New insights into grain hydrogels with reinforced textural properties: design of low-calorie jelly desserts technology

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Abstract. Traditionally jelly desserts are sweet, calorie products which are appreciated due to their pleasant texture and a variety of taste. Sweet jelly desserts based on natural polysaccharides contain up to 20% sucrose. Excessive consumption of sugar leads to various diseases. Number of studies is aimed at the partial or complete replacement of sugar with sweeteners in confectionery industry. The aim of this investigation is to design of low-calorie jelly desserts technology with non-starch polysaccharides, sweeteners and with addition of cereal flour. Commercial samples of following food hydrocolloids were used for preparation of food gels: konjac glucomannan, xanthan gum (Danisco, France); iota carrageenan (Sarda Starch Pvd. Ltd. India); locust bean gum from Ceratonia siliqua seeds (Sigma-Aldrich Co. LLC, USA). Fructose, Steviliya-E, sorbite, maltose syrup, honey were used as sweeteners. Flour from flax and amaranth seeds was used for improving texture properties and nutritional value of jelly desserts with sweeteners.

1. Introduction

According to WHO, about 1 billion people on the planet suffer from overweight and 300 million of them suffer from obesity [1-3]. More than 200 million people suffer from diabetes, which is a consequence of excessive consumption of easily digestible carbohydrates, among which in the first place is sucrose [4-5]. Technologists and scientists have made numerous attempts to reduce or replace sugar in food products with various sweeteners [6-10].

Some sweeteners play an important role in creating the structure of product. Correct selection of sweeteners in the right quantity is important for human health. Of particular interest is the effect of sweeteners on the glycemic response of the body and its management. By reducing glycemia after a meal, caused by the action of sweeteners along with other low-glycemic carbohydrates (non-starch polysaccharides), calorie reduction and exercise, can reduce the prevalence and risk of metabolic disorders associated with the consumption of highly glycemic foods rich in easily digestible carbohydrates.

Design of low-calorie and functional products is an important direction of food industry. The desire for a healthy lifestyle is reaching an increasing part of population. Modern studies conducted in Europe, the USA and Russia show that almost every fourth consumer is interested in additional...
"functional" properties of the selected product. Use of natural ingredients, rejection of synthetic additives, reducing caloric and sucrose content, added of components with biologically active properties – one of the main trends that play an important role in food technology, including jelly desserts.

Our recent study was devoted to the designing of technology of jelly desserts with replacement of gelatin with non-starch polysaccharides [11]. Present study is a continuation of recently work. The aim of this investigation is to design of low-calorie jelly desserts technology with non-starch polysaccharides, sweeteners and with addition of flour from flax and amaranth seeds.

2. Materials and methods

Commercial samples of following food hydrocolloids were used for preparation of jelly desserts: konjac glucomannan, xanthan gum (Danisco, France); iota carrageenan (Sarda Starch Pvd. Ltd. India), locust bean gum from *Ceratonia siliqua* seeds (Sigma-Aldrich Co. LLC, USA).

Recipe components were used as the basis of product: milk 3.2 % of fat, milk cream 35 % of fat, vanillin which were bought in a supermarket (Mashhad, Iran), commercial samples of following sweeteners: beet sugar (Krasnodar, Russia), fructose (Novgorod, Russia), Steviliya-E (Moscow, Russia), sorbit (sorbitol powder) (Novgorod, Russia), maltose syrup (Shandong, China), honey (Mashhad, Iran).

Flour from flax and amaranth seeds was obtained from Russian regional vegetable raw materials and used for improving texture properties and nutritional value of jelly desserts with sweeteners.

Preparation of dessert samples.

Design of jelly desserts technology was carried out in two stages. Assortment of jelly desserts was developed with the replacement of sugar with sweeteners using only non-starch polysaccharides as gelling agents at the first stage. Assortment of jelly desserts with sweeteners was developed using iota-carrageenan as a gelling agent and with additives of flour from flax and amaranth seeds to increase the nutritional value and improve the texture properties of the finished product at the second stage. Flour from flax and amaranth seeds was added in the preparation of a dry mixture.

Technology of jelly dessert preparation includes following stages.

Take ingredients (g): polysaccharides, vanillin, beet sugar or sweeteners (except honey and maltose syrup) according recipe. Mix up ingredients, gets a dry mixture (flour from flax and amaranth seeds was added in a concentration of 5 % in the process of dry mixture preparation). Take required amount of milk or milk cream according recipe. Mix up. Get a liquid base (add honey or maltose syrup). Heat the liquid base to 60 °C. Put a dry mixture into a liquid base at constant stirring. Heat until almost boiling, but do not boil. Put hot dessert into a mould, cool it.

Choice of concentrations of used sweeteners was based on sensory determination of the degree of sweeteners in comparison with sucrose (figure 1).

As shown in figure 1, degree of sweetness of used sweeteners is different and is due to their chemical composition, molecular weight, structure and nature of sweeteners [12]. Sugar manifests itself not only as a source of sweetness in jelly desserts, but also, what is especially important, as a structuring agent that increases viscosity, gelling temperature of polysaccharide solutions and firmness of gels. When sugar is replaced with sweeteners in jelly desserts, it is necessary to take into account the fact that used sweeteners do not have such properties as sugar, and optimal results could be achieved when additional structuring agents use in dessert formulation.

In this study, sugar was completely replaced by sweeteners.

Concentration of sweetener was determined according equation (1):

\[ C_{sw} = C_{sucrose} / D_{sw} \]  \hspace{2cm} (1)

Where \( C_{sw} \) – concentration of sweetener, %; \( C_{sucrose} \) – amount of sucrose in the product according recipe, %; \( D_{sw} \) – degree of sweetness.
However, as shown by our sensory studies, the calculated concentrations of sweeteners do not satisfy the taste needs of consumers. Therefore, concentrations of sweeteners were determined empirically by modifying of desserts recipe. Types of designed jelly desserts with sweeteners, in comparison with the control sample are presented in Table 1.

Table 1. Types of designed jelly desserts with sweeteners.

| Types and concentrations of sweeteners, % | Types and concentrations of polysaccharides, % |
|------------------------------------------|-----------------------------------------------|
| Jelly desserts with sucrose (control samples) | iota carrageenan (0.4) |
| sucrose (8.5) | LBG (0.2): xanthan gum (0.8) |
| fructose (5.5 - 6.5) | konjac glucomannan (0.4): xanthan gum (0.6) |
| Steviliya-E (1.0 - 1.7) | |
| sorbit (10.0 – 15.0) | |
| maltose syrup (10.0 – 28.0) | |
| honey (6.0 - 8.0) | |
| Jelly desserts with sweeteners | iota carrageenan (0.4) |
| LBG (0.2): xanthan gum (0.8) | |
| konjac glucomannan (0.4): xanthan gum (0.6) | |

Note: *Types and concentrations of polysaccharides were determined by us in previous studies. Data are presented in the work [11].

Best concentrations of sweeteners were selected: fructose with concentration of 6 %, Steviliya-E with concentration of 1.5 %, sorbit with concentration of 10 %, maltose syrup with concentration of 10 % and honey with concentration of 8 % based on organoleptic evaluation of experimental samples of jelly desserts in comparison with the control sample with sucrose (8.5 %).

Back extrusion test (BET).

Textural properties of jelly desserts were measured using a texture analyzer (Stable micro system, TA.XTplus, England), equipped with a 5 kg load cell. The BET was carried out using the probe with 35 mm diameter (prob code: A/BE-d35) and samples' size of 4×2×2 cm. Two consecutive cycles with a pressure equivalent to 50 % of the sample height was performed on the samples. The time between the two cycles was 15 s and the test speed was 1 mm/s [13]. The quantitative parameters extracted from force-time curve were: firmness (peak positive force), cohesiveness (peak negative force), viscosity index (total negative area), consistency (total positive area).
Water activity and moisture content analysis.

Water activity (aw) of jelly desserts was measured with water activity meter (Novasina, Lab Master, Swiss).

Moisture content (W) of jelly desserts was determined using a moisture analyzer "Evlas - 2M" (Russia). Three grams of sample was loaded on an aluminium plate and heated at 160 °C for 5 min.

Statistical analysis.

All experiments were performed at least at three replications via SPSS software version 16. Results were considered significant if p < 0.05.

3. Results and discussion

Properties of jelly desserts with sucrose and different sweeteners.

Back extrusion test: the effects of sweeteners on jelly desserts formation during gelation.

Texture plays an important role on the creating jelly products. Results for back extrusion test parameters of jelly desserts with sucrose and different sweeteners obtained from texture analyzer curves are shown in table 2.

Table 2. Back extrusion test parameters of jelly desserts with sucrose and different sweeteners.

| Sweeteners                  | Back extrusion test parameters | Firmness, g       | Cohesiveness, g | Viscosity index, g.s | Consistency, g.s |
|-----------------------------|--------------------------------|-------------------|-----------------|----------------------|-------------------|
| jelly desserts based on iota carrageenan 0.4 % | sucrose (control sample)          | 180.790           | -28.917         | -582.261             | 4187.998          |
|                             | fructose                        | 161.705           | -20.242         | -370.100             | 2454.918          |
|                             | Steviliya-E                     | 193.513           | -19.664         | -432.683             | 1092.572          |
|                             | sorbit                          | 155.805           | -20.936         | -434.828             | 2131.118          |
|                             | maltose syrup                   | 152.220           | -17.466         | -337.488             | 1092.572          |
|                             | honey                           | 201.726           | -39.906         | -641.298             | 3266.576          |
| jelly desserts based on LBG 0.2 % and xanthan gum 0.8 % | sucrose (control sample)          | 881.162           | -64.312         | -895.147             | 15718.050         |
|                             | fructose                        | 1090.060          | 80.852          | -1219.810            | 10005.023         |
|                             | Steviliya-E                     | 1648.623          | -77.382         | -1222.080            | 6789.584          |
|                             | sorbit                          | 1174.613          | -83.860         | -1106.870            | 11012.120         |
|                             | maltose syrup                   | 1010.480          | -70.211         | -1066.680            | 13307.600         |
|                             | honey                           | 1338.978          | -90.106         | -1496.080            | 13818.960         |
| jelly desserts based on konjac glucomannan 0.4 % and xanthan gum 0.6 % | sucrose (control sample)          | 1516.067          | -52.745         | -699.996             | 17643.900         |
|                             | fructose                        | 1202.721          | -50.316         | -577.010             | 14755.210         |
|                             | Steviliya-E                     | 1158.420          | -41.409         | -459.743             | 16423.838         |
|                             | sorbit                          | 1638.097          | -63.039         | -817.341             | 16397.030         |
|                             | maltose syrup                   | 816.966           | -48.581         | -639.411             | 15905.883         |
|                             | honey                           | 781.341           | -68.938         | -922.516             | 14704.463         |

As can be seen from table 2, the textural properties of jelly desserts primarily depend on the nature of gelling agents. Highest values of firmness, cohesiveness and consistency have desserts based on konjac glucomannan: xanthan gum and LBG: xanthan gum, which is primarily associated with a synergistic effect of these polysaccharides [14-15]. Desserts based on iota carrageenan had a pleasant delicate creamy texture. Formation of gel structure of jelly desserts with used polysaccharides takes place already at temperatures of 18 ± 2 °C during 20-40 minutes.

The firmness of jelly desserts using iota carrageenan with concentration 0.4 % does not depend on the nature of sweeteners and will not change significantly. The firmness of jelly desserts based on
LBG : xanthan gum (0.2 : 0.8) varies depending on used sweeteners. Highest firmness is observed for samples using Stevilliya-E (1649 g) and honey (1339 g), compared with a control sample using sucrose (881 g). Tendency to decrease of firmness is observed in jelly desserts based on konjac glucomannan: xanthan gum (0.4: 0.6) in comparison with control sample (1516 g). However, firmness increases to 1638 g of jelly dessert with sorbitol as a sweetener.

Despite some differences in firmness data of desserts, the cohesive properties of designed desserts with sweeteners are improved compared with samples containing sucrose.

The cohesiveness of desserts based on iota carrageenan with concentration 0.4 % and konjac glucomannan: xanthan gum 0.4 %:0.6 % (accordingly) with different sweeteners practically do not change. Cohesive properties of desserts based on LBG: xanthan gum with concentration 0.2% : 0.8 % (accordingly) with used sweeteners are higher compared with control sample containing sucrose.

As can be seen from presented data in table 2, using of sweeteners affects on consistency of jelly desserts. In all samples of jelly desserts with sweeteners, decrease in viscosity was observed, in comparison with samples containing sucrose, which is technologically preferable, since the process of molding products is facilitated, at reducing product losses during packaging.

Water activity and moisture content analysis.

Water activity is one of the most important physical characteristic that determines either textural properties of the product or the velocity of chemical and biological processes in it [16-17]. Data of water activity and moisture content of jelly desserts with sucrose and different sweeteners are presented in table 3.

| Sweeteners                                    | Water activity | Moisture content, % |
|-----------------------------------------------|----------------|---------------------|
| jelly desserts based on iota carrageenan 0.4 % |                |                     |
| sucrose (control sample)                      | 0.947          | 89.1                |
| fructose                                      | 0.943          | 84.5                |
| Stevilliya-E                                   | 0.943          | 85.5                |
| sorbite                                        | 0.943          | 85.2                |
| maltose syrup                                 | 0.945          | 84.2                |
| honey                                         | 0.937          | 85.4                |
| jelly desserts based on LBG 0.2 % and xanthan gum 0.8 % |    |                     |
| sucrose (control sample)                      | 0.940          | 87.1                |
| fructose                                      | 0.938          | 85.8                |
| Stevilliya-E                                   | 0.939          | 84.2                |
| sorbite                                        | 0.937          | 85.5                |
| maltose syrup                                 | 0.939          | 85.0                |
| honey                                         | 0.933          | 85.8                |
| jelly desserts based on konjac glucomannan 0.4 % and xanthan gum 0.6 % |    |                     |
| sucrose (control sample)                      | 0.941          | 91.5                |
| fructose                                      | 0.933          | 84.2                |
| Stevilliya-E                                   | 0.936          | 86.9                |
| sorbite                                        | 0.938          | 85.3                |
| maltose syrup                                 | 0.937          | 85.0                |
| honey                                         | 0.936          | 84.1                |

As can be seen from table 3, all samples can be attributed to the group of perishable products, since their water activity index is more than 0.9. However, it can be seen from presented data that used sweeteners reduce the water activity index compared with the control samples of desserts with sucrose. Water activity of used sweeteners affects microbiological stability of jelly desserts and their “freshness”. Used sweeteners are characterized by high osmotic pressure and, accordingly, lower water activity than sucrose. This means that in jelly desserts, sweeteners have a greater preservative
effect than sucrose. In addition, using of sweeteners leads to decrease in the moisture content of desserts and increase dry components, which is an important factor for improving the microbiological stability of jelly desserts.

Properties of jelly desserts with different sweeteners and additives of cereal flour.

Influence of cereal flour on texture properties of jelly desserts.

Flour from flax and amaranth seeds (like other cereals) have a high protein and fat content as well as a more rich composition of essential amino acids and, thus, a high nutritional value. Therefore, adding cereal flour increases the nutritional value of different ready-made product [18-20]. In our case flour from flax and amaranth seeds in concentration of 5 % was added to dessert recipe based on iota-carrageenan for increasing concentration of dry components, for gel structure formation and enriching desserts with essential amino acids, polyunsaturated fatty acids, vitamins and minerals.

Results for back extrusion test parameters of jelly desserts with different sweeteners and additives of cereal flour obtained from texture analyzer curves are presented in table 4.

| Sweeteners | Firmness, g | Cohesiveness, g | Viscosity index, g.s | Consistency, g.s |
|------------|-------------|-----------------|----------------------|------------------|
| sucrose (control sample) | 180.790 | -28.917 | -582.261 | 4187.998 |
| fructose | 161.705 | -20.242 | -370.100 | 2454.918 |
| Steviliya-E | 193.513 | -19.664 | -432.683 | 1092.572 |
| sorbit | 155.805 | -20.936 | -434.828 | 2131.118 |
| maltose syrup | 152.220 | -17.466 | -337.488 | 856.079 |
| honey | 201.726 | -39.906 | -641.298 | 3266.576 |
| fructose | 174.775 | -26.835 | -593.190 | 2879.548 |
| Steviliya-E | 136.026 | -19.548 | -591.603 | 2031.310 |
| sorbit | 158.350 | -22.671 | -659.209 | 2129.496 |
| maltose syrup | 178.245 | -29.842 | -786.863 | 3146.439 |
| honey | 252.389 | -33.891 | -907.792 | 3266.531 |
| fructose | 302.242 | -82.356 | -1740.610 | 1680.841 |
| Steviliya-E | 202.883 | -65.237 | -925.248 | 1033.720 |
| sorbit | 199.297 | -47.308 | -878.215 | 2305.999 |
| maltose syrup | 331.737 | -139.959 | -1419.780 | 1728.457 |
| honey | 307.909 | -76.920 | -1251.030 | 3450.256 |

As can be seen from table 4, the texture properties of jelly desserts based on iota carrageenan 0.2 % with flour from of flax and amaranth seeds are comparable with control sample based on iota carrageenan 0.4 % without additives of cereal flour. Herewith, using of flour from seeds of flax and amaranth can reduce the concentration of iota-carrageenan by two times, which indicates on synergistic interactions of proteins and polysaccharides [21-22].

The firmness of jelly desserts with additives of flax and amaranth flour is improved, compared with the control sample based on iota carrageenan with concentration 0.4 %. Increasing firmness of jelly desserts is due to presence of plant polysaccharides (cellulose, pectin, lignins, etc.), lipids and proteins that contain in cereal flours. Desserts with amaranth flour had the greatest firmness, apparently due to aggregation of protein particles and formation of protein-polysaccharide complexes, which contributes to formation of a more durable gel product.

The cohesive properties of jelly desserts with additives of flax and amaranth flour are improved, compared with the control sample based on iota carrageenan with concentration 0.4 %. Ready-made
desserts had a delicate plastic consistency typical for jelly desserts. Using of cereal flour on the cut of dessert may be included particles of the additive.

Desserts with addition flour from flax and amaranth seeds have an increased nutritional value. Protein content increases on average two times. Fat content is also increasing, but mainly due to omega-3 and omega-6 polyunsaturated fatty acids. Dietary fiber content increases in desserts with additives of flax flour, since flax flour is more enriched with dietary fibers than amaranth flour. It should be noted that the using of amaranth flour makes it possible to enrich the product with such important components as selenium, squalene, magnesium, calcium, zinc, phosphorus and all essential amino acids.

5. Conclusion
Based on the above:

- Technologies of jelly desserts with sweeteners, non-starch polysaccharides and additives of cereal flour were developed;
- Such sweeteners as fructose (at a concentration of 6 %), Stevilya-E (at a concentration of 1.5 %), sorbite (at a concentration of 10 %), maltose syrup (at a concentration of 10 %), and honey (at a concentration of 8 %) in combination with non-starch polysaccharides, as well as lipids, proteins and polysaccharides of flour from flax and amaranth seeds could be used to create low-calorie jelly desserts with improved properties. Using of sweeteners for creating designed products has an additional technological advantage, namely, decrease viscosity of the food system that facilitates molding of desserts and thereby reduces losses of product;
- Additives of flour from flax and amaranth seeds improve textural properties of jelly desserts, increase their nutritional value and lead to decrease concentration of structure-forming agent - iota-carrageenan in recipe of jelly dessert.

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