The impact of addition of xanthan gum and guar gum on rheological properties of foams produced by continuous method

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Abstract: The paper presents the effect of the addition of hydrocolloids – xanthan gum and guar gum – on the rheological properties of ovoalbumin-based food foams, produced by continuous method. The foaming was carried out in a column apparatus with additional aeration equipped with a paddle stirrer. In order to determine the rheological parameters, a hysteresis loop test was carried out. The results of the study were described using the Ostwald-de Waele equation. The effect of the addition of hydrocolloid on the rheological properties of the obtained foams was characterized, and the synergistic effects between the hydrocolloids used were described.

Keywords: food foams, xanthan gum, guar gum, rheology.

Wpływ dodatku gumy ksantanowej i gumy guar na właściwości reologiczne pian wytwarzanych metodą ciągłą

Streszczenie: Zbadano wpływ dodatku hydrokoloidów – gumy ksantanowej i gumy guar – na właściwości reologiczne wytwarzanych metodą ciągłą pian spożywczych na bazie albuminy jaja kurzego. Spienianie prowadzono w zaopatrzonym w mieszadło łopatkowe aparacie kolumnowym z dodatkowym napowietrzaniem. W celu określenia parametrów reologicznych wykonano test pętli histerezy. Wyniki badań opisano z zastosowaniem równania Ostwalda-de Waele. Scharakteryzowano wpływ dodatku hydrokoloidu na właściwości reologiczne otrzymanych pian oraz opisano efekty synergistyczne użytych hydrokoloidów.

Słowa kluczowe: piany spożywcze, guma ksantanowa, guma guar, reologia.

Aerated systems are an increasingly large group of food industry products. They constitute an important line of confectionery, dairy, meat and gastronomic products [1, 2]. One of the substances used as the basis for the production of foams is albumin [3]. It is the most important protein in the chicken egg and belongs to the family of globular single-chain proteins [4]. Food foams made on the basis of albumin show low mechanical strength [5] and thermodynamic instability [6]. The improvement of foam stability and strength can be obtained by increasing the viscosity of the continuous phase, which in practice means the addition of various hydrocolloids [7]. One of the most popular hydrocolloid used in food industry are xanthan gum and guar gum, used as thickeners, structure stabilizers and gelling agents [8]. Xanthan gum is a high molecular weight polysaccharide secreted by the microorganisms and produced in fermentation processes. The structure of xanthan gum consists of a cellulosic backbone of β-(1,4) linked D-glucose units. This food additive is used in production of sauces, bakery goods, ice creams and desserts [8]. Guar gum is a vegetable gum derived from guar plant seeds. This gum belongs to the galactomannans group, composed of linear (1-4)-β-D-mannan chains with single D-galactose units linked to the main backbone by (1-6)-α-glycosidic bonds to the 4,6-mannose units. Guar gum is used in the cosmetic, textile, food and chemical industries [8]. In aqueous solutions based on these gums mixtures, synergistic effect can be observed [8, 9]. A traditional and still widely used in the industrial practice method of obtaining foams is conducting operations in devices with periodic vessels. However, continuous methods, using aerated static mixers or columns equipped with stirrers, are gaining more and more recognition due to: high production ef-

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ficiency, small dimensions of devices, uniform shear and lower energy consumption [10, 11].

The aim of this work is to investigate the effect of xanthan gum and guar gum addition on rheological properties of foams based on ovoalbumin, produced by continuous method.

EXPERIMENTAL PART

Materials

The research was carried out using foam bases in the form of 9 % aqueous solution of ovoalbumin (ALB; Ovopol, Poland) with a 1 % addition of selected food hydrocolloids, such as xanthan gum (XG; Regis Food Technology, Poland) and guar gum (GG; Regis Food Technology, Poland), occurring in various mass proportions.

Solutions foaming

The prepared solutions were foamed using a continuous method in a column apparatus equipped with instruments enabling the regulation of the flow rate and air pressure, the rotational speed of the peristaltic pump and the rotational speed of the agitator (Fig. 1).

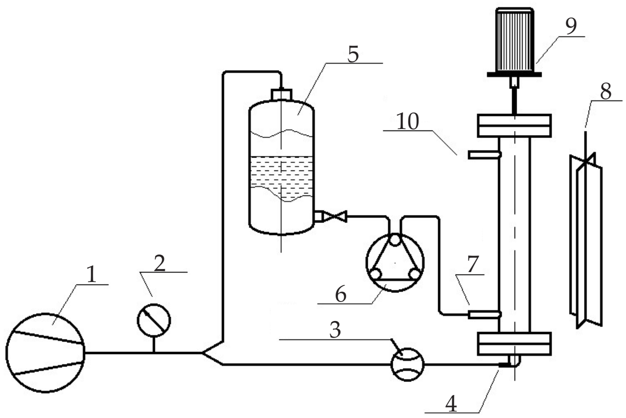

Fig. 1. The foaming system diagram: 1 – compressor, 2 – manometer, 3 – flowmeter, 4 – gas inlet, 5 – liquid tank, 6 – peristaltic pump, 7 – liquid inlet, 8 – paddle stirrer, 9 – engine, 10 – foam outlet

The column was equipped with a close-clearance paddle stirrer. The operation was carried out under the following conditions: air flow rate 10 dm^3/min, air pressure 0.07 MPa, pump speed 2 rpm, rotational speed of the stirrer 1200 rpm.

Methods of testing

The foams were subjected to rheometry tests using a Haake RS6000 rotational rheometer with a cone-plate measuring system, with 2 degrees cone angle. A hysteresis loop test was carried out in the shear rate range of 0–300 s^{-1}, during 1200 s. The data obtained in rheometry measurements were used to determine the parameters of the Ostwald-de Waele equation for the flow curves related to the increase and decrease of the rotational speed of the rheometer sensor, according to the equation [12]:

$$\tau = K\dot{\gamma}^{n} \tag{1}$$

where: τ – shear stress [Pa], $\dot{\gamma}$ - shear rate [s^{-1}], K – consistency coefficient [Pa · s^n], n – flow behavior index [-].

RESULTS AND DISCUSSION

The results of the rheological analyzes carried out for the produced foams are shown in Fig. 2.

The highest values of shear stress (and also apparent viscosity) are characteristic of a system containing only guar gum (ALB 9% + GG 1%). The lowest values of this parameter were observed for a system containing 0.66 % xanthan gum and 0.33 % guar gum (ALB 9% + XG 0.66% + GG 0.33%). In the case of foam containing 0.66 % xanthan gum, viscoelastic features are also clearly visible. These effects are also found in a system containing xanthan gum and guar gum in identical proportions (ALB 9% + XG 0.5% + GG 0.5%), however, they are much weaker. The shapes of the flow curves of the analyzed foams are characteristic for shear thinning systems. The hysteresis loop patterns of the analyzed systems indicate the occurrence of the phenomenon of thixotropy.

In order to more accurately characterize the rheological properties of the studied food foams and the changes of these properties over time, the values of the parameters of the power law equation were calculated. The results of calculations are presented in Table 1.

For all investigated systems, the value of the consistency coefficient decreased as a function of time. This change can be related to the destruction of the structure of shearable media, which is characteristic for thixotropic

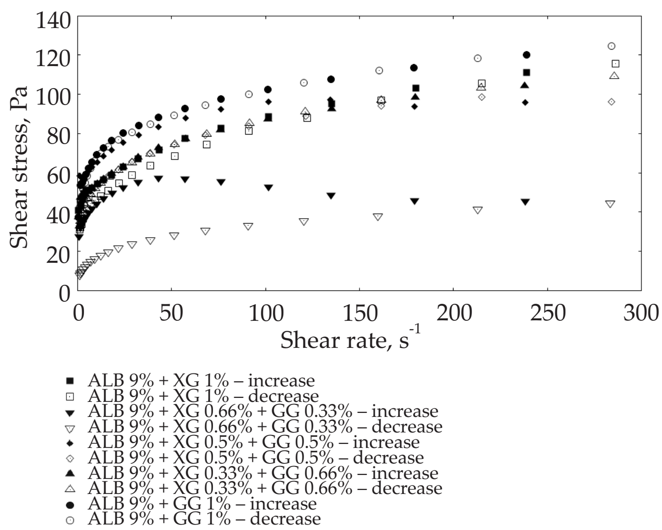

Fig. 2. Hysteresis loops for investigated foams

T a b l e 1. The values of power law equation for investigated foams

Foam	Rotational speed increase		Rotational speed decrease		ΔK, %	Δn, %
	K	*n*	*K*	*n*		
ALB 9% + XG 1%	35.92	0.20	26.15	0.25	-23	+25
ALB 9% + XG 0.66% + GG 0.33%	35.69	0.08	8.23	0.31	-77	+287
ALB 9% + XG 0.5% + GG 0.5%	51.71	0.12	33.13	0.20	-36	+66
ALB 9% + XG 0.33% + GG 0.66%	37.87	0.18	31.66	0.22	-16	+22
ALB 9% + GG 1%	47.11	0.17	42.01	0.19	-11	+12

systems. The highest change in this parameter was observed for the system with the addition of 0.66 % xanthan gum. Flow behavior index values for each foams are characteristic of strongly shear thinned systems. As a function of time, a decrease in the deviation of rheological behaviors of the described systems from the Newton law was also observed. Apparently this change was visible again for the system with the addition of 0.66 % xanthan gum. The data presented in Table 1 can also be interpreted as follows: an increase in the guar gum concentration in the system results in a favorable increase in viscosity and rheological stability, while increasing the xanthan gum concentration will result in a decrease in viscosity with simultaneous increase in time-dependent phenomena. Differences in rheological behavior of both hydrocolloids can be explained by comparing the structure of their solutions. Guar gum forms superstructures/aggregates which are the results of segment-segment interactions of the mannose backbones [13]. Whereas, xanthan gum forms a complex network of entangled rod-like molecules, which are more vulnerable to disruption under shearing [8].

The synergistic effects between xanthan gum and guar gum were found for the foam containing an equal mass addition of these hydrocolloids. These effects are caused by associations formed between galactose-free region in the mannose backbones and xanthan helices. Another important factor is a molecular weight of the guar gum, directly correlated to synergy with xanthan gum in terms of viscosity and elasticity [8]. In the system included equal masses of analyzed gums was achieved the optimal proportion between described association factors.

Analysis of the literature showed differences between the obtained experimental data and data provided in the literature, for example in the works [8, 9, 14]. These differences are caused by the different medium types with the addition of xanthan gum and guar gum (*e.g.*, aqueous solutions, doughs, two-phase model systems, foams) and methods of their preparation (in vessels or by continuous methods).

CONCLUSIONS

One of the methods to improve foam stability is to increase the viscosity of the continuous phase. This effect can be obtained by selecting the right composition of the base solution or by using various thickening agents. These substances, including xanthan gum and guar gum, are characterized by different rheological behavior, resulting in a change in the properties of the final products. Food foams containing xanthan gum and guar gum produced by the continuous method are characterized by rheological properties specific for shear thinning systems. In addition, such foams show thixotropy and viscoelastic properties. The synergistic effects between these hydrocolloids depend on the mass proportions of these hydrocolloids in the base solution. The presented research results can be used in practice – can help food technologists involved in the production of foams in the selection of the raw material composition in order to obtain a product with the highest stability.

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REFERENCES

[1] Balerin C., Aymard P., Ducept F. *et al.*: *Journal of Food Engineering* **2007**, *78*, 802. https://doi.org/10.1016/j.jfoodeng.2005.11.021

[2] Narchi I., Vial Ch., Djelveh G.: *Food Hydrocolloids* **2009**, *23*, 188. https://doi.org/10.1016/j.foodhyd.2007.12.010

[3] Abu-Goush M., Herald T.J., Aramouni A.M.: *Journal of Food Processing and Preservation* **2010**, *34*, 411. https://doi.org/10.1111/j.1745-4549.2008.00284.x

[4] Tankovskaia S.A., Abrosimova K.V., Paston S.V.: *Journal of Molecular Structure* **2018**, *1171*, 243. https://doi.org/10.1016/j.molstruc.2018.05.100

[5] Li X., Pizzi A., Cangemi M. *et al.*: *Industrial Crops and Products* **2012**, *37*, 149. https://doi.org/10.1016/j.indcrop.2011.11.030

[6] Indrawati L., Wang Z., Narsimhan G. *et al.*: *Journal of Food Engineering* **2008**, *88*, 65. https://doi.org/10.1016/j.jfoodeng.2008.01.015

[7] Thakur R.K., Vial C., Djelveh G.: *Journal of Food Engineering* **2003**, *60*, 9. https://doi.org/10.1205/026387603770866227

[8] Imeson A.: "Food Stabilisers, Thickeners and Gelling Agents", Wiley-Blackwell Publishing, 2010, ISBN 978-1-4051-3267-1.

[9] Martin-Alfonso J.E., Cuadri A.A., Berta M. *et al*.: *Carbohydrate Polymers* **2018**, *181*, 63.
https://doi.org/10.1016/j.carbpol.2017.10.057
[10] Laporte M., Della Valle D., Loisel C. *et al*.: *Food Hydrocolloids* **2015**, *43*, 51.
https://doi.org/10.1016/j.foodhyd.2014.04.035
[11] Nicorescu I., Vial C., Loisel C. *et al*.: *Food Research International* **2010**, *43*, 1585.
https://doi.org/10.1016/j.foodres.2010.03.015
[12] Dziubiński M., Kiljański T., Sęk J.: „Podstawy teoretyczne i metody pomiarowe reologii", Wydawnictwo Politechniki Łódzkiej, 2014, ISBN 978-83-7283-641-0 (in Polish).
[13] Szopinski D., Luinstra G.A.: *Carbohydrate Polymers* **2016**, *153*, 312.
https://doi.org/10.1016/j.carbpol.2016.07.095
[14] Mardani M., Yeganehzad S., Ptichina N. *et al*.: *Food Hydrocolloids* **2019**, *93*, 335.
https://doi.org/10.1016/j.foodhyd.2019.02.033

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