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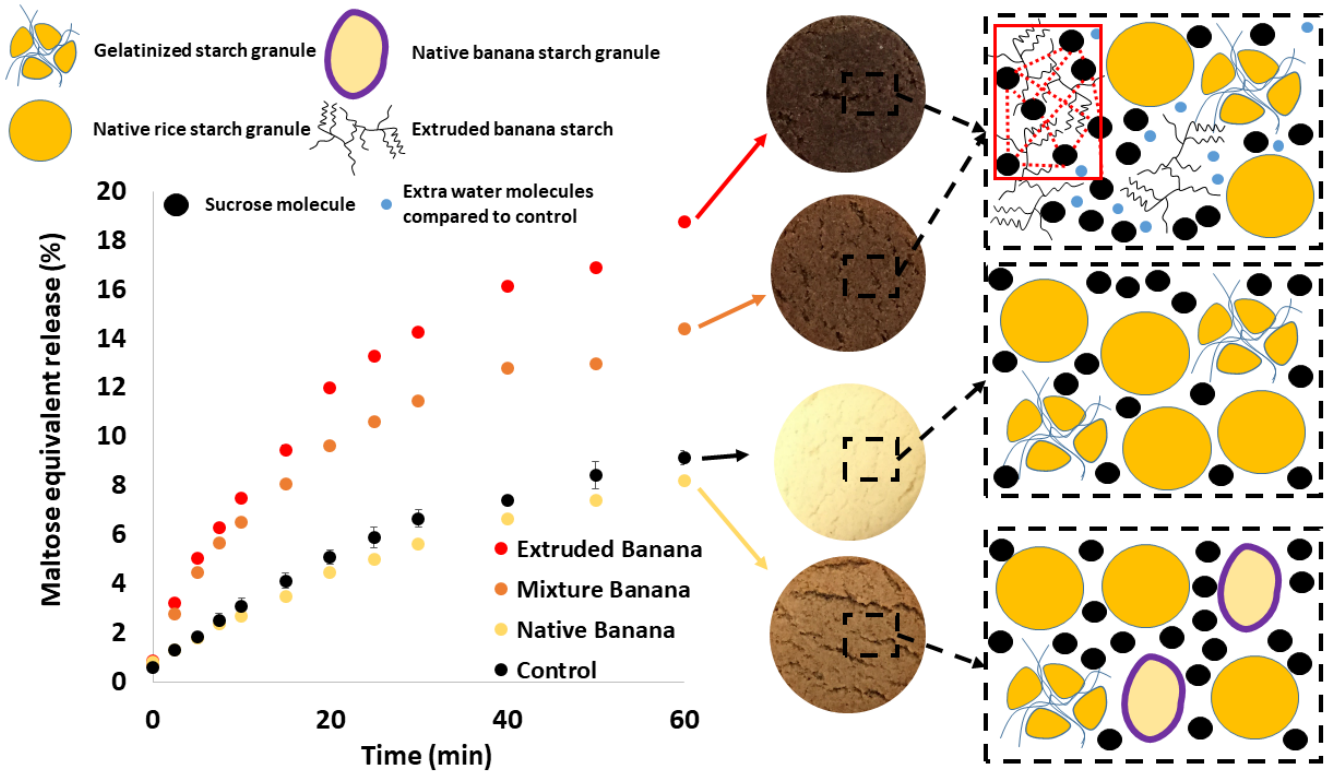

Nutritional, rheological and sensory characterization of sugar-snap cookies: Effect of banana starch in native and molten states

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Abstract

Starch is the major glycemic carbohydrate related to postprandial glycaemia and it naturally exists in the form of partially crystalline starch granules. Interestingly, the microstructural and granular features of banana starch have been reported to be inherently resistant to enzyme digestion. Converse to bread, sugar-snap cookie dough undergoes minimum starch gelatinization during baking. Therefore, the inclusion of banana starch in sugar-snap cookies could have a major role on starch susceptibility to be undigested or digested slowly, which could be especially relevant in gluten-free diets, typically characterized by a lower fiber intake and higher glycemic index. Here, we demonstrate that the starch digestion rate (k) and consumer's acceptance of gluten-free sugar-snap cookies can be simultaneously improved by a 30 % replacement of rice flour by native banana starch. Furthermore, the content of resistant starch was increased from 0.1 to 3.6 % (g /100 g cookie), which would allow labeling of cookies as "source of fiber" in some food regulations. We also showed that the inclusion of fully gelatinized banana starch causes an increase of the water fraction that dramatically shifts the texture from brittle to soggy, according to the three-point bending test, that contributed to worsen consumer's acceptance. Classic sugar-snap cookies are composed mainly of a continuous glassy sucrose-water matrix which confers this product its brittle textural properties. Therefore, when selecting novel starches for low/sustained glycemic response, it is paramount to deliberately formulate sugar-snap cookies to begin their shelf-lives in a glassy state that allows a desired crispy texture.

Keywords: resistant starch; digestion kinetics; banana starch; extrusion; cookie

1 Introduction

Starch was a major energy source required for proper growth and development of human beings. Indeed, it was recently revealed that diets with a high ratio of glycemic carbohydrates to protein can improve health and longevity.[1] However, starch is the major glycemic carbohydrate related to postprandial glycaemia and a high glycemic index, i.e., a spike in post-meal blood glucose. A diet consisting of high glycemic index foods is associated with poor health outcomes.[2] For starchy baked goods, the rate of starch digestion has been correlated with its degree of gelatinization.[3] Converse to bread, sugar-snap cookie dough contains a moisture content (up to 5 %) not enough to ensure complete starch gelatinization during baking, resulting in only around 11 % of starch gelatinization.[4] Therefore, the native semi-crystalline microstructure of starch granules remaining un-gelatinized in sugar-snap cookies will have a major role on the susceptibility of starch to be undigested or digested slowly.

Native banana starch has been reported to be inherently resistant to enzyme digestion[5,6] and enter the large intestine where it can be partially or fully fermented. The fermentation of undigested starch in the colon leads to the production of short chain fatty acids (SCFAs), which provide the energy fuel for the colonocytes, leading to an improved colonic health.[7] The factors responsible for its resistance to digestion remain unclear, although the degree and type of crystallinity related to starch composition, granule size, and the absence of porosity seem to be part of this natural physical barrier to human digestion.[6] Undigested starch due to these factors is termed resistant starch type 2 (RS2). For most sources of RS2, including banana starch, normal cooking temperatures at high moisture contents will tend to disrupt the structure of the granule, potentially leading to gelatinization and increasing its digestibility.[8,9] However, its resistance to digestion will remain in sugar-snap cookies, where minimum starch gelatinization occurs. Using a cookie model with no sugar in the formulation, Agama-Acevedo et al.[10] reported an increase in the RS content from 2.3 to 8.4 % with a 50 % replacement of the wheat flour by unripe banana flour, which typically contains more than 50% starch (dry basis). However, information about the physical and sensory quality of those cookies was not shown. Furthermore, the effect of banana starch/flour on the RS content of gluten-free cookies has never been reported. This could be of particular interest for people following a gluten-free diet, which is typically characterized by a lower fiber intake and higher glycemic index as a consequence of the use of refined flours low in fiber and high in rapidly digested starch.[11]

The objective of this study is, therefore, to obtain a highly palatable sugar-snap cookie rich in RS and/or starch with low digestion rate. Secondarily, we aimed at studying the effect of incorporating the aforementioned banana starch after extrusion based on 2 approaches. Firstly, the slow digestion property of fully gelatinized banana starch through retrogradation was recently reported to improve after molecular fragmentation.[12] Secondly, although in detriment of texture quality, the use of a fully gelatinized starch with high water retention capacity during baking could alter the cookie texture from glassy to rubbery,[13] which could enable cookies to persist dispersion (be more cohesive and elastic) in gastrointestinal fluids during digestion. To do so, native and extruded banana starch, and a 1:1 composite of native:extruded banana starch were used to replace rice flour in gluten-free cookies. Resistant starch and *in vitro* starch digestion kinetics as well as the physical and sensory quality of cookies was assessed. We expect that the resistant/slow digestion property of banana containing cookies may lead to a lower and more sustained rise in postprandial blood glucose, which could be a small step towards the reduction of the prevalence of metabolic syndrome diseases, such as obesity, type II diabetes and cardiovascular disease.[14] Furthermore, banana pulp is usually disposed of improperly at the producer level and represents a massive untapped resource from food waste that could be converted into nutritious edible materials.

2 Materials and methods

2.1 Materials

Rice flour (9.58 % moisture, 7.43 % protein, 0.11 % RS) was provided by Molendum Ingredients (Zamora, Spain). Native banana starch from green lady finger bananas (6.30 % moisture, 3.17 % protein, 42.21 % RS) was purchased from Natural Evolution (Walkamin, Queensland, Australia). Extruded banana starch (3.33% moisture, 3.29 % protein, 0.84 % RS) was obtained after extrusion using a Werner and Pfleiderer ZSK-25 twin screw extruder (Ramsey, NJ, USA) under the conditions already explained in detail by Roman, Gomez, Hamaker and Martinez.[12]

White sugar (AB Azucarera Iberica, Valladolid, Spain), "Argenta crema" margarine (Puratos, Girona, Spain) and sodium bicarbonate (Manuel Riesgo S.A., Madrid, Spain) were also used for cookie making. Rice flour and banana starches were characterized according to AACC[15] methods for moisture (44-15.02), protein (46-30.01) with a Leco TruSpec device (Leco, St. Joseph, MI, USA) and resistant starch (32-40.01).

2.2 Methods

2.2.1 Cookie-making

Ingredients used for cookie-making (as g/100 g on dough basis) were as follows: rice flour (54.0 g/100 g), sugar (19.5 g/100g), margarine (12.1 g/100g), water (13.3 g/100g) and sodium bicarbonate (1.1 g/100 g). Native banana starch (NB), extruded banana starch (EB) and a 1:1 mixture of native and extruded banana starches (MB) were used as a replacement of 30 % of the rice flour. The moisture of the different starchy materials was adjusted to 15% so that the final dough moisture was the same in all formulas. The margarine was heated upon melting in the microwave for 1 minute at 1000 W. The margarine and sugar were then creamed at speed 4 for 180 s in a Kitchen Aid 5KPM50 mixer (Kitchen Aid, Michigan, USA) with a flat beater, scraping down every 60 s. Water was then added and mixing proceeded at speed 4 for 120 s with intermediate scraping. At the end of the mixing process, the cream was scraped down. Finally, flour and sodium bicarbonate were added, followed by mixing at speed 2 for 120 s, scraping down every 30 s. After mixing, the dough was allowed to stand for 30 min covered with transparent foil before sheeting. The dough pieces were sheeted to a final height of 6.00 mm with a Salva L-500-J sheeter (Salva, Lezo, Spain). Cookie dough was cut with a circular cookie cutter (40 mm inner diameter) and baked in an electric modular oven for 14 minutes at 185 ºC. The cookies were let to cool down for 60 min and packaged in sealed polyethylene bags for storage at 20 °C until further analyses. All the cookie elaborations were performed twice.

2.2.2 Viscoelastic properties of cookie dough

The linear viscoelastic properties of cookie doughs were studied by a small amplitude oscillatory test (SAOS) using a controlled stress rheometer (Haake RheoStress 1, Thermo Fisher Scientific, Schwerte, Germany). The controlled stress rheometer was equipped with a titanium parallel plate geometry sensor PP60 Ti (60 mm diameter, and 3 mm gap) and a Phoenix II P1-C25P water bath (Thermo Fisher Scientific, Schwerte, Germany). Cookie dough was allowed to rest for 300 s at the gap position before further tests. Frequency dependence experiments were conducted from 10 to 0.1 Hz at 25 ºC using an applied stress within the linear viscoelastic region. From this experiment, G’ and G’’ at 1 Hz were selected. At least two replicates of each oscillatory shear test were performed.

2.2.3 Cookie characteristics

Cookie characteristics were determined 24 h after baking. Four cookies were weighed and their width (diameter) was measured with a caliper. For better observation of differences in cookie shape, cookies were pictured with a Canon EOS 1300D (Tokyo, Japan). Cookies were also analyzed for moisture content according to approved method 44-15.02.[15] Cookie texture was determined by a fracture test, using a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) equipped with the "Texture Expert" software and a three-point bend rig probe (HDP/3PB). The experimental conditions were: supports 30 mm apart, a 20 mm probe travel distance, a trigger force of 5 g and a test speed of 2.0 mm/s. The hardness, calculated as the maximum force (N), and the displacement at rupture (mm) were measured in four cookies per elaboration.

2.2.5 *In vitro* starch digestion kinetics and resistant starch

The rate at which starch amylolysis products become bioaccessible (i.e., available for absorption) during duodenal digestion was determined *in vitro* following the method described by Sun et al. (2016)16 with minor modifications. Samples were incubated with 0.2 mU of porcine-pancreatic α-amylase of a high purity (Grade 1-A, A6255, EC 3.2.1.1 from Sigma Aldrich) per mg of starch. Manually crushed cookies (100 mg) were suspended in 10 mL of Phosphate Buffered Saline (PBS) (10X Powder, pH 7.4, Fisher BioReagents). The mixture was incubated at 37 ºC with constant stirring at 350 rpm with a 3 mm × 6 mm magnetic stirrer bar. At defined time intervals, aliquots of 200 μL were withdrawn into Eppendorf tubes containing 200 μL of ice-cold 0.3M sodium carbonate to stop the reaction. The tubes were vortex-mixed and centrifuged at 12,000 g for 6 min at 4 ºC. The supernatant was used to determine the reducing sugar content using the para-hydroxybenzoic acid hydrazide (PAHBAH) assay (H9882, Sigma Aldrich) based on a previously reported method.[17] 100 μL of supernatant was withdrawn into epppendorf tubes containing 1 mL of freshly prepared PAHBAH reagent. To develop the colorimetric reaction, the tubes were heated for 6 min and 100°C. Afterwards, the tubes were let to cool down to room temperature prior to absorbance reading at 410 nm. Absorbance results for each time interval were transformed into maltose equivalent release (%). Only the first 60 min of amylolysis was assayed, as this provided sufficient information for the application of the kinetic model. The digestion results were the mean of at least two replicates.

To check if the digestion rate (k) remained unchanged throughout the reaction, the partial logarithm of the slope (LOS) was obtained, expressing the first derivative of the first-order equation in logarithmic form:[18]

$$\ln\left(\frac{\partial C}{\partial t}\right) = -kt + \ln(C_{\infty}k)$$

This gives a linear plot in which the values of digestion rate and extent constants, k and C_{∞}, are calculated from the slope (-k) and y-intercept ($\ln[C_{\infty}\ k]$), respectively.

Resistant starch content of cookies was measured following AACC method (32-40.01)[15] using RS Megazyme assay kit.

2.2.5. Consumer test

Hedonic sensory test of the cookies was conducted with 66 regular cookie consumers with ages from 18 to 65 and of various socioeconomic backgrounds. Samples were analyzed one day after baking. Cookies were presented as whole pieces, placed on white plastic dishes coded with four-digit random numbers and randomly served. Cookies were evaluated based on the acceptability of their appearance, odor, texture, taste and overall liking on a nine-point hedonic scale. The scale ranged from “extremely like” to “extremely dislike”, corresponding to the highest and lowest scores of “9” and “1” respectively. Extruded banana cookie was not included in the sensory analysis due to its extremely hard texture (see Table 1).

2.2.6 Statistical analyses

Differences among cookie characteristics were studied by a one-way analysis of variance. Fisher's least significant difference (LSD) was used to describe means with 95% confidence intervals. Statistical analysis of the data was performed with the Statgraphics Centurion XVI software (Statpoint Technologies, Inc., Warrenton, USA).

3 Results and Discussion

3.1 Dough and cookie characteristics

Dough and cookie rheological characteristics are summarized in Table 1. Small amplitude oscillatory shear test revealed in all samples a marked elastic solid-like behavior (G' higher than G'') throughout the frequency range studied. A 30 % replacement with banana starch, both in its native and extruded form, caused an increase in both dynamic moduli because of the higher water absorption capacity of banana starch,[10,12] especially when fully gelatinized after extrusion processing.[12,19] It is well known that the use of starchy materials with elevated water binding capacity can diminish the free water content enhancing the structure of the food system.[20] These results agree with the higher weight and moisture content found in cookies made with banana starch, and in particular with extruded banana starch, which is the result of a greater water retention that persist throughout cooking. The dough consistency, as objectively and comparatively reported in this work through the dynamic moduli, is an important parameter to consider since it affects dough expansion and/or relaxation,[21,22] which has been previously explained based on the water binding ability of the starch source.[23,24] Thus, a high consistency brings about a lower dough expansion/relaxation,[21,22,25] as also shown in our current work by a reduced width of banana starch-containing cookies (Table 1 and Figure 1).

The incorporation of native banana starch did not affect cookie hardness (maximum breaking strength), whereas a 30 % of rice flour replacement with extruded banana starch caused a dramatic increase. The high values of dough consistency attained with the use of extruded banana starch lower dough expansion during baking which could have resulted in a more compact and harder cookie.[21,22,25] Interestingly, the bending capacity before cracking, as measured by the distance to fracture (Table 1), remarkably increased with the use of extruded banana starch. Classic sugar-snap cookies are composed mainly of a continuous glassy sucrose-water matrix containing embedded ungelatinized starch granules,[26] which confers this product its brittle textural properties. However, it seems that a 30 % rice flour replacement by a molten extruded banana starch causes an enough increase of the water fraction that lowers the glass transition, changing the texture from glassy to rubbery.[13,27] This explains the soggy texture and fracture behavior of MB and EB cookies and the importance to modulate the water fraction in cookie making when selecting new ingredients. Sugar-snap cookies must be deliberately formulated and processed to begin their shelf-lives in a kinetically metastable, glassy state commensurate with optimal brittle texture.[26]

3.2 Starch digestion properties of cookies

Experimental LOS plots and starch digestion curves for cookie samples are depicted in Figs. 2 and 3, respectively. Interestingly, LOS plots exhibited a single digestion rate (k) over the incubation performed *in vitro* with pancreatic α-amylase simulating the human luminal digestion in the small intestine. The plots revealed that the starch substrates do not seem to consist of distinct fractions that differ in digestion rate, that is, there is no evidence for the presence of separate rapidly digested and slowly digested starch components. This event was also found in potato crisps, another food material with amorphous phase in a glassy state, by Butterworth, Warren, Grassby, Patel and Ellis[18] after re-plotting as LOS plots the digestion data taken by Goni, Garcia-Alonso and Saura-Calixto.[28] A mechanistic explanation was provided during our *in vitro* assay by the easy dispersion and pipetting of samples in the PBS buffer (evidence not shown), which could suggest a rapid crumbling and dispersion of cookies in human gastrointestinal fluids. The easy crumbling of cookies in liquid was attributed to the weakening of hydrogen bonds and the dissolution of sucrose.[29]

The *in vitro* digestion kinetic parameters after fitting to the LOS model are comparatively reported alongside the Resistant Starch (RS) content in Table 2. Cookie samples exhibited significant differences in starch digestion rate (k) and extension (C_∞) as a function of the physical state of the banana starch incorporated. Thus, a significant reduction in k and C_∞ was attained when 30 % rice flour was replaced by native banana starch, whereas the opposite trend was observed when extruded banana starch was the replacer. As the presence of a single digestion rate suggested, cookie hardness seems not to hinder the enzyme access to the substrate, which may be logical considering the rapid softening of the cookie structure after soaking in the buffer. These differences may be understood based on the low degree of starch gelatinization reported for this type of products already 30 years ago,[4] which is due to the high amount of sugar and insufficient water for starch granules to gelatinize.[29] In granular state (ungelatinized material), banana starch granules are inherently more resistant to the action of α-amylase than those of rice starch,[30] which likely may result in lower k and C_∞ of the non-gelatinized fraction. Furthermore, this native banana starch exhibited higher onset and conclusion temperatures of starch gelatinization (71.74 – 87.69 ºC) compared to those from rice flour (67.57 – 81.64 ºC) [data from Roman et al.[12]], which may reduce even the extent of starch gelatinization during baking, and therefore, increase the amount of undigested native banana starch. These mechanisms are depicted in Fig. 4. A lower digestion rate has been also found in a sugar-free wheat cookie with a 30 % replacement by native banana flour, although the physical and sensory quality of such cookies were not reported.[10]

Conversely, the addition of gelatinized extruded banana starch (MB and EB samples) resulted in a significant increase in k and C_∞. It is well known that the disrupted amorphous structure of gelatinized starch results in a greater susceptibility to enzyme hydrolysis[31] and therefore, the slow and resistant digestion property of native banana granules is lost. Our rationale of investigating the effect of pre-gelatinized banana starch on the digestibility of cookies was based on two points. Firstly, we already reported that fully gelatinized extruded banana starch, with significant fragmentation of amylopectin molecules, was more prone to form slowly digestible structures involving amylopectin upon retrogradation.[12] Therefore, the resistant present in native banana starch would be transformed into structurally-driven slowly digestible starch provided that molecules have the sufficient mobility. However, glass-forming materials, such as a cookie system, can have an indefinite number of molecular arrangements, which may not be slowly digested, taken place during ‘freezing’ of molecules during glass formation.[13] In other words, the amorphous phase of the cookie system will rapidly quench amylopectin molecules upon cooling, which would decrease the magnitude of slowly digestible amylopectin interactions during retrogradation. This occurrence is schematically shown in Fig 4 within the red box, where the network of red lines indicates immobilization (or slowdown of retrogradation rate) of dispersed amylopectin molecules embedded in a continuous glassy sucrose-water matrix. Secondly and compromising the texture quality of cookies, we wanted to demonstrate the effect of a less brittle and crumbly cookie that could potentially persist dispersion in gastrointestinal fluids. Interestingly, the dramatic reduction of cookie brittleness, as shown by the ten-fold increase in the distance to fracture during the three-point bending texture test, was not enough to counteract the higher enzyme accessibility to the substrate.

The starch fraction resistant to digestion, termed RS, was also measured by incubating with pancreatic α-amylase and amyloglucosidase for 16 h at 37°C, which has been reported to yield values that are more physiologically relevant. RS and C_∞ values followed a similar trend in Control and NB cookies. Specifically, the RS content increased from 0.1 to 3.6 % after the replacement with 30 % native banana flour. RS is categorized as dietary fiber, which possess numerous beneficial effect for human health. According to the European Food Safety Authority (EFSA),[32] NB cookie, with 3.6 % RS content, could be labeled with the claim “source of fiber”, since it contains more than 3 g of fiber per 100 g of product (Regulation (EC) No 1924/2006). The higher content of RS in MB sample seems to be part of the native banana starch present in the mixture, although the different trend found when comparing RS and C_∞ in Control and MB cookies is worth of mention. Nevertheless, it is noted that errors higher than 5 % are found for samples containing RS contents < 2% w/w using the Megazyme method.[33]

3.3 Sensory evaluation

A hedonic sensory test was conducted to evaluate the feasibility of including native and extruded banana starch (NB and MB samples) in gluten-free cookies (Table 3). EB cookie was not considered for the sensory analysis due to its unpalatable hard texture.

The inclusion of native banana starch resulted in cookies with enhanced overall liking. This is in agreement with our previous results with the inclusion of native banana starch in gluten-free rice-based breads.[12] The individual evaluation of sensory descriptors showed an improved odor and flavor of NB compared to the control counterpart, which may be associated to the addition of desirable aroma compounds present in native banana starch (or formed during baking) or to the more bland/neutral flavor of rice flour, less appealing for consumers. In agreement with instrumental textural analysis, no significant differences were found for texture between control and NB cookies, both best ranked by consumers. On the other hand, the texture rating was significantly worsened (down to 2.50) by replacing with the 1:1 native to extruded banana composite (MB), which should be attributed to the relatively harder and soggier texture already reported in section 3.1. The use of MB also worsened the appearance and flavor compared to control sample. Extrusion leads to starch dextrinization and a slight formation of reducing sugars[34] that can participate in Maillard and caramelization reactions in the cookie during baking.[35] This could result in changes in the aroma profile and color of MB cookies that are not desired by consumers.

In short, these results would confirm the feasibility of including native banana in the formulation of gluten-free cookies with an improved nutritional value and without declining their acceptability. However, attention must be paid to the inclusion of gelatinized banana starch, since it can go in detriment of textural parameters desired for consumers in a cookie system.

4 Conclusion

This work shows for the first time the feasibility to increase the resistant and slowly digested starch fractions alongside consumer's acceptance of gluten-free sugar-snap cookies by replacing 30 % of the starchy source by native banana starch. The use of banana starch increased resistant starch (RS) from 0.1 to 3.6 % (g / 100 g cookie), which interestingly would enable native banana-containing cookie (NB) to be labeled as "source of fiber" according to the regulation (EC) No 1924/2006 from the European Food Safety Authority (EFSA).[32] Results therefore indicate that the utilization of native banana starch in sugar-snap cookies could contribute to diminish the existing gap between recommended and actual dietary fiber intakes beneficial for human health. This is especially important in gluten-free diets, typically characterized by a lower fiber intake and higher glycemic index, as a consequence of the use of rapidly-digested refined flours. Furthermore, the use of banana by-products as nutritious edible materials could improve its sustainability and environment due to sustainable use of natural resources.

The current work also showed that the incorporation of extruded banana starch worsens consumer's acceptance of cookies and does not result in the formation of structurally-driven slowly digestible starch (SDS) through retrogradation. Converse to fully gelatinized bread crumb, sugar-snap cookies are composed mainly of a continuous glassy sucrose-water matrix containing embedded starch granules mostly ungelatinized. This entails that only a minor fraction of dispersed amylopectin molecules would be available to form structurally-driven SDS, which in turn, may be rapidly quenched by the glassy sucrose-water matrix.

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Conflicts of interest

There are no conflicts to declare.

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Tables

Table 1. Rheological properties of sugar-snap cookies.

	Dough measurements		Cookie characteristics				
	G´ (x10^4 Pa)	G´´ (x10^4 Pa)	Weight (g)	Moisture (g/100 g)	Width (mm)	Hardness (N)	Distance to fracture (mm)
Control	17.35a ±0.78	3.86a ±0.31	8.0a ±0.0	3.4a ±0.1	44.0c ±0.0	11.91a ±0.14	0.35a
Native Banana (NB)	30.75b ±1.34	5.52b ±0.40	7.8a ±0.2	4.0a ±0.1	41.3b ±0.9	14.13a ±0.59	0.32a
Mixture Banana (MB)	43.20c ±0.57	7.19c ±0.57	8.7a ±0.5	5.5b ±0.4	39.3a ±0.1	93.80b ±10.65	1.45b
Extruded Banana (EB)	45.67c ±2.79	7.43c ±0.80	10.6b ±0.1	6.4c ±0.3	38.6a ±0.4	132.17c ±0.44	3.22c

Values followed by the same letters within each parameter indicate no significant differences ($p \leq 0.05$).

Table 2. *In vitro* starch digestion kinetics and resistant starch of sugar-snap cookies.

	k	**C_∞**	**Resistant starch (g/100 g)**
Control	0.023b ±0.001	12.04b ±0.31	0.1a ±0.01
Native Banana (NB)	0.019a ±0.000	10.70a ±0.04	3.6d ±0.02
Mixture Banana (MB)	0.052c ±0.001	13.60c ±0.08	1.9c ±0.09
Extruded Banana (EB)	0.051c ±0.000	16.85d ±0.03	0.3b ±0.09

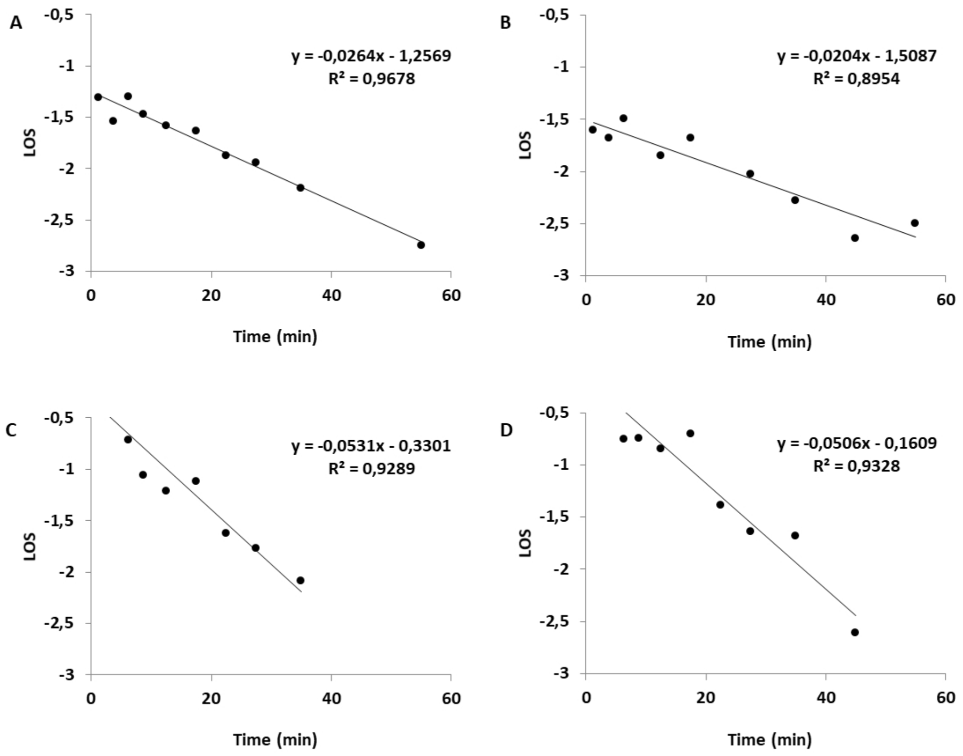
Values followed by the same letters within each parameter indicate no significant differences ($p \leq 0.05$).

Table 3. Hedonic sensory properties of sugar-snap cookies.

Sample	**Appearance**	**Odor**	**Flavor**	**Texture**	**Overall liking**
Control	6.90b ±1.55	5.19a ±1.46	4.77b ±2.22	6.42b ±1.58	5.21b ±1.93
Native Banana (NB)	6.53b ±1.30	6.18b ±1.52	6.23c ±1.68	6.35b ±1.36	6.35c ±1.45
Mixture Banana (MB)	5.69a ±1.78	5.53a ±1.69	3.74a ±2.27	2.50a ±1.84	3.66a ±1.76

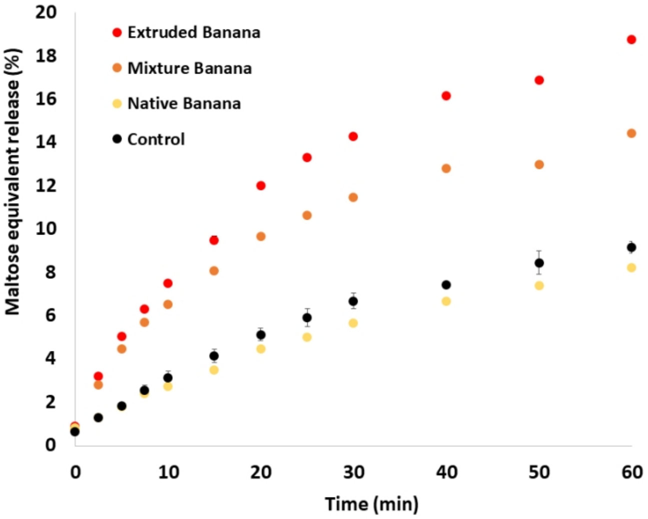
Values followed by the same letters within each parameter indicate no significant differences ($p \leq 0.05$).

Pictures of sugar-snap cookies. From left to right: control; cookie with a 30 % replacement by native banana starch; cookie with a 30 % replacement by a 1:1 mixture of native to extruded banana starch; cookie with a 30 % replacement by extruded banana starch.



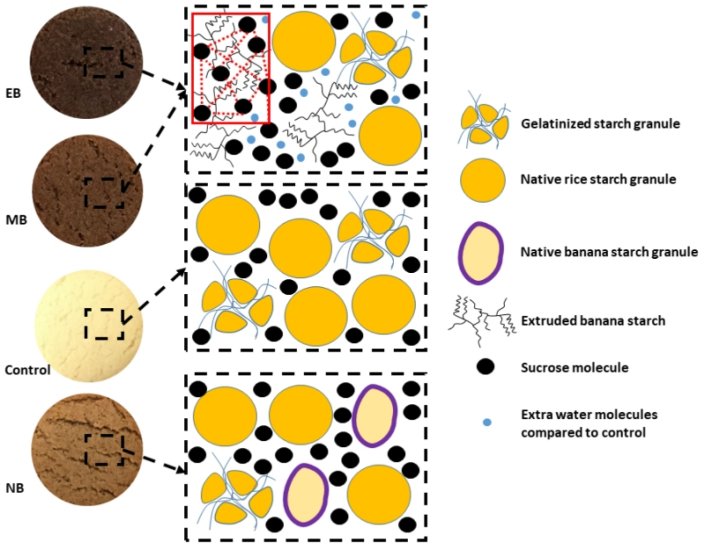
Experimental LOS plots of sugar-snap cookies. Control (A), cookie with a 30 % replacement by native banana starch (B), cookie with a 30 % replacement by a 1:1 mixture of native to extruded banana starch (C), and cookie with a 30 % replacement by extruded banana starch (D).

300x250mm (96 x 96 DPI)



Experimental digestion kinetics plot of sugar-snap cookies.

338x190mm (96 x 96 DPI)



Schematic representation of potential systematic events that determine the starch bioaccessibility in sugar-snap cookies after the inclusion of native and extruded banana starch. From top to bottom: cookie with a 30 % replacement by extruded banana starch (EB); cookie with a 30 % replacement by a 1:1 mixture of native to extruded banana starch (MB); control; and cookie with a 30 % replacement by native banana starch (NB). The network of red lines shown within the red square indicates immobilization (or slowdown of retrogradation rate) of dispersed amylopectin molecules embedded in the continuous glassy sucrose-water matrix.

338x190mm (96 x 96 DPI)