Rheological properties of gel-like food products for athletes

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ABSTRACT

Introduction. One of the promising areas of diversification of food products for athletes is gel-like products. Gel-like products need to have stable rheological properties. The purpose of the article was to study rheological properties of gel-like products and how they are influenced by the ingredients and temperature.

Materials and methods. Gel-like products with thickeners: pectin (0.5 wt %) and xanthan gum (0.05-0.2 wt%) were analyzed. Viscosity of the samples was investigated by rotation measurements and limiting shear stress by extrapolation of $\eta=f(\tau)$ dependence to the value $\tau\to 0$.

Results. It was established that viscosity and limiting shear stress increase as the xanthan gum concentration in the gel-like food products is raised: addition of 0.05 wt% xanthan gum increases the viscosity of system on 38%, and 0.2 wt% − on 62%. Addition of acid causes a sharp decrease of viscosity and limiting shear stress of a system containing pectin because of acid hydrolysis process of pectin molecules, while for a system containing both pectin and xanthan gum rheological properties stay virtually unchanged as intermolecular bonds formed by xanthan gum are acid stable. Increase of the xanthan gum concentration in the system also decreases the influence of ambient temperature on the strength of the system: the strength of the system only with pectin decreases on 43% as the temperature is raised to 40°C, and with addition of 0.2 wt% xanthan gum – only on 9.4% as increasing of the xanthan gum concentration in the system contributes to the increase of intermolecular bonds number and their destruction requires additional energy. The results of the undertaken study can be used to develop formulations of gel-like food products for athletes.

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Структурно-механічні властивості драглеподібних продуктів для спортсменів

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Introduction

Sports nutrition makes a separate segment of the market that is growing actively. For now the world market of sports nutrition is estimated at 5 billion USD (it makes up over 3% of the total world's food production). In Ukraine this segment is developing as well and is estimated at 6 million UAH [1]. And there is room for further growth of the sports nutrition market as consumers are undeniably becoming more interested in improving their health and fitness. In addition to professional athletes general consumers are also entering the category as distribution of sports nutrition products becomes more mainstream. Among the 20 countries surveyed by the market analyst company Datamonitor, 28% of consumers overall were characterized as potential lifestyle users of sports nutrition products. Expanding markets and increasing demands, however, encourage manufacturers to develop new products that better meet customer needs [2].

To date sports nutrition is produced mainly in three forms: powders, bars and drinks [1]. One of the promising areas of diversification of food products for athletes is the development and implementation of gel-like products.

Sports competitions take place in different climate zones. Professional athletes can compete even at ambient temperature 35-38 ° C (with low humidity) [3−5]. As gel-like products intended for consumption directly during exercises, their properties should remain unchanged over a wide temperature range of storage and use.

The peculiarity of the gel-like products' formulation is the high content of organic acids (up to 2%) that are used not only as a flavoring, but also as functional additives.

In order to form a gel-like structure and prevent exfoliation of the product thickeners are used.

In a previous study [6], pectin was selected as the main thickener for gel-like products.

Pectin is a polysaccharide composed of galacturonic acid residues [7]. The viscosity of pectin solution depends on its concentration in the system, acid content and temperature [8,9]. Pectin is most stable in solutions with pH 4. In a more acidic environment hydrolysis of ester groups and glycoside bonds in the molecule and in alkaline − saponification of esters and cleavage of the main chain are observed [10]. An increase of temperature reduces the viscosity of the pectin solutions and the temperature higher than certain limit causes an irreversible decrease of viscosity due to dehydration of molecules [8]. Thus, introduction of the additional thickener to stabilize the properties of the product is necessary.

Xanthan gum is a polysaccharide which is produced by fermentation using the bacterium Xanthomonas campestris. The main chain of the polymer molecule is identical to cellulose and branches are the remains of molecules of glucose, mannose, glucuronic acid, pyruvate and acetyl groups. Xanthan gum solutions are resistant to enzymes, alcohols, surfactants, acids and alkalis, high (120°C) and low temperatures (up to -18°C) [9,11]. Due to the high thermal and acid stability of solutions, xanthan gum was chosen as additional thickener.

Study of ingredients' and temperature influence on the rheological properties of gel-like products enables to determine the suitability of such thickeners' combination and final formulation.

Purpose of the article is to study rheological properties of gel-like products.

In accordance with purpose the following objectives were put:

- to study rheological properties of gel-like products;
- to measure gel-like products' viscosity and limiting shear stress and its dependence on the content of xanthan gum;

- to establish dependence of the gel-like products' limiting shear stress on the content of organic acids;
- to establish the influence of ambient temperature on the change of gel-like products' limiting shear stress.

Materials and methods

To prepare the basic dry carbohydrate composition maltodextrin DE 7-13 and glucose (manufacturer Qingdao Century Longlive Int'l Trade Co., China), and fructose (manufacturer Meelunie BV, The Netherlands) in a ratio of 1:1:1 were used. In order to form a gel-like structure of product xanthan gum H1500 (manufacturer Foodchem International Corporation, China) and LM pectin NECJ-A3 (manufacturer Pektowin, Poland) were used. To change the acidity citric acid (manufacturer Ukroptbakaliya, Ukraine) was used. All samples were made with distilled water.

To prepare samples 1/10 part of the dry carbohydrate composition was mixed with thickeners. The water was heated to 85°C and mixed with the resulting blend, and then it was stirred until complete dissolution. The rest of the dry carbohydrate composition was gradually added to the formed gel-like mixture keeping up the same temperature. Samples were gently stirred until complete dissolution of the ingredients. Gel-like product was cooled at room temperature, continuing to stir during the first 5 minutes. To stabilize the structure samples were stored at room temperature for 24 h.

Mixing ratio in samples of gel-like product was as follows: dry carbohydrate composition 78%, thickeners 0.5-0.7 %, acid 0-2% and water 19,3-21,45 %.

Study of the rheological properties of the systems was carried out on a rotary viscometer VPN-0, 2M, size of the measuring unit - 20 mm. The principle of the viscometer [12] is that the sample is placed in a gap between two coaxial cylinders and while driving one of them the investigated system, which stuck to the walls of the cylinder, starts to move creating resistance. It is determined by the value that characterizes the speed of rotation. The viscosity is calculated using formula:

$$\eta = k \cdot U \cdot T \cdot A \quad (1)$$

where η - effective viscosity, *Pa·s*;

k - constant of the measuring unit, *Pa/V*;

U - voltage, *V;*

T - period of rotation, *s*;

A - shape factor of the measuring unit.

Shear rate is determined using formula:

$$\dot{\gamma} = \frac{1}{T \cdot A} \quad (2)$$

Shear stress is determined using formula:

$$\tau = k \cdot U \quad (3)$$

Limiting shear stress is determined by extrapolation of $\eta = f(\tau)$ dependence to the value $\tau \rightarrow 0$.

Results and discussions

On the first stage of the experiment concentration and shear rate dependence of viscosity in gel-like products was studied (Fig.1).

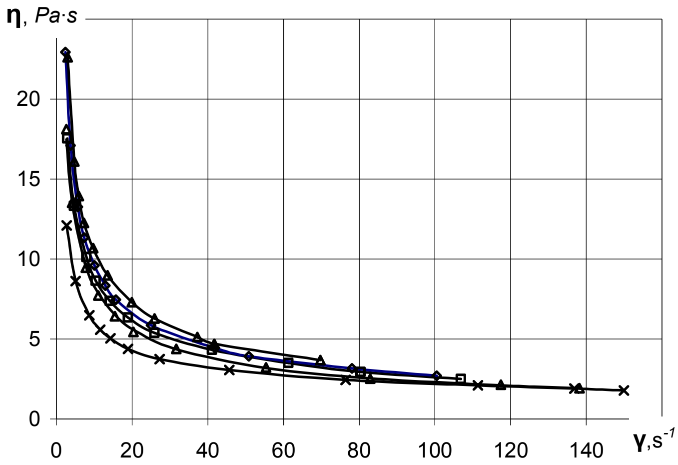

Fig.1. Shear rate dependence of the effective viscosity for gel-like products' samples with pectin (0.5%) and xanthan gum at concentrations:
× - 0%, □ - 0.05%, △ - 0.1%, ◊ – 0.15%, ▽ - 0.2%

The analysis of the viscosity/shear rate relation shows the formation of supramolecular coagulation structures in all systems. Viscosity decreases with increasing shear rate as shown by the data of Fig. 1 due to the destruction of supramolecular structures. The destruction of the structure occurs gradually, indicating a predominance of elastic strain in the system.

Fig. 2 shows the viscosity of the gel-like products at constant shear rate ($20s^{-1}$) that makes it possible to trace the impact of ingredients on their properties.

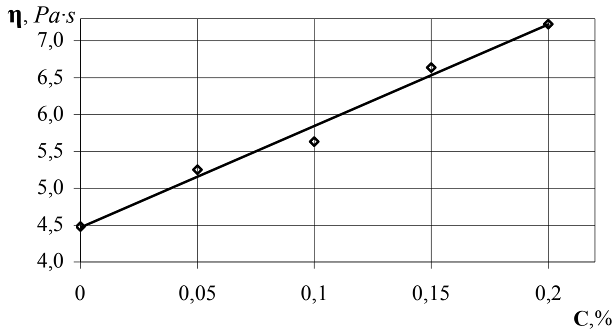

Fig. 2. Concentration dependence of viscosity for gel-like products' samples with pectin (0.5%) and xanthan gum at shear rate $20s^{-1}$

The analysis of the viscosity/concentration relation shows the viscosity increases as the xanthan gum concentration in the system is raised. Addition of 0.05% xanthan gum increases the viscosity of system on 38% (from 4.479 *Pa·s* to 6.184 *Pa·s*), and 0.2% - on 62% (to 7.227 Pa·s).

In order to establish the strength of the structure limiting shear stress for gel-like products' samples was also calculated (Fig. 3).

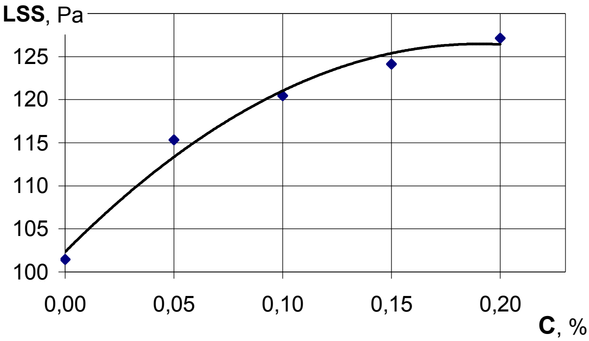

Fig.3. Concentration dependence of limiting shear stress for gel-like products' samples with pectin (0.5%) and xanthan gum

The analysis of the limiting shear stress/concentration relation shows the strength of the system also increases as the xanthan gum concentration in the system is raised. Addition of 0.05% xanthan gum increases the limiting shear stress on 13.7%, and 0.2% - on 25%.

On the second step of the experiment concentration and shear rate dependence of viscosity in gel-like products was studied (Fig. 4, 6).

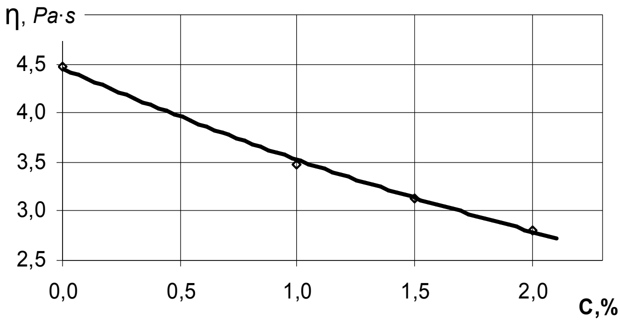

Fig.4. Concentration dependence of viscosity for gel-like products' samples with pectin (0.5%) and acid at shear rate 20s^{-1}

Fig.4 shows the addition of acid causes sharp decrease of viscosity of the gel-like product with pectin. Addition of 1% acid decreases viscosity of the system on 30%, and 2% − on 37%. Limiting shear stress of the system decreases similarly (Fig. 5).

Fig.5 shows the addition of 1% acid decreases strength of the system on 33%, and and 2% − on 47%. This can be explained by the acid hydrolysis process of pectin molecules in the system, and the conformational state of the molecules.

Fig.6 shows the addition of acid causes a minor decrease of viscosity of the gel-like product with pectin and xanthan gum. Addition of 1% acid decreases viscosity of the system only on 4.5%, and 2% acid − on 6%. Limiting shear stress of the system changes similarly (Fig.7).

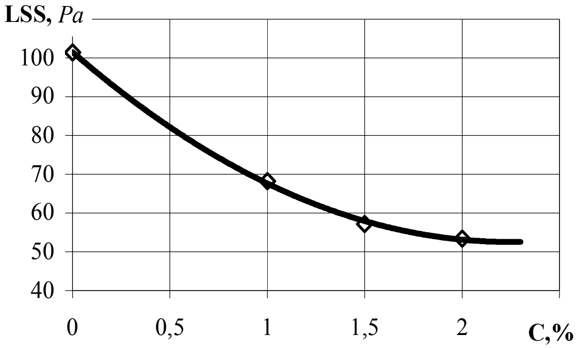

Fig.5. Concentration dependence of limiting shear stress for gel-like products' samples with pectin (0.5%) and acid

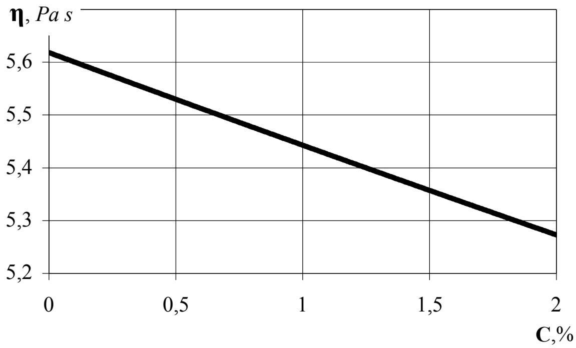

Fig.6. Concentration dependence of viscosity for gel-like products' samples with pectin (0.5%) and xanthan gum (0.1%) and acid at shear rate 20s^{-1}

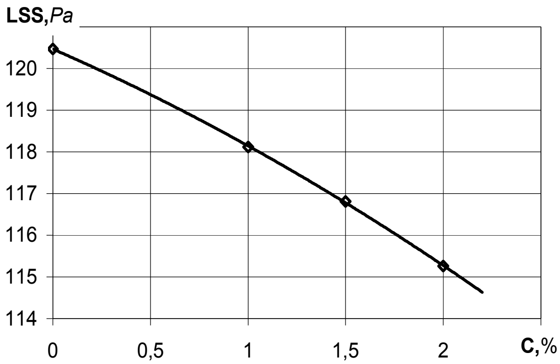

Fig.7. Concentration dependence of limiting shear stress for gel-like products' samples with pectin (0.5%) and xanthan gum (0.1%) and acid

Fig.7 shows the addition of acid also causes a minor decrease of viscosity of the gel-like product with pectin and xanthan gum (2% acid − on 4%). This can be explained by the acid stability of intermolecular bonds formed by xanthan gum.

On the next stage of the experiment ambient temperature dependence of limiting shear stress in gel-like products was studied (Fig.8).

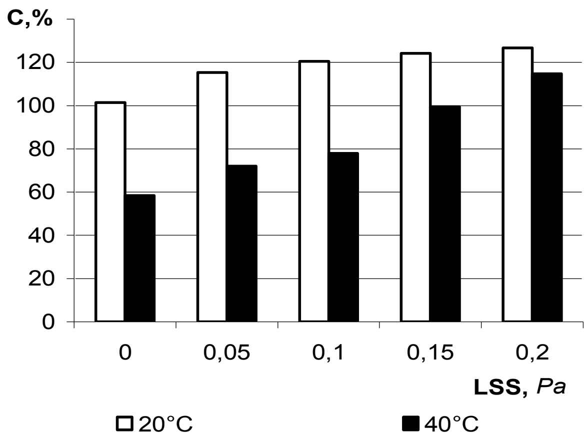

Fig.8. Ambient temperature dependence of the limiting shear stress for gel-like products' samples with pectin (0.5%) and xanthan gum

The analysis of the limiting shear stress/ambient temperature relation shows the strength of the system only with pectin decreases on 43% as the temperature is raised to 40°C compared to the limit shear stress at 20°C, limiting shear stress of the system with pectin and 0.05% xanthan gum decreases on 37%, 0.1% xanthan gum - on 35%, 0.15% xanthan gum – on 20%, and 0.2% xanthan gum – only on 9.4%. Thus, influence of ambient temperature on the strength of the system decreases as the xanthan gum concentration in the system is raised.

The analysis of the data shows that increasing of the xanthan gum concentration in the system contributes to the increase of intermolecular bonds number, most likely – hydrogen. Increasing of the thickener concentration leads to breaking of systems fusion, despite the low energy of hydrogen bond (20 kJ/mol), as their destruction requires additional energy.

Conclusions

Rheological properties of gel-like products were studied.

It was established that viscosity and limiting shear stress increase as the xanthan gum concentration in the system is raised.

It was established that addition of acid causes sharp decrease of viscosity and limiting shear stress of the gel-like product with pectin, while for system with pectin and xanthan gum rheological properties stay virtually unchanged.

It was established that influence of ambient temperature on the strength of the system decreases as the xanthan gum concentration in the system is raised.

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