TECHNOLOGICAL ASPECTS OF THE RESULTS ON RHEOLOGICAL STUDIES OF CANDY MASS

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Abstract

The aim of the research was to study the rheological behavior of candy mass depending on recipes in order to optimize technological regimes for processes of tempering and molding products with specified structural and mechanical properties. The objects of the study were fondant, jelly and whipped semi-finished products made according to the classical recipes and with application of vegetable powders and phytonutrients. According to the research results, the effect of dosing and dispersion of phytonutrients and vegetable powders on candy mass viscosity at different temperatures and strain rates allowed to develop recommendations for selecting modes of thermomechanical processing of fondant and jelly masses at the stage of tempering and molding.

It was found that the nature of changes in plastic strength of semi-finished products depends on regimes of structure formation and influence of plant additives on this process. The research showed that powder additives contribute to significant reduction in the duration of structure formation.

The paper also studies the effect of phytonutrients and vegetable powders on the strength of adhesive contacts between the layers of candy mass in forming multilayered confectionery products. Defined interval of strength values of adhesive contacts allows to prevent delamination and to formulate the main requirements for the conditions and methods for molding candies with a combined body.

The obtained results of complex rheological studies make it possible to implement the evidence-based approach to the management of technological processes of confectionery products manufacture and ensure the achievement of specified technological and consumer characteristics.

Keywords: rheology, adhesion, candy mass, phytonutrients.

Introduction

Rheological and structure-mechanical characteristics are important indicators of the properties of the candy mass as a semi-finished product coming to further process steps, as well as determine the structural and mechanical characteristics of the finished product. Investigation of adhesion properties allows to evaluate the possibility of using various molding methods or fusion of different physico-chemical and rheological properties of the candy mass for making combined products.

Currently the enrichment of confectionery products with various additives increasing their quality, improving organoleptic and structure-mechanical characteristics of the finished product has become very common, as it allows meeting the human need for biologically active substances. Great contribution to the development of scientific bases of confectionery production using herbal additives were made by famous scientists in this scientific area: Aksenov, Koryachkina, Magomedov, Obolkina, Savenkov, Skobelskaya, etc. In this regard, it is necessary to conduct a thorough rheological study of semi-finished products with the addition of non-traditional raw materials in candy recipes and structure-mechanical characteristics of candies produced from them. The aim of the research is to validate the modes of candy production using the rheological and structural and mechanical properties of semi-finished products.

Materials and Methods

The objects of the study were samples of fondant, jelly and whipped mass and candies made on their basis according to classic recipes, as well as with the addition of vegetable powders (pumpkin, carrot) and medicinal-technical raw materials (nettle leaves, lemon balm, raspberry) of various concentration and dispersion. Herbal additives used in the form of powder, hydrated powders (puree) and water-alcoholic extracts.

The study of rheological properties of semi-finished products and structure-mechanical characteristics of candy bodies were performed on viscotester HAAKE VT6R plus (Thermo Fisher Scientific, Germany) and texture analyzer Brookfield CT-3 (Brookfield Engineering laboratories, inc., USA) equipped with a wide range of sensors, devices and accessories to meet the challenges associated with the analysis and measurement of texture. Detailed description of methods for analysis of raw materials, semi-finished and finished products is given in (Смолихина, 2013).

Results and Discussion

Studying rheological properties of investigated candy mass has shown that, irrespective of the recipe, they belong to pseudoplastic materials. In a wide range of shear rates 0–100 s^{-1} the flow of the fondant mass is well approximated by the equation of Herschel-Bulkley, while the jelly and whipped mass satisfies the equation of Ostwald de Waele. In all cases, the rheological curves are well approximated by a linear function over a fairly wide range of shear rates (by a factor of no less than 0.98 approximation), which explains the choice and use of these rheological equations.

The curves of changes in viscosity versus shear rate have a form that is characteristic of structured systems. The viscosity decreases when the shear rate is increasing and especially fast in the range of relatively low shear rates, while the further increase in rate varies viscosity slightly. This rheological property is explained by the fact that in a stationary environment the arrangement of the particles is characterized by strong randomness, and under the influence of increasing shear forces the orientation of the particles in the flow direction is raising. Increasing the rate leads to decreasing the interaction between particles. Tests were conducted at temperatures typical of molding for this candy mass (Fig. 1).

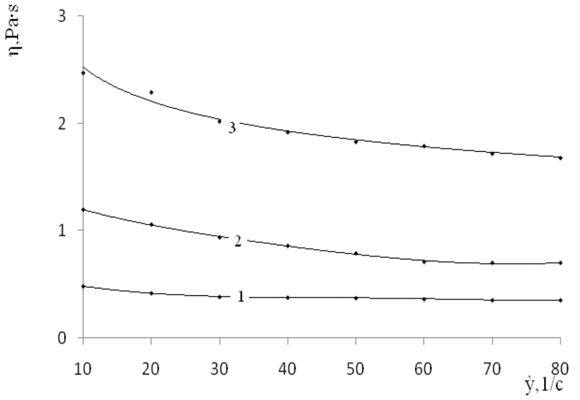


Figure 1. Dependence of the candy mass viscosity on shear rate

1 – jelly mass (85 °C), 2 – fondant mass (70 °C), 3 – whipped mass (50 °C)

The viscosity of the whipped mass is five times higher than jelly mass and twice than fondant mass that is due to the presence in the system of a surfactant adsorbed and coagulated to egg protein films forming strong bonds and large amounts of air phase.

Thus, adding dry powder from 2 to 10% (dispersity of 0.14–0.25 mm) into the whipped mass increases the viscosity in 3–10 times, hydrated – in 3.5–11.0 times. The used additives have high adsorption and water-holding capacity, therefore when mixed with the candy mass they swell and form a spatial grid with strong intermolecular bonds. This leads to the "expansion" of the system which causes the reduction in thickness of dispersion environment layers and increase of resistance force, and, accordingly, significant increase in viscosity (Fig. 2). A stronger effect of the hydrated powders, besides the phenomena described above, may be connected with the restoration of powder polymeric structures during its hydration and the dissociation of organic amino acid capable of participating in the jelly forming process which leads to hardening of the mass structure and a high viscosity, respectively.

Adding powdered vegetable semi-finished products of different dispersion into the candy mass significantly changes the rheology of semi-finished products.

Decreasing the size of nettle powder particles results in increasing the viscosity of candy mass (Fig. 3).

According to the results of studies on rheological properties temperature modes for specific stages of candy production were set (Table 1) (Муратова et al., 2008, 2009).

Plastic strength of candy bodies is a key indicator for characterizing the form retention quality. Changes in strength can show the process of structure formation the rate of which is of great importance for selecting regimes for structure formation process of candy mass (Muratowa, Smolikhina, 2013; Смолихина, Муратова, 2013).

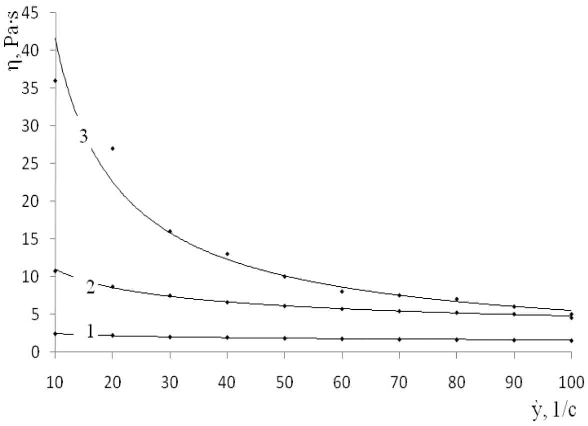


Figure 2. Dependence of the whipped mass viscosity on deformation rate

1 – control; *2, 3* – with the addition of 5% dry and 5% hydrated vegetable powder respectively

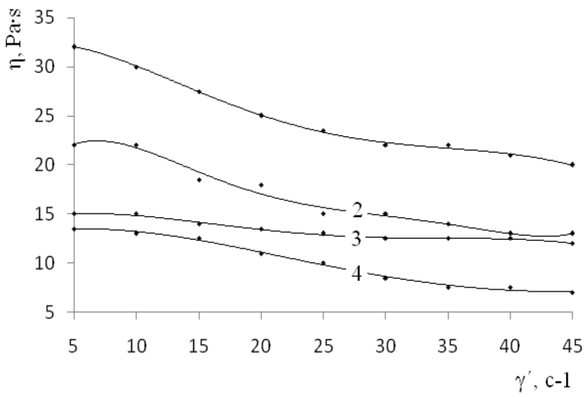


Figure 3. Dependence of the fondant mass viscosity on the shear rate for different dispersion of the nettle powder

1 – 0.08–0.14 mm; 2 – 0.14–0.2 mm; 3 – 0.2–0.25 mm; 4 – 0.25–0.5 mm

Table 1

Temperature modes for specific stages of candy production

Candy mass	Production stages		
	Whipping	**Tempering**	**Forming**
Control			
Fondant	65–75 °C	70–75 °C	65–70 °C
Jelly	–	85–95 °C	75–90 °C
Whipped	55–65 °C	–	45–55 °C
New recipe			
Fondant	75–85 °C	85–95 °C	80–85 °C
Jelly with the			
extract	–	80–85 °C	75–80 °C
powder	–	85–95 °C	95–105 °C
Whipped		–	

The analysis of experimental studies about the effect of functional ingredients on the process of jelly mass formation showed that the use of powder reduces the plastic strength of jelly by 22% (Fig. 4).
Introduction of vegetable powders at the tempering stage of the jelly mass leads to destruction of the jelly monolithic and formation of uneven structure. Polysaccharides of powders that have high sorption properties violate hydrostatic equilibrium while absorbing moisture from the system the result of which becomes an irregular jelly body.

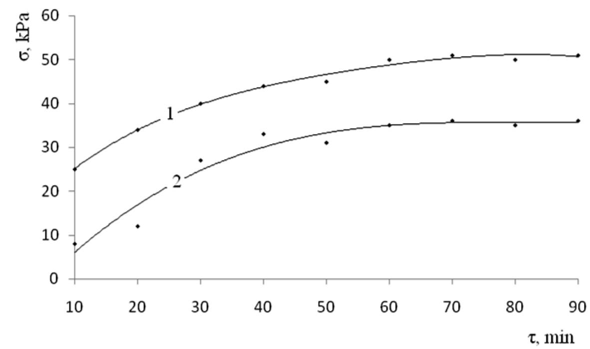
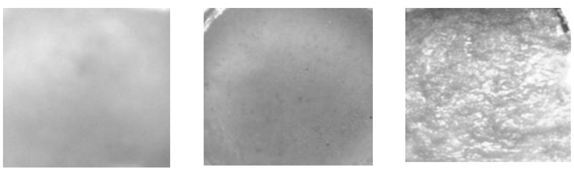


Figure 4. Changes in the jelly plastic strength during structure formation process

1 – control, 2 – with the addition of 0.5% pumpkin powder

Introduction of vegetable powders at the tempering stage of the jelly mass leads to destruction of the jelly monolithic and formation of uneven structure. Polysaccharides of powders that have high sorption properties violate hydrostatic equilibrium while absorbing moisture from the system the result of which becomes an irregular jelly body.
When introducing the functional additives with pectin at the syrup preparation stage we can see the maximum dissolving and swelling of the polysaccharide powder. The formed jelly surface is smooth, on the fracture it is glassy with even distribution of insoluble fiber parts (Fig. 5).



a) b) c)

Figure 5. Jelly mass with the addition of vegetable powders 3%

a – control, b – at the stage of syrup production,
c – at the tempering stage

The strength of whipped jellies with the use of powdered semi-finished products, on the contrary, increases due to the combined action of agar molecules and pectin substances presented in vegetable powders in large quantities. Thus, the hydrated powder increases the strength 2.0 fold, the dry powder – 8.0 fold. When using hydrated powder the whipped mass strength increases owing to additional filling of the space frame surrounding the bubbles with swollen fibers of the vegetable powder. Gelation occurs within 40 minutes after casting at a temperature of 20–22 °C, but a large amount of swollen polysaccharides makes the mass aqueous and prone to syneresis.
In samples containing dry powder syneresis is avoided by narrowing the channel, increasing the roughness of the walls and forming local „gates” from the particles not adhered to the bubbles (Зубченко, 2001). However, the presence of solid particles may have the opposite effect: they may undergo the adsorption of surfactants and the concentration decrease of surfactants in the solution leads to the increase of the surface tension and decrease of the foam dispersion, whereby the syneresis speed can be boosted.
Factors affecting the rate of fondant mass structuring are the ratio of solid and liquid phases, the presence of large crystals, the concentration and dispersion of functional additives, and body temperizing modes. The rate of fondant mass structuring can be judged by the increase in the limit shear stress (Горбатов et al., 1982).
For classical fondant mass at low temperatures (70–75 °C) the limiting shear stress raises dramatically in a short period of time which indicates a high rate of sucrose crystallization. A high degree of supersaturation of the solution leads to intensive crystallization of sucrose not only on the surface but also in internal layers of the body. Structuring process in the mass casting with temperature of 95 °C is slower and the mass cast at temperature of 100 °C reaches normal consistency (critical shear stress of 30–40·103 N m^{-2}) after 3 hours of structure formation process (Зубченко, 1986).
The structure formation process of the fondant mass can be traced according to increase in the strength of the structure of candy body. Figure 6 shows the dependence of the strength of the fonadant sample on the depth of the indenter.

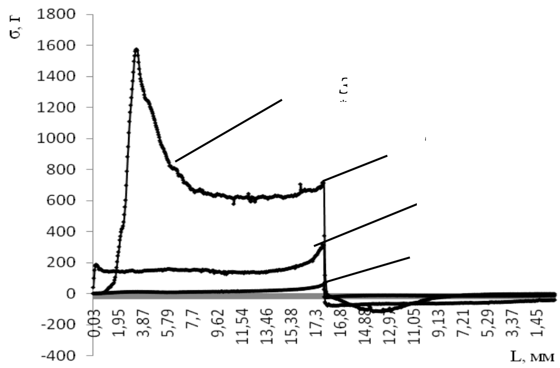


Figure 6. Changes in the consistency of the fondant mass in the process of structuring after casting in

1 – 15 min, 2 – 35 min, 3 – 60 min.

On the surface of the semi-finished product there is a dense crystalline crust formation the hardness of which increases during the first hour (up to 1600 g), and after two hours of temporizing the thickness reaches 2.5 mm. Inside the formed body there is thick mass

with large crystals of sucrose (the presence of crystals characterizes the presence of peaks within curve) (section 3*). In the crystallization process the adhesion of samples decreases to stainless steel.
In 2.5–3 hours of structure formation process at ambient temperature of 23–25 °C the candy body has a solid crystalline structure with the strength $4 \cdot 10^3$ g (Fig. 7).
The study on adhesive properties of the candy mass helps to evaluate the possibility of using various molding techniques for the manufacture of candy bodies.
The violation of production modes, moisture migration between the layers and syneresis during the storage leads to weakening of the adhesive interactions and changing in structural and mechanical characteristics of the products.

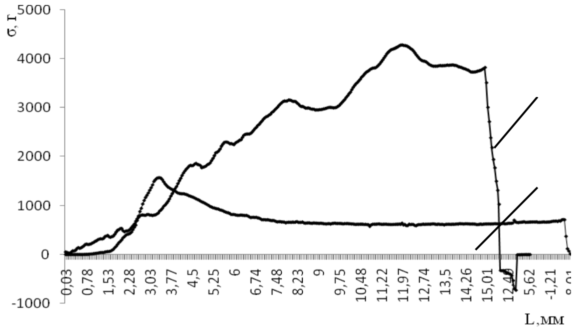


Figure 7. Changes in the consistency of fondant mass in the process of structuring in
1 – 15 min, 2 – 60 min

While forming the adhesive bonding through the combination of jelly and whipped semi-finished products in the combined body, highly viscous masses come into contact. In this case, for describing the process of contact formation rheological characteristics of the adhesive and the terms of the contact become important depending on the method of molding semi-finished products.
The molding of combined jelly-whipped candies can be produced with methods of co-extrusion, smearing followed by cutting, and casting.
The practice of molding by co-extrusion method showed that for each production it is necessary to make corrections of technological modes taking into account the constructive features of the molding equipment, or using them for combining confectionery masses close by rheological characteristics and having thixotropic properties (Оболкина et al., 2008).
The formation of candies by casting and smearing minimizes mechanical effect on the formable candy mass which does not destroy their structure and reduces the residual stress at the phase boundary. The smearing method allows to make multilayer products, but in the process of cutting there may be possible violations of structures, displacement of the layers due to their deformation (Fig. 8).

Figure 8. Adhesion failure in forming combined bodies by smearing and cutting methods

The formation of jelly-whipped candies was performed by the smearing method followed by cutting and casting. The ability to control rheological properties of the jelly mass by changing the temperature at the molding stage is a determining factor in the choice of jelly layer as the top. When the temperature is increased, the viscosity of the jelly mass decreases non-linearly with average increase of temperature by 1 °C per 0.01 Pa·s (Леонов, Муратова, 2011). At low viscosity the liquid adhesive wets the surface of the substrate providing a flawless full contact with the whipped mass with the maximum filling of micropores on the surface, but there is a formation of adhesive interaction and hardening of adhesive contact. However, even in this case, the adhesive strength of the contact is insufficient to prevent full separation of the structure by mechanical action on the semi-finished product during cutting the layer obtained by smearing or during removing candy bodies made by the method of casting to the starch forms (Fig. 9).

Figure 9. Mixed destruction of adhesive compound in forming combined candy bodies by smearing and cutting methods

When adding vegetable powders in the whipped layer in the amount of less than 2%, the adhesive strength between the layers of the body does not differ significantly from indicators obtained for the combined bodies without additives. Introducing powders into the whipped layer in the amount more than 10 wt. % leads to excessive development of microrelief which adversely affects the achievement of maximum contact area: a large number of connections reduces the mobility of macromolecules in the boundary layer, increases internal pressure, changes the structure of the surface layer, which results in defective areas that serve as centers where the destruction of adhesive compounds begins (Зимон, Евтушенко, 2008; Смолихина, Муратова, 2012). The maximum adhesion between the layers of candy mass is attained by adding vegetable powders in the whipped layer in the amount of 5–10 wt.%, in the jelly layer – less than 3%, while the strength of adhesion contacts increases by more than 30% compared to control samples (Fig. 10 and 11).

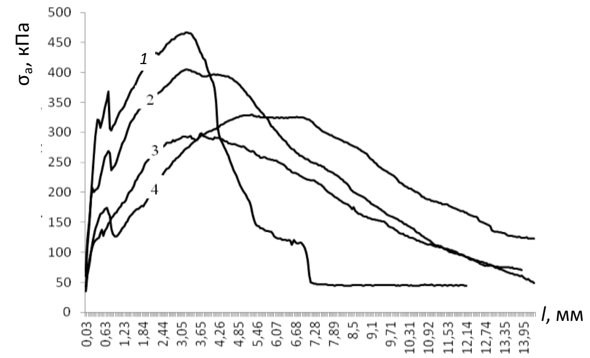


Figure 10. Dependence of adhesive contacts strength on the depth of separation with the powder in the whipped mass and molding temperature of the jelly layer

1 – 5%, 105 °C; 2 – 5%, 95 °C; 3 – without powders, 95 °C; 4 – without powders, 105 °C

Figure 11. Cutting of combined candy bodies with 5% carrot powder in the whipped layer; 3% powder pumpkin in the jelly layer

Based on the above, it can be concluded that adding the carrot powder into the whipped mass allows to improve the contact area of the adhesive-substrate and to increase the adhesive connection strength due to the formation of a rough surface of the whipped mass and maximum filling of microdefects in the jelly mass. Moreover, the persistence of structural and mechanical properties of the whipped mass in the result of enhancing foam frame by rough fibers of the carrot powder provides the structuring capacity of the whipped layer and allows the operation of casting the jelly mass with density of 1350 kg m^{-3} at 45–60 minutes after the formation. Vegetable powders having high water-binding capacity absorb moisture from the candy mass surface to improve their adhesion to the combinable layer. Adding powders into the jelly mass reduces jelly strength and allows to change the adhesive tense on its surface which has a positive impact on the quality of the adhesive contact with the whipped mass (Смолихина, Муратова, 2013).

The studies have shown that during tests of control samples there is usually a mixed adhesive breaking, and that during tests of samples with the addition of vegetable powders the breaking is predominantly cohesive.

Based on the influence of phytonutrients dependencies on structural and mechanical characteristics of the fondant and whipped masses, the recommendations were made for the conditions and methods of molding (Table 2).

Table 2

Recommended methods of molding candy mass at different temperatures

Molding temperature, °C	Candy mass	
	Control	**New recipe**
Fondant mass		
>70	Casting followed by prolonged structure formation process	
40–70	Casting, smearing	Smearing, pressing
<25–40		
Whipped mass		
>60	Casting	
45–60	Casting, smearing	Smearing
30–45	Smearing	Smearing, pressing
25–30	Smearing	Settling, pressing
<25	Not recommended	

When the molding temperature is above 70 °C, the fondant structuring occurs after casting the bodies, thus the shear rate in the molding can be set arbitrarily. Temporizing of the bodies proceeds to a temperature of 20–22 °C for 35–40 minutes. Structuring process is characterized by the formation of crystallization centers with the addition of new molecules to the grid and proceeds spontaneously as it is accompanied by decreasing free energy of the system. When using the fondant mass as fillings at the temperature range of 40–70 °C, their supply to product bodies may be performed at any shear rate. While molding the fondant mass at temperatures below 40 °C in order to avoid destroying the structure of the mass, the shear rate should be less than the lowest critical rate, i.e. 25 s^{-1}.

Structuring occurs after casting of the whipped mass at high temperatures, so the shear rate during the formation process can be set arbitrarily. At temperatures below 60 °C the process of jelly formation begins, therefore the impact on the structure should be minimal. This requirement corresponds to the smearing method. For the temperature range of 30–45 °C the whipped mass made according to traditional recipes should be formed by smearing, while for the whipped mass with the addition of vegetable powders the pressing method can be used because the moulded products retain their shape well in the form of a slice. If the temperature is 25–30 °C the whipped mass with the addition of vegetable powders can be molded by settling. Thus molded product retains their shape well as the process of structure formation by the time of molding has largely been completed. To prevent the destruction of the mass structure during the molding the shear rate should be below the lowest critical rate, i.e. 30 s^{-1}.

Conclusions

Research results testify to operational parameters for candy mass forming which can be recommended for practical use in the candies production according to traditional recipes and adding powders and herbal extracts. It is found that rheological behavior in the range of shift rates studied is similar to mixture composition which contains powders of medicative, technical and vegetable raw materials characterized by similar parameters of water-retaining and adsorption capacities. Thus, the results gained could be recommended not only for candies production with above mentioned additives but also for using different herbal additives with the same physical and chemical properties.

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