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AERATED CONFECTIONERY: PHYSICO-CHEMICAL AND TEXTURAL EVALUATION

Raluca - Olimpia ZIMBRU[1], *Sergiu PĂDUREŢ[1], Sonia AMARIEI[1]

[1]*Faculty of Food Engineering, Stefan cel Mare University of Suceava, Romania*
sergiu.paduret@fia.usv.ro
*Corresponding author
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Abstract: *The effect of raw materials and production process on stress - relaxation texture parameters (hardness, total mechanical work, elastic mechanical work, deformability modulus, relaxation and relaxation work) and physico-chemical properties (protein content, fat content, dry matter, soluble substances concentration, a_w, density and specific volume) of aerated confections were investigated in this study. The aeration process of confectionery samples was based on mechanical beating, using a six wire whip. According to Pearson's correlation the samples' hardness and relaxation were positively influenced by the dry matter content (r = 0.943*) and density (r = 0.997**), whereas the specific volume had a negative effect (r = -0.982**). The highest soluble substances concentration was recorded by the vegetable cream aerated samples; the ANOVA factorial analysis showed a significant difference, P < 0.001.*

Keywords: *stress-relaxation, hardness, confectionery, density, deformability modulus.*

1. Introduction

There are many food products which contain air bubbles or other gases distributed in a liquid or solid viscoelastic mass, such as: confectionery products or other desserts, ice cream, beating cream or bread dough. The appearance, textural characteristics, sensory properties and shelf life of these products are strongly affected by the dimensions and concentration of bubbles and it is important to prevent bubbles' properties changes over time [1]. Aerated confections have air trapped and dispersed as small bubbles throughout the food matrix, thus the density of these products is lower than that of nonaerated food products and also are frequently more brittle. As a means to characterize these products, density's measurements are often used, which can vary greatly from 1.1 g/ cm^3 (nougat) to 0.2 g/ cm^3 (marshmallows) [2]. The gases of greatest relevance used in food products' aeration are represented by: air, carbon dioxide, steam, nitrogen, nitrous oxide or oxygen, applied separately or in different combinations [3]. In the case of aerated confectionery products the air is trapped in the product structure and can accelerate the oxidative changes like fats rancidity, vitamins or flavor oxidation and thereby reduce the products' shelf life [4]. This process could be diminished or even stopped by substituting the air, during the whipping stage, with another gas like carbon dioxide, nitrogen or nitrous oxide. Furthermore, it should be mentioned that these aeration agents can also provoke some tainting to the products; the aeration agents based on nitrogen and carbon dioxide can dissolve in the fats and carbon dioxide is water soluble, which can then determine a modification in the products' flavor [5]. Texture is extremely important to products acceptability, especially when it comes to confectionery and the textural parameters of aerated confections are influenced to a large extent by the air/gas content, although the characteristics of the continuous phase imparts some particular properties, too [4]. For the mechanical beating process various type of whip wire have been developed to facilitate aeration [6]; first large air bubbles are incorporated in the food matrix, but in order to form a stable aerated product, these large air bubbles must be broken up into smaller ones. This occurs in turbulent flow during the first phase of mechanic beating followed by the second phase of beating when the air bubbles are coated by a thin layer of fat globules [7]. To the authors knowledge there are few studies based on the evaluation of aerated confectionery products' texture. Therefore, the purpose of this research was to study the influence of the raw materials and the production process on the stress-relaxation texture parameters and also to characterize the main physicochemical composition of the aerated confections.

2. Matherials and methods

Experimental samples preparation. For the aeration process was used a six wire whisk whip, the speed was set at an approx. 600 rotations/min and the beating time was 5 minutes. The raw materials used in the production process were: white chocolate (Callebaut, Belgium, 36 % fat), sugar, yolk, milk, gelatin, 25 % fat vegetable cream for A1 and A3 samples and 32 % fat dairy cream for A2 and A4 samples. The production of aerated confectionery samples followed the procedure described by *Zimbru 2020* [8], thus A1 and A2 samples were produced by incorporation of the mixture of chocolate, sugar, yolk, milk and gelatin in the whipped vegetable or dairy cream, while the A3 and A4 samples were produced by the incorporation of the chocolate, sugar, yolk and gelatin one at a time in the whipped vegetable or dairy cream.

Physico-chemical analysis. Total protein content of aerated samples was determined by Kjedahl method [9], the dry matter was measure by oven drying method [10] and the fat content was carried out using a Soxhlet extractor [11]. For water activity (a_w) was used a water activity meter (AquaLab Lite) and for the concentration of soluble substances measurements was used a Leica Mark II Plus refractometer. Also density and specific volume were determined [12]. All reagents used were of analytical grade.

Texture evaluation. The stress-relaxation compression test was performed at room temperature (approx. 20 ºC) on cubic samples (30 mm) using a Mark 10-ESM-301 Texture Analyzer (Mark 10 Corporation, USA). The compression probe was flat (Ø 50 mm), the test speed was set at 10 mm/min and the trigger force was set at 0.05 N. The sample loading was established at 10 mm and the relaxation time was 200 seconds. The MESUREgauge software was used for load (N), deformation (mm) and time (s) recording at a reading rate of 10 points per second. Resulting load - deformation and load - time curves were used for the evaluation of textural parameters like: hardness (H, N), total mechanical work (Wt, J) calculated as the total area under the loading curves, mechanical work of elastic deformation (We, J) calculated as the area under the unloading curves, the loading modulus of deformability (Ed, Pa) [13], relaxation (R, N/s) calculated as the differences of initial load of relaxation (F_i) and the final load of relaxation (F_f) reported on relaxation time ($t_{relaxation}$, s), (eq.1). The relaxation work (Rw, N·s) was calculated as the area under the relaxation curves [14].

$$R = \frac{\Delta F}{t_{relaxation}} = \frac{F_i - F_f}{200} \quad (1)$$

Statistical analysis. The results were subjected to analysis of variance ANOVA by Statgraphics Centurion XVI (Trial Version); the statistical significance being set at α = 5%, while Pearson correlation was calculated with SPSS 13.0 (SPSS Inc. Chicago, IL).

3. Results and discussion

Physico-chemical analysis. The physico-chemical analysis of aerated confectionery samples, respectively the protein, fat, dry matter, Brix concentration, water activity, density and specific volume are presented in Table 1 and we can observe that the protein content ranged between 9.55 % - 11.12 %, the ANOVA analysis highlighted this difference based on the ingredients used at a level of P< 0.05. Fat content ranged between 15.35 % and 20.18 %; the aerated samples based on dairy cream, A2 and A4, presented a higher fat content than A1 and A3 samples, which contain whipped vegetable cream. One way ANAOVA highlighted this difference at a level of P< 0.001. Proteins and fats are of great importance in the aeration process of confectionery products; in the first phase initial large air bubbles are stabilized by proteins and as these bubbles are broken into smaller sizes they are covered by a film of fat globules [15; 7]. The dry matter content of aerated confectionery samples varied considerably from 52.38 % to 57.72 %, A4 sample had the highest content and according to *Nardozza, 2011* [16] in the case of some food products the dry matter content influences texture properties. When it comes to confections, another important parameter is represented by water activity which has an important role in quality control, establishing the shelf-life of the products and influences texture and sensory parameters [17]. Water activity of aerated confections is between 0.826 - 0.848 and according to *Subramaniam, 2016* [2] foods that show a water activity value greater than 0.750 are not stable against microbial spoilage. The highest soluble substances concentration was recorded by the vegetable cream aerated samples, while the dairy cream aerated samples showed smaller values; the ANOVA factorial analysis showed a significant difference (P < 0.001). Fixing air into the product structure results in a decrease of density, obtaining a lighter product in terms of calories [18]. The samples' density ranged between 0.400 and 0.780 g/cm^3, A1 and A2 samples showing smaller values than A3 and A4 samples; thus, the one step incorporation (first procedure) of the other ingredients in whipped vegetable or dairy cream introduced and fixed a larger amount of air in the product structure. In addition to a low density, aerated confections show a more fragile texture and a shorter shelf life due to the oxidative changes of fats (fats rancidity) or vitamins [5]. As regarding the specific volume of the analyzed samples, it was between 1.28and 2.50 cm^3/g; the A1 and A2 aerated samples presenting higher values than A3 and A4 samples. The specific volume results were similar to those reported for marshmallow (2.2cm^3/g), whipped cream (1.7-2.5 cm^3/g), cake batter (1.25-1.8 cm^3/g) or aerated chocolate bar (1.25-1.45cm^3/g), but smaller than those reported for meringue (5.5-6 cm^3/g) and sponge cake (3-4 cm^3/g) [18].

Table 1.

Physico-chemical parameters of aerated confectionery samples

Sample	Protein	Fat	Dry matter	Brix	a_w	Density	Specific volume
	[%]	[%]	[%]	ºB	-	[g/cm^3]	[cm^3/g]
A1	11.12^a (0.70)	15.35^c (0.40)	52.38^d (0.20)	25.96^a (0.28)	0.836^a (0.20)	0.400^c (0.02)	2.50^a (0.15)
A2	9.55^b (0.35)	20.10^a (0.52)	55.01^c (0.24)	24.58^b (0.22)	0.826^a (0.15)	0.520^b (0.05)	1.92^b (0.17)
A3	10.83^a (0.53)	16.42^b (0.35)	56.13^b (0.19)	26.14^a (0.20)	0.845^a (0.17)	0.771^a (0.07)	1.30^c (0.12)
A4	9.70^b (0.40)	20.18^a (0.50)	57.72^a (0.28)	24.80^b (0.50)	0.848^a (0.21)	0.780^a (0.06)	1.28^c (0.10)
F – ratio	6.66	59.30	285.82	22.68	0.13	32.65	56.25
P-Value	< 0.05	< 0.001	< 0.001	< 0.001	> 0.05	< 0.001	< 0.001

Different lowercase letters (a–d) in a row show significant differences between the groups (p<0.05). NS – not significant (p > 0.05), * p < 0.05, ** p < 0.01, *** p < 0.001.

Texture properties measurements. Figure 1a and 1b shows the stress - relaxation and loading - unloading compression curves of aerated confectionery samples, of which two were produced with whipped dairy cream and two with vegetable cream, following two different procedures. There was observed that the aerated samples exhibit both elastic and viscous behavior, namely a viscoelastic solid behavior, with a decrease of stress (required to maintain the strain) during time (figure 1b). Based on loading - unloading (load-travel) and stress - relaxation curves were calculated the texture parameters of aerated samples, as shown in the Table 2. Hardness (H) values were calculated as the force measured at the end of loading and express in Newton; lower values were measured for A1 (1.92 N) and A2 (2.7 N) samples, which were produced by homogenization of the mixture formed from other raw materials in beating vegetable or dairy cream. Furthermore A1 and A2 samples showed lower density values which means that these samples are more aerated, containing a larger amount of air in the structure, leading to lower hardness, while the A3 and A4 samples showed higher hardness and density values which corresponds to a less aerated structure. According to *Campbell, 2016* [3] the mechanical strength of solid aerated foods depends on the amount of air incorporated into the food matrix. In the same way, total mechanical work of compression was higher in the case of A3 and A4 aerated samples, while for A1 and A2 samples presented smaller values. The mechanical work of elastic deformation (We) represents the recoverable energy invested in the sample deformation [19] and varies from 0.771 to 3.348 $\cdot 10^{-3}$ Joules, the highest value being observed for A4 and the lowest for A1 sample. The modulus of deformability (Ed) is a measure of food material stiffness [13] and it was calculated as the slope of the stress - strain curves (Figure 1 a), being associated with hardness texture parameter [20]. As the data shows, the modulus of deformability was higher (15.615 KPa) for aerated confectionery samples with high hardness.

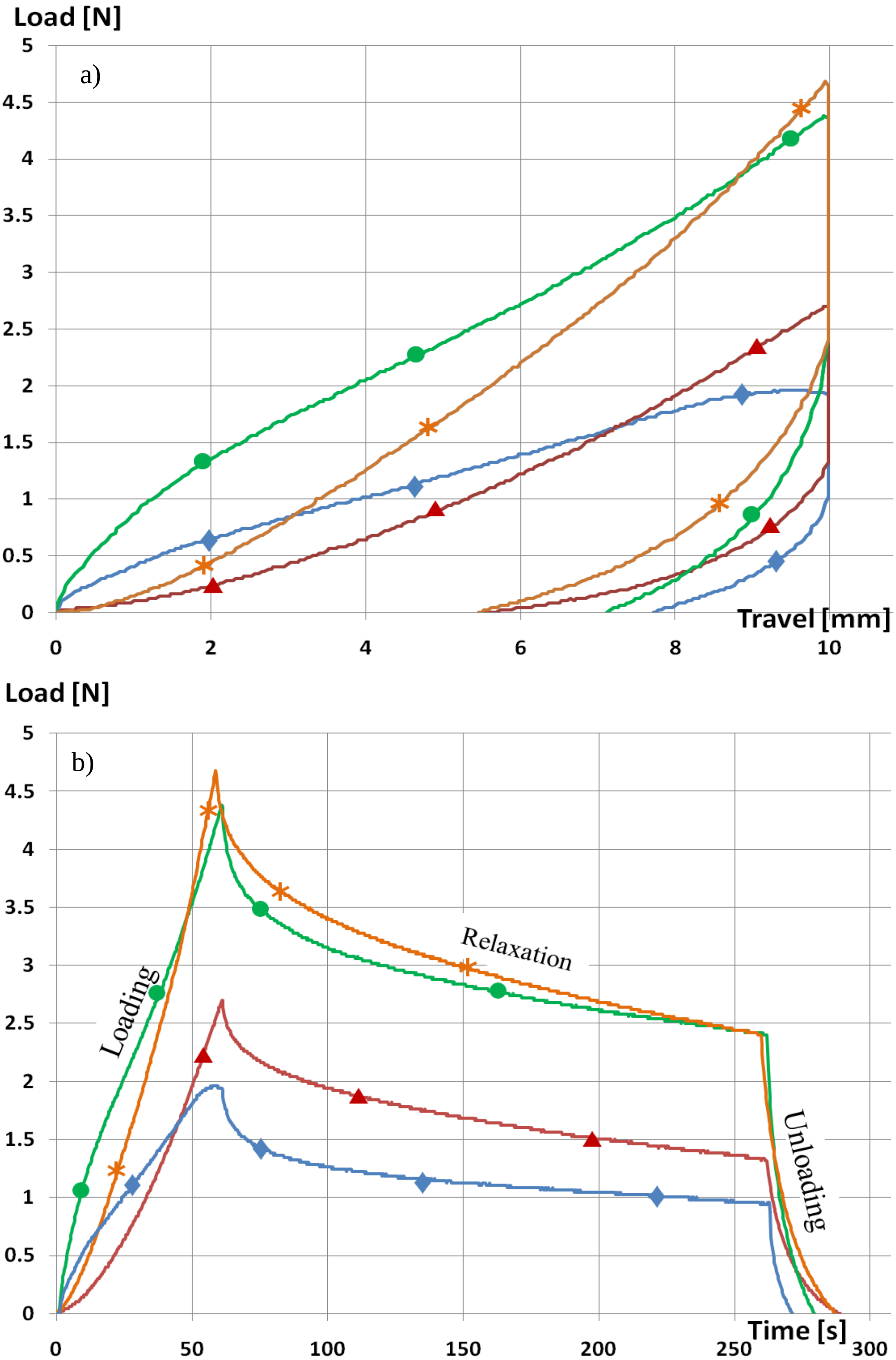

Fig. 1. Loading - unloading (a) and stress - relaxation (b) curves of aerated confectionery samples:
A1 (◆), A2 (▲), A3 (●), A4 (✱)

From Table 2, it can be seen that the relaxation, R, and the relaxation work, Wr, of the aerated confectionery samples were about 0.0049 - 0.0111 N/s and 233.5 - 607.8 N·s, which were smaller to those reported by *Gutt,2014* [14] for fresh meat (0.0113 – 0.044 N/s). The samples produced by second procedure (A3 and A4), which involved the incorporation of the raw materials one at a time in the beating vegetable or dairy cream presented a higher density associated with a less aerated structure and showed also a higher relaxation and higher relaxation work, respectively.

Table 2.

Texture parameters of aerated confectionery samples

Texture parameters / Sample		A1	A2	A3	A4
Hardness - H	[N]	1.92	2.7	4.38	4.680
Total mechanical work - Wt	[$\cdot 10^{-3}$ J]	11.56	10.37	23.28	19.830
Elastic mechanical work - We	[$\cdot 10^{-3}$ J]	0.771	1.703	2.053	3.348
Modulus of deformability - Ed	[KPa]	6.406	9.009	14.614	15.615
Relaxation - R	[N/s]	0.0049	0.0068	0.0099	0.0111
Relaxation work - Wr	[N·s]	233.5	339.6	574.6	607.8

Pearson Correlation. Table 3 shows the Pearson correlation matrix between physico-chemical properties and stress – relaxation texture parameters of confectionery samples. As regarding the physico-chemical properties a negative Pearson correlation was recorded between fat and protein content (r = -0.996**) and also between fat content and Brix concentration (r = -0.956*). The specific volume of the aerated samples was negatively correlated with dry matter (r = -0.956*) and density (r = -0.988**). Another correlation was observed between dry matter and density (0.931*). According to Pearson correlation matrix the stress-relaxation texture parameters are highly positively connected between them (hardness with modulus of deformability, relaxation and relaxation work; elastic mechanical work being correlated with relaxation). The samples' hardness was highly positively influenced by the dry matter content (0.943*) and density (0.997**); agreeing with *Fontana, 2005* [17], while the specific volume had a negative effect on this texture parameter (r = -0.982**). Furthermore, the dry matter content positively influenced the We, Ed, R and Wr values and density was correlated with Ed, R, Wr and Wt. Another Pearson correlation was recorded between specific volume and Ed, R and Wr stress-relaxation texture parameter.

Table 3.

Pearson correlation between physico-chemical and texture parameter.

	P	F	DM	B	a_w	D	Sv	H	Wt	We	Ed	R	Wr
P	1	-0.996**	-0.598	0.970*	0.216	-0.271	0.385	-0.298	0.143	-0.619	-0.298	-0.371	-0.286
F		1	0.659	-0.956*	-0.124	0.342	-0.447	0.372	-0.068	0.687	0.372	0.445	0.360
DM			1	-0.417	0.588	0.931*	-0.956*	0.943*	0.705	0.971*	0.943*	0.966*	0.939*
B				1	0.339	-0.057	0.166	-0.093	0.350	-0.479	-0.094	-0.175	-0.080
a_w					1	0.767	-0.659	0.785	0.881	0.629	0.785	0.763	0.785
D						1	-0.988**	0.997**	0.914*	0.867	0.997**	0.988**	0.998**
Sv							1	-0.982**	-0.853	-0.875	-0.982**	-0.978*	-0.982**
H								1	0.900	0.897	0.999**	0.996**	0.999**
Wt									1	0.631	0.900	0.860	0.906*
We										1	0.897	0.933*	0.889
Ed											1	0.996**	0.999**
R												1	0.994**
Wr													1

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed). Protein - P, Fat -F, Dry matter DM, Brix concentration - B, Water activity- aw, Density - D, Specific volume - Sv, Hardness - H, Total mechanical work - Wt, Elastic mechanical work - We, Modulus of deformability - Ed, Relaxation - R, Relaxation work - Wr.

4. Conclusion

The analyzed aerated confectionery products presented both elastic and viscous behavior, respectively a viscoelastic solid behavior, with a decrease of load during time. The A2 and A4 samples based on dairy cream presented the highest fat content, while the highest soluble substances concentration was recorded by the vegetable cream aerated samples (A1 and A3); the ANOVA factorial analysis showed a significant difference ($P < 0.001$). The stress -relaxation texture parameters of aerated confections were influenced by the amount of air fixed into the product structure (density) and also by dry matter content. As regarding the samples preparation the one step ingredients' incorporation procedure introduced and fixed a larger amount of air, resulting in a decrease of density, a more fragile texture and also a decrease of relaxation and relaxation work.

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