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Proceeding Paper

Impact of Rosehip (Rose Canina) Powder Addition and Figure Height on 3D-Printed Gluten-Free Bread †

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Abstract: Three-dimensional (3D) food printing is a technique that satisfies the criteria for manufacturing personalized food and for specific consumer groups, both in terms of sensorial and nutritional properties. Rose hips are recognized as valuable food and medicine constituents due to their high-level content of bioactive compounds. The aim of this study was to investigate the printability in terms of dimensional properties (variation in length, width and height) of 3D-printed, rectangular base (7 × 3 cm), gluten free bread doughs containing rosehip powder or rosehip powder encapsulated with maltodextrin. The effect of the addition of rose hips on rheology and the colour of dough plus texture and colour of final product was studied. The addition of rosehip increased both elastic and viscous modulus of dough and changed its colour from white to orange. After printing process, height effect on figure dimension was remarkable in comparison with dough formulation. The addition of rosehip powder in dough and the use of 2 cm of figure height improve the printability in terms of dimensional properties, achieving 3D structures with more stability and resistance to baking.

Keywords: 3D food printing; celiac; bread; rosehip; functional and technological properties

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1. Introduction

Food products are in constant innovation. Currently, two food trends are personalization of food and specific consumer groups, both in term of sensorial and nutritional properties. Three-dimensional (3D) printing is a good production tool to develop this trend [1]. There are so many printable materials, such as cookies [2,3], snacks [4], gels [5], peanut butter and cream cheese [5]. In the last 10 years, 3D printing has been used to make functional foods or to manufacture new shapes, textures, flavor, colors, etc. [6].

On the other hand, another food trend is the elaboration of functional foods. It emerged in Japan with the name FOSHU and includes those foods that have specific beneficial effects on the consumer's health due to the ingredients they incorporate or eliminate [7]. Gluten-free products are functional because they eliminate the risk of disease status in the celiac population. However, the strict following of a gluten-free diet has certain nutritional deficiencies. The main deficiencies are B vit., especially folic acid, vit. D, Ca, Fe and fiber [8]. To alleviate these needs, gluten-free foods must be enriched with other ingredients that supplement these nutrients.

Currently, there is growing interest in wild plants, as they have a high content of bioactive compounds with positive effects on health [9]. Rose hip (Rosaceae canina) has been used for medicinal remedies for years. Recent studies shows that vitamin C, proanthocyanidins, galactolipids and folate predominate in rosehip components. There are also flavonoids, pectic, vit. A, other B complex vit., vit E and minerals such as Ca, Mg, K, S, Si, Fe, Se and Mn [10]. In addition, rose hips have a moderate content of carotenoids [11].

The aim of this study was to investigate the printability in terms of dimensional properties (variation in length, width and height) of 3D-printed, rectangular base (7 × 3 cm) gluten-free bread doughs containing rosehip powder or rosehip powder encapsulated with maltodextrin. The effect of the addition of rose hips on rheology and color of dough plus texture and color of final product was studied.

2. Materials and Methods

2.1. Raw Materials

For the elaboration of the bread doughs, a gluten-free flour preparation was used (Sinblat Alimentación Saludable SL, Foios, Spain), containing salt, water, chemical yeast and oil, which were purchased at a local supermarket. The rose hip was collected in September–October 2020 in Aldehuela (Teruel, Spain).

2.2. Rose Hip Powder Obtainment

Rose hips were washed and homogenized with a Thermomix (TM 21, Vorwerk, Valencia, Spain) for 1 min at 5200 rpm. Once homogenized, 1000 g of distilled water was added and homogenized again for 5 min at 5200 rpm. The mixture obtained was filtered through a sieve (diameter 1 mm, Cisa 029077, 1 series). Two formulations were prepared, one called rose hip I, and another with maltodextrin incorporation (MD), 10 g MD to 90 g of filtered mixture, and called rose hip with maltodextrin (EM). Afterwards, the mixtures were frozen and lyophilized in aluminum trays (15 cm diameter and 5 cm height), forming a layer 0.5 cm thick. The two mixtures were frozen at −42 °C in a vertical freezer (CVF450/45, Ing. Climas, Barcelona, Spain) for 24 h for subsequent lyophilization in Lioalfa-6 Lyophyliser equipment (Telstar, Spain) at 2600 Pa and −56, 6 °C for 48 h. The product obtained after lyophilization was ground in a mill (Minimoka, Taurus, Lleida, Spain) to obtain the powder that was incorporated into the doughs.

2.3. Dough Preparation

For each analysis and printing, three different doughs were made: control dough (MB), dough with rose hip (ME) and dough with rose hip and maltodextrin (MEM). Each elaborated dough weighed 500 g grams and was composed of 56% water, 40% flour without gluten, 2.4% chemical yeast, 1.2% vegetable oil and 0.4% salt. In those that incorporated rosehip or rosehip with maltodextrin, 7% was introduced, which was subtracted from the amount of gluten-free flour. These ingredients were incorporated into a mixer (Kenwood chef classic, KM400/99 plus, Kenwood Corporation, Tokyo, Japan) where they were first mixed by hand to avoid the loss of the dry components, then stirred for 45 s at a minimum speed followed by 5 min at speed 2.

2.4. Dough 3D Printing

To carry out the printing test, first the different shapes of the products were designed. Three rectangular shapes of 7 cm long, 3 cm wide and variable in height between 1, 2 and 3 cm were designed using the Autodesk 123D design program (Autodesk Inc., San Rafael, CA, USA). The designed shape was entered into the Slic3r program (Alessandro Ranellucci) to configure the printing parameters: needle speed 20 mm/s, increase in needle height between layer and layer of 1.7 mm and rectilinear filling of the layers with 60% layer filling, except for the first layers with 100% filling.

Dough printing was carried out in a 3D food printer (BCN·D+, BCN3D Technologies, Barcelona, Spain). The 3D printer consisted of an extrusion system (syringe plus pump) and an X-Y-Z positioning system. The printing was carried out at room temperature, with an extrusion speed of 3 mL/min, a needle of 1.63 mm diameter and on a stainless-steel tray for later baking. The baking was done at 190 °C and the baking time was adapted to the height of the sample, 16, 22 and 26 min for 1, 2 and 3 cm, respectively.

2.5. Determinations

2.5.1. Rheological Characterization

The rheological properties of the three types of dough (control, with rose hips and with rose hips and maltodextrin) were characterized in a Kinexus Pro + rheometer (Malvern Instruments, Worcesterchire, UK). A 25 mm plate–plate oscillatory test was carried out with a space between sample and plate of 2 mm, stress of 1 Pa, frequency range of 0.1 to 10 Hz and at a constant temperature of 25 °C.

2.5.2. Image Analysis

The image of the bars was taken before and after baking. These images were analyzed with ImageJ program (ImageJ, NIH, Bethesda, MD, USA) to determine the evolution of the shape before and after the baking process. With the values obtained from the unbaked images, the difference between the real proportions and those given in the printing was calculated (7 cm long, 3 cm wide and 1, 2 or 3 cm high). Once baked, the difference in proportions was calculated with respect to those they had once printed.

2.5.3. Color Analysis

To measure the color of the samples, the CIE L* a* b* coordinates (L*: luminosity, a*: green/red abscissa axis, b*: yellow/blue ordinate axis) were obtained with a CM−700 d spectrophotometer (Konica Minolta Sensing, Inc., Tokyo, Japan) and a SAV aperture size accessory. Measurements were made with illuminant D65 and 10° observer angle for the doughs, bread crust and the crumb. With the data of the coordinates, the rest of the colorimetric parameters were calculated: tone (h), chroI(C) and color difference (ΔE).

2.5.4. Textural Characterization

Textural characterization was carried out with a TPA test with TA.XT.plus texturometer (Stable Micro Systems, Godalming, Surrey, UK) using the Texture Exponent 32 program (Stable Micro Systems, Godalming, Surrey, UK) with a 4 cm diameter plate accessory reaching 40% deformation. A puncture test of the crust was also carried out.

2.5.5. Statistical Analysis

Analysis of variance (ANOVA) was performed for a 95% confidence interval ($p < 0.05$) to evaluate the differences between the different breads. All these analyzes were carried out with the Statgraphics Centurion 18 program, version 18.1.13 (Statgraphics Technologies, Inc., The Plains, VA, USA).

3. Results and Discussion

3.1. Rheological Characterization

The parameters of the oscillatory test have been recorded in Table 1. It shows that doughs have high elastic modulus (G′), as with the complex modulus (G*). These results and Tanδ < 1 indicate that the behavior of the doughs is predominantly elastic. The incorporation of rose hip differs and makes the dough more elastic. The increased resistance may be related to the increase in fiber [12] when incorporating rose hip. Rose hip with maltodextrin's incorporation inhibits the rheological modification by the rose hip.

Table 1. Rheological parameters of the doughs (B: control; E: rose hip; EM: rose hip with maltodextrin).

Masa	G* (Pa)	G′ (Pa)	G″ (Pa)	Tanδ (°)	η* (mPa s)
B	1444 (65) [a]	1408 (64) [a]	324 (14) [a]	0.2300 (0.0003) [a]	230 (10) [a]
E	1690 (90) [b]	1639 (88) [b]	410 (19) [b]	0.2499 (0.0018) [c]	269 (14) [b]
EM	1450 (95) [a]	1409 (92) [a]	339 (21) [a]	0.2408 (0.0011) [b]	231 (15) [a]

The letters ([a–c]) that are expressed in the results indicate the homogeneous groups according to ANOVA ($p < 0.05$).

3.2. Image Analysis

Figure 1a shows the deviation of the proportions (%) of the samples from the proportions given (7 cm long, 3 cm wide and 1, 2 or 3 cm height). The 3 cm EM sample presents the higher value in height. Three cm are also the samples that show more deviation of width; among them the higher is the E sample. Regarding the length, the samples with the most deviation are the 3 cm, being B and EM, which stand out. It is observed that the samples with the highest deviations are those of 3 cm, so it could be set as the limit height.

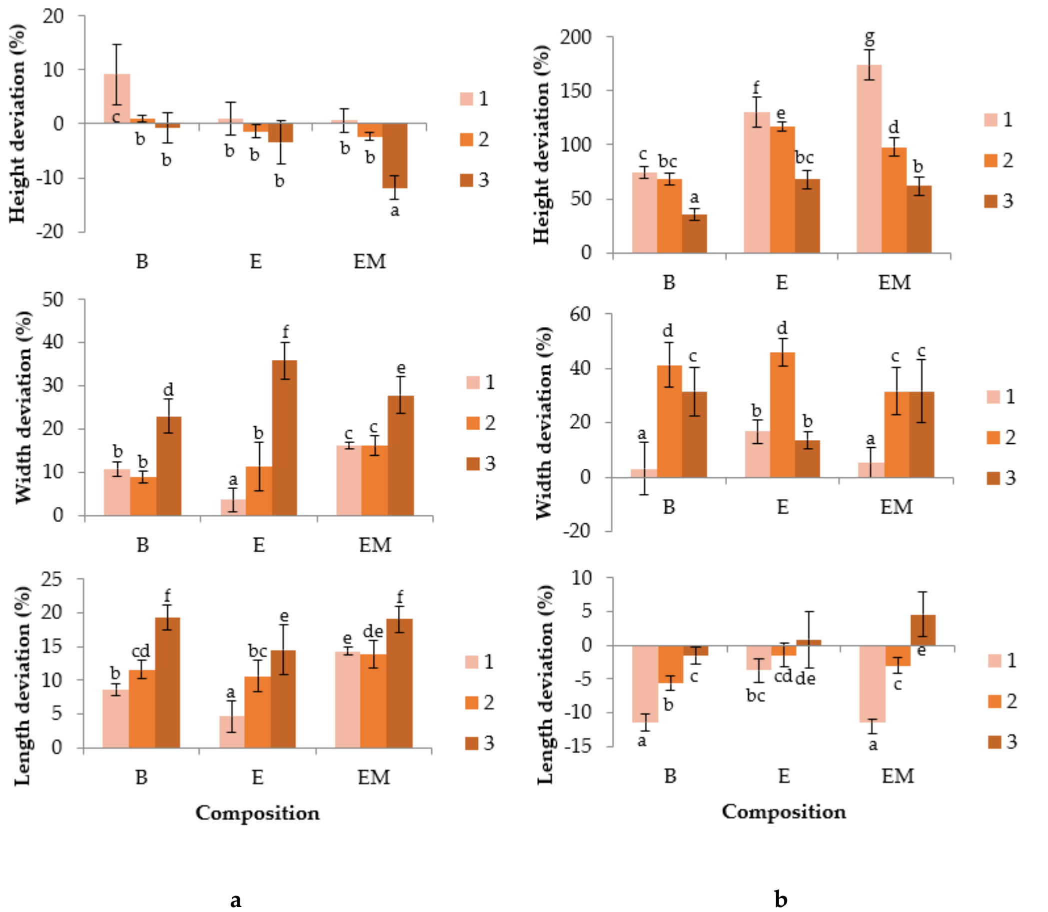

Figure 1. (**a**) Deviations of the proportions of the recently printed samples; (**b**) Deviations of the proportions of the samples after baking (B: control; E: rose hip; EM: rose hip maltodextrin; 1, 2, 3: height cm). Letters (a–g) indicate homogeneous groups according to ANOVA ($p < 0.05$).

Figure 1b shows the deviation of the proportions of the samples once baked compared to those that had just been printed. The sample with the highest deviation in height is 1 cm E and 3 cm B had the lowest value. Regarding the width, the ones with the greatest differences are 2 cm, being E and B (the largest). On the other hand, the one with the smallest deviation is 1 cm B. Finally, in the proportion of length, 1 cm B sample and EM show higher modification. In these samples, the deformation is negative because when the loaves increased the size in height they were retracted at the ends.

3.3. Color Analysis

Table 2 shows the values of the different parameters that define the color of the doughs and the crust and crumb of the final samples.

Table 2. Mean values and standard deviation in brackets of colorimetric parameters of the samples for a D65 illuminant and 10° observer. M: dough; C: crust; Mi; crumb B: control; E: rose hip; EM: rose hip maltodextrin. The numbers 1, 2 and 3 correspond with the height of samples (cm).

Sample	L*	a*	b*	h	C	ΔE
MB	81.221 (0.019) [c]	−1.7 (0.2) [a]	9 (0.2) [a]	100.5 (0.3) [c]	9 (0) [a]	-
ME	64.1 (0.3) [a]	14.1 (0.4) [c]	29.2 (0.4) [c]	64.2 (0.3) [a]	32.4 (0.6) [c]	30.8 (0.6) [b]
MEM	66.6 (0.2) [b]	10.6 (0.3) [b]	24.7 (0.3) [b]	66.7 (0.5) [b]	26.9 (0.3) [b]	24.7 (0.3) [a]
C1B	59 (8) [cd]	7.1 (1.8) [b]	25 (6) [cd]	73 (7) [d]	26 (5) [bc]	-
C1E	60 (7) [cd]	7.7 (0.8) [bc]	24 (2) [cd]	72 (3) [d]	25.5 (1.9) [bc]	11 (6) [a]
C1EM	65 (5) [d]	5.3 (1.4) [a]	20 (3) [abc]	75 (4) [d]	21 (3) [ab]	11 (8) [a]
C2B	64 (3) [d]	7.4 (0.8) [bc]	28 (2) [d]	75.3 (1.6) [d]	29 (2) [c]	-
C2E	47 (8) [ab]	10.4 (1.5) [e]	17 (8) [ab]	55 (12) [ab]	20 (7) [ab]	21 (10) [b]
C2EM	54 (7) [bc]	8.6 (1.5) [cd]	22 (5) [bcd]	68 (4) [cd]	24 (5) [abc]	13 (8) [a]
C3B	62 (5) [d]	6.9 (1.2) [b]	27 (4) [d]	75 (3) [d]	28 (4) [c]	-
C3E	46 (9) [a]	10 (2) [de]	15 (10) [a]	48 (9) [a]	19 (9) [a]	21 (10) [b]
C3EM	50 (10) [ab]	8.8 (1.6) [cd]	19 (9) [abc]	59 (19) [bc]	22 (8) [ab]	16 (14) [ab]
Mi1B	50 (4) [b]	1.4 (0.9) [a]	7.5 (0.9) [a]	79 (7) [d]	7.7 (0.9) [a]	-
Mi1E	47 (1.3) [a]	12.4 (1.2) [e]	23.1 (1.6) [d]	61.8 (1.3) [c]	26.3 (1.8) [e]	20 (2) [e]
Mi1EM	45 (5) [a]	8.1 (0.7) [b]	14 (3) [b]	59 (5) [bc]	16 (2) [b]	12 (3) [a]
Mi2B	56 (3) [c]	0.6 (0.9) [a]	9 (2) [a]	86 (4) [e]	9 (2) [a]	-
Mi2E	44 (3) [a]	11.7 (1.2) [e]	17 (4) [c]	54 (4) [a]	20 (3) [c]	18 (3) [de]
Mi2EM	47 (3) [a]	9 (1.2) [bc]	15 (3) [bc]	59 (2) [bc]	18 (4) [bc]	15 (3) [bc]
Mi3B	55.0 (0.8) [c]	1 (2) [a]	9 (4) [a]	85 (6) [e]	9 (4) [a]	-
Mi3E	44.1 (1.5) [a]	10.3 (1.5) [d]	16 (2) [bc]	57 (3) [ab]	19 (3) [c]	17 (3) [cd]
Mi3EM	47 (2) [a]	9.6 (0.8) [cd]	16 (2) [bc]	59 (2) [bc]	18 (2) [bc]	14 (3) [ab]

The letters ([a–e]) that are expressed in the results indicate the homogeneous groups according to ANOVA ($p < 0.05$).

Regarding the doughs from which the samples come, it is observed that the MB presents high luminosity and very low coordinate values, resulting in a white achromatic sample. Among the samples that incorporate rose hip, it can be distinguished that the one that presents the rose hip protected with maltodextrin has more centric values in the CIELab space, but greater luminosity. The incorporation of maltodextrin whitens the color, giving a less saturated orange color compared to the rosehip dough.

In the case of the crusts, as the rose hip is rich in carotenoids [11], the samples that incorporate it present higher a* coordinate values than the others. Those that also contain maltodextrin have intermediate values between the control and rose hip samples due to the white-brown hue of maltodextrin.

With the crumbs, the control samples are the ones with the brightest colors. These samples have a light yellowish hue. In those that incorporate rose hip, the color is a little less luminous, with an orange hue.

3.4. Textural Characterization

Table 3 shows the different parameters of the TPA test as well as the maximum force obtained in the puncture test for the different samples. Analyzing parameter by parameter, it is observed that the 3 cm B and 2 cm B crumbs need the greatest force for deformation. The adhesiveness of the samples is negligible. The cohesion of the samples is high; in some cases, 87% deformation is reached to cause the crumb to break. It is observed that those that incorporate EM or E present more cohesion. The addition of rose hips in general gives the product greater resistance to breakage.

Regarding the elasticity in general, most of the samples almost completely recover their initial state. The one with the least elasticity is 1 cm B. Regarding chewing, the 3 cm and 2 cm B are the ones that would have to be chewed the most to be able to swallow. Finally, the resilience shows that the samples that take the least time to recover their initial state are those that incorporate rose hip, both encapsulated and non-encapsulated.

The puncture test shows that 1 cm B requires the highest force to perforate. In the texture parameters, the effect of height is more pronounced than an effect of dough type.

Table 3. Mean values and standard deviation in brackets of TPA test parameters and crust puncture (H: hardness; A: Adhesiveness; C: cohesiveness; S: springiness; Ch: chewiness; R: resilience; P: puncture; B: control; E: rose hip; EM: rose hip maltodextrin; 1, 2, 3 cm sample height).

Sample	H	A	C	S	Ch	R	P(F máx)
1B	66 (12) ^{ab}	−0.9 (0.9) ^{a}	0.59 (0.06) ^{a}	0.65 (0.12) ^{a}	26 (9) ^{a}	0.32 (0.04) ^{a}	402 (62) ^{f}
1E	43.6 (1.2) ^{a}	−6 (5) ^{a}	0.73 (0.16) ^{bc}	0.92 (0.05) ^{bc}	29 (8) ^{a}	0.38 (0.06) ^{b}	303 (133) ^{e}
1EM	122 (21) ^{abc}	−1.2 (1.8) ^{a}	0.84 (0.03) ^{d}	0.924 (0.014) ^{c}	94 (17) ^{bc}	0.525 (0.009) ^{c}	248 (57) ^{de}
2B	223 (26) ^{de}	−10 (19) ^{a}	0.69 (0.06) ^{ab}	0.88 (0.03) ^{bc}	136 (24) ^{cd}	0.36 (0.04) ^{ab}	247 (62) ^{de}
2E	135 (31) ^{bc}	−3.8 (2.9) ^{a}	0.82 (0.04) ^{cd}	0.93 (0.02) ^{c}	103 (23) ^{bc}	0.49 (0.04) ^{c}	226 (80) ^{cd}
2EM	95 (12) ^{ab}	0 (0) ^{a}	0.818 (0.019) ^{cd}	0.93 (0.04) ^{c}	72 (11) ^{b}	0.5 (0.02) ^{c}	180 (76) ^{bc}
3B	277 (92) ^{e}	−2 (2) ^{a}	0.71 (0.04) ^{b}	0.85 (0.04) ^{b}	163 (39) ^{d}	0.38 (0.04) ^{b}	160 (21) ^{b}
3E	190 (66) ^{cd}	−0.6 (0.9) ^{a}	0.84 (0.03) ^{cd}	0.959 (0.003) ^{c}	153 (58) ^{d}	0.508 (0.013) ^{c}	119 (36) ^{ab}
3EM	141 (14) ^{bcd}	−2.3 (3.2) ^{a}	0.88 (0.03) ^{d}	0.9555 (0.0009) ^{c}	118 (8) ^{bcd}	0.5427 (0.0002) ^{c}	76 (18) ^{a}

The letters ($^{a–f}$) that are expressed in the results indicate the homogeneous groups according to ANOVA ($p < 0.05$).

4. Conclusions

With this study, it has been possible to characterize three doughs of different composition (control, rose hip and rose hip with maltodextrin). With knowledge of rheology, the results can be extrapolated to other printable biomaterials. In general, the print height showed the greatest effect on the physicochemical properties studied. However, the composition of formulates was the one that most affected the colorimetric properties due to the contribution of carotenoids.

The addition of rosehip powder in dough and the use of 2 cm of figure height improve the printability in terms of dimensional properties, achieving 3D structures with more stability and resistance to baking.

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