Functional and technological properties of food nanoadditive based on double oxide of ferrous and trivalent iron in production molded jelly marmalade

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Abstract

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Introduction. The functional and technological properties of food nanoadditive based on double oxide of divalent and trivalent iron “Magnetofood”(Fe₃O₄) in the production of molded jelly marmalade were studied.

Materials and methods. Prototypes of molded jelly marmalade on agar and pectin. Functional and technological properties were studied with the help of Sensory (taste, smell, color, consistency, shape and surface – on a 5-point scale); physico-chemical (mass fraction of moisture, total acidity, determined by gravimetric and titrimetric methods, respectively); structural and mechanical methods. The strength of the marmalade well was determined by the shear stress on the penetrometer AP-4/1.

Results and discussion. The ability of nanoparticles of food additive Fe₃O₄ “Magnetofood” to promote: improvement of Sensory characteristics of molded jelly marmalade: the shape, surface and consistency is improved by 0,1–0,2 points (for agar marmalade) and 0,1–0,3 points (for pectin marmalade); increase in the moisture content by 1,15–1,16 times in the experimental samples on agar and 1,13–1,14 times in the experimental samples on pectin due to the moisture-binding and moisture-retaining ability of the chemically active nanoparticles of the additive “Magnetofood”; reduction of the total acidity by 1,05–1,08 times in the test samples on agar and 1,06–1,09 times in the test samples on pectin due to the amphoteric and sorption properties of the additive.

The strength of jelly-marmalade jelly was increased by 1,3–1,5 times (for agar marmalade) and 1,22–1,4 times (for pectin marmalade) with the introduction of 0,1–0,2% “Magnetofood” due to the structural and stabilizing action of the nanoparticles of the additive. The rational content of the food additive “Magnetofood” was determined – 0,15% by weight of the prescription mixture for both gelling agents (agar and pectin).

The optimal conditions of temperature-humidity regime during storage of molded jelly marmalade are established: relative humidity $\varphi=(75\pm 2)\%$, temperature $(18\pm 2)^{\circ}\text{C}$, recommended storage duration is 90 days.

Conclusions. For the first time, the functional and technological properties of food nanoadditives based on double oxide of ferrous and trivalent iron in the production of molded jelly marmalade were studied.

Introduction

Jelly-marmalade products have a colloidal dispersed structure, so the problem of its stabilization is relevant. In addition, in the conditions of competition in the domestic market, manufacturers of jelly and marmalade products are looking for ways to increase their competitiveness by improving the functional and technological characteristics of raw ingredients; consumer properties of finished products, reducing the cost and extending their shelf life [1, 2]. To improve the structural and mechanical properties of gel-like masses and consumer characteristics of finished products, non-traditional raw materials are used, such as waste from the food industry (Canning, wine, sugar beet industries) and agriculture (seed State Farms, Cotton, melon) [14-16]; as well as alternative raw materials: chitosan, vegetable, vegetable and fruit and vegetable products [17, 18] in that puree feijoa, Kiwi, Jerusalem artichoke [19, 20]; extracts and powders of spicy-aromatic herbs and vegetable, fruit and Berry powders (help to improve the consistency and consumption characteristics of the finished product (their disadvantage is insufficient stability of the gel-like structure) [21, 22]; sorbitol [23]; hydrocolloids: carrageenan and its sodium, potassium, ammonium salts, including furcellaran; xanthan, tara, guar gum, carob gum, xanthan gum, etc. (help to increase moisture-retaining ability and improve elasticity – elastic properties of jelly-marmalade products with a long shelf life) [4, 5, 8-10]. Combined systems of structure – forming agents are widely used, in particular combinations of gelatin with pectin, with sulfated polysaccharides, gelatin-K – carrageenan, gelatin-pectin LM [5, 7, 8]; pectin with hydrocolloids (Herbagel SW – 010, rikogel 8100), pectin LM-K-carrageenan [7, 10]; Agar with animal protein concentrate “Scanpro” [4, 11]; various modifying systems: sodium-carboxymethylcellulose (S-CMC) with iron chloride [4, 7]; sodium lactate, sodium citrate with glycerin [10, 11], mannite or sodium alginate [12, 13]; modifications of metal nanoparticles and their oxides with polysaccharides, vegetable and animal proteins: egg and whey protein albumin, gelatin, whey protein, gliadin, legumes and soy proteins, elastin, Zein, milk protein [24-28].

Analysis of literature sources [1-28] showed that there is insufficient data on the effect of nanoadditives, in particular, food nanoadditives based on double iron oxide (“Magnetofood”) [UA Patent No. 126502] on the physico-chemical, structural-mechanical and Sensory characteristics of molded jelly marmalade. Food nanoadditives “Magnetofood ” (Fe_3O_4) have a wide range of functional and technological properties (structure-forming, stabilizing, sorption, etc.) and promising technological applications [29, 30].

In this regard, the study of the functional and technological potential of the food Nano-supplement “ Magnetofood ” in terms of its impact on the quality and timing of preserving the freshness of jelly and marmalade products is relevant.

The aim of the research is to determine the functional and technological properties of a food additive based on double iron oxide “Magnetofood” (FAM) in the production of molded jelly marmalade on agar and pectin.

To achieve this goal, the following tasks were set:

- to study the effect of the food additive “Magnetofood” on Sensory parameters (taste, smell, color, consistency, shape and surface) of experimental samples of molded jelly marmalade on agar and pectin;
- to study the effect of the food additive “Magnetofood ” on the physical and chemical characteristics (mass fraction wet, total acidity) of prototypes of molded jelly marmalade on agar and pectin;

- to study the effect of the food additive “Magnetofood” on the structural and mechanical properties (strength of jelly-marmalade jelly) of prototypes of molded jelly marmalade on agar and pectin;
- to establish the rational content of the food additive “Magnetofood” and optimal conditions for the temperature and humidity regime during the storage of molded jelly marmalade on agar and pectin.

Materials and methods

Materials

Object of research: functional and technological properties of powder ingredients of food raw materials, in particular nanoparticles of a food additive based on iron oxides “Magnetofood” – Fe_3O_4 (FAM).

Research subjects:

- Food grade nanoadditive based on iron oxides “Magnetofood” – Fe_3O_4 (FAM);
- Highly dispersed brown or black nanopowder with a particle size of 70-80 Nm. According to the chemical composition, “Magnetofood” is a double ferum oxide ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$ або Fe_3O_4), which was obtained by Chemical Co – deposition from aqueous solutions of two – and trivalent ferum salts in an alkaline medium (patent UA No. 126507. 53. method for obtaining the food additive “Magnetofood”);
- Experimental samples of shaped jelly marmalade based on agar and pectin, which are based on basic recipes No. 11 and No. 49, respectively (see Table 1 and [31]) [29, 30]. FAM was introduced into prescription compositions in the form of an aqueous suspension during swelling-dissolution of the gelling agent in the amount of 20.0 g; 30.0 g; 40.0 g per 1000.0 g of the prescription mixture, which is equal to 0.1%; 0.15%; 0.2% of the FAM, respectively, by the mass of the prescription mixture [30]. An aqueous suspension of FAM in 5% agar and pectin Solutions was obtained by introducing FAM suspension into a 5% polysaccharide solution at a temperature of (55–60)°C with constant stirring $n=(2,0-2,2) \text{ c}^{-1}$ for (5-7)×60 C, followed by cooling the mixture to a temperature of (18–20)°C with constant stirring $n=(2,0-2,2) \text{ c}^{-1}$ [29].

Research methods

Sensory parameters

Sensory parameters (taste and smell, color, consistency, structure, shape, surface) were analyzed on a 5-point scale [29, 30]. When evaluating the smell of marmalade, attention was paid to the presence or absence of foreign, unusual odors.

Physical and chemical parameters

The total acidity and mass fraction of moisture were studied using standard and generally accepted methods [29, 30]. The acidity of experimental samples of molded jelly Marmalade was determined by titrimetric method using phenolphthalein [29]; mass fraction of moisture [30].

Table 1

Recipes for jelly shaped marmalade on agar and pectin

Raw material	Raw material consumption per 1000 g of finished products, g							
	Prototypes of jelly shaped marmalade							
	On agar				On pectin			
	Sample 1 – control	Sample 2 – experiment with 0.1% FAM	Sample 3 – experiment with 0.15% FAM	Sample 4 – experiment with 0.2% FAM	Sample 5 – control	Sample 6 – experiment with 0.1% FAM	Sample 7 – experiment with 0.15% FAM	Sample 8 – experiment with 0.2% FAM
Granulated sugar for sprinkling	86,6	86,6	86,6	86,6	86,6	86,6	86,6	86,6
Granulated sugar in jelly	525,6	524,6	524,1	523,6	718,9	717,9	717,4	716,9
Molasses	262,7	262,7	262,7	262,7	262,7	262,7	262,7	262,7
Agar	10,5	10,5	10,5	10,5	–	–	–	–
Pectin	–	–	–	–	18,0	18,0	18,0	18,0
Citric acid	11,8	11,8	11,8	11,8	12,0	12,0	12,0	12,0
Sodium lactate	–	–	–	–	10,0	10,0	10,0	10,0
Different essences	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
Different dyes	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6
Water suspension of FAM	–	20,0	30,0	10,0	–	20,0	30,0	10,0
Water	100,7	87,7	77,7	97,7	152,3	132,3	122,3	142,3
Output of the finished product	1000,0	1000,0	1000,0	1000,0	1000,0	1000,0	1000,0	1000,0

To simulate the storage of marmalade, a polyethylene film (HDPE, 15 microns) was used as a packaging material. Prototypes of molded jelly marmalade (thickness – 10^{-2} m, diameter – 2×10^{-2} m) 18 hours after casting and cooling were wrapped in film and stored in the dark in an air thermostat (dry-air thermostat TP-80-1) at a temperature of $(18 \pm 3)^{\circ}\text{C}$ and relative humidity $\varphi=40-90\%$ in increments of 10% (periodically measured relative humidity, $\varphi\%$, using a hygrometer psychrometric VIT-2) for 90 days.

As a criterion for choosing a rational storage mode, we chose the constancy of the moisture content of marmalade (the moisture content of molded jelly marmalade after production is 0.179–0.181 kg/kg) [30], which depends on the humidity of the environment and the duration of storage of marmalade [29, 30]. The proposed criterion looks like this:

$$Q_{\varphi} = \sum_{i=1}^N |W_i - W_3| \rightarrow \min \quad (1)$$

where N – the number of tests during storage, PCs; W_3 – standard moisture content equal to 0,18 kg/kg; W_i – current moisture content, kg / kg; φ – ambient humidity,%.

Structural and mechanical properties

The strength of jelly-marmalade masses was studied by the maximum shear stress on the AR-4/1 penetrometer; rheological properties (effective viscosity) were determined on the Rheotest-2 device [29, 30].

Results and discussion

Table 2 shows the results of Sensory analysis of prototypes of molded jelly Marmalade with different gelling agents (fgar and pectin) and with different amounts of food additive based on iron oxides “Magnetofood” (FAM). This shows that the introduction of FAM in the form of an aqueous suspension at the stage of "swelling-dissolution" of the gelling agent improves the shape, surface and consistency by an average of 0.1–0.2 points (for molded jelly marmalade on agar) and 0.1–0.3 points (for molded jelly marmalade on pectin).

Table 2
Dependence of sensory parameters of experimental samples of molded jelly marmalade on agar and pectin on the mass fraction of a food additive based on iron oxides “Magnetofood” (FAM)

Replacing the indicator	Prototypes of jelly shaped marmalade			
	On agar			
	Sample 1 – control	Sample 2 – experiment with 0.1% FAM	Sample 3 – experiment with 0.15% FAM	Sample 4 – experiment with 0.2% FAM
Fragrance	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Color	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Taste	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Consistency	4,8±0,1	4,9±0,1	5,0±0,1	5,0±0,1
Shape and surface	4,8±0,1	4,9±0,1	5,0±0,1	5,0±0,1

Replacing the indicator	Prototypes of jelly shaped marmalade			
	On pectin			
	Sample 5 – control	Sample 6 – experiment with 0.1% FAM	Sample 7 – experiment with 0.15% FAM	Sample 8 – experiment with 0.2% FAM
Fragrance	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Color	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Taste	5,0±0,1	5,0±0,1	5,0±0,1	5,0±0,1
Consistency	4,7±0,1	4,9±0,1	5,0±0,1	5,0±0,1
Shape and surface	4,8±0,1	4,9±0,1	5,0±0,1	5,0±0,1

It should be noted that the best Sensory parameters were found in samples 3, 4 (shaped jelly marmalade on agar) and samples 7, 8 (shaped jelly marmalade on pectin) with 0.15% and 0.2% FAM, respectively. Samples of marmalade had a brown-cognac color; a uniform, glassy, elastic consistency; a regular, without deformations, with a clear contour shape with a smooth, elastic and dry surface; a pleasant pronounced taste and smell characteristic of marmalade. At the same time, the rational content of FAM is 0.15% by weight of the recipe mixture. A further increase in the amount of FAM to 0.2% is impractical. Improvement of the consistency and appearance (shape, surface) of experimental samples of molded jelly marmalade is associated with the structure-forming and stabilizing effect of amphiphilic, surfactant FAM nanoparticles [29, 30].

In the production of marmalade products, the main loss of moisture occurs during casting and cooling of marmalade, which affects the quality of marmalade products. Therefore, important physical and chemical indicators of marmalade are humidity and acidity. Table 3 shows the dependence of the acidity and moisture content of prototypes of molded jelly marmalade on the mass fraction of a food additive based on iron oxides “Magnetofood” (FAM).

Hence it follows that the introduction of FAM in the amount of 0.1%; 0.15%; 0.2% by weight of the recipe mixture improves the physical and chemical parameters of prototypes of molded jelly marmalade: increases the moisture content by 1.15–1.16 times (for marmalade on agar) and by 1.13–1.14 times (for marmalade on pectin) due to the moisture-binding and moisture-retaining ability of chemically active FAM nanoparticles [29]; reduces the total acidity in 1.05–1.08 times (for agar marmalade) and 1.06–1.09 times (for pectin marmalade) due to the Amphoteric properties of FAM and sorption of acidic substances on magnetofood nanoparticles, inhibiting acid hydrolysis of the main gelling component (agar, pectin).

Table 3

Dependence of physical and chemical parameters of experimental samples of molded jelly marmalade on agar and pectin on the mass fraction of a food additive based on iron oxides “Magnetofood” (FAM)

Prototypes of molded jelly marmalade	Physical and chemical parameters of experimental samples of marmalade			
	Mass fraction of moisture, %		Total acidity, °	
	on agar	on pectin	on agar	on pectin
Sample 1-control	16,2±0,5	—	18,3±0,4	—
Sample 2-with 0.1% FAM	18,6±0,8	—	17,0±0,3	—
Sample 3-with 0.15% FAM	18,8±0,9	—	17,4±0,3	—
Sample 4-with 0.2% FAM	18,8±0,9	—	17,4±0,3	—
Sample 5-Control	—	16,6±0,6	—	18,9±0,5
Sample 6-with 0.1% FAM	—	18,8±0,8	—	17,4±0,3
Sample 7-with 0.15% FAM	—	18,9±0,9	—	17,8±0,3
Sample 8-with 0.2% FAM	—	18,9±0,9	—	17,8±0,3

At the same time, a decrease in acidity practically does not affect the process of dragle formation [29, 30].

Thus, the presence of FAM in the recipe contributes to less moisture loss when cooling products after casting the marmalade mass into the mold, stabilizes the acidity at a lower level and improves the quality indicators of molded jelly marmalade.

From the analysis of physical and chemical parameters of prototypes of molded jelly Marmalade, the rational content of FAM-0.15% by weight of the recipe mixture was established.

With a further increase in the mass fraction of FAM to 0.2%, the indicators do not change, which is due to the specific properties of nanoparticles, in particular, a large specific and chemically active surface, and the achievement of the expected result even at low concentrations [29, 30].

In order to establish the storage conditions for molded jelly Marmalade, the Q criterion was determined according to Formula (1) for experimental samples of molded jelly marmalade on agar and pectin using 0.15% FAM by weight of the recipe mixture.

This mass fraction of FAM is rational and was established by previous studies [29, 30] and the study of Sensory and physico-chemical parameters given in this paper.

The results of calculating the Q criterion for samples of molded jelly marmalade are shown in Table 4.

This shows that the use of 0.15% FAM slows down changes in the Q criterion: in experimental samples on agar, Q changes (compared to the standard value of moisture content at $\varphi=70\%$) – by 1.79–3.42 times in sample 1 and 1.03–2.87 times in sample 3; in experimental samples on pectin – by 1.66–3.33 times in sample 5 and 1.00–2.90 times in sample 7.

Table 4

Criterion Q for experimental samples of molded jelly marmalade on agar and pectin at specified ambient humidity ($\varphi=40-90\%$) and temperature ($\tau=18\pm 2$ C)

Relative humidity, $\varphi, \%$	Value of the Q criterion for experimental samples of jelly marmalade			
	Sample 1- control	Sample 3 – with 0.15% FAM	Sample 5- control	Sample 7 – with 0.15% FAM
40	1,405	1,257	1,392	1,237
50	1,304	1,139	1,289	1,105
60	1,179	0,990	1,136	0,869
70	0,490	0,480	0,471	0,461
80	0,876	0,492	0,789	0,459
90	1,679	1,378	1,571	1,354

Analysis of Criterion Q establishes the lowest total value of deviation of moisture content (W_i) of prototypes of molded jelly marmalade from the standard value $W_n=0.180$ kg/kg – at $\varphi=70\%$, which determines the optimal conditions of temperature and humidity regime during storage of molded jelly marmalade: relative humidity $\varphi=75\pm 2\%$, temperature $18\pm 2^\circ\text{C}$.

Fig.1 shows the maximum shear stress of experimental samples of jelly-marmalade masses with a rational amount of the additive “Magnetofood” (0.15% FAM – samples 3, 7) compared to control samples (0% FAM – samples 1, 5).

Figure 1. Maximum shear stress of samples of jelly-marmalade masses at different temperatures with different gelling agents:
a – on agar; *b* – on pectin

—◆— – control samples – without FAM;
 —△— – samples with 0.15% FAM

From Figure 1 it can be seen that the introduction of FAM increases the strength of jelly-marmalade jelly by 1.3–1.5 times (for agar marmalade) and by 1.22–1.4 times (for pectin marmalade). This is due to the ability of nanowires of the Magnetofood additive to interact with polysaccharide molecules, which forms an ordered spatial framework that strengthens gel-like structures. As a result, a beautiful texture of molded jelly marmalade is formed, which gives it high consumer properties and extends the period of preserving its freshness, in particular, the release of moisture during storage is significantly reduced.

Thus, studies of the structural and mechanical properties of jelly-marmalade masses with various gelling agents confirm the hypothesis of stabilization of the dispersed structure by FAM nanoparticles. In addition, the introduction of FAM molded jelly marmalade in the amount of 0.15% by weight of the recipe mixture at the stage of "swelling-dissolution" of the gelling agent reduces the amount of agar by (9–11)% and pectin by (7–9)% and increases the strength of jelly-marmalade jelly by (10±1)% for agar and (8±1)% for pectin.

The conducted studies indicate a complex effect of food nanoadditives based on double oxide of divalent iron "Magnetofood" (FAM) due to its structure – forming and stabilizing abilities, which in the technologies of jelly-marmalade production can improve the functional and technological properties of colloidal dispersed systems.

Conclusions

The ability of nanoparticles of the food additive Fe_3O_4 “Magnetofood” to contribute compared to the control was noted:

1. Improvement of Sensory parameters of shaped jelly marmalade: the shape, surface and consistency improves by 0.1–0.2 points (for agar marmalade) and by 0.1–0.3 points (for pectin marmalade).
2. An increase in the moisture content by 1.15–1.16 times in experimental samples on agar and by 1.13–1.14 times in experimental samples on pectin—due to the moisture-binding and moisture-retaining ability of chemically active nanoparticles of the additive “Magnetofood”. In addition, the total acidity decreases by 1.05–1.08 times in experimental samples on agar and by 1.06–1.09 times in experimental samples on pectin—due to the Amphoteric nature of the Magnetofood additive and its ability to interact with acidic substances of jelly-marmalade masses;
3. The positive effect of introducing the food additive “Magnetofood” in the amount of 0.10–0.20 WT is proved. % on the structural and mechanical properties of molded jelly marmalade: increases the strength of jelly-marmalade jelly by 1.3–1.5 times (for marmalade on agar) and 1.22–1.4 times (for marmalade on pectin) due to the structure-forming and stabilizing action of nanoparticles “Magnetofood”, which contributes to the formation of an ordered spatial framework, which strengthens gel-like structures.
4. The rational content of the food additive “Magnetofood” is determined – 0.15% by weight of the recipe mixture for both gelling agents (agar and pectin).
5. Optimal conditions of temperature and humidity regime during storage of molded jelly marmalade are established: relative humidity $\varphi=(75\pm 2)\%$, temperature $(18\pm 2)^\circ\text{C}$, recommended storage duration of 90 days.

The conducted studies indicate a complex effect (water – retaining, structure-forming and stabilizing a

bility) of food nano-additives based on double oxide of two- and trivalent iron “Magnetofood” (FAM), which in the technologies of jelly-marmalade products can improve the functional and technological properties of colloidal dispersed systems, improve the quality and extend the time of preserving the freshness of finished products.

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