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INVESTIGATION OF THE EFFECT OF APPLE POMACE ON THE TEXTURAL CHARACTERISTICS, FIBRE CONTENT, AND MOISTURE CONTENT OF SPONGE CAKES

Z. Goranova, PhD, Associate Professor
Z. Manev, PhD, Chief Assistant
Department of Food Technologies
Institute of Food Preservation and Quality - Plovdiv
Agricultural Academy
154 Vassil Aprilov Blvd., 4000, Plovdiv, Bulgaria

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Correspondence:

Z. Goranova
*E-mail:*jivka_goranova@abv.bg

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Abstract. Apple pomace, a by-product from apple processing industries, is a popular raw material, which has characteristics of a rich nutritional component, so its utilisation is of great interest. The purpose of this research was to study the effect of apple pomace on the textural characteristics and moisture and fibre contents of sponge cakes.Besides, the relationship between the properties under examination has been investigated. Rheology encompasses many characteristics of the product and plays a pivotal role in consumer acceptance. Rheology, in particular, considers the flow and deformation of bakery products. Sponge cakes were produced with wheat flour partially (by 15%, 25%, and 50%) replaced with apple pomace powder. The addition of 15% and 25% of apple pomace to sponge cakes leads to significant differences in the textural indicators, and with the addition of 50% of apple pomace, there is a maximum improvement in all textural characteristics. With an increase in the amount of apple pomace added, there is an increase in the content of fibre and moisture in the sponge cakes. Apple pomace is used as a valuable source of food fibre in the cake technology. The correlation analysis has found that fibre and moisture changes exhibit a strong correlation with rupture deformation and stickiness.Very strong and statistically significant dependence with a negative value has only been found between the moisture content and stickiness ($r = -0.965$, $p<0.05$). This statistically significant dependence shows that as the fibre content in sponge cakes increases, the stickiness values decrease due to the negative value of the Pearson coefficient ($r = -0.965$, $p<0.05$). From the correlation coefficients, it has been shown that the rupture force and deformation exhibit the same very strong and statistically significant correlation with the textural characteristics – rupture energy, hardness, gumminess, and compressive strength ($r = 0.993$, $r = 0.984$, $r = 0.996$, and $r = 0.999$, $p<0.05$). The Pearson correlation coefficients of rupture energy are positive and statistically significant in relation to hardness, gumminess, and compressive strength ($r = 0.957$, $r = 0.983$, and $r = 0.992$, $p<0.05$). These strong and statistically significant dependences are found between Pearson's hardness coefficient on the one hand and gumminess and compressive strength on the other ($r = 0.992$ and $r = 0.984$, $p<0.05$).

Keywords: apple pomace, textural characteristics, moisture, fibre, bakery product.

Introduction. Formulation of the problem

The cake contains plenty of important nutritional components which positively influence human health. However, the consumption of bakery products has been decreasing over the last decades, which is mostly caused by factors such as changes in eating habits and a larger choice of substitutes.Increasing the nutritional value of sponge cakes is a topical problem. Nowadays, it is important to use inexpensive supplements to make products cheaper and available to all social groups. That is why the addition of fibre to bakery products is still more important.Apple fibre contains neither gluten nor phytic acid. It has a relatively high content of soluble dietary fibre with thickening properties. These fibre-rich by-products can fortify foods, increase their dietary fibre content, and result in healthy products, low in calories, cholesterol, and fat. They may also serve as functional ingredients to improve the textural and structural properties of hydration, oil holding capacity, viscosity, texture, sensory characteristics, and shelf-life [1].

Analysis of recent research and publications

Sponge cake is one of the most common bakery products liked by all age groups. It is consumed frequently and usually contains large amounts of carbohydrates, calories, and fats, but is poor in fibre, vitamins, and minerals [2]. Fruit pomace has been previously used in preparing bakery products like muffins andsponge cakes.Quiles *et al.* (2018) [3]used blackcurrant and aronia pomace to replace flour, fat, and sugar in cakes.Sudha, Baskaran, and Leelavathi (2007) [4] incorporated apple pomace in cakes, and Diez-Sánchez *et al.* (2019) [5] included blackcurrant pomace in muffins. Apple pomace powder can be considered a functional component enriching sponge cake and is used to replace wheat flour in the recipe. Apple pomace is made up from 95% of apple peel and pulp, from 2% to 4% of seed, and 1% of apple stems, and can be used as natural flavouring in beverages and as a source of fibre and antioxidants [6]. Apple pomace contains different types of polyphenols, which have been scientifically proved to protect against prostate and colon cancer [7]. Another component of apple pomace, very important and valuable for human health, is fibre. Fibre, which accounts for about 40% of the dry weight of apple pomace, can help treat various health problems such as diabetes, obesity, atherosclerosis, and others [8].

To obtain a test product with optimal quality indicators, it is necessary to observe accurately the recipe and modes of all technological processes. The texture of sponge cake appears during the formation of the cake dough from soft foam and after baking in the crumb [9]. Each adjustment leads to a significant change in the quality and texture of the finished products. The texture of bakery products is an important factor of the consumer choice of the product. The texture is one of the main features of bakery products, which can be affected by the addition of fibre. It has been found that adding high concentrations of apple pomace, which is rich in fibre, leads to an increase in hardness and density when baking cakes, and so it can be used as a thickening ingredient in foods [10,11]. The texture can be assessed by sensory and instrumental methods. Instrumental methods offer some advantages over sensory analysis because they are fast and objective [12].

The purpose of the work was to investigate the technological properties of apple pomace on the textural characteristics, moisture, and fibre content in sponge cakes.

To accomplish this purpose,thefollowing **objectives** havebeen achieved:

1. studying the technology of making sponge cakes enriched with apple pomace;
2. investigating the effect of apple pomace on the texture of sponge cakes;

investigating the effect of apple pomace on the fibre and moisture content of sponge cakes.

Research materials and methods

Apple pomace powder

Apples ofthe variety Red Delicious were cooled and stored until they were processed to obtain juice. Apple pomace was obtained after isolating the juice from the fruit using a juicer, the residues were dried at 60°C in a dryer to the optimal moisture content 10% and ground into 100 μmflour. The flour was packed and stored in a refrigerator at 4°C [13].

Preparation of sponge cakes enriched with apple pomace

The ingredients for the preparation of sponge cakes were type 500 wheat flour, white refined crystal sugar, and eggs. All the food products used were purchased prior to their expiry date from a food supermarket BILLA, Bulgaria. The control sample (P00) was prepared by the technology and recipe used by Goranova*et al.*(2020) [14]. The cake batter formula of the control cake (P00) was as follows (depending on the weight of the flour): egg yolk – 43.23%, egg white – 96.77%, refined sugar – 83.87%, and wheat flour – 100%. In particular, double mixing was applied by whipping egg whites and egg yolks separately. Apple pomace powder was added to the sponge cake in different quantities: 15 % (P01), 25 % (P02), and 50 % (P03), replacing the equivalent quantities of wheat flour. The control (P00) did not contain apple pomace powder. The cake batter was dosed in metal moulds and baked in an electric oven at 180°C for 30 minutes. After baking, the sponge cake was placed in a polypropylene food box at room temperature for 24 hours before being used for textural measurements.

Determination of the total moisture content of sponge cakes

The moisture content was determined by Moisture Analyser model XY-100W in the automatic operating mode and at the constant temperature 105°C. In each sample, the measurement was done in triplicate [15].

Determination of the texture of sponge cakes by a penetration test

All textural measurements were carried out by a penetration test. The textural characteristics of cakes with apple pomace were measured with Stable Microsystems Texture Analyser (SMS) in the single-axis deflection mode on the Y-axis at a strain of 50 %, at the test speeds 2 mm/s and 10 mm/s, using an aluminium cylindrical probe with a diameter of 5 mm (P/5) and an area of 19.634 mm^2. The rupture force and deformation were defined as the maximum value of the first inflection point from the penetration curves obtained using the textural analyser. The rippling energy was calculated from the area under the force-deflection curve to the rupture point [16]. Firmness is defined as the force-deflection curve inclination recorded in N/mm and reflects the apparent elasticity module [17].Gumminess is one of the main mechanical properties of food products and is defined as the amount of energy the material can absorb in a unit of volume before rupture [18]. The compressive strength is calculated as the rupture force divided by the cross-sectional area of the piston at the rupture point [19]. Adhesiveness is the energy for lifting and separating the piston from the food glued to it, which is determined at 50% compression strain as the negative area under the force-deformation or force-distance curve [20,21]. Stickiness is defined as the minimum force of the negative peak from the force-time curve [22,23].

Determination of the fibre content of sponge cakes

The fibre content of sponge cakes was determined using methods from the Association of Official Analytical Chemists (AOAC, 2000) [11].

Statistical analysis

The results of the studies conducted were processed with MS Excel 2010 software. The statistical processing of the data was carried out by preliminary comparison of the dispersions of two samples by applying the *F*-test.Depending on the statistical significance of the dispersions of the two samples, a *t*-test was applied to compare the mean values of two independent samples with equal (*t*-Test: Two-Sample Assuming Equal Variances) or different dispersions (*t*-Test: Two-Sample Assuming Unequal Variances) at the statistical significance level α=0.05. The correlations between the fibre content, humidity, and textural characteristics of sponge cake were determined by Pearson's sampling factor with the use of MS Excel 2010. The statistical significance of the Pearson coefficient was defined as Pearson's sampling factor compared withPearson's critical coefficient values at the level of significance α=0.05 and degrees of freedom f=n-2, where *n* is the number of measurements (number of samples): n=4; f=2; r cr.=0.950. If Pearson's absolute value ratio is equal to or higher than the critical value (0.950), the coefficient is statistically significant.

Results of the research and their discussion

Textural characteristics of sponge cakes

Table 1 shows the changes in the textural characteristics of sponge cakes with and without the functional component – apple pomace.

From the results shown in Table 1, it is clear that the rupture force of the control (P00) is higher than that of the sponge cakes containing 15 % and 25% of apple pomace (P01 and P02). This effect is due to the higher wheat flour content and, consequently, a higher gluten content in the control, which makes the final product (P00) more prone to hardening. On the other hand, the addition of apple pomace leads to a decrease in gluten elasticity and a lower rupture force. A similar effect is observed when adding 10 or 20% of gelatinised retrograded starch to wheat flour to make cookies and muffins and when adding peanut flour to fortified flatbreads [24,25]. The higher rupture force of sponge cake (P03), as compared with the control (P00), is the result of a higher content of apple pomace (fibre respectively) and a lower gluten content in P03 relative to P00. This fact leads, on the one hand, to a reduction in the gluten-forming network structure and, on the other hand, to a decrease in the ability to retain air and increase the density of the texture of the finished product. Similar trends associated with the hardening of the structure of the finished product are observed in bakery products enriched with 50% of bean flour [26]. From the data shown in Table 1, it appears that at a content of 50% of apple pomace, the rupture force of P03 increases from 1.5 to 2 times in comparison with P00 and P02, which means that the functional component used as a substitute for wheat flour has a significant effect on the rupture force.

The data set out in Table 1 show that the rupture energy of P01 and P02 decreases and that of P03 increases relative to P00. The smaller rupture energy of P01 and P02 is due to the apple pomace added, which increases the starch content and, on the other hand, leads to a greater degree of starch gelatinisation and the formation of a softer texture and lower rupture energy of P01 and P02 relative to P00. A similar effect is observed when boiling pasta for 3 and 7 minutes with sweet potato powder added [27]. Sponge cake with 50% of apple pomace (P03) has higher rupture energy than P00 does. This fact is due to the higher fibre content in P03 compared with P00 (Fig. 2), which, on the other hand, leads to an increase in the rupture force and, respectively, in the rupture energy. This textural effect is confirmed by the statistically significant and very high correlation relationship (Table 2) between them (r=0.993 at p<0.05).

Table 1 – Textural characteristics of sponge cake

Textural characteristics	Type of sponge cakes			
	Control	15%	25%	50%
	Sample №			
	P00	P01	P02	P03
Rupture force, (N)	4.42*±0.39^a	3.55*±0.42^b	3.29*±0.66^c	6.60*±0.81^d
Rupture deformation, mm	13.43±0.70^a	12.08±0.89^b	11.85±0.33^c	10.61±1.77^d
Rupture energy, mJ	29.66±2.66^a	23.81±4.06^b	22.70±8.05^c	38.36±10.24^d
Hardness, N/mm	0.32±0.02^a	0.29±0.02^b	0.26±0.04^c	0.59±0.10^d
Gumminess, mJ/cm^3	114.80±6.86^a	99.54±15.82^b	98.44±36.20^a	175.32±35.79^d
Compressive strength, MPa	0.22±0.02^a	0.18±0.02^b	0.16±0.03^c	0.33±0.04^d
Adhesiveness, N.mm	- 0.37±0.09^a	-0.47±0.12^b	-0.47±0.13^c	-0.41±0.06^a
Stickiness, N	- 0.42±0.05^a	-0.43±0.02^a	-0.48±0.10^b	-0.56±0.07^c

* Mean values of fifteen measurements (n=12) ± standard deviation. The different letters in each row show the statistically significant differences (p<0.05) of the *t*-test control sample.

From the textural measurements carried out, it has been found that the hardness of P01 and P02 was lower and that of P03 was almost twice as high as in P00. This fact associated with a reduction in the hardness of P01 and P02 relative to P00 is most likely due to the higher content of hydrocolloids such as highly esterified pectin and others,which can jelly and lead to weakening of the starch structure in the product by suppressing intrapartum inter-starch granules, resulting in a reduction in the hardness of sponge cake (P01 and P02). The addition of 50% of apple pomace results in the almost double hardness of the P03, compared with the control. This effect is due to the higher fibre content in P03 relative to P00 (Fig. 2). For this reason, dietary fibre from the added apple pomace in P03 may interact with wheat flour gluten, resulting in a decrease in volume and weakening of the gluten network in the final product, which leads to an increase in the hardness of P03. A similar hardness-related effect is observed in wheat bread enriched with apple pomace [28] and in muffins with partiallydeoiled chia meal added [29].

From the data presented in Table 1, it is clear that the toughness of P01 and P02 is lower than that of the control. This textural effect is due to the gelatinisation of starch when heated from 55 to 75°C, which causes an outflow of amylose and amylopectin from starch granules, resulting in a decrease in the hardness of the finished product. Another probable reason for reducing the strength of P01 and P02 relative to the control is the smaller amount of energy (lower rupture energy) that the product can absorb before it is torn under a certain force (Table 1), due to the replacement of part of the gluten from wheat flour with apple pomace. A similar reduction in gumminess was found when adding erythritol and turmeric to low-calorie sponge cakes [30]. With the addition of 50% of apple pomace to sponge cakes, there is an increase in gumminess (P03), as compared with P00.This effect is most likely due to the higher content of insoluble fibre (cellulose, hemicellulose, and lignin) of apple pomace in P03 interacting through hydrogen bonds with the gluten matrix, which in turn leads to an increase in gumminess. According to the correlational dependences set out in Table 2, it is shown that the gumminess of sponge cakes is significantly affected by the rupture energy and hardness ($r = 0.983$; $r = 0.992$ at $p<0.05$) of the finished product.

From the results presented in Table 1, it can be seen that the compressive strength of sponge cakes with 15 and 25% of apple pomace is lower, while those with 50% have a higher compressive strength relative to the control. The lower compressive strength of P01 and P02 is most likely due to the greater drag force between the different molecules of the constituents inside the sponge cakes (greater adhesiveness of P01 and P02) and the lower rupture force and hardness relative to the control. The results in Table 1 show that with an increase in apple pomace from 25% to 50%, the compressive strength increases twice (P02 and P03). This textural effect results from the increase in the rupture energy and gumminess of the finished product due to the higher content of apple pomace in P03. The results obtained for the compressive strength of sponge cake are very close in numerical value to those of pasta obtained from 100% wheat semolina [31] and many times higher compared with the compressive strength of biscuits with 9–16% of fat and pan bread [32]. The compressive strength of sponge cakes has a strong correlation with rupture force and gumminess, which is confirmed by Pearson's statistically significant and high positive coefficients ($r = 0.999$; $r = 0.998$ at $p<0.05$).

The results presented in Table 1 make it clear that regardless of the concentration of apple pomace added, the adhesiveness of P01, P02, and P03 is always higher than in P00. The increase in the adhesive values of sponge cakes with apple pomace (P01, P02, and P03) relative to P00 is due to the higher fibre content in them (Fig. 2), which leads to a decrease in tearing deformation and an increase in hardness when apple pomace increases from 25 to 50%. This fact is confirmed by the strong negative correlation between fibre and rupture deformation ($r = -0.839$) on the one hand, and by the moderate dependence between fibre and hardness ($r = 0.399$) on the other. A similar increase in hardness and adhesiveness is observed when enriching noodles with 15% of apple pomace [33].

Textural measurements have revealed that the stickiness of sponge cakes with apple pomace added (P01, P02, P03) was higher than that of P00. The increase in the stickiness of the apple pomace cakes relative to (P00) is due to the ability to viscose and texture apple pomace on the one hand and increase moisture (Fig. 2) on the other, which leads to an increase in the stickiness of the finished product. A similar textural effect is observed in noodles with added pumpkin flour and when sponge cakes are made with rice flour [34,35].

Penetration curves of sponge cakes with apple pomace. Fig. 1 shows typical penetration curves determined by a penetration test using atexture analyser. The data in Fig. 1 show the type and inclination of the typical penetration curves of each sample. Each penetration curve is characterised by a linear section that corresponds to the linear deflection of the sample. Fig. 1 shows that as the tearing force increases, the linear section on the penetration curves of the sponge cakes with apple pomace decreases, leading to the reduction in the rupture deformation of P01, P02, and P03, as compared with P00. According to the data in Fig. 1, when 15% and 25% of apple pomace is added to sponge cakes, there is a lower inclination of the curves P01 and P02 relative to the control, and in the case of 50% of apple pomace added, an inclination of the P03 curve increases significantly. This effect is most likely due to the different fibre content and hardness of the samples examined.

Moisture and fibre content of the sponge cakes

Fig. 2 shows the change in the content of total moisture and fibre in the sponge cakes.

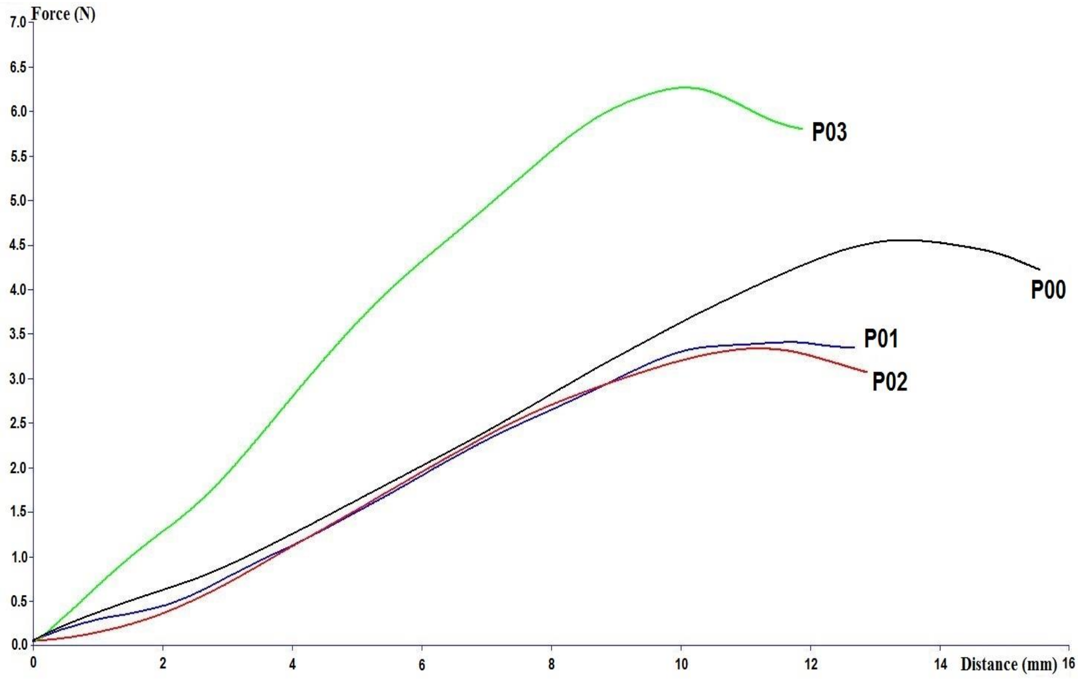

Fig. 1. Typical penetration curves ofsponge cakes

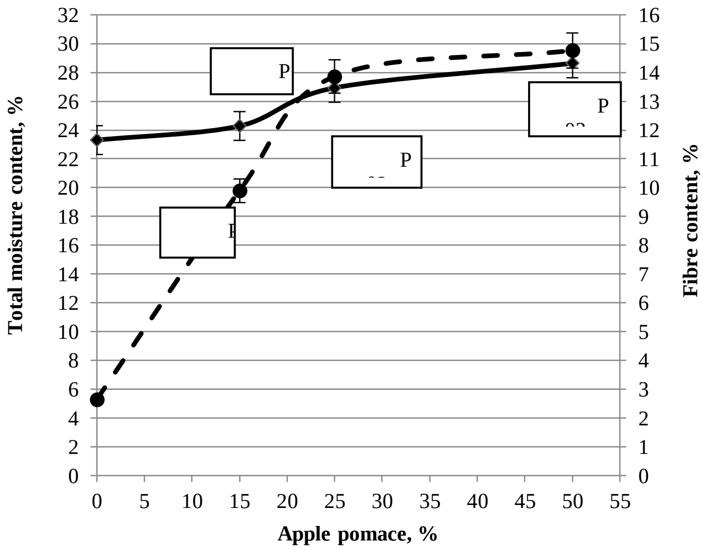

Fig. 2. Total moisture (-) and fibre (- - -) content of the sponge cakes as a function of the concentration of apple pomaceadded.

From the data presented in Fig. 2, it is clear that the moisture and fibre content of sponge cakes with apple pomace added (P01, P02, and P03) is higher than the control (P00). This effect is due, on the one hand, to apple pomace flour, which has a higher content (10.20%) than wheat flour (9.30%), and, on the other hand, to the higher fibre content in P01, P02, and P03 relative to the control (P00), which in turn retain a greater amount of water. The results shown in Fig. 2make it clear that as the amount of apple pomace added increases, the moisture and fibre content is higher than in P00. This effect is because a higher fibre content leads to greater retention and more difficult separation of water during baking of sponge cakes.

Correlation dependences

Table 2 presents the determined Pearson correlation coefficients between the fibre content, moisture, and textural characteristics of the sponge cakes.

Correlation coefficients are used to determine the interdependence between two or more pairs of variables (the textural characteristics of sponge cakes) as a linear function obtained by a penetration test. Of the results presented in Table 1, there was a strong positive dependence (r = 0.901) between the fibre content and moisture in the sponge cakes. Another dependence, which is as strong but negative in the numerical value, is found between the fibre content and the moisture relative to the tearing deformation (r = -0.839 and r = -0.859).

The data in Table 2 show that other textural characteristics do not have a statistically significant and strong correlation with the fibre content. From the results shown in Table 2, it can be seen that a very strong and statistically significant dependence with a negative value has only been found between moisture and stickiness (r= -0.965 at $p<0.05$). This statistically significant dependence shows that as the fibre content in sponge cakes increases, the stickiness values decrease due to the negative value of the Pearson coefficient (r = -0.965 at $p<0.05$). From the correlation coefficients shown in Table 2, it is clear that the rupture force and deformation exhibit the same very strong and statistically significant correlation against the textural characteristics – rupture energy, hardness, gumminess, and compressive strength (r = 0.993, r = 0.984, r = 0.996, and r = 0.999 at $p<0.05$). Pearson's correlation coefficients of rupture energy are positive and statistically significant relative to hardness, gumminess, and compressive strength (r = 0.957, r = 0.983, and r = 0.992 at $p<0.05$). Such strong and statistically significant dependencies are found between Pearson's hardness coefficient on the one hand and gumminess and compressive strength on the other (r = 0.992 and r = 0.984 at $p<0.05$). From the coefficients shown in Table 2, one can see that the correlation between gumminess and compressive strength is very strong and statistically significant (r = 0.998 at $p<0.05$). It is clear from the Pearson coefficient values presented that there is no correlation between adhesiveness and stickiness (r = 0).

Table 2 – Correlations between the textural characteristics, moisture and fibre contents in the sponge cakes

Penetration test										
Textural characteristics of the sponge cakes										
	Fibre	**M**	**RF**	**RD**	**RE**	**F**	**G**	**CS**	**A**	**S**
Fibre	**1**									
M	0.901	**1**								
RF	0.240	0.565	**1**							
RD	-0.839	-0.859	-0.661	**1**						
RE	0.144	0.494	0.993*	0.993*	**1**					
F	0.399	0.669	0.984*	0.984*	0.957*	**1**				
G	0.280	0.577	0.996*	0.996*	0.983*	0.992*	**1**			
CS	0.233	0.548	0.999*	0.999*	0.992*	0.984*	0.998*	**1**		
A	-0.611	-0.217	0.559	0.559	0.649	0.402	0.506	0.555	**1**	
S	-0.789	-0.965*	-0.760	-0.760	-0.701	-0.838	-0.769	-0.746	0	**1**

Note: M – moisture, RF - rupture force, RD – rupture deformation, RE – rupture energy, F – firmness, G – gumminess, CS – compressive strength, A – adhesiveness, S – stickiness.

*Pearson's coefficient is statistically significant at the level α = 0.05.

Conclusion

The addition of apple pomace in a certain concentration has a significant impact on the textural characteristics and the moisture and fibre content of sponge cakes. With the addition of 15% and 25% of apple pomace, the textural characteristics (rupture force, rupture energy, hardness, gumminess, and compressive strength) decrease, and rupture deformation, adhesives, and stickiness increase, as compared with the control. The introduction of 50% of apple pomace leads to a significant increase in all textural characteristics except for rupture deformation. Regardless of the amount of apple pomaceadded, the moisture and fibre content is always higher than it is in the control, indicating that apple pomace is a very good source of dietary fibre. Correlation analysis has revealed that fibre and humidity exhibit a strong correlation with rupture deformation and stickiness. Due to the high content of dietary fibre, phenolic compounds, and other nutrients, apple pomace is regarded as a good functional ingredient to be incorporated in various food products. However, the addition of apple pomace is reported to cause a decline in certain quality parameters of food products.

Therefore, the amounts of pomace as a functional ingredient should be carefully monitored.

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