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Hydrocolloid effect on the stabilization of vegetable purees in the process of freezing, refrigerating and defrosting

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Abstract: The analysis of modern concepts of the use of hydrocolloids for the stabilization of mashed products of plant origin in the freezing – storage – defrosting circle is given. The effect of hydrocolloids on the structure of vegetable purees using the example of xanthan gum, starch and inulin was studied. The most significant characteristics of the structure was identified and their descriptors were considered. Experimental data on the effect of hydrocolloids on the microstructure of vegetable purees was obtained. The expediency of using starch and xanthan gum in combination with inulin was shown. To create a viscous structure, modified starch with small granules that exhibit thermal stability in cold storage and further heat treatment were most suitable. Inulin was also not subject to changes during temperature treatments for the products with a pH higher than 3.5, but probably would not be widely used as a structurant for vegetable purees due to the weak expression of the structure-forming properties. The synergistic combinations of inulin and xanthan gum improved the organoleptic characteristics of the product, especially in cold storage. In addition, the ability of inulin to form a smooth structure in vegetable purée when enveloping the oral cavity was revealed, despite the fact that the initial product had a rather coarse fibrous consistency due to the plant origin of the ingredients. Thus, it is promising to use inulin in combination with thickeners to give the product prebiotic properties with the improved perception in consumers. The results of the studies confirm the possibility of storing vegetable purees at low temperatures for a long time without the deterioration of the structural and organoleptic properties resulting from the slowly occurring degradation processes of the individual components of the product at low temperatures, provided that the hydrocolloids under study are used.

Keywords: Hydrocolloids, vegetable purees, frost, puree texture, inulin

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INTRODUCTION

Frozen vegetable purees are a relatively new form factor of the popular type of food products. The increasing popularity of their use as substitutes for fresh puree or crushed vegetable raw materials in producing sauces, dressings, spreads, fillings and soups, multicomponent frozen ready-made products (soup-mashed potatoes) and semi-finished products is related to the convenience to use, and also to a longer shelf life.

The processes of freezing and defrosting have a negative effect on plant tissues causing structural changes and degradation in puree sensory properties. Structure is understood as the internal structure of the product and the nature of interaction between its individual elements (particles), which cause the reaction of tactile sensations to the physical stimuli that result from the contact with the food product [19]. Structural properties are closely related to rheological properties but the latter does not cover all the factors that determine the structure of food products. Thus, the concept of structure is complex and includes a number of such physical properties of the product as appearance, sensations in the oral cavity, dispersion, and viscosity.

It should be noted that the terms *structure* and *texture* are treated differently in the world literature.

The Russian-language term "texture" in American and English literary sources is treated as "structure". Therefore, to avoid a different interpretation, the authors give the definition of the term "texture" used in this paper. In the Russian-language literature, texture refers to the preferential orientation and relative arrangement of the elements that make up the product.

The desired structure can be obtained by adding supplementary ingredients to the product. Thus, to increase the viscosity and induce gelling, water-soluble biopolymers, hydrocolloids, are used.

Modified starches xanthan gum, galactomannans (guar gum and locust bean gum), and cellulose derivatives have been most used among food hydrocolloids as thickeners in the food industry. As gellants, modified starches, gelatin, agar, gum arabic, carrageenans, pectin, etc. are applied. A lot of hydrocolloids show both of these properties simultaneously [2].

For the products with neutral pH, in most cases, starches which can be combined with the ingredients that reduce the sense of viscosity in the mouth, such as oxidized starches, and also hydrocolloids with a low viscosity are used as thickeners. Opaque thickeners may be used for opaque products, for example, starches from waxy maize varieties.

In the products subjected to heat treatment in the production process, such ingredients as xanthan gum or heat-resistant methylcellulose are used to maintain viscosity. They have the ability to form an extended spatial network [1, 2].

For the products with pH = 3.5–4.0, such hydrocolloids as xanthan and guar gum, locust bean gum and their combinations are used, while starches are of limited use. The reason is that when combined with heat treatment and a low pH, starches and some hydrocolloids undergo partial molecular degradation [16].

Xanthan gum is an exopolysaccharide of microbiological origin obtained by fermentation. In the dissolved form, it has a high viscosity and thixotropy. It forms a spatial network structure [1].

An important property of vegetable hydrocolloids (such dietary fibers as inulin, pectin, etc.) is their prebiotic effect, which increases the nutritional value of the products that contain these components for the consumers that adhere to the principles of healthy nutrition [17, 18].

Different types of dietary fibers play a different role in the formation of the structure and can be conditionally classified into thickening and non-thickening ones. The second group includes short chain molecular oligosaccharides or mono-, di- and trisaccharides that are able to bind water well. Their introduction into the composition of the product increases the sweetness of the product and swelling capacity, improves consistency and sensations in the oral cavity, and changes the boiling point (for liquid products), the freezing point as well as the product density [1].

A significant amount of studies is devoted to the study of the effect of hydrocolloids on the pureed products subjected to freezing, refrigerated storage and subsequent defrosting.

In [3], the effect of cryoprotecting on the taste and structure of frozen/defrosted mashed potatoes was studied. Kappa-carrageenan, xanthan gum, chitosan, inulin, trehalose, oat fiber, starch and hydroxypropylmethylcellulose was used as cryoprotectants either individually or in the form of compositions.

The analogous results of the studies were obtained in [4]. The authors estimated the effect of introduction of inulin in various concentrations both independently and with the addition of cryoprotectants (kappa-carrageenan and xanthan gum) on the visco-elastic properties and microstructure of fresh and frozen/defrosted mashed potatoes. The results of the study showed that if the introduction of inulin resulted in a smoother (soft) and creamy texture of the product, its concentration did not significantly affect the rheological properties of puree, elasticity and the overall sensory evaluation of the samples. At the same time, the addition of kappa-carrageenan and xanthan gum resulted in significant changes. Apart from that, the fresh mashed potatoes had a more rigid structure than the samples of frozen/defrosted purees. This led to the conclusion that inulin can be used as a texturing agent that agrees with [5].

Nevertheless, the final conclusion in [4] stated that inulin as a texturizing agent for mashed potatoes would have limited industrial application in view of its partial hydrolysis (the shortening of the molecular chain) during heat treatment that interferes with gel formation.

It has been established in [6] that dietary fibers (pea fibers, inulin and their compositions) can be applied as functional ingredients for the enrichment of frozen/defrosted mashed potatoes. When introduced into the puree, the fibers exhibited opposite properties (softness – with inulin, hardness – with pea fibers), which is explained by different mechanisms of their interaction with the starch matrix of mashed potatoes. The simultaneous introduction of pea fibers in a low concentration (< 15 g/kg puree) and inulin in large concentrations (> 45 g/kg puree) in recommended to achieve a physiological effect. Herewith there was not an adverse effect on the texture and rheological properties, color and overall sensory perception of the product.

Other pureed objects were analized in [7, 8]. The effect of mixtures of tapioca starch, low-esterified starch and calcium on the stability of fruit pureed fillings in the processes of freezing and baking of bakery products has been studied [9]. It has been shown that a “tapioca starch-pectin” composition can simulate the viscoelastic properties of waxy modified corn starch, which is commonly used in the food industry.

In [10], the effects of introduction of inulin and polydextrose on the physicochemical and sensory properties of banana puree in the cold storage process have been studied.

Thus, at the moment, the range of the studies devoted to the problem of texture stabilization with pure hydrocolloids and their compositions in the process of freezing, refrigerating and defrosting is extremely limited, and a number of issues remain unresolved.

The paper is aimed at studying the effect of the addition of stabilizers and thickeners on the taste and texture of the vegetable purees subjected to freezing, storage and subsequent intensive thermal effects in microwave treatment. To justify their choice and dosage, a complex analysis texture requirements, the cost of the finished product, and stability during heat treatment (freezing, heating, and cooking) was used.

STUDY OBJECTS AND METHODS

The samples of single-component vegetable purees from carrots, beets and zucchini were considered.

The experimental samples were prepared as follows. The vegetables were hand-washed, cooked until ready in water, the broth was poured. After cooling, the raw material was cleaned, cut into cubes and crushed in a knife mixer (the blade speed was 6.28 r/s). The hydrocolloids were introduced into the products obtained in the form of dry powder. The samples were homogenized (the blade speed was 5.24 r/s) then wiped through a stainless steel sieve (∅ 1.5 mm). Some of the samples were analyzed fresh, the others were frozen in plastic containers at –18°C (the control temperatures were measured in the thermal centers of the samples.) The frozen samples were evacuated and placed in cold storage at –18°C. Defrosting was carried out in a microwave oven until the temperature in the thermal center reached 20 ± 5°C, then samples were heated to a consumption temperature (50°C).

One type of hydrocolloids or their compositions were introduced in each test sample. In the study, hydrocolloids were represented by xanthan gum E415, modified starch E1414, and inulin.

The frozen samples were stored for two months. After defrosting, the taste and structure were evaluated.

Table 1. Descriptors of the structure of vegetable purees and their corresponding sensory indices [1]

No.	Structure descriptor	Sensory perception or estimation method
1	Density	The ability of the product to drain from a spoon
2	Water separation	Visual observation of the surface of the puree, as well as after immersion in a spoon
3	Texture	Visual observation of the surface after mixing the product with a spoon
4	Density (sensation in the oral cavity)	Resistance to the fluidity of the product kneaded between the palate and the tongue
5	Viscosity	Perceived cohesiveness of the mixed product when it is drained from a spoon
6	Smoothness	Sensation in the oral cavity determined when the product is compressed between the palate and the tongue

A combination of several methods was used to determine the structure [11–13], including free choice profiling and a procrustean analysis [14]. The organoleptic estimation of the samples was carried out using a quantitative descriptive analysis [15] based on the development of a list of terms and procedures for determining the characteristics of the structure that describe the properties of the product (descriptors). Each descriptor was assigned with an appropriate touch index. The severity of a descriptor for a given product was estimated with a certain scale with the help of a group of tasters as the organoleptic (sensory) perception of the product quality. To eliminate duplication, the multistage estimation of the results was carried out.

During the analysis, some of the most significant characteristics of the structure were identified, and their descriptors were defined (Table 1).

The tasting group included 20 people without special training. For each of the descriptors of the texture, a 7-step scale was used (1-no property is detected, 7-the property is distinct). The tasters also estimated the general perception of the samples on the basis of all the sensory indexes using a similar scale. The results of the sensory analysis were statistically handled.

Scanning electron microscopy (SEM) was used to analyze a change in the texture of purees. The microstructure of fresh, frozen and defrosted purees was examined using a ZEISS EVO 50 microscope (Karl Zeiss, Germany). For the deionization of the material, a layer of aluminum with a thickness of 20 nm was deposited on the pre-dehydrated plates of the puree samples by thermal evaporation. Sputtering was carried out at a VUP-4 (Russia) vacuum universal station. Micrographs were obtained using a SmartSEM digital system.

RESULTS AND DISCUSSION

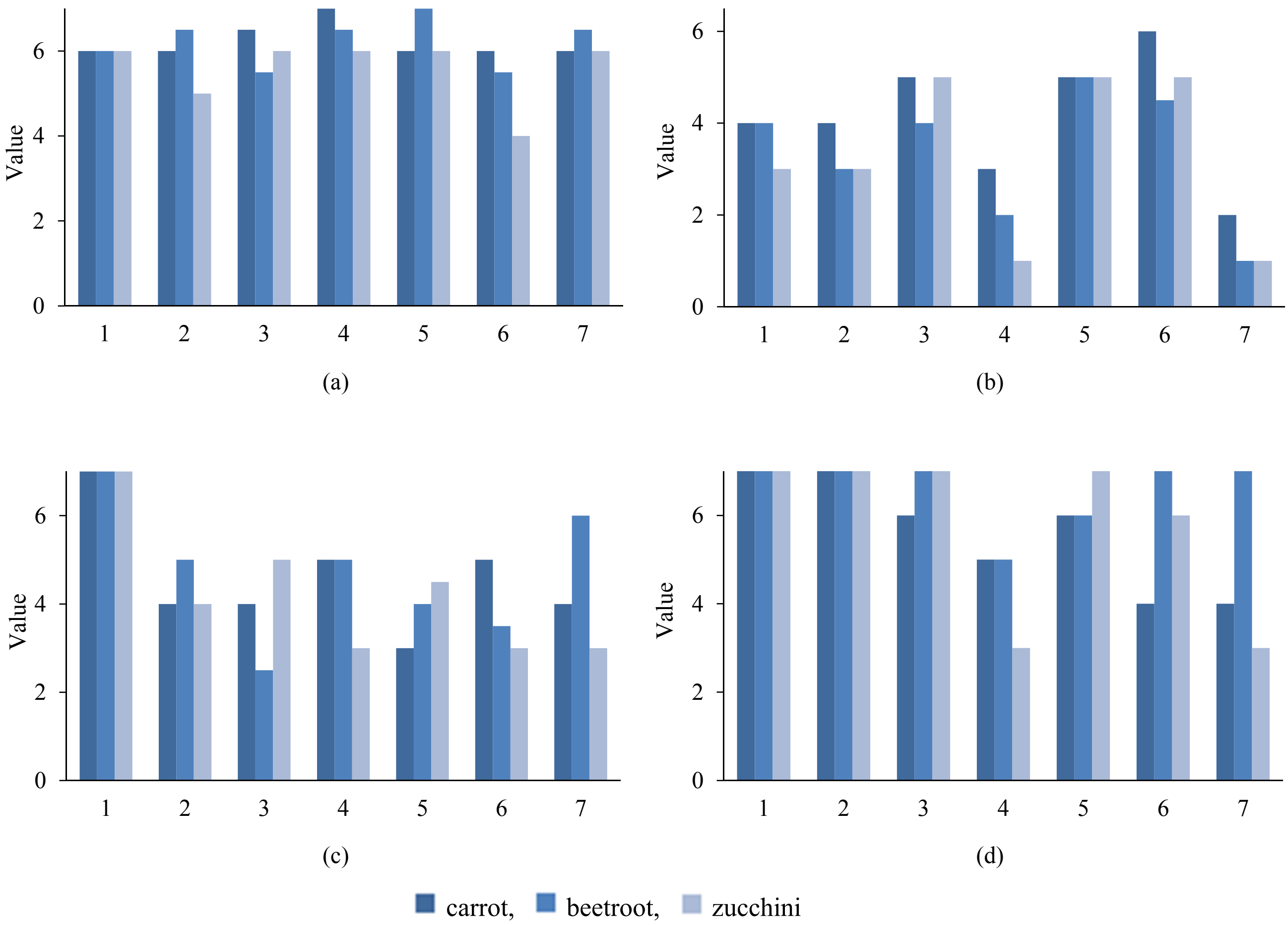
Sensory studies have been carried out and the severity of descriptors for vegetable purees as well as the overall estimation of the taste and color of the product have been numerically estimated (Table 2).

The results of statistical processing of sensory estimation of experimental samples are graphically presented in the form of histograms (Fig. 1) for each descriptor. The analysis showed the distinct effect of hydrocolloid species on such descriptors as texture and smoothness (Fig. 1a and b) as well as on color and the overall sensory estimation of taste (Fig. 1c and d). The values of the other controlled descriptors were approximately at the same level for one or another type of frozen/defrosted puree regardless of the type of the structurant used (with the exception of fresh mashed potatoes). Therefore, the histograms of these descriptors are not shown here.

The change in the intensity of descriptors of experimental samples is also clearly visible in the case of the graphical interpretation of the results of sensory estimation using the profile method. This method shows in a more comprehensive manner the pattern relating to the sensory comparative estimation of samples in general rather than the image in Cartesian coordinates.

Table 2. Results of the statistical processing of sensory evaluation of experimental samples

Sample/ No. / description / composition				Structure descriptors						Taste	Color
				1	2	3	4	5	6		
Carrot puree	1	fresh	no additives	7.0	1	6.0	6	3.0	4.0	7.0	7
	2	frozen/defrosted	no additives	6.5	1	6.0	6.5	2.0	4.0	4.0	7
	3	frozen/defrosted	xanthan gum 0.5%	6.5	2	6.5	6.5	2.0	5.0	4.0	6
	4	frozen/defrosted	starch 5%	6.0	1	7.0	6.5	3.0	3.0	5.0	5
	5	frozen/defrosted	inulin 2%	6.0	1	6.0	6.0	2.0	5.0	3.0	6
	6	frozen/defrosted	xanthan gum 0.5%, inulin 2%	7.0	1	6.0	6.5	2.0	6.0	5.0	4
	7	frozen/defrosted	starch 5%, inulin 2%	6.5	1	6.0	6.5	2.0	2.0	4.0	4
Beet puree	1	fresh	no additives	7.0	1	6.0	5.0	3.0	4.0	7.0	7
	2	frozen/defrosted	no additives	7.0	1	6.5	5.0	2.0	3.0	5.0	7
	3	frozen/defrosted	xanthan gum 0.5%	7.0	1	5.5	5.0	2.0	4.0	2.5	7
	4	frozen/defrosted	starch 5%	7.0	1	6.5	6.0	2.0	2.0	5.0	5
	5	frozen/defrosted	inulin 2%	7.0	1	7.0	6.0	3.0	5.0	4.0	6
	6	frozen/defrosted	xanthan gum 0.5%, inulin 2%	7.0	1	5.5	6.0	3.0	4.5	3.5	7
	7	frozen/defrosted	starch 5%, inulin 2%	7.0	1	6.5	7.0	2.5	1.0	6.0	7
Zucchini puree	1	fresh	no additives	7.0	1	6.0	5.0	4.0	3.0	7.0	7
	2	frozen/defrosted	no additives	7.0	2	5.0	4.0	3.0	3.0	4.0	7
	3	frozen/defrosted	xanthan gum 0.5%	7.0	1	6.0	6.0	4.0	5.0	5.0	7
	4	frozen/defrosted	starch 5%	7.0	1	6.0	6.0	3.5	1.0	3.0	3
	5	frozen/defrosted	inulin 2%	7.0	1	6.0	5.5	4.0	5.0	4.5	7
	6	frozen/defrosted	xanthan gum 0.5%, inulin 2%	7.0	1	4.0	5.0	4.0	5.0	3.0	6
	7	frozen/defrosted	starch 5%, inulin 2%	7.0	1	6.0	6.0	4.0	1.0	3.0	3



11 – fresh, no additives; 2 – frozen/defrosted, no additives; 3 – xanthan gum (0.5%); 4 – starch (5%); 5 – inulin (2%); 6 – xanthan gum (0.5%) + inulin (2%); 7 – starch (5%) + inulin (2%).

Fig. 1. Results of statistical processing of sensory evaluation of experimental samples: (a) texture, (b) smoothness, (c) taste, and (d) color.

Each specific profilogram shows the values of descriptors of puree samples on the divergent rays with and without the addition of a certain composition that were subjected to have undergone the same refrigeration treatment.

Negative qualities (water separation, texture, and viscosities) are given in advance at the bottom of the profiles below the horizontal one. This is for the convenience of analyzing the results, because slipping down the profilogram sample with the additive indicates a negative effect on the quality of the hydrocolloids introduced into the sample. Profilograms are grouped depending on the composition of hydrocolloid or composition administered.

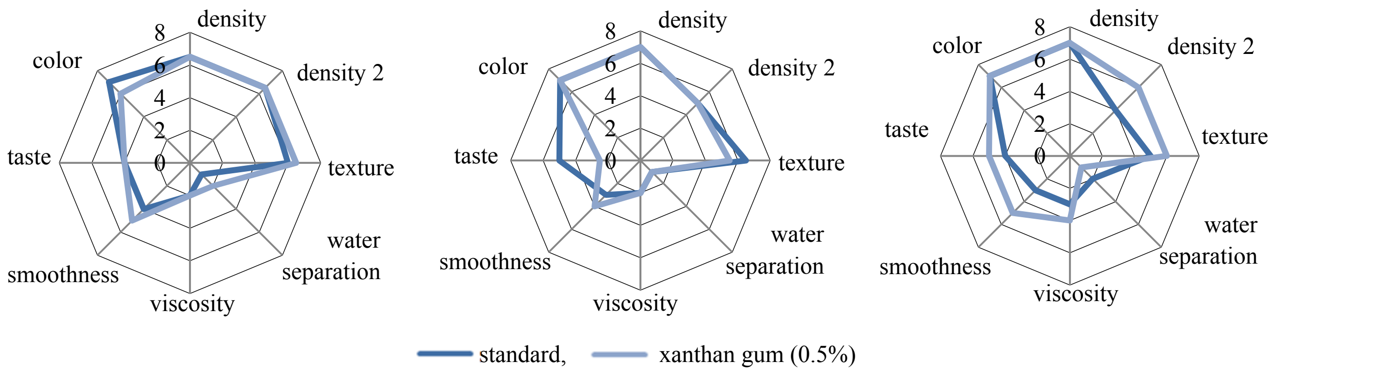
Xanthan gum exerted its effect on the structure irrespective of the technological process and formed viscosity of the samples regardless of the conditions and types of processing (Figs. 1a, 2, 5). The fresh samples as well as frozen/defrosted ones with the addition of xanthan gum are rated as thick ones. When the surface of the puree was visually observed, and after the spoon was immersed therein, there was no water separation (Fig. 2).

The starch imparted the most pronounced density in the mouth as well as visually (Figs. 3 and 6). There was no water separation in both the fresh and frozen/defrosted samples. The starch also had an effect on taste and color (Figs. 1c, 1d, and 3). It was especially pronounced for the zucchini puree, which acquired a whitish shade, as well as on the carrot puree (gray tint). In general, the puree with xanthan gum was estimated as more palatable to taste than the puree with starch at the same values of structure descriptors (Fig. 1c).

A significant effect of inulin and xanthan gum on the sense of smoothness of the samples in the oral cavity was noted after squeezing the product between the palate and the tongue (Figs. 4, and 5). At the same time the starch provided a granular structure (Figs. 1a, and 2) especially noticeable for the zucchini puree because of its natural, more tender taste and not such a fibrous structure as in the puree made from carrots and beets.

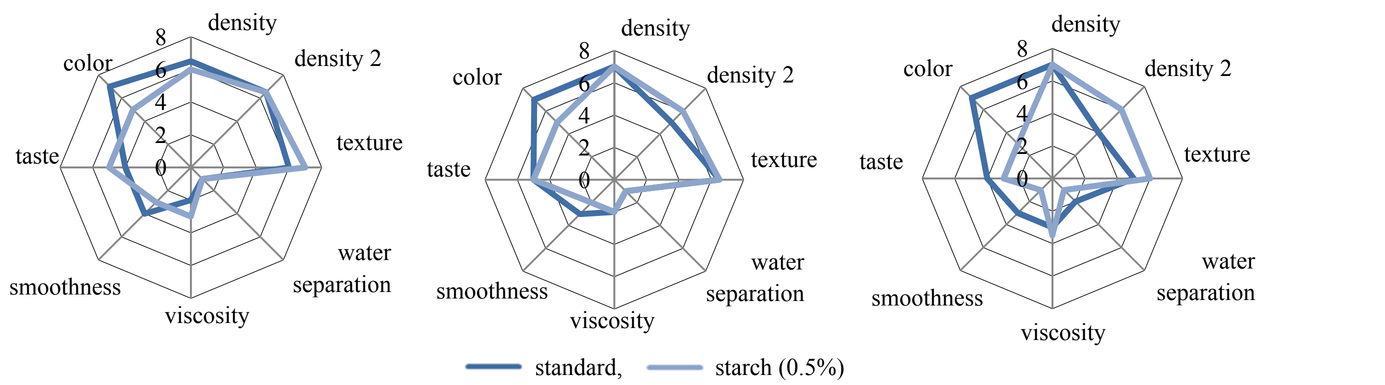
It was established that in the vegetable purees susceptible to freezing, storage and defrosting, inulin has a low thickening capacity and does not exhibit any synergistic properties with xanthan gum and starch. The weak thickening capacity of inulin can supposedly be associated with the partial molecular degradation of the gel in the freezing-storage-defrosting cycle. However, the frozen/defrosted puree samples containing inulin had more pronounced flavor (Fig. 1c) and smooth texture (creaminess) (Fig. 4) than their analogues without additives.

During the visual observation of the surface after mixing the product with a spoon (descriptor-texture), the samples with inulin had a more glossy, flat surface (Fig. 1a).



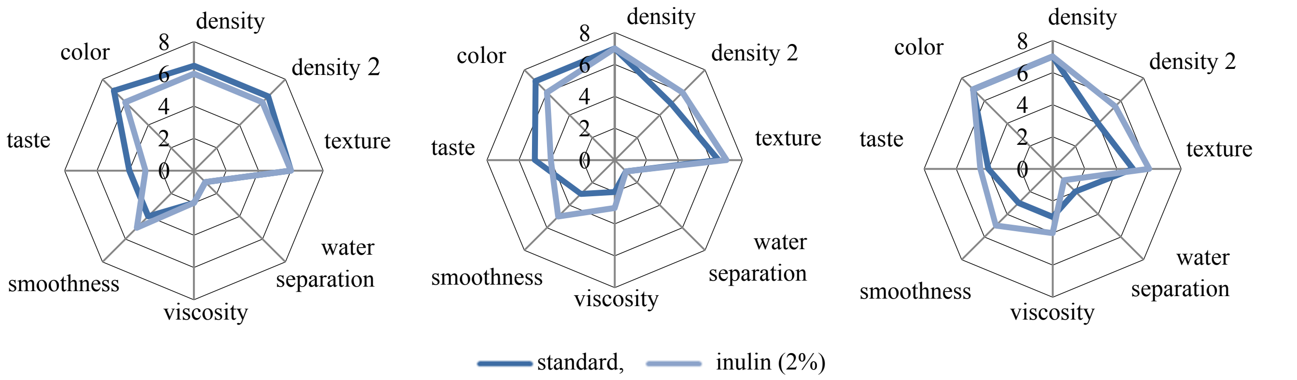
(a) (b) (c)

Fig. 2. Profilograms for change in the descriptors of the structure of the samples that were subjected to refrigeration: (a) carrot, (b) beetroot, and (c) zucchini.



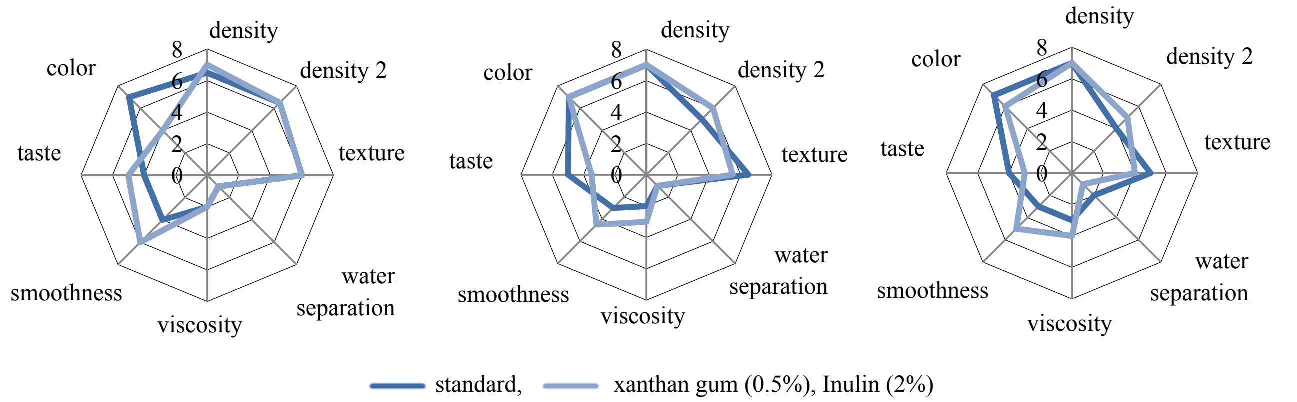
(a) (b) (c)

Fig. 3. Profilograms for change in the descriptors of the structure of the samples that were subjected to refrigeration: (a) carrot, (b) beetroot, and (c) zucchini.



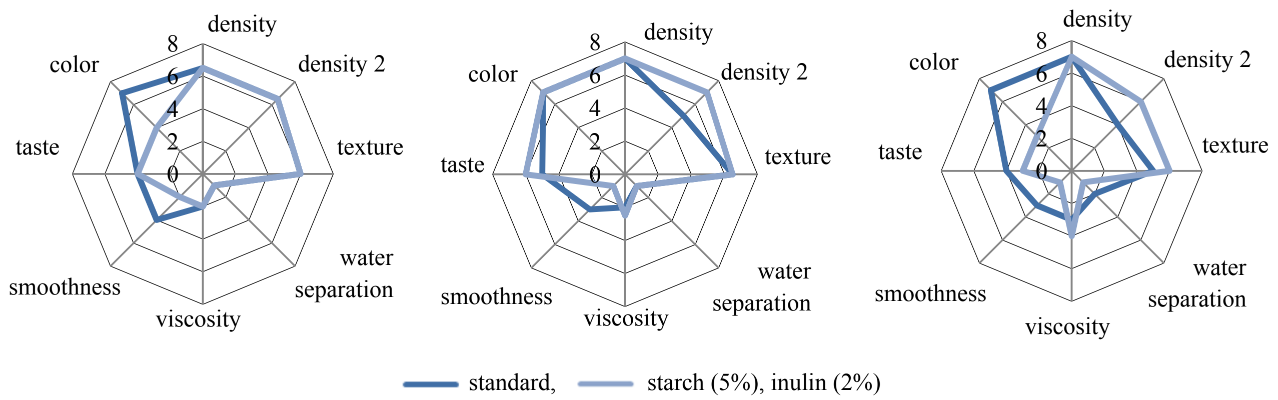
(a) (b) (c)

Fig. 4. Profilograms for a change in the descriptors of the structure of the samples that were subjected to refrigeration: (a) carrot, (b) beetroot, and (c) zucchini.



(a) (b) (c)

Fig. 5. Profilograms for a change in the descriptors of the structure of the samples that were subjected to refrigeration: (a) carrot, (b) beetroot, and (c) zucchini.



(a) (b) (c)

Fig.6. Profilograms for a change in the descriptors of the structure of the samples that were subjected to refrigeration: (a) carrot, (b) beetroot, and (c) zucchini.

It has been established that the undesirable taste of xanthan gum and starch is covered by a pleasant aftertaste provided by the introduction of inulin into the puree. Thus, the optimal samples of taste estimation were obtained with the addition of inulin and its combinations with starch or xanthan gum (Fig. 1c). Hence, the simultaneous incorporation of prebiotics (inulin) and stabilizers in small amounts into the formula ensures the preservation of high taste qualities of vegetable purees and a stable structure during the storage period and in the heat treatment processes.

In all the samples studied, as a result of introduction of hydrocolloids, the formation of weakly structured gel with the pronounced retention capacity in relation to the components of the products was noted, as confirmed by the microstructural analysis (Figs. 7, and 8).

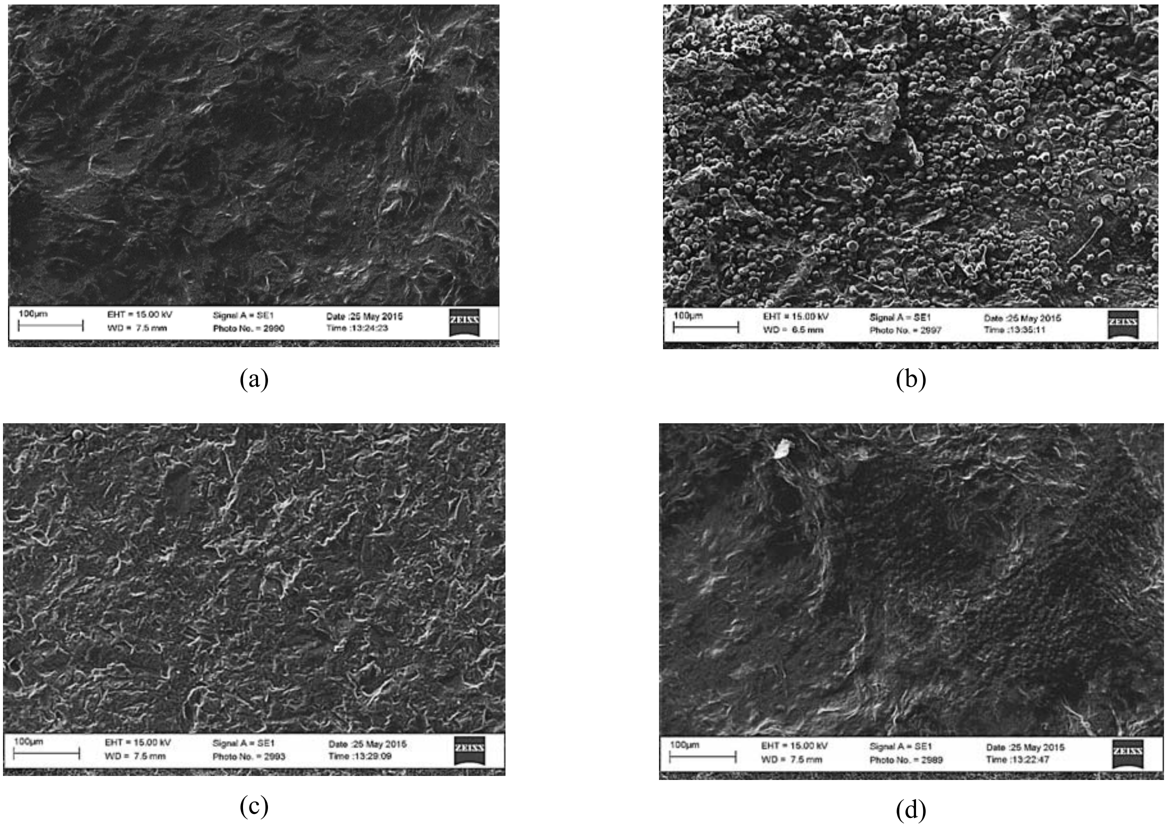


Fig. 7. Effect of hydrocolloids on the microstructure of zucchini puree: (a) the fresh puree with no addition of hydrocolloids after the freezing-storage-defrosting cycle ; (b) the frozen/defrosted puree with the addition of 5% starch; (c) the frozen/defrosted puree with the addition of 0.5% xanthan gum; (d) the frozen/defrosted puree with the addition of 2% inulin.

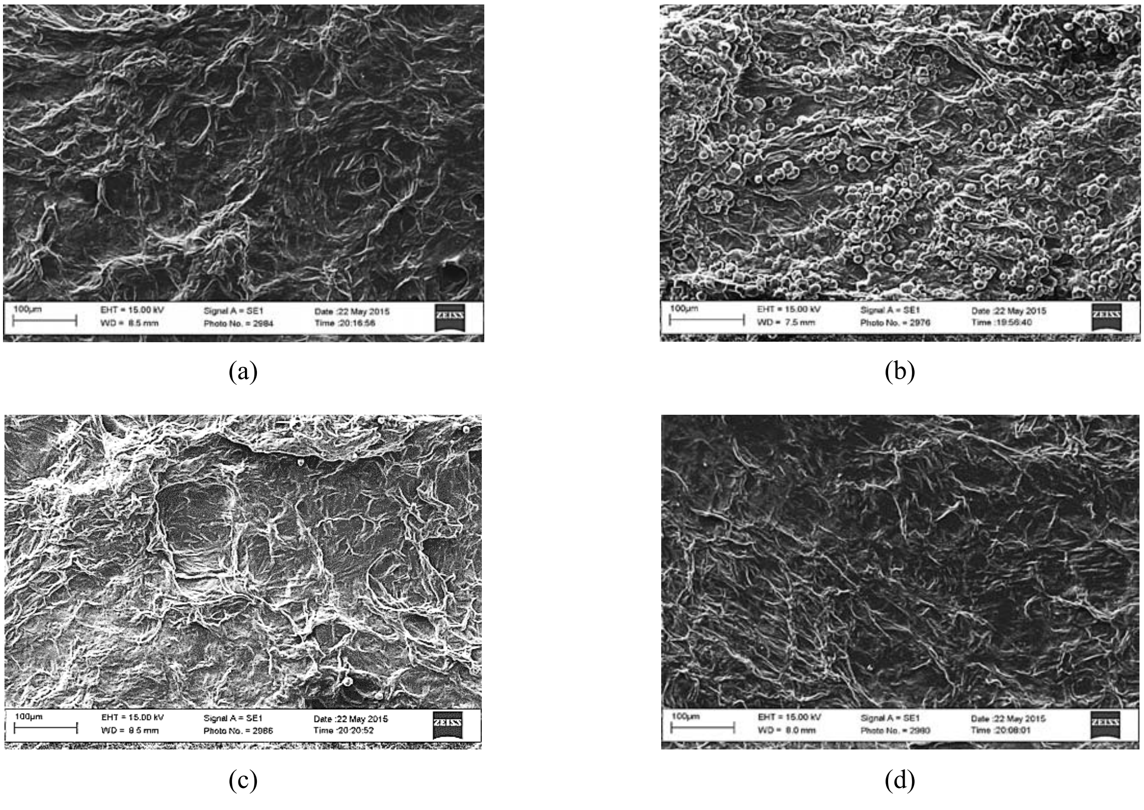


Fig. 8. Effect of hydrocolloids on the microstructure of carrot puree: (a) the fresh puree with no addition of hydrocolloids after the freezing-storage-defrosting cycle ; (b) the frozen/defrosted puree with the addition of 5% starch; (c) the frozen/defrosted puree with the addition of 0.5% xanthan gum; (d) the frozen/defrosted puree with the addition of 2% inulin.

Figs. 7b and 8b show, indicates that the grains of starch do not degrade or degrade insignificantly as during the entire freezing-storage-defrosting treatment cycle, this hydrocolloid. The sensory evaluation of experimental samples of mashed potatoes with starch marked a granular structure.

In the samples with xanthan gum (Figs. 7c and 8c), the presence of a developed spatial structure was noted, which explained high values of descriptors of the structure (density, texture, etc.) for the vegetable purees and a softer structure compared to the puree with the addition of starch (descriptor–smoothness).

Figs. 7d and 8d present the resulting cellular structure of puree with the addition of inulin in the form of weak gel characterized by a low shear modulus, an insignificant shear stress, and weak viscoelastic properties noted in the sensory evaluation.

CONCLUSIONS

A possibility of using traditional products (xanthan gum and modified starch) and products unused earlier for this group (inulin) of structurizing ingredients due to various manifestations of their basic structure-forming properties in the freezing-refrigerated storage-defrosting cycle has been proved.

In the cold state, the binder acts as a stabilizer to prevent settling and should not lose its binding properties when heating the sample. Due to this, the modified starches with small granules which exhibit a thermal stability in cold storage and further heat treatment are most suitable for creating a viscous structure.

Inulin is also not subject to any changes during temperature treatments for the products with a pH higher than 3.5, which include the study objects, but probably will not be widely used as a structure-forming agent for vegetable purees due to the weak of structure-forming properties. The synergistic combinations of inulin and xanthan gum improve the organoleptic characteristics of the product, including consistency, especially in cold storage. In addition, the ability of inulin to form a smooth structure in vegetable purée when enveloping the oral cavity has been revealed despite the fact that the initial product has a rather coarse fibrous consistency due to the plant origin of the ingredients. Thus, it is promising to use inulin in combination with thickeners to give the product prebiotic properties with the improved perception in consumers.

The results of the studies confirm the possibility of storing vegetable purees at low temperatures for a long time without the deterioration of the structural and organoleptic properties resulting from the slowly occurring degradation processes of the individual components of the product at low temperatures provided that the hydrocolloids under study are used.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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