How isomaltulose and oligofructose affect physicochemical and sensory properties of muffins?

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Abstract

This paper analyses, the replacement of sucrose in muffins with nine different combinations of isomaltulose and oligofructose. Being a structural isomer of sucrose with approx. 50% of sucrose sweetness, isomaltulose is non-cariogenic and with a low glycaemic profile but having the same calories as sucrose. Oligofructose is composed of fructose polymers, with a reduced caloric value and prebiotic effect. Specifically, height, percentage of alveoli, water content, a_w, mechanical and optical properties have been measured along with a sensory evaluation. The results showed that all combinations of sweeteners gave place to softer muffins than control ones. Moreover, isomaltulose caused a darkening of the products likely due to an enhancement of the Maillard reactions. The highest amount of isomaltulose and the absence of sucrose meant the worst score in sweetness and flavor due to the low sweetening powder of isomaltulose.

Keywords: muffins; sweeteners; isomaltulose; oligofructose; color; texture; sensory properties

Introduction

The Global Bakery Goods Manufacturing industry has been growing for five years until 2019 despite numerous challenges (IBISWorld 2020). Overall, IBISWorld anticipates industry revenues will increase at an annualized rate of 4.2% to $586.2 billion for five years until 2019. This includes an expected increase of 2.6% in 2019 only if healthier options continue to grow in popularity. Just like bread, the bakery product market is affected by a rapid urbanization and change in living conditions. In recent years, producers' tendency towards healthy, instant and accessible products in bakery products market continues (Parantez Fair 2020), which has rapidly come out of the economic uncertainty lately. Industrial pastries are habitually consumed by different population groups, but children are the biggest consumers due to the sweet flavour of these products. However, due to their components, this kind of products can cause serious health problems.

Ingesting these kinds of products implies a high amount of sugar, saturated fats and a high caloric value. Some of the most important problems linked to their consumption are tooth decay, diabetes and obesity (Peris et al. 2020). The growth in the excessive consumption of sugar is so evident that a tax on soft drinks is applied in different countries. In the particular case of the UK, this tax started in April 2018 but was not intended to directly reduce their consumption. It was designed to work indirectly by encouraging beverage manufacturers to reformulate products and reduce their sugar content below the taxable thresholds (Rathbone Greenbank Investments 2020). Although no health tax is yet applied to bakery products, there is no doubt that the reduction in sugar is in great demand to improve their nutritional quality (Aidoo et al. 2013). In fact, The World Health Organization (WHO) recommends reducing the intake of free sugars to less than 10% of total energy intake in its Guideline: Sugars intake for adults and children (WHO 2020). Another relevant aspect to take into account is the trend towards the "clean label", which implies that foods are composed of ingredients that consumers can understand (Milner 2020).

The food industry is using different alternatives to sucrose in bakery products (Peris et al. 2020). In this regard, intensive sweeteners such as aspartame, cyclamate, acesulfame K or saccharine have the particularity of providing high sweetness with low amounts of them. However, they cannot provide technological properties, associated with sucrose, for the development of bakery products. For this purpose, this industry uses sweeteners in bulk or by volume, being polyols (sorbitol, xylitol, maltitol, lactitol…) the best known. They are obtained from glucose syrup using enzymatic techniques, and they are subsequently hydrogenated (Edwards 2000). Table 1 shows the characteristics of some of them.

This study is focused on the use of isomaltulose and oligofructose, as they have technological properties that are highly compatible with the reformulation of sweet bakery products such as muffins. Isomaltulose is a reducing disaccharide composed of glucose and fructose, just like sucrose, but joined by a stronger glycoside bond type α-(1-6). It is non-cariogenic and it is slowly released in the bloodstream. PalatinoseTM (isomaltulose) has a soft, natural sweetness (approximately 50% of sucrose), without any aftertaste. It replaces sucrose on a scale of 1:1 and can be easily combined with other sweeteners to achieve a unique and tailored sweetness profile. PalatinoseTM is a very low hygroscopic powder. It barely absorbs moisture and remains stable at a temperature of 25 °C and a relative humidity of up to 85% (Edwards 2000; Lina et al. 2002; Holub et al. 2010). However, there are some drawbacks to this sweetener associated with its low solubility. Isomaltulose had a negative impact on cookie-baking yield for this reason, although it has a positive impact on batter-based cake systems because of its much higher formula water level (Kweon 2016a, 2016b). Recently, possible alternatives to sucrose (allulose, isomaltulose, and Mylose) for muffin baking were investigated for their processing suitability without deterioration of product quality through sucrose level reduction (Lee et al. 2020). Oligofructose also belongs to the carbohydrate group, but it is composed of a long chain of fructose similar to that of inulin, although with a different degree of polymeration (higher in inulin). It is not only widely used in bakery products as a method of increasing moisture, supplementing fiber and replacing sugar, but also for their prebiotic effect, which raises the level of Lactobacillus and Bifidobacterium [Milnet et al. 2020; Beikzadeh et al. 2017; Volpini-Rapina et al. 2012; Handa et al. 2012). Inulin is often used to replace fat, as its sweetness is very low, while oligosaccharides are used as substitutes for sugar in food [Beikzadeh et al. 2017; Volpini-Rapina et al. 2012). The addition of oligofructose and inulin to cakes has been shown to increase their browning and hardness properties (Volpini-Rapina et al. 2012).

In view of the above, the aim of this research was to study the effect of the partial or total replacement of sucrose by isomaltulose or oligofructose on the height, water activity, water content, color and texture of muffins. In addition, a selection of the formulations was subjected to a sensory analysis.

Materials and Methods

Muffins preparation and formulations

The preparation of muffins was made using 21.7% (w/w) of eggs, 21.7% (w/w) different types of sugar (sucrose, isomaltulose or oligofructose), 21.7% (w/w) wheat flour and 21.7% (w/w) sunflower oil together with 10.85% of whole milk and 2.35% of baking powder (sodium bicarbonate, malic acid and tartaric acid). First of all, the eggs, sugar and sodium bicarbonate were blended for 20 minutes at maximum speed in an electric mixer (Kenwood, model KM240 serie, United Kingdom). Then, oil, flour, milk and malic and tartaric acids were added, mixing everything for 10 minutes at minimum speed. The batter was then left to rest for 20 minutes before filling the paper cases (60x35 mm) with 65 g of batter. Finally, the muffins were baked for 25 minutes at 145 ºC.

Ten different formulations of muffins were studied by changing the content of sucrose, isomaltulose and oligofructose. Two different batches were carried out. Table 2 shows the notation used according to the percentage of sweeteners in the muffins.

Analytical determinations

Height, image analysis and percentage of alveoli

After baking, the height (mm) of twelve muffins from each batch was measured by means of caliper. Moreover, in order to evaluate the percentage of alveoli according to the studied sweeteners, samples were cut perpendicular to their base and projected onto a scanner (HP Desjet 3637). Both the total area of the muffins and the area of alveoli were measured by Image J Free software (National Institutes Health, Bethesda, MD, USA). Three replicates of this analysis were performed for each formulation in each batch of muffins.

Water activity (aw) and water

Water activity was measured with a dew point hygrometer (Decagon Devices, Inc, model 4TR, Pullman, Washington, USA) at 25 ºC. Water content was obtained by a gravimetric method (AOAC 2000). Both determinations were performed in triplicate in each batch of muffins.

Textural and color properties

To obtain a flat surface without crust, the top of the muffins (crown) was removed by cutting it horizontally. Then, 40 mm high and diameter cylinders were taken from the muffins by means of a hole puncher. Each cylinder was subjected to a double compression study (TPA) on a universal press (Texture analyzer TA.ST.plus, Stable Micro Systems, Godalming, United Kingdom) provided with a load cell of 50 kg. For this study, a 40 mm diameter cylindrical probe was used in its circular base, with the following test conditions:

deformation up to 50% (penetrations from original height) at 1 mm/s and with a 30 s interval between compressions. Five samples were analyzed for each formulation in each batch of muffins. Hardness and elasticity were the parameters obtained.

The color of the crust and the crumb of the muffins was determined by means of a spectrocolorimeter (Konica Minolta, Inc., model CM-3600d, Tokio, Japan). The results were expressed according to the CIE L*a*b* reference system with the D65 Standard Illuminant and 10° Standard Observer. The color of the crust was directly measured from the top of the muffins of each formulation, while the color of the crumb was measured from the top of the cylinders prepared for the analysis of the mechanical properties previously described.

Sensory evaluation

The possible acceptance of two muffins formulated with the sucrose alternatives together with the control sample was carried out with a panel composed of 57 tasters, being all them employees or students of Universitat Politècnica de València (UPV) between 18 and 65 years old. This study was carried out in the sensory lab in individual booths at the Institute of Food Engineering for Development (IUIAD) of UPV. Coded with random numbers of three digits, the samples were shown to the tasters simultaneously. The appearance, color (internal and external), aroma, texture, sponginess with fingers, sponginess in mouth, sweetness and flavor of each formulation were evaluated on a nine-point hedonic scale (ISO 4121:2003 and UNE-87025:1996) considering different levels from “I dislike it very much” to “I like it very much”. Furthermore, the parameters external and internal color, sweetness and firmness were evaluated with the Just About Right test to know if they would prefer a higher or lower intensity in the attributes analyzed (Fernández et al., 2018). For that, three levels were used. Concretely, one end point for each attribute was that it should be “much lower”, in the middle point as it was “just right” or “just about right” and in the other end point it should be “much higher”.

Statistical analysis

In order to know the possible influence of the sucrose alternative in the studied parameters, different ANOVAs were applied with the software Statgraphics Centurion version XVI.I.

Results and discussion

Height, image analysis and percentage of alveoli

Figure 1 shows the average height values of muffins formulated with different amounts of new sweeteners. As can be observed, muffins prepared with the 33I67S formulation reached a significantly greater height, followed by those formulated with pure sweeteners (Control, 100I and 100O). However, the combination of the higher proportions of oligofructose or isomaltulose with sucrose together with the 33O67S formulation implied a significant reduction in the final height of the muffins. According to these results, a total replacement of sucrose with isomaltulose or oligofructose did not reduce the height of the muffins and therefore, from this point of view, it would be possible to use any of these new sweeteners or maybe combinations of both of them.

The aforementioned decrease in the final height is related to the number and size of the pores. Thus, Figure 2 shows the images of the cross-sections at the base of the studied muffins in order to give evidence of the different aspects of these new products depending on the formulation of the sweeteners considered. Besides, Table 3 provides information on the total amount of the cross-section, the surface area of the alveoli and, consequently, the percentage of alveoli in each formulation. In all cases, the new samples were darker than the control muffins, especially when the isomaltulose content was the highest, but also in 33I67O where there was no sucrose to counteract this darkening effect. In this regard, isomaltulose will enhance the Maillard reactions as it is usual for this type of product as indicated in the description of the patent “Isomaltulose-containing instant beverage powder” registered by Dörr et al., (2009). Moreover, these results were also observed by Lee et al. (2020) in muffins reformulated with isomaltulose and allulose. These authors reported that Maillard color enhancement using isomaltulose could be used to produce whole-grain wheat flour muffins, which would typically have a dark crumb color compared to those made with refined flours. The opposite effect was described by Martínez-Cervera (2013), when she replaced sucrose with erythritol in the muffins, since this sweetener is not involved in Maillard reactions.

As for the percentage of alveoli, it is remarkable that the control muffins showed the highest values (Table 3). Furthermore, the control samples were conical in shape while the others cases showed a rectangular shape due to the difficulties for the CO_2 to rise through the new matrices. Consistent with these results, during the baking, a more limited rise of the batters with the new sweeteners was observed compared to the batters composed of sucrose, forming a crust on the upper surface of the muffins.

Water activity and water content

Figure 3 shows the results of the water activity (aw) and the water mass fraction of the studied muffins. As can be seen, all values of aw are around 0.925±0.003. Therefore, the substitution of sucrose by the different amounts of sweeteners did not significantly modify this parameter. From the physicochemical point of view, aw values were close to those found by other authors in muffins (Channaiah et al. 2017).

With regards to water content, the higher the amount of sucrose, the lower the mass fraction in muffins. This behavior evidences that isomaltulose and oligofructose are able to retain more water during baking than sucrose, especially when they are the only sweeteners used in the formulation (100I or 100O). It would therefore be necessary to adapt the storage and packaging conditions of these new muffins.

Mechanical and optical properties

Figure 4 shows the results of the texture parameters (hardness and elasticity) analyzed in muffins formulated with different percentages of isomaltulose or oligofructose. As can be observed, not only the samples prepared with sucrose but also those prepared with isomaltulose registered significantly higher values of hardness and elasticity than the others. In contrast, the formulation 33O67S showed the lowest hardness. Besides, in most cases there was a concordance between hardness and elasticity, except for muffins 33I33O33S and 67I33O which had an intermedium hardness but a low elasticity in the range of the homogenous group with the lowest value of these parameters. According to these results, apart from 100I muffins, all combinations of sweeteners resulted in muffins that were softer and had lower elasticity than the control ones, consistent with the results reported by Lee et al. (2020), who observed that muffins with 75% of sucrose substitution by isomaltulose or Mylose showed significantly lower firmness than those made with sucrose. This fact might condition their sensory acceptance and also their ability to withstand possible impacts on their shape during transport.

Figure 5 shows the location in the b*a* chromatic plane of the external and internal part of the muffins together with their luminosity. In all cases, the combination of the new sweeteners significantly increased the values of coordinate a* in relation to the control muffins according to the results showed in the Figure 2 and as a consequence of the enhancement of Maillard reaction when isomaltulose is present [Lee et al. 2020; Dörr et al. 2009). In the external part, it is relevant that the total or partial substitution of sucrose by isomaltulose provoked a significant decrease in the b*coordinate and luminosity, giving rise to a darker brown color of the surface of muffins since in this layer the reaction between heat, monoacids and sugars is more noticeable.

Sensory analysis

Figure 6 shows the results given by the tasters on a hedonic scale of different attributes (appearance, internal and external color, aroma, sponginess, sweetness, texture, sponginess in mouth, flavor). In this case, only two muffins formulated with the isomaltulose and oligofructose (67I33O and 33I33O33S) were analyzed together with the control muffin since they joined certain consistency in parameters with regards to control and both isomaltulose and oligofructose were included. As can be seen, all parameters were significantly affected by the formulation, being the control sample the best scored. It is remarkable that sweetness, external color and appearance were the most differentiated attributes by the tasters. As for sweetness and flavor, the highest amount of isomaltulose and the absence of sucrose (67I033) meant the worst score. This response is consistent with the low sweetening powder of isomaltulose (approximately 50% of sucrose) (Beneo 2020). However, no differences were found by the sensory panel between the 67I33O and 33I33O33S samples in terms of appearance, color, aroma or sponginess.

Figure 7 shows the indications of the panel of as to whether they would prefer an increase or a decrease in the intensity of the assessed attributes. The results confirm that the low score obtained in the new muffins was a consequence of a too dark color, especially in the external part, as a consequence of the enhancement of Maillard reaction due to the presence of the aforementioned isomaltulose. As expected, the sweetness was considered too low ("much less") in the muffins when the isomaltulose content increased. In terms of firmness, only about 20% of tasters considered the 67I33O muffins to be "much tougher" than what they liked and around 14% in the case of 33I33O33S muffins.

Conclusions

It is feasible to partially replace sucrose with a combination of isomaltulose and oligofructose in equal parts to counteract the lower sweetening powder of both and the darkening of the product caused especially by isomaltulose. Furthermore, from the mechanical point of view, these sweeteners give rise to spongy textures typical of muffins, although with a flatter shape due to the lesser presence of alveoli.

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Ethical Statements

Conflict of Interest: The authors declare that they do not have any conflict of interest

Ethical Review: A sensory test was conducted with human subjects. The data obtained were treated in accordance with the Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).

Informed Consent: Panellist were informed and gave their consent about the objective of the sensory analysis and how data are treated.

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Table 1. Summary of the characteristics of possible alternatives to sucrose which might be used in bakery products. SP: sweetening power, GI: glycaemic index and C: cariogenic

Table 2. Notation of samples according to the quantity of the different sweeteners used in their preparation

Table 3. Total surface and surface of alveoli in muffins prepared with different percentages of sweeteners

Figure caption

Figure 1. Height of muffins prepared with different percentages of sweeteners. The same letters in the bars refer to homogeneous groups (significant level >95%)

Figure 2. Cross section of muffins prepared with different percentages of sweeteners

Figure 3. Water activity (a_w) and water mass fraction (x_w) of muffins prepared with different percentages of sweeteners. The same letters in the bars refer to homogeneous groups (significant level >95%)

Figure 4. Hardness (N) and elasticity of muffins prepared with different percentages of sweeteners. The same letters in the bars refer to homogeneous groups (significant level >95%)

Figure 5. Location in the b*-a* chromatic planes and luminosity of the internal and external part of the muffins prepared with different percentages of sweeteners

Figure 6. Hedonic scale scores of sensory attributes evaluated on the muffins by the tasters. F-ratios obtained in the ANOVA to analyze de significant effect of the formulations in the attributes are presented in parenthesis. *95% significance level and **99% significance level

Figure 7. Just-about-right (JAR) scale percentages of responses grouped in three levels of the analyzed muffins

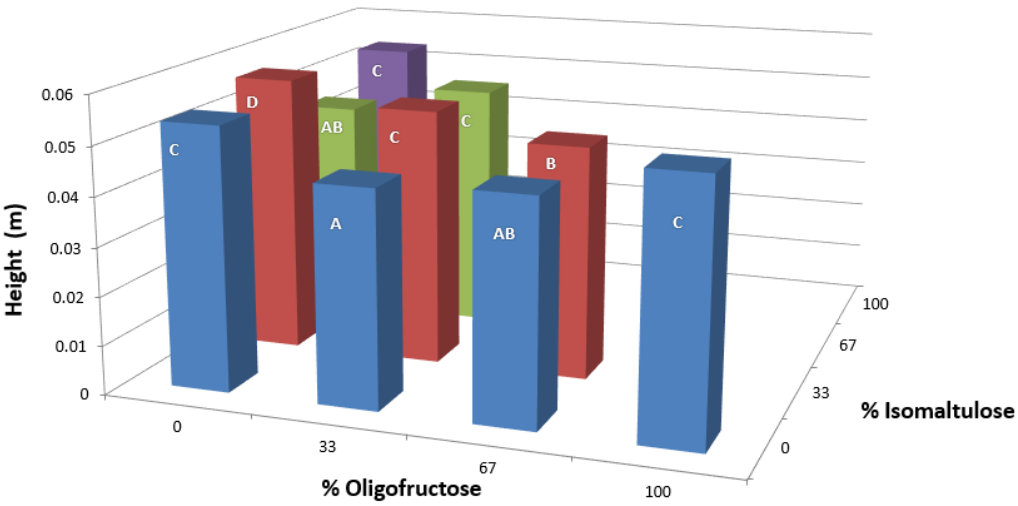
	Compound	SP	GI	Kcal/g	C	Relevant information	Reference
CARBOHYDRATES	Sucrose	1	61-65	4	Yes	*Obesity, caries, diabetes…*	WHO, 2020
	Glucose	0.5	100	4	Yes	*Dependent metabolism to insulin*	Edwards, 2000
	Isomaltulose	0.33	32	4	No	*Similar crystalline format to sucrose. Use "spoon-spoon". Solubility limit ≈30%*	Lina et al., 2002; Holub et al., 2010; Beneo, 2020
	Fructose	1-2	23	4	Yes	*Independent metabolism to insulin*	Edwards, 2000
	Allulose/D-Psicose	0.7	≈0	0.2-0.4	No	*GRAS since 2012. In 2019 exempted from the total or added sugar content on nutrition labels. ≈70% is excreted*	Todd, 2020; Lee et al., 2020; Ogawa, 2020
	Invert sugar	1.3	30	4	Yes	*High biology stability*	Edwards, 2000
	Corn syrup	1-1.3	30	4	Yes	*Increase the resistance of organism to insulin. Metabolic diseases: obesity, cholesterol and diabetes type II*	Rippe et al., 2013; García-Almeida, 2013; Halimi et al., 2010
	Agave nectar	2.0	20	3.1	Yes	*It might have a positive influence on weight gain and glucose control*	Hooshmand et al., 2014
	Maple syrup	2.0	50	2.60	Yes	*Rich in calcium, potassium and zinc*	Edwards et al., 2016
	Honey	1.3	57	3.04	Yes	*Prevention and treatment of respiratory and intestinal diseases*	Edwards et al., 2016
	Oligofructose	0.3-0.6	Bajo	2	No	*It improves calcium absorption and reduces cholesterol and blood sugar levels. Prebiotic effect.*	Milner et al., 2020; García-Almeida et al., 2013; Villalobos, 2006; Alles et al., 2013
	Inulin	0.1	Bajo	2	No		García-Almeida et al., 2013; Beikzadeh et al., 2017; Volpini-Rapina et al., 2012
POLYOLS	Xylitol (E-967)	1	12	2.4	No	*Laxative effect and cause flatulence*	Edwards, 2000
	Maltitol (E-965)	1	35-52	2.1	No		
	Sorbitol (E-420)	0.6	9	2.6	No		
	Mannitol (E-421)	0.5-0.72	2	1.6	No		
	Lactitol (E-966)	0.35-0.5	3	2.4	No		
	Erythritol (E-968)	0.75	1	0.2	No	*No interaction with intestinal flora*	
INTENSIVE SWEETENERS	Aspartame (E-951)	160-200	0	4	No	*RDI: 50. Heat decomposes it. Controversy about its security. It may cause headaches and dizziness.*	García-Almeida et al., 2013; Bhardwaj et al., 2020; Kweon et al., 2016a
	Sucralose (E-955)	600	0	0	No	*It is not decomposed by heat*	
	Saccharine (E-954)	300	0	0	No	*It tolerates high temperatures and has a bitter aftertaste*	
	Acesulfame k (E-950)	200	0	0	No	*It is not metabolized and is eliminated without modifications.*	
	Cyclamate (E-952)	30-50	0	0	No	*Heat stable and long storage life. Prohibited use in the US due to association with the development of bladder tumours.*	
	Steviosides (E-960)	300	0	0	No	*Bitter taste*	

Table 2.

FORMULATION	ISOMALTULOSE	OLIGOFRUCTOSE	SUCROSE
CONTROL (100S)	0	0	100
100I	100	0	0
67I 33O	67	33	0
67I 33S	67	0	33
33I 67O	33	67	0
33I 33O 33S	33	33	33
33I 67S	33	0	67
100O	0	100	0
67O 33S	0	67	33
33O 67S	0	33	67

Table 3

Formulation	**Area Muffin** (cm^{2})	**Area Alveoli** (cm^{2})	**% alveoli**
CONTROL	31.35±0.13^{B}	0.45±0.03^{f}	1.422±0.102
33I 33O 33S	38.8±0.2^{G}	0.22±0.03^{cde}	0.6±0.07
33I 67O	37.9±0.4^{FG}	0.20±0.04^{cd}	0.5±0.09
33I67S	32.5±0.9^{C}	0.09±0.003^{ab}	0.3±0.02
33O67I	35.0±0.2^{E}	0.14±0.09^{bc}	0.4±0.3
33O67S	37.7±0.6^{F}	0^{a}	0
67I33S	35.7±0.5^{E}	0.13±0.07^{bc}	0.4±0.2
67O33S	29.07±1.01^{A}	0.26±0.006^{de}	0.9±0.01
100I	33.1±0.6^{CD}	0.29±0.05^{e}	0.9±0.2
100O	33.56±0.17^{D}	0.21±0.03^{cde}	0.6±0.08



0.06
0.05
0.04
0.03
0.02
0.01
0
Height (m)
C
D
AB
C
C
A
C
C
B
AB
C
0
33
67
100
% Oligofructose
100
67
33
0
% Isomaltulose

Figure 1.

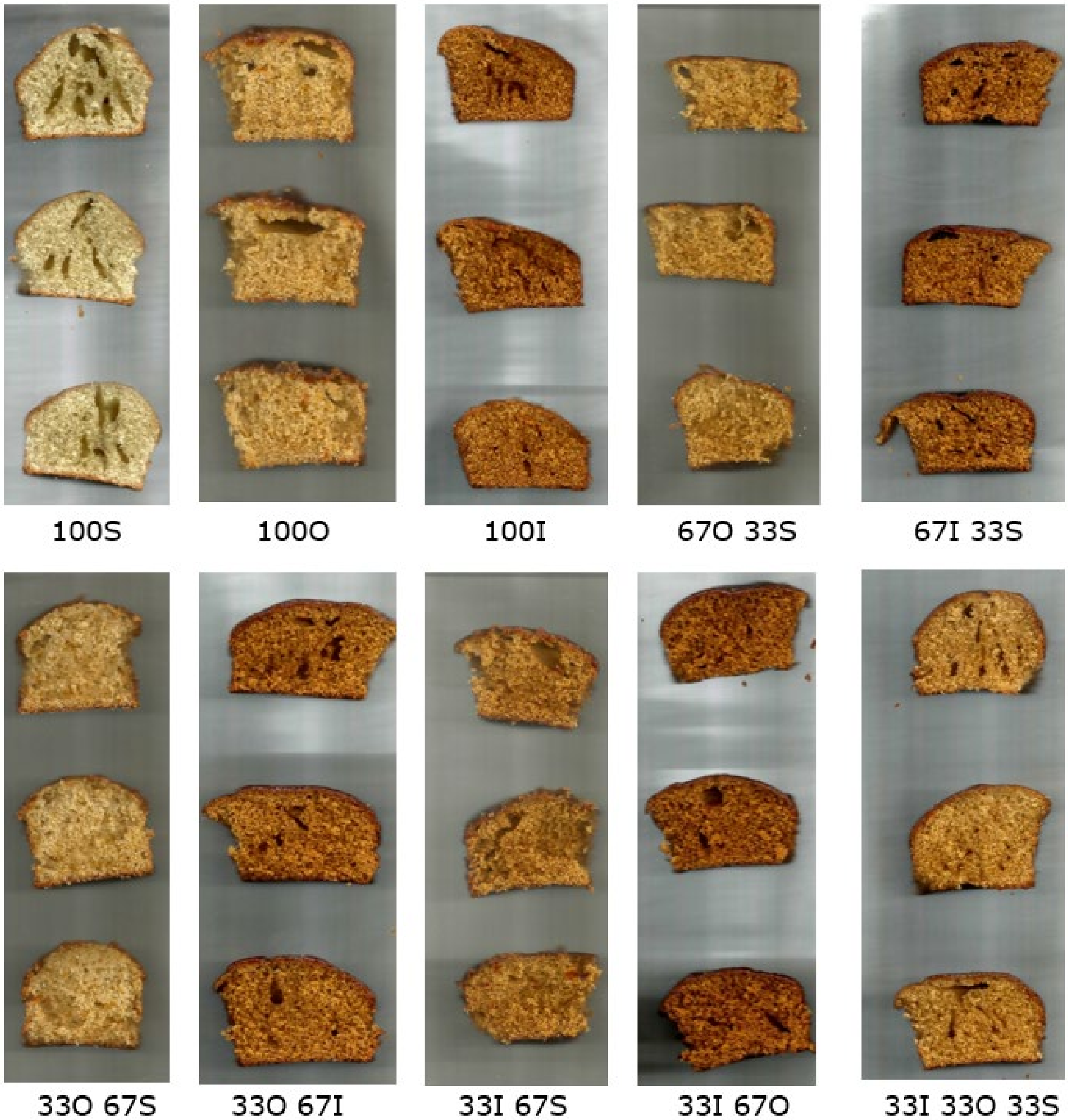
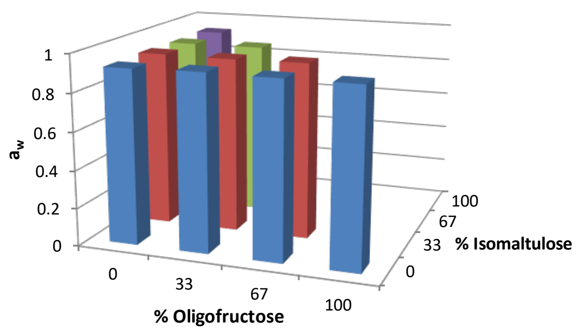
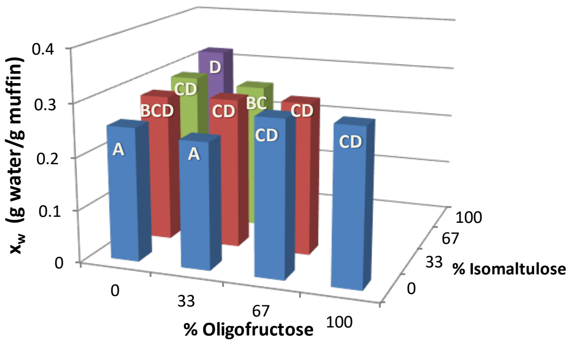

100S
100O
100I
67O 33S
67I 33S
33O 67S
33O 67I
33I 67S
33I 67O
33I 33O 33S

Figure 2.



1
0.8
0.6
0.4
0.2
0
a_w
0
33
67
100
% Oligofructose
0
33
67
100
% Isomaltulose



0.4
0.3
0.2
0.1
0
x_w (g water/g muffin)
D
CD
BCD
CD
BC
CD
A
A
CD
CD
0
33
67
100
% Oligofructose
0
33
67
100
% Isomaltulose

Figure 3

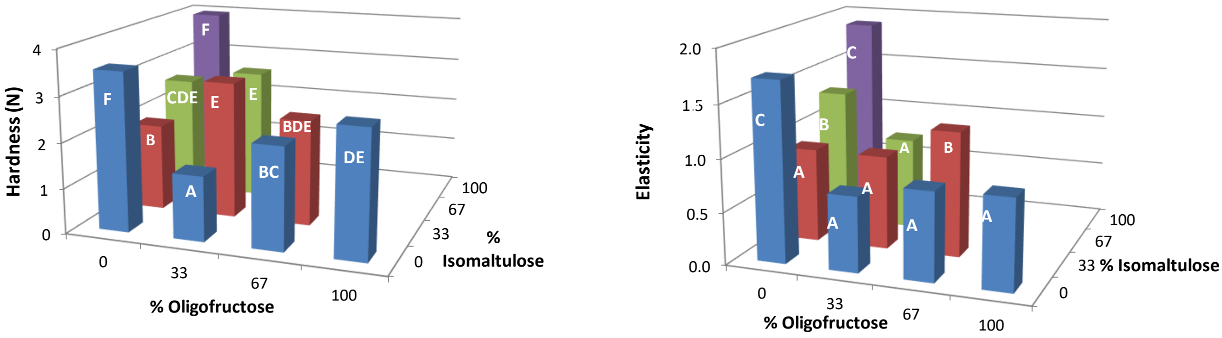
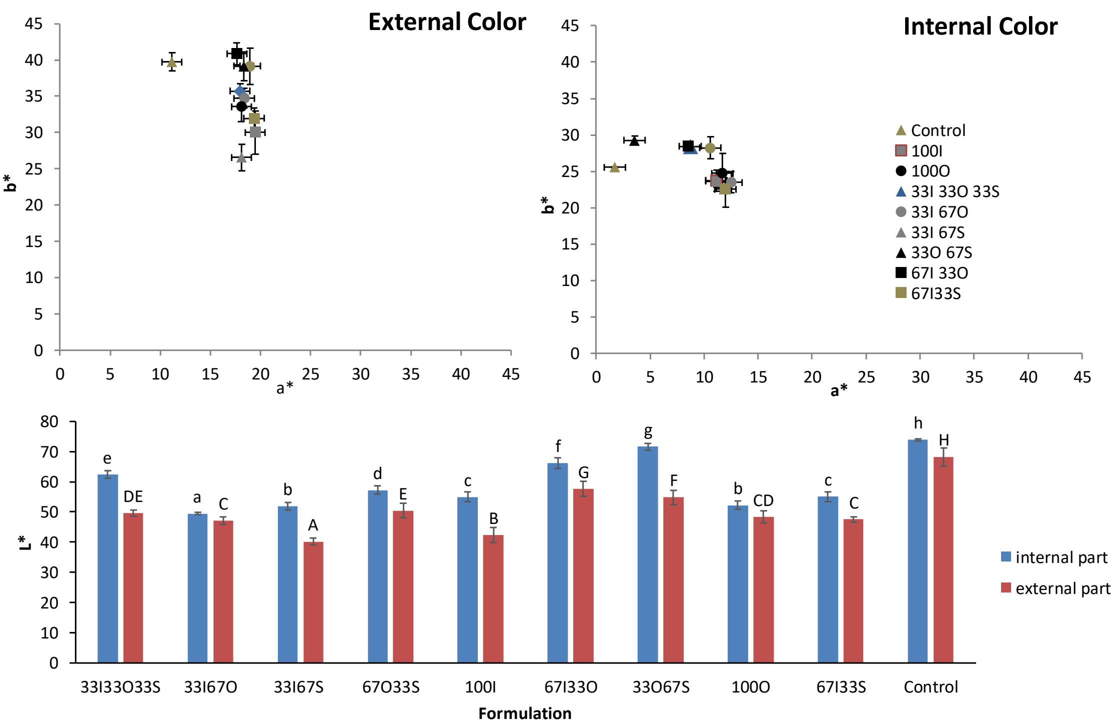
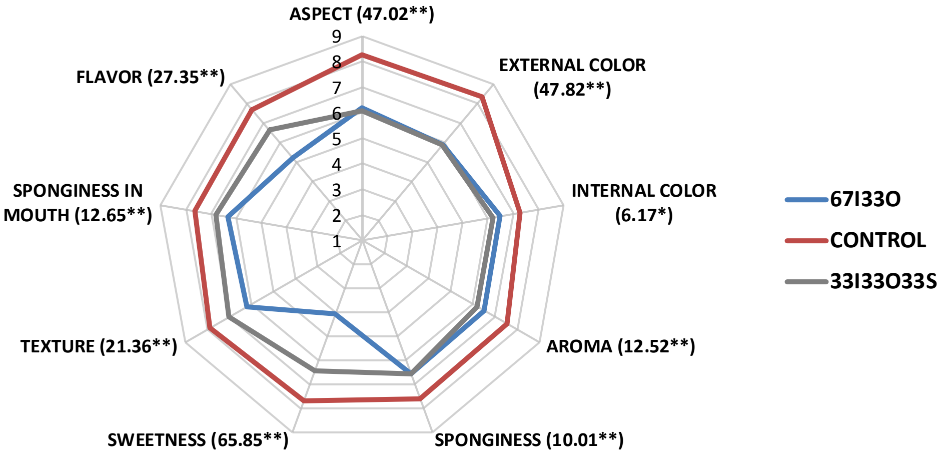

Hardness (N)
4
3
2
1
0
F
B
CDE
F
E
E
A
BDE
BC
DE
0
33
67
100
% Oligofructose
100
67
33
0
% Isomaltulose
Elasticity
2.0
1.5
1.0
0.5
0.0
C
A
B
C
A
A
A
B
A
A
0
33
67
100
% Oligofructose
100
67
33
0
% Isomaltulose

Figure 4.



External Color
Internal Color
b*
a*
Control
100I
100O
33I 33O 33S
33I 67O
33I 67S
33O 67S
67I 33O
67I33S
L*
e
DE
a
C
b
A
d
E
c
B
f
G
g
F
b
CD
c
C
h
H
internal part
external part
33I33O33S
33I67O
33I67S
67O33S
100I
67I33O
33O67S
100O
67I33S
Control
Formulation

Figure 5.



ASPECT (47.02**)
EXTERNAL COLOR (47.82**)
INTERNAL COLOR (6.17*)
AROMA (12.52**)
SPONGINESS (10.01**)
SWEETNESS (65.85**)
TEXTURE (21.36**)
SPONGINESS IN MOUTH (12.65**)
FLAVOR (27.35**)
9
8
7
6
5
4
3
2
1
67I33O
CONTROL
33I33O33S

Figure 6

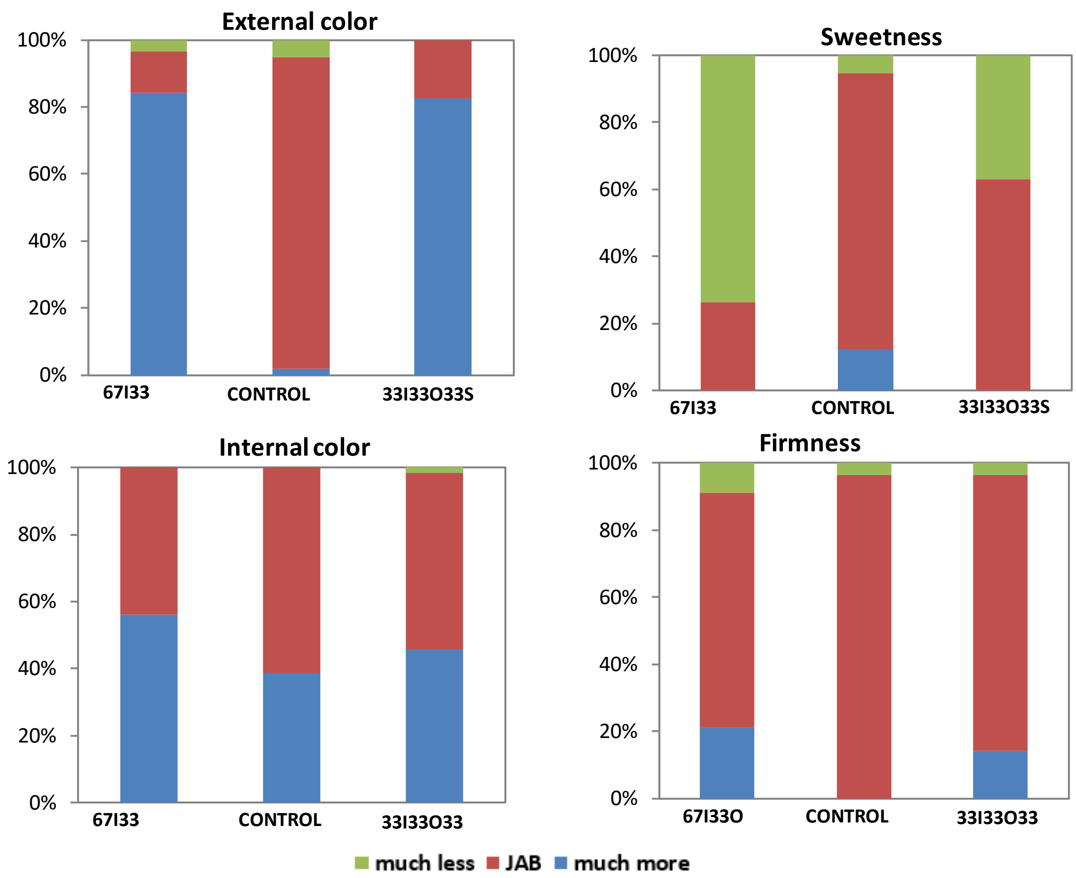

External color
100%
80%
60%
40%
20%
0%
67I33
CONTROL
33I33O33S
Sweetness
100%
80%
60%
40%
20%
0%
67I33
CONTROL
33I33O33S
Internal color
100%
80%
60%
40%
20%
0%
67I33
CONTROL
33I33O33
Firmness
100%
80%
60%
40%
20%
0%
67I33O
CONTROL
33I33O33
much less
JAB
much more

Figure 7.