

Research Article

Raquel P. F. Guiné*, Paula M. R. Correia, Cátia Reis, Sofia G. Florença

Evaluation of texture in jelly gums incorporating berries and aromatic plants

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Abstract: In the confectionery market, jelly gums are one of the most relevant sectors, being frequently consumed by many people, from children to adults. The present work intended to evaluate the textural properties in newly developed jelly gums made with berry fruits and herbs, given the critical role of texture in products with a gel-like structure. Four types of gums were developed (Strawberry & Anise, Strawberry & Mint, Raspberry & Mint, Blueberry & Mint) and their texture was evaluated through two types of tests (compression with a 75 mm probe and puncture with a 2 mm probe) allowing to calculate several textural properties. The results showed some differences between the two faces of the jelly gums analysed, i.e. on the top and on the bottom. As for the compression test, the Strawberry & Anise gums were among the softer (25.6 N) and with lower resilience (36.3%) and chewiness (16.9 N), despite being more adhesive (−0.5 N s). As for the puncture test, the sample Strawberry & Mint had the highest adhesiveness (−2.0 N s) but the lowest stickiness (−0.38 N). Additionally, very strong correlations were encountered between some of the properties studied ($r = 0.861$ or $r = 0.822$), and the factor analysis allowed defining three factors, the first clearly associated with the puncture properties while the other two were related to the compression properties. This work allowed concluding that the jelly gums presented different textural properties, particularly when assessed through different types of measurements. Hence, the use of different types of tests for texture analysis is recommended, since the results are complementary. This is relevant when developing

food products intended for industrial production and commercialization.

Keywords: textural properties, compression test, puncture test, fruit gums

1 Introduction

Jelly gums, also known as fruit candies or jelly sweets, are systems with a gel-like structure, made with a minimum of 45 g/100 g of fruits, and then they contain sugars, in concentrations of about 55 g/100 g, and gelling agents like pectin and organic acids (Cappa et al. 2015). These products can be very diverse in their properties, like for example form, composition and most especially colour or texture. They are highly appreciated due to their appearance, flavour and textural properties. They represent an important sector of the confectionery market and they are consumed by varied groups of people, including young children or on the opposite side, the elderly. Hence, their composition and nutritional value are much relevant, especially having in mind the high sugar content normally present in the formulations (Cappa et al. 2015).

Kushner and Kahan (2018) in their report The State of Obesity in 2017 alert for the need to redesign the public health environment, so as to offer highly effective and efficient obesity prevention, in a world where obesity is considered one of the global noncommunicable diseases recognized by the World Health Organization (WHO). Factors such as diet, physical activity or genetic influences critically contribute to obesity both in children and adults. However, dietary behaviours like dietary intake pattern, and most particularly sugar consumption, are unquestionably related with a potential impact on a fast gain of weight, thus contributing to overweight and obesity (Regev-Tobias et al. 2012; Song et al. 2012). Furthermore, the high sugar intake also contributes to a number of other problems, like type 2 diabetes. Diabetes is included in the metabolic disorders, which are a major cause of morbidity and mortality all over the world. Diabetes comprises hyperglycaemia that develops from abnormalities in insulin secretion or

* **Corresponding author: Raquel P. F. Guiné**, CERNAS-IPV Research Centre, Polytechnic Institute of Viseu, Viseu, Portugal, e-mail: raquelguine@esav.ipv.pt

Paula M. R. Correia: CERNAS-IPV Research Centre, Polytechnic Institute of Viseu, Viseu, Portugal

Cátia Reis: Department of Food Industry, Agrarian School of Viseu, IPV, Viseu, Portugal

Sofia G. Florença: FCNAUP - Faculty of Food Sciences and Nutrition, University of Porto, Porto, Portugal

action, or both. About 90% of the patients with diabetes suffer from type 2 diabetes, which is linked with insulin resistance and a low tolerance to glucose, being closely associated with obesity. The rest of the cases, which represent about 10%, are type 1 diabetes, and they result from insulin deficiency owing to the autoimmune destruction of β cells in the pancreas (Codella et al. 2017; Villa et al. 2018).

It has been observed that there is an increasing interest in the design of new food products with a more balanced nutritive composition, including low sugar content, and that provide additional health benefits by incorporating bioactive compounds (Cappa et al. 2015). Phenolic compounds are known to have very high antioxidant activity and constitute an effective means of providing beneficial compounds for the human body. They are secondary metabolites in plants, and possess high antioxidant activity, having been associated with multiple health benefits, such as reducing dyslipidaemia or atherosclerosis as well as many inflammatory processes associated with cardiovascular diseases, and prevention of cancer, diabetes and obesity. Besides, they have been successfully applied as food functional ingredients owing to their capacity to prevent lipid oxidation as well as moulds and bacterial growth (Rossi et al. 2018; Verardo et al. 2018; Vu et al. 2018). Anthocyanins are natural pigments found in a wide variety of small fruits and berries. In the work of Maier et al. (2009), anthocyanin extracts were added into gelatin and pectin gels, and these extracts proved to be an encouraging alternative to the use of traditional synthetic colourants. Besides, they also have the advantage of bearing additional beneficial health effects for those who consumed the products (McCann et al. 2007; Fang 2015; Teng et al. 2017; Xie et al. 2018).

Presently, the market of fruit gums or jelly candies is dominated by products with a high sugar content, although some attempts have been done to try to improve their formulation, like for example replacing the added sugars by honey, in an attempt to provide healthier ingredients, still the content of sugars is high (Mutlu et al. 2018). Hence, the development of jelly gums with improved nutritional characteristics while at the same time maintaining the desired textural characteristics is an opportunity targeted by our research group. In a previous work, Guiné et al. (2018a) tested 16 different formulations and a sensory evaluation allowed to select the best four, which were those used in this later phase of the work. These formulations were based on fruits and herbs, in an attempt to introduce flavour derived from these ingredients as well as colour, derived from natural colourants.

Anthocyanins are natural colourants which are present in berry fruits in high amounts, including strawberry, raspberry and blueberry, apart from other phenolic compounds with antioxidant activity (Soutinho et al. 2013; Gonçalves et al. 2015; Guiné et al. 2018b; Dzhanfezova et al. 2020). Herbs such as anise and mint are natural flavour enhancers containing beneficial components with bioactive activity (Guiné and Gonçalves 2015, 2016).

The objective of the present work was to evaluate the textural characteristics in four newly developed jelly gums made with berry fruits and herbs and no addition of sugar, given the pivotal role of texture for this particular type of product. Furthermore, to explore more deeply the textural characteristics, two types of instrumental tests were performed, allowing determining different textural attributes. Finally, the intercorrelations between different textural properties and some agglomeration structure were also assessed.

2 Material and methods

2.1 Samples

This work is in sequence of a previous work by the same research team (Guiné et al. 2018a), in which 16 formulations of jelly gums with fruits and herbs, in different combinations, were tested and evaluated for selection of the best formulations. This previous work included a sensory analysis, which allowed to select four variations of the product as the most promising, and those were the ones that were produced on this phase for the texture analysis. These four variations of the jelly gum products were established using small fruits, berries, plus some aromatic herbs, specifically: Blueberry & Mint, Raspberry & Mint, Strawberry & Mint, and finally Strawberry & Anise. The formulation was identical for all varieties, as follows: a base of apple puree (48%) with the small fruits (35%, strawberry, raspberry or blueberry), plus gelling agents (pectin (7%) and agar-agar (5%)) and finally aromatic herbs (6%, mint or anise).

To prepare the gums, first the apple was peeled and cut into small pieces and after addition of the berry fruit, the mixture was triturated to obtain a puree and then boiled for 20 min. During ebullition, after approximately 15 min, the mass of aromatic herb was carefully added and in the end the mass was poured into the forms (cuvettes) and left in the refrigerator to cool (Guiné et al. 2018a).

2.2 Evaluation of textural properties

A texturometer model TA-XT2 from Stable Micro Systems was used for the measurement of textural parameters. For this, two different texture measurements were performed: a test by compression and another by puncture. For all textural evaluations, 20 jelly gums were used for each variety and the measurements were performed on both faces of the gum: top side and bottom side. The results were processed using Exponent software TEE from Stable Micro Systems.

2.2.1 Compression test

The texture profile analysis (TPA) was obtained through two consecutive compression cycles, made on the sample between parallel plates. For this was used a flat compression probe with 75 mm in diameter (P/75). The time elapsed between cycles was 5 s. The test conditions were as follows: a load cell of 30 kg, all speeds equal to 1.0 mm/s (pre-test, test, post-test), the compressing distance was 5 mm and the trigger force considered was 0.1 N. The obtained graphs allowed calculating the textural properties: hardness, adhesiveness, resilience, springiness, cohesiveness and chewiness by the following parameters (see Figure 1):

$$\text{Hardness (N)} = F_1 \quad (1)$$

$$\text{Adhesiveness (N s)} = A_3 \quad (2)$$

$$\text{Resilience (\%)} = (A_5/A_4) \times 100 \quad (3)$$

$$\text{Springiness (\%)} = (T_2/T_1) \times 100 \quad (4)$$

$$\text{Cohesiveness (\%)} = (A_2/A_1) \times 100 \quad (5)$$

$$\text{Chewiness (N)} = F_1 \times (T_2/T_1) \times (A_2/A_1) \quad (6)$$

2.2.2 Puncture test

The puncture test was obtained using a 2 mm diameter drilling rig. The pre-test was performed at 2 mm/s rate while the test and post-test rates were made at 1 mm/s. The perforating distance considered in the test was 10 mm and the trigger force was set at 0.05 N. The textural parameters analysed in this case were: crust firmness, flesh firmness, adhesiveness and stickiness. These parameters were obtained by the following equations (see Figure 2):

$$\text{Crust firmness (N)} = \text{maximum force} \quad (7)$$

$$\text{Inner firmness (N)} = \text{average force between 1 and 2} \quad (8)$$

$$\text{Adhesiveness (N s)} = \text{negative area} \quad (9)$$

$$\text{Stickiness (N)} = \text{minimum force} \quad (10)$$

2.3 Statistical analysis

In order to confirm if the results obtained for mean values of the analysed parameters were statistically different between samples, the statistical treatment of the results was performed. An ANOVA was carried out when the comparisons were made between three or more groups. This procedure was complemented with the Tukey Honestly Significant Difference *post hoc* test, which allows identifying where the differences are situated.

Additionally, the Pearson correlations (r) were calculated to analyse the degree of association between all textural properties. For interpretation of the correlations, the following limits were considered: if $r = 0$ there is no correlation, if $r \in [0.0, 0.2]$ the correlation is very weak, if $r \in [0.2, 0.4]$ the correlation is weak, if $r \in [0.4, 0.6]$ the correlation is moderate, if $r \in [0.6, 0.8]$ the correlation is strong, if $r \in [0.8, 1.0]$ the correlation is very strong and in the case of $r = 1$ the correlation is perfect (Maroco 2012; Pestana and Gageiro 2014).

Finally, the results obtained were subjected to a factor analysis (FA). Firstly, the correlation matrix between all variables was evaluated to see if there were any correlations between them. The, the Kaiser–Meyer–Olkin (KMO) measure of adequacy of the sample and the Bartlett's test were considered to identify the level of intercorrelation between the considered variables (Broen *et al.* 2015). Following these initial procedures aimed at confirming if the data would be suitable to apply FA, the FA was applied by principal component analysis (PCA) extraction with Varimax rotation. The number of extracted factors was established with the Kaiser criterion, which considers eigenvalues equal to or higher than 1. The communalities, which indicate the percentage of variance explained by the factors extracted, were also calculated (Broen *et al.* 2015). In the analysis, factor loadings with absolute value lower than 0.4 were excluded (Rohm and Swaminathan 2004; Stevens 2009).

The software SPSS version 24 (IBM, Inc.) was used for all statistical analyses, and the level of significance considered was 5% ($p < 0.05$).

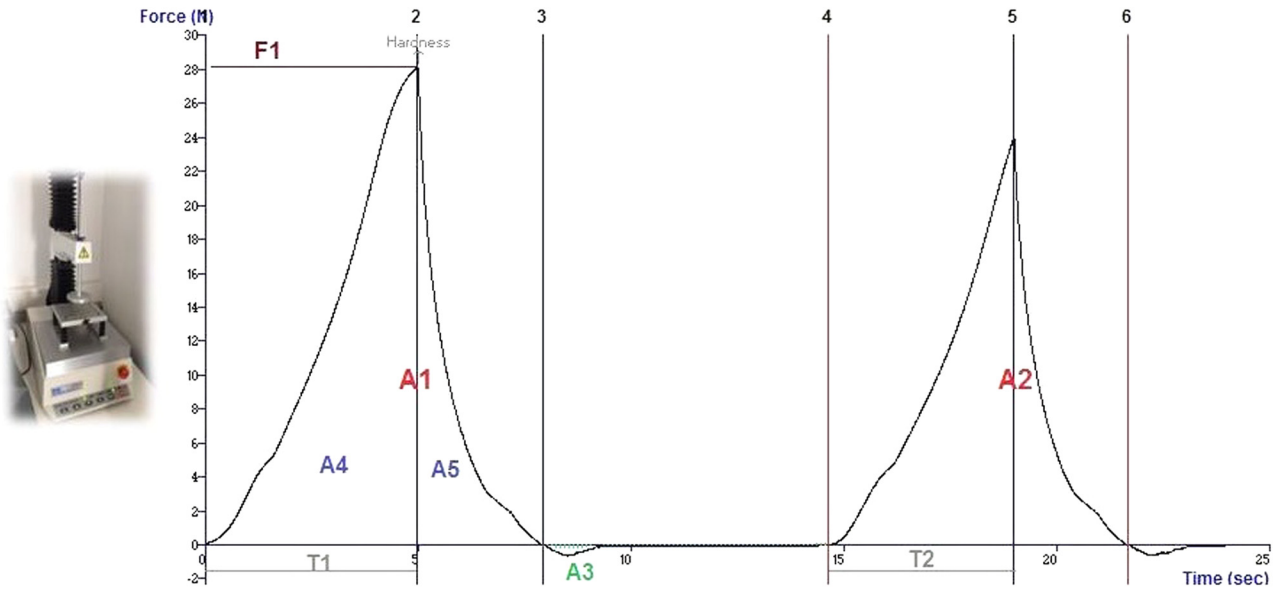


Figure 1: Example of a TPA obtained for the sample Strawberry & Anise, making the compression test with the P/75 probe.

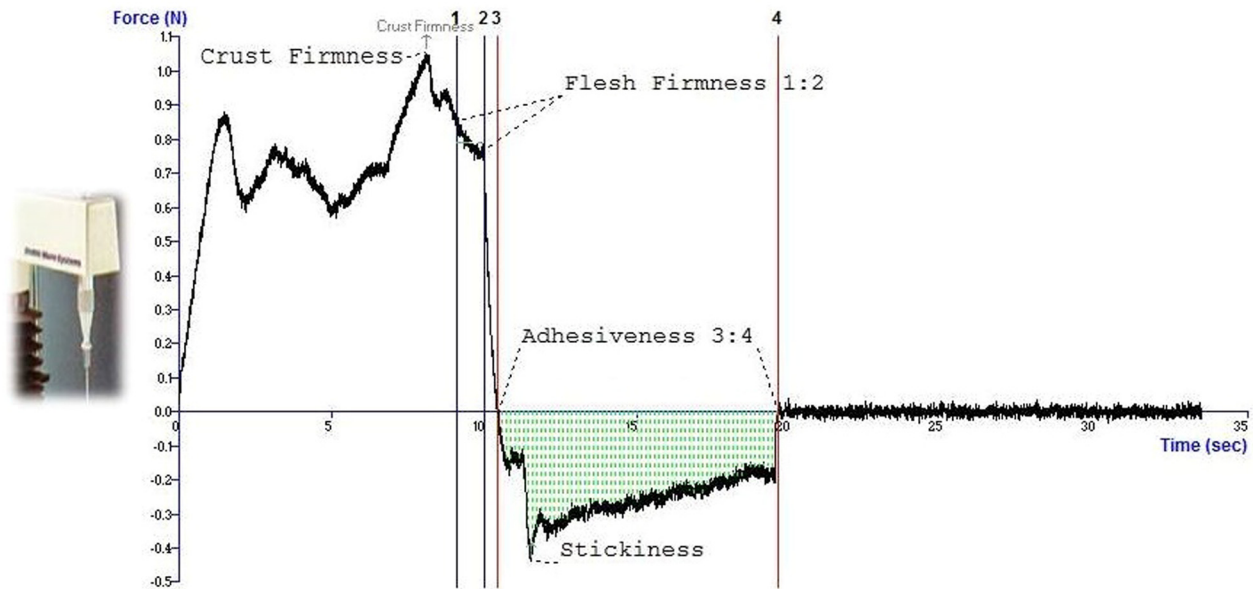


Figure 2: Example of a texture analysis obtained for sample Raspberry & Mint, making the puncture test with the P/2 probe.

3 Results and discussion

3.1 Textural properties

3.1.1 Compression test

Figure 3(a) presents the textural properties obtained by the compression test separately on both sides of the jelly gum samples (top and bottom faces). Hardness corresponds

to the force necessary to compress a food between the teeth or alternatively between the tongue and the upper part of the mouth, and represents the force necessary to produce a deformation (Cruz et al. 2015). The results obtained for hardness were statistically different among samples (ANOVA, $F = 6.643, p < 0.0005$), with the top face of the Raspberry & Mint gum being the softest (22.8 N) and the bottom of the Strawberry & Mint gum being the hardest (30.3 N). In general, for the four varieties analysed, the bottom face was recurrently

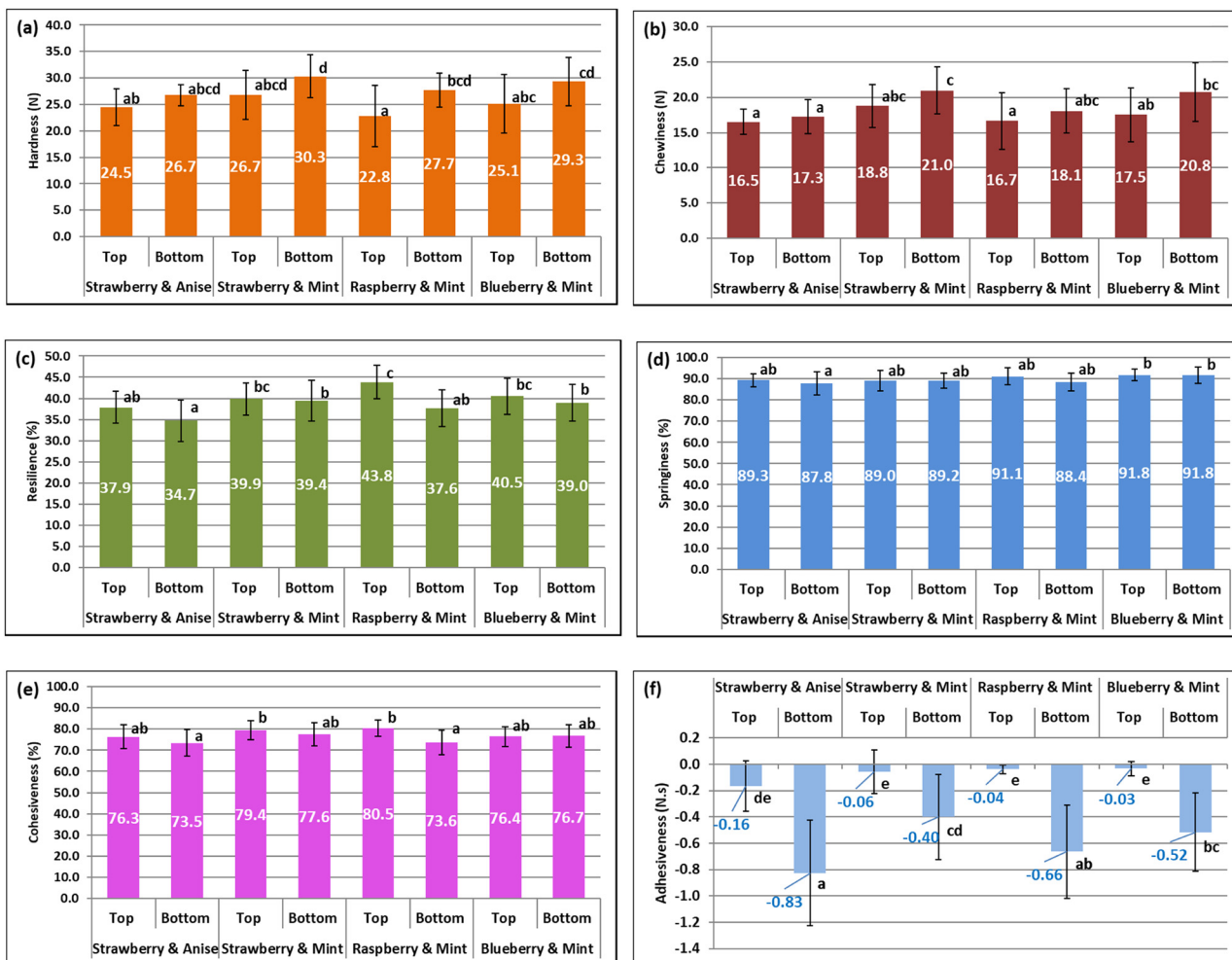


Figure 3: Textural properties on top and bottom faces of the jelly gums, obtained by the compression test: (a) hardness, (b) chewiness, (c) resilience, (d) springiness, (e) cohesiveness and (f) adhesiveness (bars with the same letter are not statistically different at 5% significance level – ANOVA with Tukey test).

harder when compared with the top face (ranges 26.7–30.3 and 22.8–26.7 N, respectively).

Chewiness corresponds to the energy required to disintegrate a food into a state that makes it suitable to swallow (Cruz *et al.* 2015). This textural property is very closely related to hardness, and therefore it is expected that the trend observed would be similar (Figure 3(b)). Also, for this property significant differences were encountered (ANOVA, $F = 5.469$, $p < 0.0005$) and the highest chewiness corresponded to the bottom faces (range 17.3–21.0 N), as it was previously observed for hardness.

Resilience represents the energy used by the application of a force to a material without producing rupture, regardless of any residual strain. This textural property is equivalent to an instant springiness (Cruz *et al.* 2015). The results obtained for resilience (Figure 3(c)) show significant differences between samples (ANOVA, $F = 7.418$, $p < 0.0005$) and reveal a trend for a higher

resilience in the top faces of all gums, with values in the ranges 37.9–43.8% and 34.7–39.4%, respectively, for top and bottom faces.

Springiness represents the ability to recuperate shape after a compression and corresponds to the rate at which the product returns to the initial state after the force was removed (Cruz *et al.* 2015). The values obtained for springiness were very similar (Figure 3(d)) in general, but with statistical differences encountered for the Blueberry & Mint sample (ANOVA, $F = 2.907$, $p = 0.007$). The values are very high, around 90% ranging from 88.4% to 91.8%, indicating that the gums are elastic, which is an expected characteristic for this type of product with a gel-like texture. Furthermore, no considerable differences were encountered between the top and bottom faces of the gums.

Cohesiveness accounts for the forces inside the food that keep the mass cohesive and stop it from

disintegrating (Cruz et al. 2015). Figure 3(e) shows that cohesiveness was relatively high, with values between 70% and 80%, but still with significant differences between samples (ANOVA, $F = 4.451$, $p < 0.0005$). For the Blueberry & Mint sample, cohesiveness on the top and bottom faces was similar (76.4% and 76.7%, respectively), with no significant differences. However, for all other samples, the top face showed a higher cohesiveness when compared with the bottom face, with values in the ranges 76.3–80.5% and 73.5–77.6%, respectively.

Adhesiveness corresponds to the force needed to remove the material that adheres to a surface, such as for example the mouth or teeth (Cruz et al. 2015). In the evaluated samples, the adhesiveness was very low, with absolute values under 1 N, being practically zero on the top faces of all the varieties of gums analysed (Figure 3(f)). The top faces showed negligible adhesiveness (absolute values in the range 0.03–0.16 N) most likely due to the dehydrating effect of the surrounding air on the exposed parts of the gums. The results of the statistical analysis revealed significant differences (ANOVA, $F = 28.029$, $p < 0.0005$) for the adhesiveness on the bottom faces, with sample Strawberry & Anise showing the highest adhesiveness on the bottom face (absolute value 0.83 N).

The graphs (a) to (e) in Figure 4 present the textural properties of the jelly gums considered as global, i.e. calculated as a mean of the measurements made on the top and bottom faces, for easier comparison between varieties. In all cases, the statistical results revealed that the differences were significant, meaning that at least one of the samples was distinguishable from the others. The results of ANOVA were, respectively, for hardness, adhesiveness, resilience, springiness, chewiness and cohesiveness: $F = 4.241$, $p = 0.007$; $F = 3.807$, $p = 0.011$; $F = 6.992$, $p < 0.0005$; $F = 4.847$, $p = 0.003$; $F = 6.883$, $p < 0.0005$; $F = 2.895$, $p = 0.037$. The results in the graphs of Figure 4 demonstrate that the Strawberry & Anise and the Raspberry & Mint gums were softer (25.6 and 25.2 N, respectively) and, consequently, had lower chewiness (16.9 and 17.4 N, respectively). Additionally, it was found that sample Strawberry & Anise had the lowest resilience (36.3%), lowest springiness (88.5%), lowest cohesiveness (74.9%) but the highest adhesiveness (absolute value of 0.5 N s).

In a previous work by the same authors (Guiné et al. 2018a), these gums, among others tested, were submitted to a sensory evaluation, which revealed that the Raspberry & Mint gum was scored as more elastic, although the instrumental measurements of texture

revealed a slightly different result, with this sample presenting the second highest springiness, which is a measure of the sample elasticity. The same work (Guiné et al. 2018a) also revealed that the Strawberry & Anise was considered by the sensorial panel as having the highest consistency, but again, instrumental measurement of texture did not confirm that result, with this sample being one of the softest. These differences might be due to low sensitivity of the panel members to evaluate the specific textural characteristics of this particular type of product.

In a work by Avelar and Efraim (2020), 18 formulations of jelly candies were developed and tested, fixing a final soluble solid content of 71°Brix, but varying the type of sugars and hydrocolloids in the formulation. They evaluated the texture, but measured only the hardness of the samples and found values varying between 37 and 79 N. Our work proposed jelly gums without sugar, which is a very important attribute not only from the point of view of the consumer worried with nutrition and health, but also brings challenges in finding the suitable textural properties. In our products, the hardness varied between 25.2 and 28.5 N and therefore was lower than the samples from the work by Avelar and Efraim (2020), but this results from different formulations and absence of added sugars. Additionally, those authors observed that hardness increased with the concentration of hydrocolloids and that adherence properties and cohesion (not measured but only observed by the authors) varied according to the sugars used. Since our formulations were similar, i.e. with the same amount and type of hydrocolloids and without added sugars, just varying the type of fruit and herb, it is expected that springiness and cohesiveness are similar among the samples, as observed.

A work by Mutlu et al. (2018) reported some properties, including also texture analysis through the compression test, of some jelly candies formulated with gelatine and fruit juices, and honey as a sweetener. They measured several textural properties and found values varying according to the gelatine dose, type of fruit and processing, in the ranges 8.07–7.30 N for hardness, 0.03–0.16 N.s for adhesiveness, 0.90–0.94 for cohesiveness, 0.93–1.07 for springiness, 754–1,593 for chewiness and 769.53–1,604 for gumminess. The gums developed in our work are more adhesive, more firm but less cohesive and a little less elastic. These characteristics are highly dependent on the presence of sugars, which is restricted to only natural sugars present in the fruit in our gums but in the case of the honey gums, the addition of honey substantially increases the sugar content

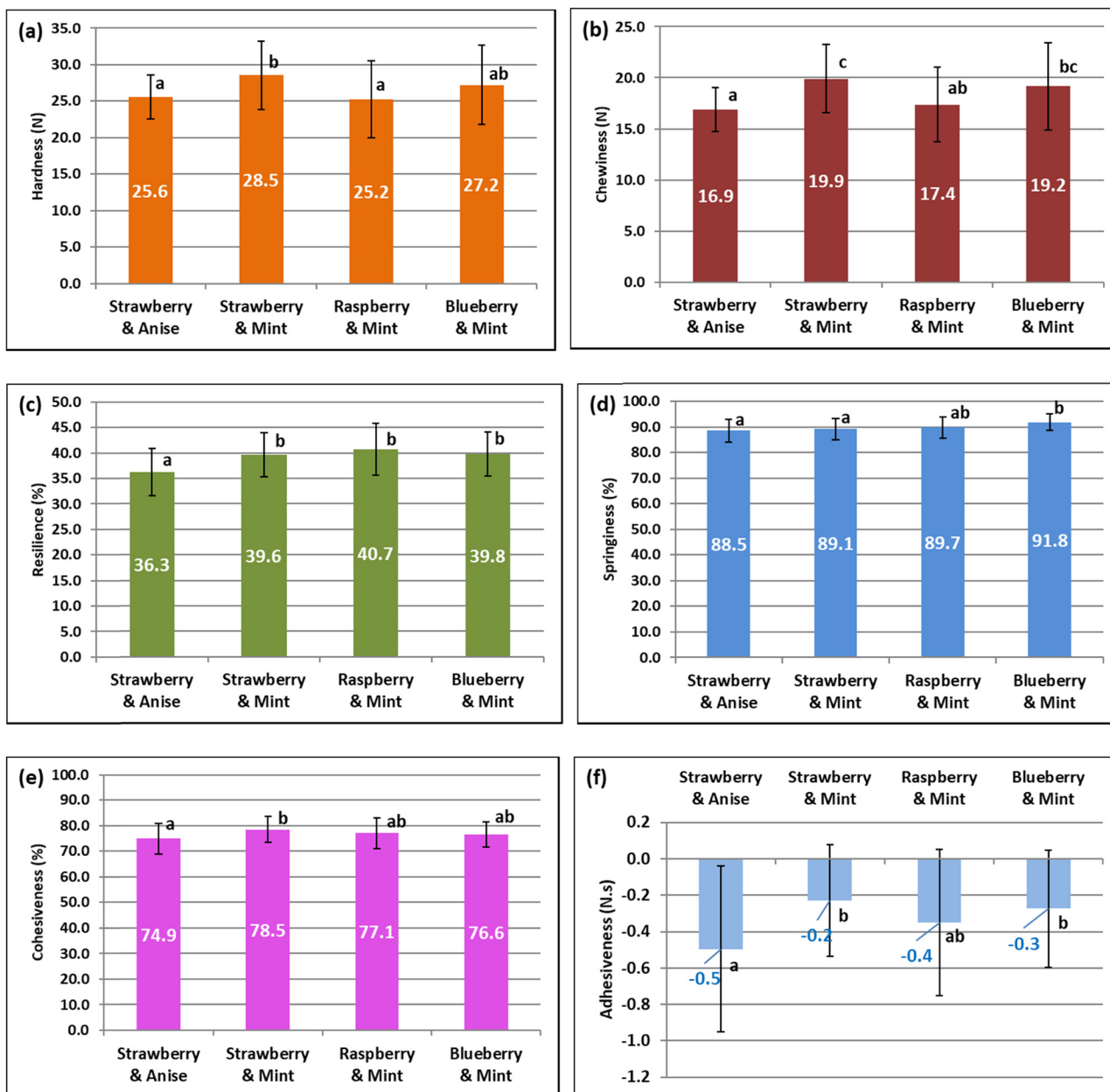


Figure 4: Textural properties of the jelly gums as a whole, obtained by the compression test: (a) hardness, (b) chewiness, (c) resilience, (d) springiness, (e) cohesiveness and (f) adhesiveness (bars with the same letter are not statistically different at 5% significance level – ANOVA with Tukey test).

due to the natural sugars present in honey in very high amounts.

3.1.2 Puncture test

Figure 5 presents the results for the crust (Figure 5(a)) and inner firmness (Figure 5(b)), i.e. the firmness of the outer layer and that of the inner mass, and that have similar meaning as the hardness previously described for

the compression test. The statistical test ANOVA evidenced that the small differences observed for the crust or inner firmness were not significant either among samples or when comparing the top and bottom faces (crust firmness: $F = 1.449$, $p = 0.190$; inner firmness: $F = 0.540$, $p = 0.803$). The Strawberry & Anise gum was softer, with lower values of crust firmness (0.86 and 0.80 N for top and bottom faces, respectively) and inner firmness (0.63 and 0.65 N for top and bottom faces, respectively).

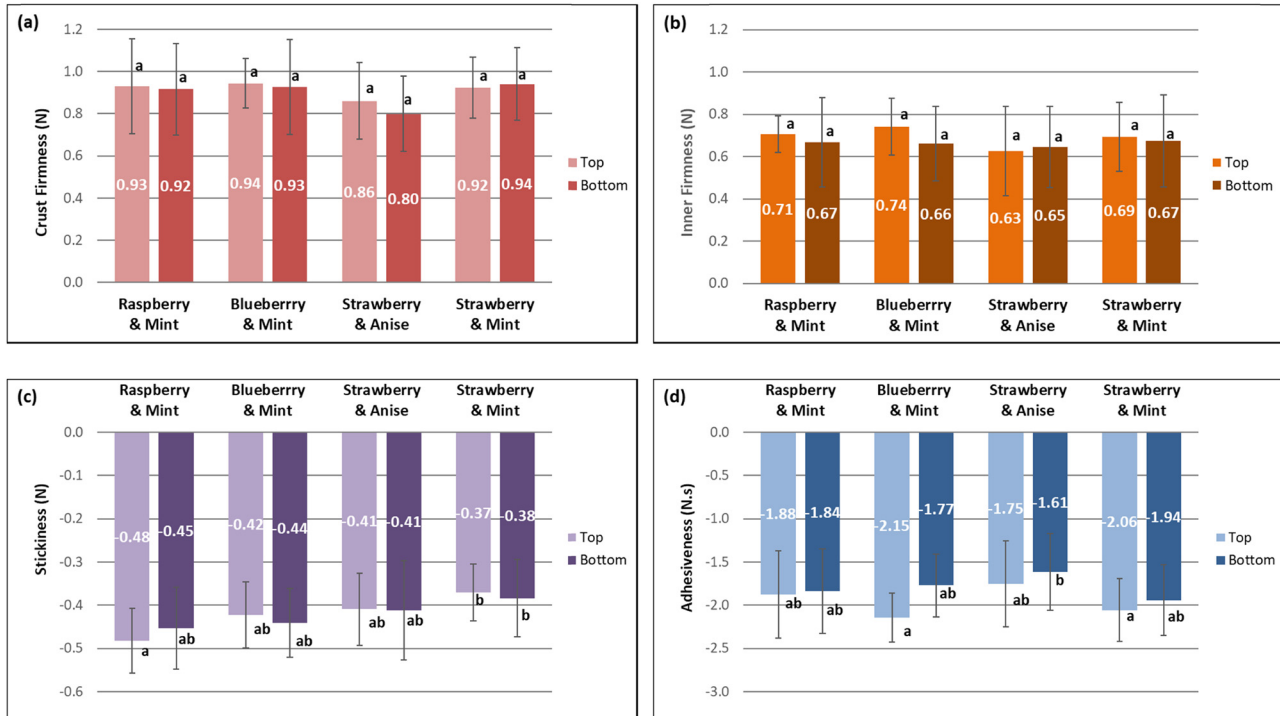


Figure 5: Textural properties on top and bottom faces of the jelly gums, obtained by the puncture test: (a) crust firmness, (b) inner firmness, (c) stickiness and (d) adhesiveness (bars with the same letter are not statistically different at 5% significance level – ANOVA with Tukey test).

Figure 5 also shows the results for adhesiveness (Figure 5(d)) as measured by the puncture test and stickiness (Figure 5(c)), which corresponds to the lowest value of force (negative). Adhesiveness was higher for the top faces of the varieties Blueberry & Mint and Strawberry & Mint, and lower for the bottom face of sample Strawberry & Anise, being these differences statistically significant (ANOVA, $F = 3.599$, $p = 0.001$). These results are different from those obtained with the compression test, because in the case of the compression test all measurements are made with the probe on the surface, while with the puncture test the probe actually penetrates inside the sample mass. Finally, stickiness was highest for the Raspberry & Mint gum (absolute values of 0.48 and 0.45 N, respectively, for top and bottom faces) and lowest for sample Strawberry & Anise (absolute value of 0.41 N for both faces), with statistically significant differences (ANOVA, $F = 3.258$, $p = 0.003$), being this last sample the one also with the lowest adhesiveness (absolute values of 1.75 and 1.61 N, respectively, for top and bottom faces).

Figure 6 (graphs (a) to (d)) also shows the results for the textural attributes calculated from the puncture test, but considering both faces jointly. The results of statistical analysis revealed that the differences for crust firmness and inner firmness were not significant (ANOVA results, respectively: $F = 3.010$, $p = 0.052$; $F = 0.547$, $p = 0.633$),

while those for adhesiveness and stickiness were significant (ANOVA results, respectively: $F = 7.916$, $p < 0.0005$; $F = 4.237$, $p = 0.007$). The sample Strawberry & Anise was softer on the outside and inside (0.83 and 0.64 N, respectively), with a low stickiness (absolute value of 0.41 N) and also a low adhesiveness (absolute value 1.68 N s).

Our results of the puncture test are a very important complement for the evaluation of the textural attributes of the products developed, although it was not possible to compare our results with similar work in the literature, because the few studies found in the literature only evaluated texture through the compression test. Nevertheless, the fact that there is nothing in the literature about this type of test also confirms the innovativeness of our approach to a more detailed analysis of the textural properties. This is important from the point of view of obtaining products with less additives and no added sugar that still have interesting properties to be marketed in this segment of food products.

3.2 Correlations

Table 1 presents the values of the Pearson correlations obtained for all the variables studied, i.e. the textural properties obtained with both tests. It is interesting to

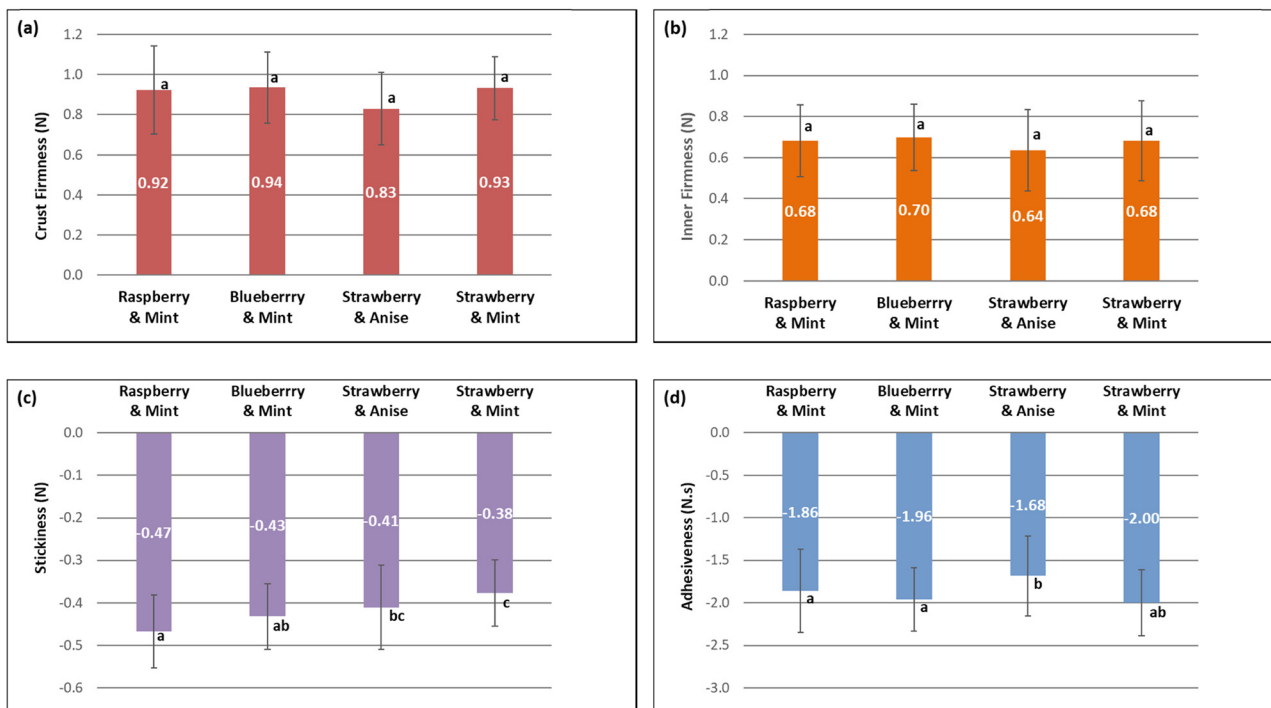


Figure 6: Textural properties of the jelly gums as a whole, obtained by the puncture test: (a) crust firmness, (b) inner firmness, (c) stickiness and (d) adhesiveness (bars with the same letter are not statistically different at 5% significance level – ANOVA with Tukey test).

Table 1: Pearson correlations between the textural properties

	Property ^b	Compression test						Puncture test			
		HAR	ADH	RES	SPR	CHE	COH	CRFIR	INFIR	ADHES	STI
Compression	HAR	1									
	ADH	-0.226 ^b	1								
	RES	-0.266 ^b	0.497 ^b	1							
	SPR	0.007	0.217 ^b	0.453 ^b	1						
	CHE	0.861 ^b	-0.039	0.145	0.396 ^b	1					
Puncture	COH	-0.267 ^b	0.359 ^b	0.822 ^b	0.440 ^b	0.214 ^b	1				
	CRFIR	0.031	0.034	-0.020	-0.118	-0.018	-0.021	1			
	INFIR	-0.118	0.084	0.066	0.056	-0.107	0.013	0.459 ^b	1		
	ADHES	-0.020	0.029	-0.010	-0.064	0.022	0.135	-0.447 ^b	-0.502 ^b	1	
	STI	0.045	-0.247 ^b	-0.087	-0.046	0.052	0.016	-0.458 ^b	-0.336 ^b	0.218 ^b	1

^a HAR = hardness, ADH = adhesiveness, RES = resilience, SPR = springiness, CHE = chewiness, COH = cohesiveness, CRFIR = crust firmness, INFIR = inner firmness, ADHES = adhesiveness (puncture), STI = stickiness. ^b Correlation is significant at the 0.01 level.

observe that, in general terms, the properties obtained with the compression test are not correlated with those obtained with the puncture test, which is explained by the highly different natures of both tests: while one test involves the compression of the sample on its surface, the other test involves the perforation into the sample inside. However, for each of the tests independently, there are expressive correlations, as demonstrated for example by the correlations between chewiness and

hardness ($r = 0.861$) and between Cohesiveness and resilience ($r = 0.822$) in the compression test, which are considered very strong. In the first case, this is expected, given that chewiness is directly related to hardness, as demonstrated by equation (6). In the second case, it is also expected that the sample having the highest cohesiveness also shows a higher capacity in terms of resilience. As for the properties of the puncture test, there are not so strong correlations but there are four

cases in which the values are considered moderate ($0.4 \leq r < 0.6$): crust firmness with inner firmness with adhesiveness and with stickiness ($r = 0.459$, $r = -0.447$, $r = -0.458$, respectively), and inner firmness with adhesiveness ($r = -0.502$). In some of these cases, the correlations are negative, which means that the variables are inversely correlated, meaning that by increasing one variable the other decreases accordingly. For example, the harder is a sample the less tendency it has to adhere to the surfaces it contacts with, so less adhesive it is. The same was verified for chewiness and adhesives, which are inversely correlated, like for hardness, which is expected considering that hardness and chewiness are directly linked (equation (6)).

3.3 Factor analysis

From the analysis of the correlation matrix, it was possible to observe that there were some correlations between the variables. From these, nine values were higher than 0.4, being the two highest of them over 0.8 (0.861 and 0.822). The values reflect some relevant correlations between the variables, which is indicative of the possibility to apply FA. The value found for the KMO in this case was poor (0.396) following the classification of Kaiser and Rice (Kaiser and Rice 1974), but, on the other hand, the results of the Bartlett's confirmed that FA could successfully be applied since the p -value was highly significant ($p < 0.0005$), which means that the null hypothesis "H0: The correlation matrix was equal to the identity matrix" is rejected. Analysis of the anti-image matrix revealed that most values of Measure of Sampling Adequacy (MSA) were higher than 0.5, meaning that in general the variables were adequate to include in the analysis (values of MSA for the variables: HAR = 0.262, ADH = 0.741, RES = 0.764, SPR = 0.216, CHE = 0.276, COH = 0.317, CRFIR = 0.599, INFIR = 0.744, ADHES = 0.618, STI = 0.579).

The solution obtained by the rotation of FA with PCA produced three components, based on the Kaiser criterion (eigenvalues ≥ 1). The solution explained 68.8% of the total variance, distributed by the different factors extracted as follows: F1 – 26.5%, F2 – 22.3% and F3 – 20.0%.

The largest fraction of variance explained by the FA solution was 98.6% for variable chewiness, followed closely by hardness (93.9%). The variable with the lowest communality was adhesiveness-puncture (0.441), and thus all variables had communalities higher than 0.400 (communalities for the extracted variables: HAR =

Table 2: Component matrix obtained by FA with Varimax rotation

	Property ^a	Factor 1	Factor 2	Factor 3
Compression	HAR	(*)	(*)	0.939
	ADH	0.694	(*)	(*)
	RES	0.911	(*)	(*)
	SPR	0.639	(*)	(*)
	CHE	(*)	(*)	0.970
	COH	(*)	(*)	(*)
Puncture	CRFIR	(*)	0.814	(*)
	INFIR	(*)	0.777	(*)
	ADHES	(*)	-0.734	(*)
	STI	(*)	-0.646	(*)

(*) Loading under 0.4 was excluded.

^aHAR = hardness, ADH = adhesiveness, RES = resilience, SPR = springiness, CHE = chewiness, COH = cohesiveness, CRFIR = crust firmness, INFIR = inner firmness, ADHES = adhesiveness (puncture), STI = stickiness.

0.939, ADH = 0.533, RES = 0.831, SPR = 0.528, CHE = 0.986, COH = 0.778, CRFIR = 0.668, INFIR = 0.616, ADHES = 0.557, STI = 0.441).

The rotation procedure achieved convergence in four iterations and allowed extracting the three factors aforementioned, which group the variables as shown in Table 2.

The Factor 2 was evidently linked to textural properties which were obtained by the puncture test, clearly distinguishing from the properties obtained by the compression test, included in Factors 1 and 3. Furthermore, variable loadings in factor 2 were considerably high, the lowest being in absolute value equal to 0.646, which is indicative that all the input variables for this factor had important contributions for the definition of factor F2. In contrast, the properties of the compression test were divided, so that hardness and chewiness constituted a separate actor (Factor 3), with very high loading for both variables. These two textural attributes are tightly related through or as seen by equation (6). Finally, adhesiveness, resilience and springiness defined Factor 1, also with high loadings, particularly for resilience. The variable cohesiveness showed an irrelevant loading (under 0.4) in any of the three factors considered.

4 Conclusions

The results of the present study confirmed the interest in recurring to more than one type of test when performing

analysis of the textural characteristics, since the obtained results complement each other. Regarding the texture of the jelly gums analysed, some differences were observed when comparing the top and bottom faces. The results of the compression test indicated that the Strawberry & Anise gums were among the softer and with lower resilience and chewiness, although being more adhesive. The puncture test revealed that the sample Strawberry & Mint presented the highest adhesiveness and the lowest stickiness. Furthermore, some of the properties determined by the compression test showed very strong correlations, while for most of the properties determined by the puncture test moderate correlations were found. Finally, FA extracted three factors, one clearly associated with the puncture properties and the other two related to the compression properties, in which case the hardness and chewiness constituted a separate factor by themselves.

These results indicated some textural properties of the jelly gums developed, which are in line with desired attributes for this kind of product. However, the role of the consumer is fundamental to achieve success in the marketing of this product, and therefore additional studies about consumer acceptance are recommended.

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