Effects of mono- and disaccharides on fruit gel formation

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Keywords:

Fruit Gels
Gelation
Pectin
Sucrose
Fructose
Glucose

Article history:

Received
30.08.2022
Received in revised form
26.12.2022
Accepted
11.01.2023

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DOI:
10.24263/2310-1008-2022-10-2-7

Abstract

Introduction. The type of added sugar is important in the structuring of fruit gels. Effects of glucose, fructose or sucrose on fruit gel for their further use in confectionery technologies were studied.

Materials and methods. Formulations for fruit gels, which included applesauce, sugar and molasses, fruit stews and structured fruit gels, were used in the research. Rheological properties were determined on a rotary viscometer; gel-forming ability by the method of sensory evaluation; resilient and plastic properties by using a structurometer ST-1; amounts of free and bound moisture were estimated on a Q-1500 derivatograph.

Results and discussion. The higher values of the effective viscosity of studied recipe mixes at a temperature of 20±2 °C are characteristic of systems with glucose within the range of values of shear stress P=2.601-17.918, Pa. The lowest values are observed for prescription mixes with fructose, which is explained by different solubility of sugars. When the research temperature increased to 65±2 °C, the solubility of sugars and the relation between the viscosity curves were changed.

The highest values of effective viscosity are characteristic of mixes with sucrose, somewhat lower for mixes with glucose and fructose. At the same time, the strength of the internal structural framework formed, for the model mass with sucrose was 114.73 Pa, with glucose 23.12 Pa, and with fructose 35.0 Pa.

Fruit gels on sucrose and glucose are easily removed from the molds, do not stick, have a dry surface, that is, they are characterized by excellent gel-forming ability under the same cooking conditions. The gel on fructose is difficult to remove from the mold and it requires an increased time for gel formation. It has been shown that fruit gels withstand different loads before breaking: the required force to break a fruit gel with sucrose is 50 N, with glucose 35 N, with fructose 30 N.

According to derivatographic studies and calculations of the content of bound water in gels, a larger part of it was found for fruit gels with sucrose. This exceeds the indicator for the gel with glucose by 2.2%, and with fructose by 4.3%.

Conclusions. The gels with sucrose had higher values of effective viscosity compared to gels with identical amounts of glucose or fructose. The strength of fruit gels with sucrose was higher in terms of the force required to break the jelly, and the overall deformation was smaller. Additionally, gels with sucrose had a lower amount of free moisture.

Introduction

Fruit gels, the basis of fruit and berry marmalade, are one of the most valuable confectionery products with a rich vitamin and mineral complex (Konar et al., 2022; Wolf, 2016). The formation of fruit gel is carried out due to the association of pectin macromolecules of the fruit part of the recipe mixture of components, which is achieved by the formation of hydrogen bonds between non-dissociated carboxyl groups and secondary alcohol groups, as well as due to hydrophobic interactions of methyl ether groups (Nath et al., 2022; Zhang T. et al., 2021).

The presence of dehydrating substances in the solution is important for the formation of fruit gels. It reduces the solvation of pectin macromolecules and the structural formation of the gel framework occurs along the dehydrated areas of the pectin molecule (Chevalier et al., 2019; Feng et al., 2023). Sugar is such a substance for fruit gels (Burey P. et al., 2008). The amount of sugar is determined by the degree of methylation and the amount of pectin in the fruit puree (Nussinovitch et al., 2013). The higher the degree of methylation and the greater the amount of pectin, the more sugar is needed to create gelling conditions. However, if the amount of sugar is disproportionately higher than the optimal one, the strength of the gels decreases, and gel formation is accelerated (Basu et al., 2023). On the contrary, if the amount of sugar is less than necessary, the gels acquire greater strength and hardness (Abboud et al., 2020).

The type of used sugar is important (Ivanov et al., 2021). To a greater extent, the confectionery industry uses sucrose, glucose, and fructose, so scientists are quite actively studying the issue of forming pectin gels with various sugars (Jiang et al., 2021; Qi J. et al., 2021). The study of the rheological properties of gels of highly methylation pectin with sucrose, glucose, fructose showed that gels with glucose or fructose were characterized by a higher dynamic modulus of resiliency, viscosity, and lower fluidity compared to gels with sucrose, which indicates more binding of water in them (Vithanage et al., 2010)). The higher strength of high-methoxyl pectin (H-pectin) gels with fructose compared to sucrose was established (Patruni et al., 2023). It is explained by better dehydration of pectin molecules in the presence of fructose, an increase in the number of desolvated areas of its macromolecule and thereby promoting their cleavage among themselves. It was determined that the effective viscosity of pectin gel in apple sauce with glucose and fructose was 1.3 times higher than the viscosity of pectin gel with sucrose (Dorohovich et al., 2016). The thixotropic properties of such gels with the mechanical method of transitioning the gel into a sol make it possible to restore the structure by 85-90%.

It was found that the weakening of the pectin gel’s strength with fructose compared to the gel with sucrose is explained by the lower ability of the monosaccharide to retain water. It means to reduce its polarity to a lesser extent, which does not contribute to the aggregation of hydrophilic pectin molecules and the formation of gels (Avetisyan, 2015). The results of studying the formation of low-methoxyl pectin (L-pectin) jelly and sugars (sucrose, glucose and fructose) established the absence of a correlation between the adsorption of water by sugars and the strength of jelly. The mechanism of formation of L-pectin gels differs from the mechanism of H-pectin in the presence of calcium ions in the medium, which contribute to the formation of bonds between pectin chains. The authors investigated the difference in the structure of gels with mono- and disaccharides and found that there is no correlation between the adsorption of water by sugars and the strength of gels. According to scientists, the structure of gels on the number of interactions between sugars and pectin with calcium cations. (Manuel et al., 2002).

The structuring of fruit gels is a complex mechanism with the participation of many accompanying substances in addition to pectin. Added sugar has a significant effect on the regimes and parameters of the formation of fruit pectin gel, as well as on its structural and mechanical properties. Effects of glucose, fructose or sucrose on fruit gel formation for their further use in confectionery technologies were studied.

Materials and methods

Preparation of samples

The following substances were used for the research: white crystalline sugar (Agroprodinvest, Ukraine), fructose (Golden-Farm, Ukraine), glucose (Twell Sansino, China), starch molasses (Intercorn Corn Processing Industry CJSC, Ukraine), aseptic applesauce (Juice Plant Kodymsky, Ukraine). The characteristics of the main raw materials were determined under laboratory conditions and are presented in Table 1.

Table 1

Characteristics of the main raw materials

Raw material	Sensory properties			Mass fraction of dry substances, %
	Colour	Smell	Taste	
White crystalline sugar	white	characteristic of sugar, without extraneous smell	sweet, without extraneous aftertaste	99.60±0.5
Fructose	snow white		very sweet, without extraneous aftertaste	97.40±0.5
Glucose			sweet, without extraneous aftertaste	89.20±0.4
Aseptic applesauce	yellowish, with a dull green tint	extraneous smell is not allowed	sweet and sour, characteristic of an apple	15.00±0.08
Starch molasses	transparent, colorless	odorless	sweet, clean, without extraneous aftertaste	78.00±0.4

*Results given as: M ± SD (mean ± standard deviation) of triplicate trials.

Model systems: model recipe mixes and fruit gels were prepared to study rheological properties. Model recipe mixes for fruit gels included applesauce, sugar, and molasses. In the control sample, 130 g of applesauce, 100 g of white sugar (sucrose) and 8 g of molasses were used. Glucose or fructose was added to the experimental samples in the equal amounts of sucrose on a dry basis.

To prepare model fruit gels, model recipe mixes were boiled to a dry matter content of 63% and cooled to a temperature of 20±2 ˚C.

Research methods

To study the structural and mechanical properties of fruit gels, they were poured into molds and left for 40 minutes in the laboratory at temperature 20±2 °C, then they were placed in a refrigerator for 2 hours at temperature 10±2 °C. The gel-forming capacity of fruit gels was determined by sensory characteristics such as appearance, surface condition, ease of removal from the mold. The structural and mechanical properties of the obtained fruit gels, namely general deformation, resilience and plasticity of gel-like masses were determined using a ST-1 structuremeter, the principle of which is based on measuring the mechanical load on the indenter nozzle, immersing it at a given speed into the prepared sample of the product. To measure the structural and mechanical properties, samples of cylindrical fruit gels with a diameter of 0.03 m and a height of 0.05 m were prepared.

The following values were set: contact force F_0 = 0.5 N; table movement speed v = 100 mm/min; maximum force, load to the sample, F = 5-5.5 N.

Based on the results of the calculations, compression-unloading curves were constructed – graphs of the dependence of the load force F, H, on the depth of penetration into the gel h, m (Figure 1):

h_1 is the total deformation, m;

h_2 is the plastic deformation, m;

h_3 is the resilience deformation, m;

a is the compression curve;

b is the unloading curve.

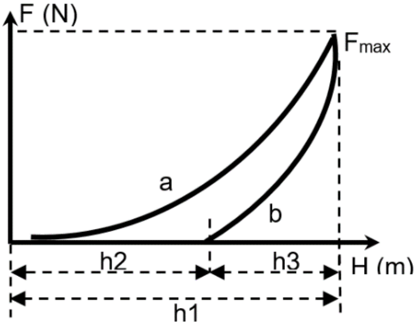


Figure 1. Compression-unloading curve

The starting and final point of the load was marked on the compression curve, a, and the total deformation h1 was determined. The final point of the measurements was marked on the unloading curve, b, at which the value of the plastic deformation, h2, was determined. The resilience deformation h3 was determined by calculation, as the difference between the general and plastic deformations, h1 and h2, the ratio of resilience deformation to plastic deformation h3/h2.

The viscosity characteristics of model recipe mixes and fruit gels were determined on the rotating viscometer (Chandra et al., 2010; Qi T. et al., 2023).

During the research, the shear stress was calculated according to the following formula:

$$\tau = Z \times \alpha,$$

τ is a shear stress, Pa;

Z is the constant of the measuring pair;

α is the value read from the scale of the recording device.

The effective viscosity of the practically intact, η_0, Pa·s, and practically destroyed, η_m, Pa·s, system was calculated using the formula:

$$\eta = \tau / \gamma$$

γ is the shear rate, s^{-1}.

Based on the obtained calculation results, rheological viscosity curves $\eta = f(\gamma)$ were constructed. They were used to determine the nature of the destruction and the beginning of the fluidity of the system.

The amount of free and bound moisture in fruit gels was studied using a Q-1500 derivatograph. Temperature, T, mass change, TG, rate of mass change, DTG, and heat capacity change, DTA, were measured in the test sample as a function of time. The amount of total moisture content, Δm, was determined as the amount of mass that was separated when the sample was heated to a temperature of 150 °C, because the chemical composition of the samples is destroyed when heated at temperature >150 °C. The moisture that is released when the samples are heated to their boiling temperature was considered as a free moisture, and moisture released after their boiling temperature was considered as a bound moisture.

Statistical processing of the data was performed, including the determination of standard deviation (±SD), with triplicate replication for each analysis. The determination of the indicator was realized using the Excel 2007 program from the Microsoft Package (Microsoft Corporation, USA).

Results and discussion

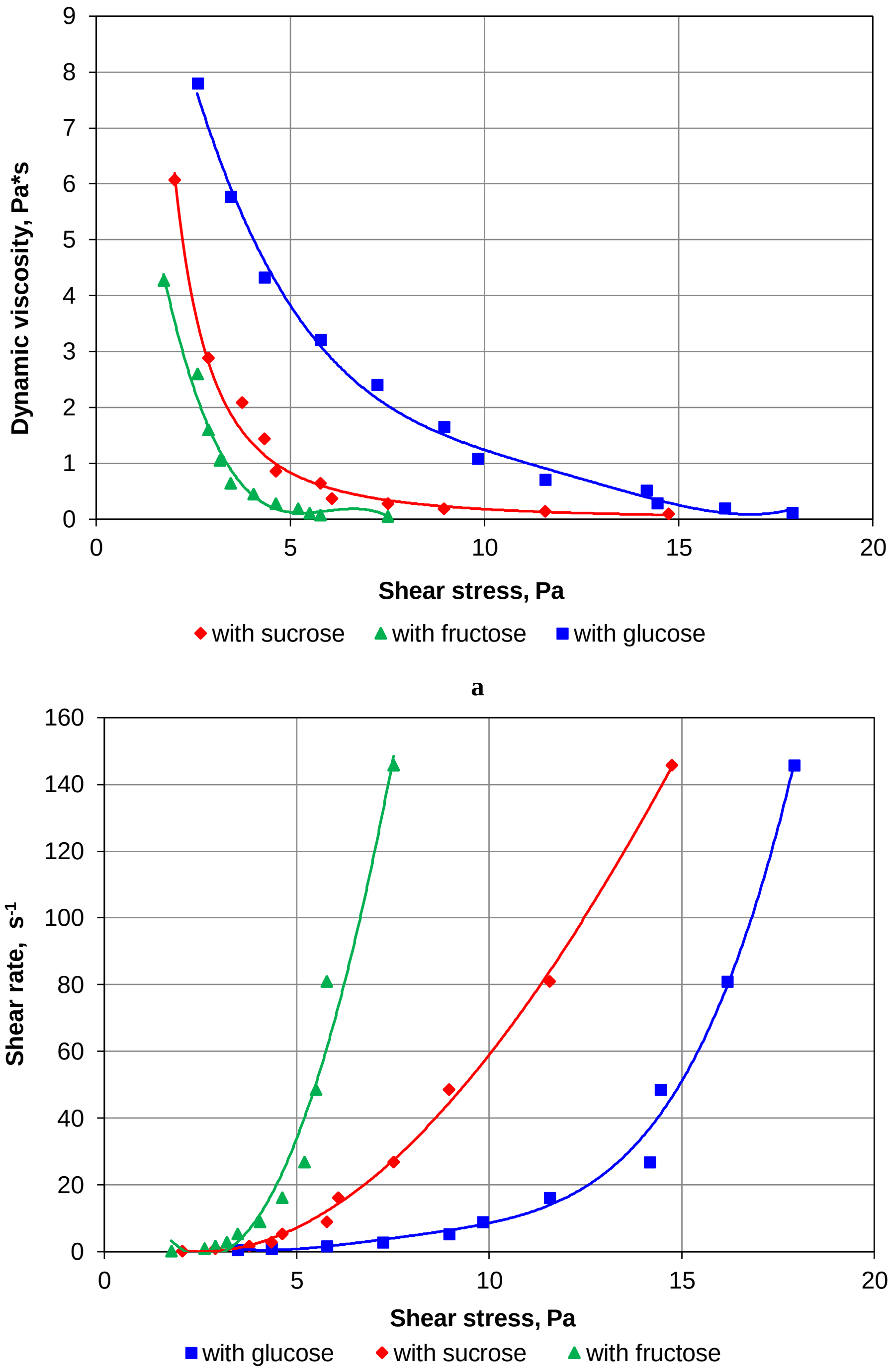
Analyzing the rheological indicators of model recipe mixes and marmalade masses it was found that there were differences in the values of the effective viscosity of the test samples (Tables 2, 3; Figures 2, 3).

Table 2

Rheological characteristics of recipe mixes for fruit gels

Recipe mix of fruit gel	Effective viscosity of almost indestructible system, Pa·s	Strength of structural frame, P_m, Pa	Strength of structural connections, P_{k1}/P_{k2}	Destruction of structure, P_m/P_{k1}
Sample 1 (with sucrose)	6.07±0,03	10.26±0,05	0.50±0,003	3.55±0,02
Sample 2 (with glucose)	7.80±0,04	15.32±0,07	0.45±0,002	2.65±0,01
Sample 3 (with fructose)	4.28±0,02	5.78±0,03	0.36±0,002	4.00±0,02

*Results given as: M ± SD (mean ± standard deviation) of triplicate trials.



a

b

Figure 2. Rheological curves of viscosity (a) and fluidity (b) of model recipe mixes for fruit gels at temperature 20 °C with various types of sugars

Table 3

Rheological characteristics of fruit gels

Recipe of fruit gels	Effective viscosity of almost indestructible system, Pa·s	Strength of structural frame, P_m, Pa	Strength of structural connections, P_{k1}/P_{k2}	Destruction of structure, P_m/P_{k1}
Sample 1 (with sucrose)	10.41±0.05	114.73±0.57	0.05±0.0003	39.70±0.2
Sample 2 (with glucose)	8.67±0.04	23.12±0.12	0.24±0.001	6.67±0.03
Sample 3 (with fructose)	8.25±0.04	35.00±0.18	0.24±0.001	10.10±0.05

*Results given as: M ± SD (mean ± standard deviation) of triplicate trials.

In model formulations, higher effective viscosity values were characteristic of systems with glucose within all values of shear stress. The lowest values were observed for formulations with fructose. Such differences are explained by the different solubility of sugars at the temperature of the studies (Zhang et al., 2021). Thus, according to literature data, at a temperature of 25 °C, the solubility of fructose is 74.6-78.9%, sucrose – 63–67%, glucose – 43.7–52.5%, which confirms the lowest solubility of glucose at the temperature of preparation of prescription mixes (Wang et al., 2019). Therefore, the recipe mix with glucose contains a significant part of undissolved sugar crystals, which leads to an increase in effective viscosity. Fructose is characterized by the highest dissolution coefficient, which allows sugar molecules to hydrate to a greater extent in the medium, and the recipe mix has the lowest values of effective viscosity among the presented samples.

Sugars are in a completely dissolved state in fruit gels subjected to boiling, that is, their solubility changes (Zhang et al., 2021). The solubility of sucrose became 77%, glucose – 81-82%, fructose – 85.6-88.1% at a temperature in the range from 60 to 90 ℃, which naturally leaves an imprint on the change of dependence between viscosity curves of fruit gels. As can be seen, the highest values of the effective viscosity are characteristic of the samples with sucrose, even they are lower for the samples with glucose and fructose. However, the resulting fruit gels were cooled after boiling. It means that the partial gelation of the systems and the influence of sugar on the gelation of pectin substances are a more significant factor affecting the experimental index (Dorohovich et al., 2016). Despite the fact that the framework of the gel-like structure is not yet fixed, and the molecules are in in a rather mobile state, sugars and pectin substances form complex compounds. Therefore, the viscosity will depend on the integrity and strength of the complex formed. The location of the viscosity curve for the model system with sucrose above the curves for the fruit gels with monosaccharides may indicate greater cohesion and strength of the formed gel structure, a higher rate of gelation of pectin substances with sucrose. This conclusion can be confirmed by the strength index of the formed structural frame, P_m (Table 2), which is 114.73 Pa for the fruit gel with sucrose, 23.12 Pa for the fruit gel with glucose, and 35.0 Pa for the fruit gel with fructose.

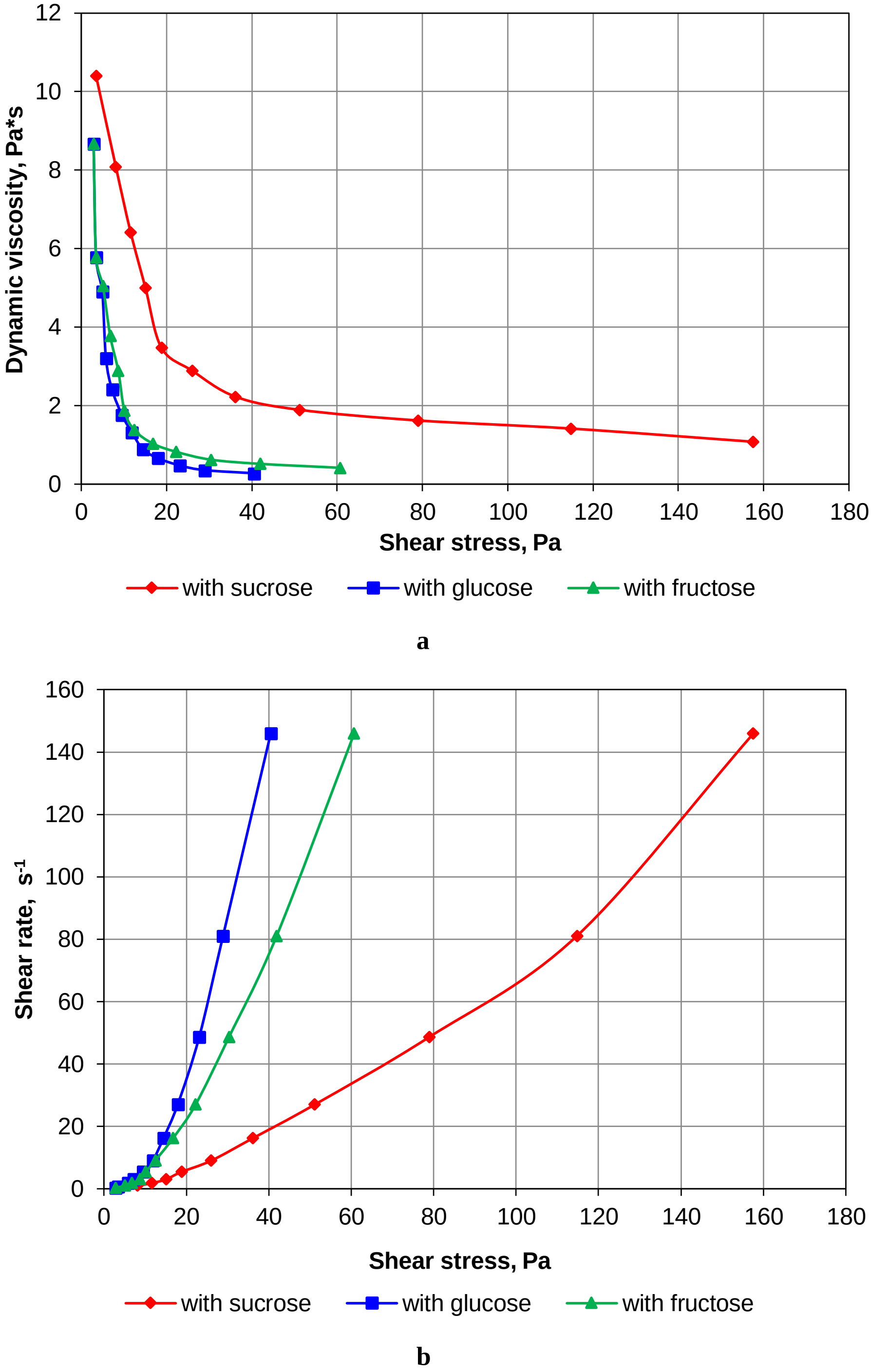


Figure 3. Rheological curves of viscosity (a) and fluidity (b) of fruit gels at temperature 20 °C with various sugars

The obtained results confirmed that the viscosity of pectin fruit gels with disaccharides is higher than the viscosity of gels with monosaccharides.

The gel-forming ability and the structural and mechanical properties of fruit gels were determined (Tables 4, 5).

Table 4

Gel-forming ability of fruit gels

Gel quality indicators	Sample 1 (with sucrose)	Sample 2 (with glucose)	Sample 3 (with fructose)
Ease of removal from the forms	The gel is easily removed from the molds		The gel is difficult to remove from the forms, it requires an increase in time for gel formation
Surface condition	The surface is smooth and glossy	The surface is smooth	Glossy surface, sticky
Detachment from the surface	Does not stick	Does not stick	Stick
Gel-forming ability	Excellent	Excellent	Satisfactory

It was found that fruit gels with sucrose and glucose were easily removed from the molds, did not stick, and had a dry surface under the same cooking conditions. This means that they have an excellent gel-forming ability. The mass on fructose required an increased gelation time, the formed gel stuck to the mold when removed, and was characterized by satisfactory strength.

Analysis of the structural and mechanical properties of fruit gels made it possible to single out the sample on sucrose as a stronger system in comparison with the samples on glucose and fructose. The maximum force to break gels is 50 N for fruit gel with sucrose, 35 N with glucose, 30 N with fructose. That is, the sample with sucrose withstands higher loads until complete destruction compared to the samples with monosaccharides, which indicates a more structured framework of its gels.

The studied samples are characterized by different resilient and plastic deformation values. The lowest plasticity and the highest value of resilient deformation were found for the sample with glucose, which can be explained by the low solubility of sugar in the systems after the gel cooling. Glucose molecules begin to change their crystal lattice, thereby influencing the strengthening of the entire structure (Archut et al., 2023). Fructose is characterized by increased solubility (compared to sucrose at 20 ˚C), so the values of resilient deformation of gel with fructose are lower compared to glucose, but somewhat higher compared to sucrose. For example, at a load of 30 N, the elastic deformation for gels with sucrose is 13.88%, for gels with fructose – 18.4%, for gels with glucose – 21.9%.

In order to explain the difference in the structural and mechanical properties of the experimental fruit gels and to confirm the conclusion regarding the relationship between the activity of water and the gelation of masses, an analysis of the moisture content in fruit gels was carried out using a derivatograph (Fig. 4, Table 6). The figures show the curves of changes in mass, TG, with increasing temperature, T, over a period of 0 to 40 minutes.

Table 5

Structural and mechanical properties of fruit gels

Sample	Load force, N	Deformation		
		General, unit	Plastic, %	Flexible, %
Sample 1 (with sucrose)	5	5.06	93.60	6.4
	10	11.73	93.55	6.45
	15	13.26	92.29	7.71
	20	14.07	90.47	9.53
	25	17.99	89.27	10.73
	30	20.02	86.11	13.89
	35	21.74	82.65	17.35
	40	22.43	82.38	17.62
	45	23.24	81.62	18.38
	50	25.38	80.32	19.68
	55	The structure of the gel is destroyed		
Sample 2 (with glucose)	5	6.34	94.60	5.40
	10	10.74	87.00	13.00
	15	11.94	84.67	15.33
	20	13.00	84.00	16.00
	25	14.19	82.36	17.65
	30	17.95	78.05	21.95
	35	18.95	76.56	23.44
	40	The structure of the gel is destroyed		
Sample 3 (with fructose)	5	6.45	89.4	10.6
	10	11.33	87.97	12.03
	15	12.61	86.51	13.49
	20	13.73	86.16	13.84
	25	14.86	85.26	14.74
	30	19.03	81.6	18.40
	35	The structure of the gel is destroyed		

Table 6

Content of free and bound moisture in fruit gels

Model fruit gels	Moisture content, %	
	free	bounded
Sample 1(with sucrose)	24.03±0.12	75.97±0.38
Sample 2 (with glucose)	25.71±0.13	74.29±0.37
Sample 3 (with fructose)	27.28±0.14	72.72±0.36

*Results given as: M ± SD (mean ± standard deviation) of triplicate trials.

The results showed that the content of bound moisture in the samples of fruit gel with sucrose was greater compared to the samples of gels based on monosaccharides. That is, a more resilient framework of pectin jellies is formed with the disaccharide sucrose, in which there is less water activity compared to systems based on glucose or fructose. Thus, according to calculations, the content of bound water in a gel with sucrose exceeds by 2.2% content of bound water in a gel with glucose and 4.3% – in a gel with fructose.

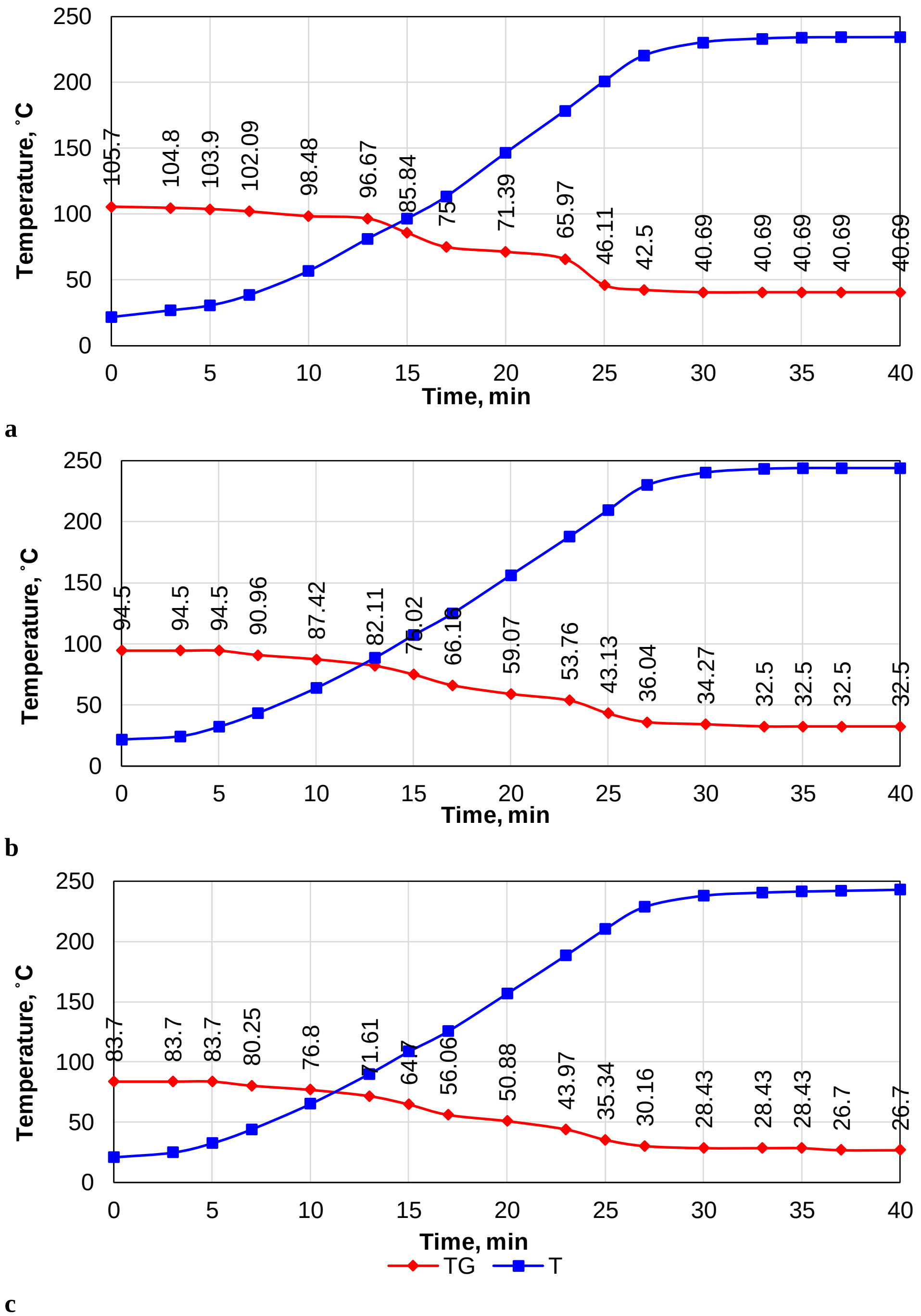


Figure 4. Change of mass of fruit gels samples with sucrose (a), glucose (b), fructose (c) under different temperature:
TG is the curves of mass, T is the curves of temperature.

Conclusions

Scientific data were obtained that showed the relationship between the rheological parameters of fruit gels with different colors, strength and total deformation and the amount of bound water.

It was found that the samples of gels with higher values of effective viscosity prior to structure formation form the gel framework faster, acquire greater strength after the final setting and are characterized by a slightly higher content of bound moisture. Gel with sucrose before structuring have higher values of effective viscosity compared to gels with glucose or fructose. The strength of fruit gels on sucrose is higher in terms of the force required to break through the jelly, and the overall deformation of the samples is correspondingly lower. Samples of gels with sucrose have a lower amount of free moisture.

The obtained results show the dependence of the rheological properties of fruit masses, the quality of their gelatinization, structural and mechanical properties on the sugar used and are important for the production of jelly-like confectionery.

References

Abboud K.Y., Iacomini M., Simas F.F., Cordeiro L.M.S. (2020), High-methoxyl pectin from the soluble dietary fiber of passion fruit peel forms weak gel without the requirement of sugar addition, *Food Chemistry,* p. 246, DOI:10.1016/j.carbpol.2020.116616.

Avetisyan K. (2015), Improvement of the technology of two-layer jelly marmalade using starch syrups, *Dissertation of the candidate of technical sciences,* ONAFT, Odesa.

Basu S., Singha S. (2023), Influence of sugar substitutes in rheology of fruit gel, Advances in food rheology and its applications (second edition), *Development in Food Rheology*, pp. 385–411, DOI: 10.1016/B978-0-12-823983-4.00017-0.

Burey P., Bhandari B.R., Howes T., Gidley M.J. (2008), Hydrocolloid gel particles: formation, characterization, and application, *Critical Reviews in Food Science and Nutrition,* 48(5), pp. 361-377, DOI: 10.1080/10408390701347801**.**

Chandra R.V., Malcolm J., Grimson P.R., Wills P.H., Bronwen G.S. (2010), Rheological and structural properties of high-methoxyl esterified, low-methoxyl esterified and low-methoxyl amidated pectin gels, *Journal of Texture Studies,* 41(6), pp. 899- 927, DOI: 10.1111/j.1745-4603.2010.00261.x.

Chevalier L.M., Rioux L.E., Angers P., Turgeon S.T. (2019), Study of the interactions between pectin in a blueberry puree and whey proteins: functionality and application, *Food Hydrocolloids*, 87, pp. 61-70, DOI: 10.1016/j.foodhyd.2018.07.038.

Dorohovich A., Dorohovich V., Kambulova J. (2016), The study of the rheological properties of pectin gels with mono- and disaccharides, *Eureka: Lifesciences,* 4, pp. 14-20, DOI: 10.21303/2504-5695.2016.00167.

Ivanov V., Shevchenko O., Marynin A., Stabnikov V., Gubenia O., Stabnikova O., Shevchenko A., Gavva O., Saliuk A. (2021), Trends and expected benefits of the breaking edge food technologies in 2021–2030, *Ukrainian Food Journal,* 10(1), pp.7-36, DOI: 10.24263/2304-974X-2021-10-1-3.

Feng S., Yi J., Ma Y., Bi J. (2023), The role of amide groups in the mechanism of acid-induced pectin gelation: a potential pH-sensitive hydrogel based on hydrogen bond interactions, *Food Hydrocolloids,* 141, DOI: 10.1016/j.foodhyd.2023.108741.

Konar N., Gunes R., Palabiyik I., Toker O. S. (2022), Health conscious consumers and sugar confectionery: Present aspects and projections, *Trends in Food Science & Technology,* 123, pp. 57-68, DOI: 10.1016/j.tifs.2022.02.001.

Manuel A.M., Francisco M., Aida J., Eugenio R.N. (2002), Rheological behaviour of an amide pectin, *Journal of Food Engineering,* 55(2), p. 123, DOI: 10.1016/S0260-8774(02)00026-2.

Nath P.C., Debnath S., Sridhar K., Inbaraj B.S., Nayak P.K., Sharma M. (2022), A comprehensive review of food hydrogels: principles, formation mechanisms, microstructure, and its applications, *Recent Developments in Food Gels,* 9(1), p. 1, DOI: 10.3390/gels9010001.

Nussinovitch A., Hirashima M. (2013), Cooking innovations: using hydrocolloids for thickening, gelling, and emulsification, *CRC Press,* DOI: 10.1201/b15547.

Patruni K., Rao P.S. (2023), Viscoelastic behaviour, sensitivity analysis and process optimization of aloe Vera/HM pectin mix gels: An investigation using RSM and ANN and its application to food gel formulation, *LWT,* 176, DOI: 10.1016/j.lwt.2023.114564.

Qi J., Liao J., Yang X. (2021), Acid/ethanol induced pectin gelling and its application in emulsion gel, *Food Hydrocolloids,* 118, p. 106774, DOI: 10.1016/j.foodhyd.2021.106774.

Qi T., Ren J., Li X., An Q., Zhang N., Jia X., Pan S., Fan G., Zhang Z., Wu K. (2023), Structural characteristics and gel properties of pectin from citrus physiological premature fruit drop, *Carbohydrate Polymers,* 309, p. 120682, DOI: 10.1016/j.carbpol.2023.120682.

Rao M.A. (2006), Rheological changes during gelation of high methoxyl pectin/fructose dispersions: effect of temperature and aging, *Journal of Food Science,* 58(1), pp. 173-176, DOI:10.1111/j.1365-2621.1993.tb03237.x.

Vithanage C.R., Grimson M.G., Wills P.R., Harrison P., Smith B.G. (2010), Rheological and structural properties of high-methoxyl esterified, low-methoxyl esterified and low-methoxyl amidated pectin gels, *Journal of Texture Studies,* 41(6), pp. 899-927, DOI: 10.1111/j.1745-4603.2010.00261.x.

Wang Y., Truong T., Li H., Bhandari B. (2019), Co-melting behaviour of sucrose, glucose and fructose, *Food Chemistry,* 275, pp. 292-298, DOI: 10.1016/j.foodchem.2018.09.109

Wolf B. (2016), Confectionery and sugar-based foods, *Reference module in food science,* DOI: 10.1016/B978-0-08-100596-5.03452-1.

Zhang H., Li X., Qian Z. M., Wang S., Yang F. Q. (2021), Glucose oxidase-mediated sodium alginate gelation: equipment-free detection of glucose in fruit samples, *Enzyme and Microbial Technology,* 148, p. 109805, DOI: 10.1016/j.enzmictec.2021.109805.

Zhang T., Wang Z., Yu S., Guo X., Ai C., Tang X., Chen H., Lin J., Zhang X., Meng J. (2021), Effects of pH and temperature on the structure, rheological and gel-forming properties of sugar beet pectins, *Food Hydrocolloids,* 116, p. 106646, DOI: 10.1016/j.foodhyd.2021.106646.