit during and after the printing process, for which 40 grams of the biscuit powder and 12 grams of water were necessary, until a completely homogeneous mixture was obtained. It is possible to observe a 3D structure in the form of a very well defined and structurally stable flower.

Table 3

Composition of blackberry with 5 % of açai for 3D printi

Nutrition Facts/Información Nutricional

Size for portion/Tamaño de la Porción: 4 cucharaditas (20g)
Portions per Container/Porciones por envase 10

Amount Per Serving/Cantidades por Porción	
Calories/Calorías 70	Calories from Fat/Calorías de la Grasa 0
	% Daily Value*/% Valor Diario*
Total Fat/Grasa Total 0g	0 %
Satured Fat/Grasa Saturada 0g	0 %
Trans Fat/Grasa Trans 0g	
Cholesterol/Colesterol 0mg	0 %
Sodium/Sodio 60mg	3 %
Total Carbohydrate/Carbohidrato Total 19g	6 %
Dietary Fiber/Fibra Dietaria <1 g	0 %
Sugars/Azúcares 2g	
Protein/Proteína 0g	0 %
Vitamin A/Vitamina A 0%	Vitamin C/Vitamina C 15%
Calcium/Calcio 0%	Iron/Hierro 0%

*Percent Daily Values are based on a 2000 calorie diet./Your daily values may be higher or lower depending on your calorie needs:
*Los porcentajes de Valores Diarios están basados en una dieta de 2000 calorías.Sus Valores Diarios pueden ser mayores o menores dependiendo de sus necesidades calóricas:

	Calories/Calorías	2000	2500
Fat Total/Grasa Total	Less then/Menos de	65 g	80 g
Sat. Fat/Grasa Saturada	Less then/Menos de	20 g	25 g
Cholesterol/Colesterol	Less then/Menos de	300 mg	300 mg
Sodium/Sodio	Less then/Menos de	2400 mg	2400 mg
Total Carbohydrate/Carbohidrato Total		300 g	375 g
Dietary Fiber/Fibra Dietaria		25 g	30 g

Calories per gram/Calorías por gramo:
Fat/Grasa 9 Carbohydrate/Carbohidrato 4 Protein/Proteína 4

Source: Own elaboration

Table 4

Cookie Formulation

Ingredient	Component
GVP 80	Confidential
Sweetening pastry	Confidential
WPC 80	Confidential
Starch	Confidential
Wheat flour	Confidential
Wheat bran	Confidential
pastry flour	Confidential
Soy Lecithin	Confidential
Iron	Confidential
Zinc	Confidential
Probiotics	Confidential

Source: Own elaboration

3D printing was subsequently subjected to a baking process at a temperature of 130 °C for 18 min. During this process, the original design is not preserved, as seen in Figure 13, so adjustments had to be done to the formulation.

When evaluating the taste of the cookie, it is possible to identify that it is very simple, so the percentage of sweetener in the formulation had to be increased; also, the cookie does not have a crispy texture or consistency. However, good crumb formation is observed (Figure 14).

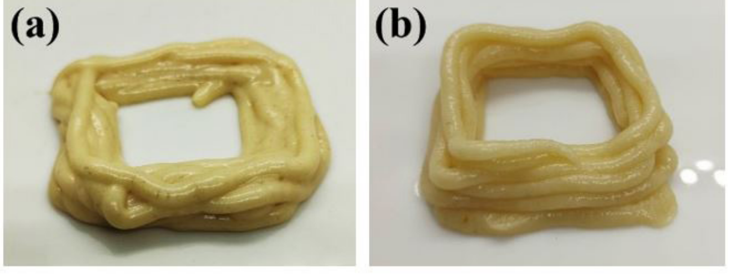

Figure 11

Powder cookie hydrated with different quantities of water (a) 5 g and (b) 3 g. Source: Own elaboration

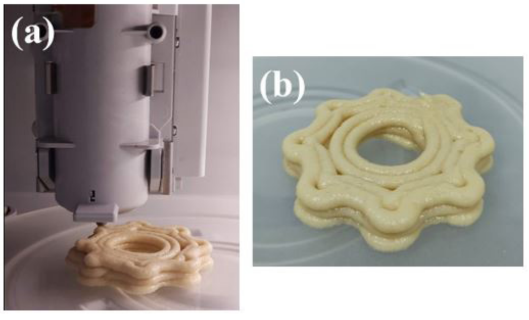

Figure 12

Flower-shaped cookie printing (a) during and (b) after the 3D printing process with Foodini equipment. Source: Own elaboration

Figure 13

Biscuit after the baking process at 130 °C/18 min. Source: Own elaboration

Figure 14

Cross-sectional view of the cookie, after the baking process at 130 °C/18 min. Source: Own elaboration

Table 5 presents an adjustment in the formulation for obtaining the biscuit, where the percentage of sweetening pastry was increased because the sweetness of the product was low; in addition, oatmeal was incorporated.

Since during the experimentation and evaluation of the cookie texture it was possible to observe that the food material in the printing process presented too much fluidity by using 3 g of water per 10 g of biscuit powder, the amount of water was reduced to 2,5 grams to slightly reduce the fluidity during the printing process and improve structural stability. Figure 15.

Figure 16 shows the front view of the printed material, where the layers of food material that were deposited one on top of the other can be clearly seen by the 3D printing addition process. A completely stable structure can be observed without any deformation.

For the printing of the two 3D figures, 70 g of biscuit powder and 17,5 g of water were required; then, the food material was manually mixed until a well homogeneous consistency was obtained and loaded into the stainless-steel cartridge of the Foodini printer, using a 4 mm diameter nozzle.

Table 5

Cookie Formulation

Ingredient	Component
GVP 80B	Confidential
Sweetening pastry	Confidential
WPC 80	Confidential
Oat flour	Confidential
Wheat flour	Confidential
pastry flour	Confidential
Soy Lecithin	Confidential
Iron	Confidential
Zinc	Confidential
Probiotics	Confidential

Source: Own elaboration

Figure 15

Cookie hydrated with 2,5 g of water for every 10 g of the powdered product. Source: Own elaboration

Figure 17 shows the 3D geometries after the baking process at 130 °C for 18 min. It is observed that the biscuits retain the design after the baking process, and favorably improves the flavor and sweetness, in addition to presenting a much crisper texture.

Rheological tests

Figure 18 presents the amplitude scan rheological test records for the avocado sample. The scan was performed from a deformation strain of 0,1 % to 10 % with a constant frequency of 1 s^{-1} and 10 seconds of sample activation.

Graphically, a slight breakage of the sample is observed when subjecting it to a deformation strain of 0,7 %, where subsequently the elastic modulus (G´) tends to decrease to almost overlap with the viscous modulus (G´´), which represents that the material must behave like a gel.

Figure 19 shows the frequency sweep records from 10 s^{-1} to 1 s^{-1} with a constant or fixed variable strain stress of 0,6 % to ensure analysis in the viscoelastic regions of the material.

The sample under study is predominantly elastic from high to low frequencies according to the elastic modulus G´. The angle of phases at high frequencies is about 45°, which makes the material at that frequency behave like a solid, while at low frequencies the angle decreases to 40°, making the material at rest during the printing process much more solid.

Figure 16

Front view of the 3D printing of the cookie. Source: Own elaboration

Figure 17

Cross-sectional view of the cookie after the baking process at a temperature of 130 °C for a time of 18 min. Source: Own elaboration

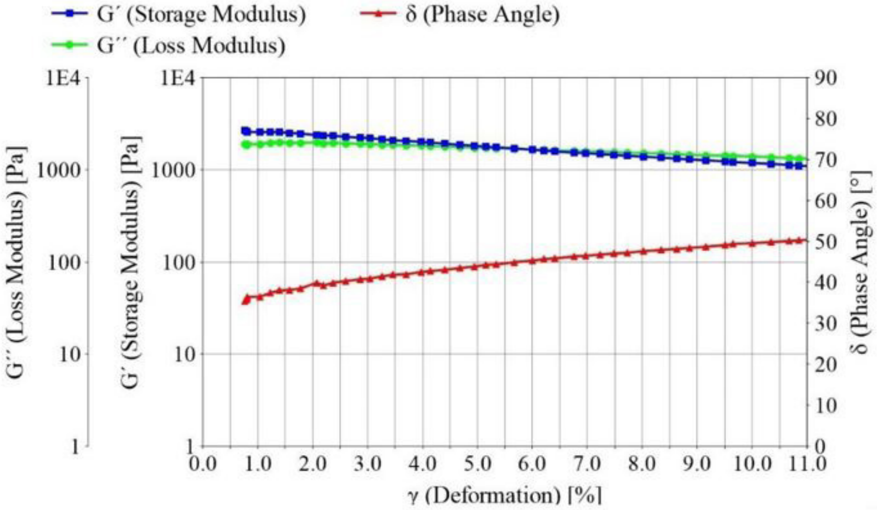

Figure 18

Amplitude scan or deformation strain of the cookie. CD Mode, τ 0,2 - 11,0 %, f 1 s-1, T:25 °C and 40 points with an activation time of 10 seconds. Source: The authors.

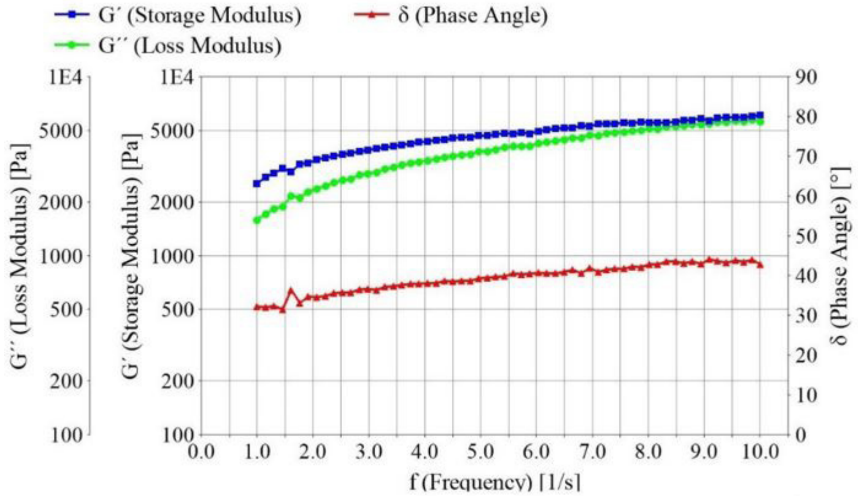

Figure 19

Frequency sweep in the viscoelastic area of the cookie. CD Mode, frequency range 10 s-1-1 s-1, fixed deformation parameter 0,7 %, T:25 °C and 60 points with an activation time of 10 seconds. Source: Own elaboration.

Nutritional Analysis

Table 6 presents the nutritional composition of the biscuit for 3D applications, where a low-fat, high mineral content product such as iron and calcium, in addition to having a considerable contribution of calories with low sugar content and a high protein content.

Sensory analysis

The results obtained during the sensory tests, as shown in Figure 20, show a good acceptance of the sensory panel, which evidence acceptance of approximately 70 %. The best results were obtained with the development of the nutritional cookie, which reached average values of 80 % acceptance. Regarding the flavor variable, the sensory panel for the cheese product presented a medium acceptance, unlike the blackberry with açaí and the biscuit, which presented an acceptance of approximately 70 %.

Table 6

Composition of cheese for 3D printing

Nutrition Facts/Información Nutricional

Size for portion/Tamaño de la Porción: 4 cucharaditas (20g)
Portions per Container/Porciones por envase 10

Amount Per Serving/Cantidades por Porción

Calories/Calorías 90 | Calories from Fat/Calorías de la Grasa 30

	% Daily Value*/% Valor Diario*
Total Fat/Grasa Total 3,5g	5 %
Satured Fat/Grasa Saturada 2g	10 %
Trans Fat/Grasa Trans 0g	
Cholesterol/Colesterol <5mg	0 %
Sodium/Sodio 80mg	3 %
Total Carbohydrate/Carbohidrato Total 11g	4 %
Dietary Fiber/Fibra Dietaria 2g	8 %
Sugars/Azúcares 1g	
Protein/Proteína 4g	8 %

Vitamin A/Vitamina A 0% | Vitamin C/Vitamina C 0%
Calcium/Calcio 4% | Iron/Hierro 6%

*Percent Daily Values are based on a 2000 calorie diet./Your daily values may be higher or lower depending on your calorie needs:
*Los porcentajes de Valores Diarios están basados en una dieta de 2000 calorías.Sus Valores Diarios pueden ser mayores o menores dependiendo de sus necesidades calóricas:

	Calories/Calorías	2000	2500
Fat Total/Grasa Total	Less then/Menos de	65 g	80 g
Sat. Fat/Grasa Saturada	Less then/Menos de	20 g	25 g
Cholesterol/Colesterol	Less then/Menos de	300 mg	300 mg
Sodium/Sodio	Less then/Menos de	2400 mg	2400 mg
Total Carbohydrate/Carbohidrato Total		300 g	375 g
Dietary Fiber/Fibra Dietaria		25 g	30 g

Calories per gram/Calorías por gramo:
Fat/Grasa 9 Carbohydrate/Carbohidrato 4 Protein/Proteína 4

Source: Own elaboration

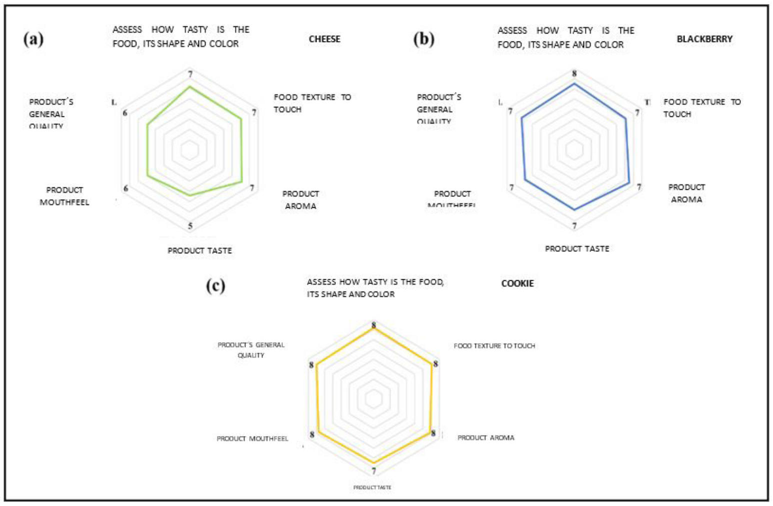

Figure 20

Sensory evaluation of (a) cheese, (b) mora-açaí and (c) biscuit. Source: Own elaboration.

Conclusions

Food products with high potential for technological application of 3D printing were developed. The cheese presented low fat and high protein content, which makes it a nutritional food product, in addition to showing good acceptance among consumers for potential applications in 3D food prints.

The application of the three-point facial hedonic scale, with gender identification, can be a useful tool to assist in the identification of food preferences and rejections.

The cookies designed for the application of 3D printing food presented a good product quality at the general, nutritional, and sensory level, with significant amounts of carbohydrates, fiber, minerals (iron and calcium), and low fat and sugar content.

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