

Comparative analysis of functional and technological properties of β -glucans from oats and yeast in whey ice cream

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Abstract

Keywords:

Ice cream
 β -glucan
Texture
Microstructure
Overrun
Melting rate

Article history:

Received 24.01.2024
Received in revised
form 16.05.2024
Accepted 30.09.2024

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DOI: 10.24263/2304-
974X-2024-13-3-6

Introduction. The effect of β -glucans from oats and yeast incorporation on the quality parameters of whey ice cream during one month of storage was studied.

Materials and methods. The viscosity of the ice cream mixes was determined using an IKA ROTAVISC lo-vi Complete viscometer, texture parameters were studied using a Brookfield CT-3 texture analyzer, and ice cream structural elements were analyzed using microstructure analysis. Overrun, melting rate, and sensory evaluation were also performed to characterize the overall ice cream quality.

Results and discussion. The incorporation of β -glucans, a natural stabilizing ingredient, into whey ice cream significantly effects on its distinctive characteristics. Addition of oat β -glucan increased the viscosity of the ice cream mix to 623.07 mPa·s. Incorporation of β -glucan derived from yeast exhibited a viscosity of 542.14 mPa·s. The addition the mixture of oat and yeast β -glucans softened the texture of the ice cream. However, the effects of the glucans on the elasticity and extensibility of the ice cream matrix were different. This is attributed to the difference in molecular weight and structural properties between the β -glucans. This effect ensures a higher overrun and melting resistance of ice cream with oat β -glucan compared to yeast β -glucan. Addition of β -glucan from yeast significantly inhibited the growth of ice crystals, reaching a size of 9.52 μ m, and provided long-term stabilization of the ice cream air phase. Conversely, β -glucan derived from oats exerted a comparatively mild influence on the recrystallization of free water in ice cream, resulting in the formation of ice crystals no larger than 16.31 μ m.

Incorporation of oat and yeast β -glucans typically result in a softer ice cream, but oat β -glucan has been shown to significantly enhance the elastic properties of ice cream, which may contribute to an improved structure. The incorporation of β -glucans into ice cream also improved flavor characteristics, such as creaminess and stickiness, and provided the desired level of sweetness and cold taste when consumed.

Conclusions. The addition of oat and yeast β -glucan has been demonstrated to exert a considerable influence on the rheological and physicochemical attributes of ice cream, including its texture parameters, structural elements, and taste perception.

Introduction

Ice cream production that meets modern consumer preferences for nutritious foods and transparent labeling has become popular around the world over the past decade (Kumari et al., 2020). Manufacturers are increasingly producing ice cream that is low in calories and fat, functional, enriched with proteins and dietary fiber, and free of synthetic structure stabilizers (Blassy & Abdeldaiem, 2024; Guler-Akin et al., 2021; Lai et al., 2024). However, such products frequently fail to meet consumer expectations for quality. The replacement of ingredients or the addition of new technological additives without adequate research on their impact on quality merely formalizes demand but fails to account for the potential occurrence of defects (Samsalee et al., 2024).

In a preliminary study, it was demonstrated that β -glucan derived from oats (facilitates a regulated process of free water recrystallization in low-fat milk ice cream (Buniowska-Olejnik et al., 2023). Nevertheless, further research is required to ascertain the influence of these polysaccharides on the quality of ice cream produced using liquid hydrolyzed whey concentrate.

β -Glucans are polysaccharides that occur naturally in the cell walls of various organisms, including cereals, bacteria, and fungi (Mykhalevych et al., 2022). In the food industry, β -glucans are of interest due to their functional properties, particularly their capacity to enhance texture and stabilize emulsions. For example, oat β -glucan has been successfully employed in the production of yogurt to enhance its viscosity and creaminess without adversely affecting the product's flavor (Qu et al., 2021). Similarly, β -glucan derived from yeast is incorporated into breads to enhance dietary fiber content and facilitate the formation of a softer crumb structure (Martins et al., 2015; Mohebbi et al., 2019).

β -Glucans influence product texture through a range of mechanisms. They function as hydrocolloids, which are substances that form gels when mixed with water, thereby imparting the desired flavor and stability to foods (Cao et al., 2023). β -glucans, by additionally converting free water into a bound state, also assist in preventing the formation of large ice crystals in ice cream (Hamed et al., 2014), which is essential for maintaining a smooth and creamy texture of the product. Furthermore, β -glucans influence the viscosity of ice cream mixes (Akal, 2023), which can enhance its texture and prevent the formation of a coarse crystalline structure during storage.

Furthermore, it is crucial to comprehend the influence of the employed processing additives on the flavor profile of ice cream. A number of food companies employ sensory profiling to provide qualitative and quantitative representation of the attributes perceived by humans, thereby enabling them to quantify the sensory response to stimuli derived from the consumption of a product (Varela & Ares, 2015). The ability of these polysaccharides to significantly improve the rheological properties and imitate the milk taste to the level of full-fat ice cream analogues has been reported (Mousakhani-Ganjeh and Goli, 2021; Piotrowska et al., 2009). The aforementioned evidence underscores the considerable potential of β -glucans in enhancing the texture of low-fat ice cream.

Since the reduction of fat and sugar content in the developed whey ice cream (Mykhalevych et al., 2024; Shevchenko et al., 2022) will affect its texture and taste properties, it is important to characterize these properties by sensory and instrumental evaluation in order to determine the magnitude of the expected effects. For this reason, the impact of β -glucans from diverse origins on the texture, physicochemical, and sensory attributes of ice cream was investigated. To this end, the initial step was to ascertain the rheological properties of ice cream mixes incorporating β -glucans. The subsequent step was to conduct a texture profile analysis and sensory evaluation of whey ice cream with these polysaccharides.

Materials and methods

Raw materials

For the production of liquid hydrolyzed concentrate of demineralized whey with a solids content of 40%, whey powder with a degree of demineralization of 90% (Milk Alliance JSC, Ukraine), an enzyme preparation lactase (β -D-galactosidase) with an activity of 5000 NLU/g (GODO-YNL2, Danisko, Denmark), activated starter based on *L. acidophilus* LYO 50 DCU-S (Danisko, Denmark), and water were used. For ice cream preparation the following ingredients were used: water, white sugar, vanillin, Cremodan SI 320 stabilization system (Danisco A/S, Denmark), whey protein isolate 90% (SPOMLEK, Radzyń Podlaski, Poland), highly soluble β -glucan (1-3, 1-4) extracted from oats (OBG) with a purity of 72% (Grupa Feniks 2050, Cmielów, Poland), and β -glucan from yeast (YBG) *Saccharomyces cerevisiae* with a purity of 70% (GOLDCELL, Biorigin, Sao Paulo, Brazil).

Production technology

The starter was activated in ultra-pasteurized skim milk at a temperature of 38–42 °C until a pH of 5.4–5.2 was reached. A liquid whey concentrate with a solids content of 40% was obtained by reconstituting demineralized whey powder in water at 40–42 °C and subsequently adding β -D-galactosidase and starter *L. acidophilus*. The enzymatic hydrolysis was conducted at 38–42 °C until a degree of lactose hydrolysis of 85% was achieved. The technology of liquid hydrolyzed concentrates is described in work of Osmak et al. (2021).

To prepare the ice cream, the dry components, as specified in Table 1, were combined with water (40–45 °C) and stirred until a homogeneous mix was achieved.

Table 1

Formulations of the ice cream samples

| Ingredients, % | Ice cream samples | | |
|--|-------------------|----------|----------|
| | Control | 0.5% OBG | 0.5% YBG |
| Hydrolyzed concentrate of demineralized whey | 75.0 | 75.0 | 75.0 |
| White sugar | 9.0 | 9.0 | 9.0 |
| Whey protein isolate (90%) | 3.0 | 3.0 | 3.0 |
| Stabilization system | 0.6 | – | – |
| β -glucan from oats | – | 0.5 | – |
| β -glucan from yeast | – | – | 0.5 |
| Activated starter | 3.0 | 3.0 | 3.0 |
| Vanillin | 0.1 | 0.1 | 0.1 |
| Water | 9.3 | 9.4 | 9.4 |
| Total | 100.0 | 100.0 | 100.0 |

OBG, extracted from oats; YBG, β -glucan from yeast *Saccharomyces cerevisiae*.

Subsequently, the mix was incorporated with the liquid whey concentrate. The resulting mixes were filtered through a 1 mm mesh filter prior to pasteurization at 83–87 °C for 5 min, followed by homogenization at 12.0±2.5 MPa using a laboratory homogenizer-disperser 15M-8TA "Lab Homogenizer & Sub-Micron Disperser" (GAULIN CORPORATION, Massachusetts, USA). Homogenized mixes were cooled to 38–42 °C, and a 3% of activated starter was added. The fermentation process was conducted until a pH of 5.25–5.10, after

which the mix was cooled to 2–6 °C, vanillin was added, and maturation was carried out for 12 h. The matured mixes were frozen using a laboratory freezer FPM-3.5/380-50 "Elbrus-400," (JSC ROSS, Kharkiv, Ukraine). In the initial phase of freezing, the mix was cooled in a cooling cylinder (volume – 7 L) to a temperature of –1 °C at a rotation speed of the scraper stirrer of 4.5 s⁻¹ for 120 s. Subsequently, in the second stage, the mix was frozen and whipped at a rotational speed of 9 s⁻¹ for 180 s to a temperature of –5.0±0.5 °C. The ice cream samples (3 kg each) were hardened and stored in a Caravell A/S freezer (Løgstrup, Denmark) at –22±1 °C for one month. To ensure the reliability of the results, ice cream samples of the same chemical composition were prepared 3 times.

According to the above formulations (Table 1) of the ice cream samples, the solids content is 42.33–42.61%, of which protein is 5.98–6.01% and fat is 0.35–0.73%.

The content of β-glucans at 0.5% was chosen in accordance with the available information in scientific works on their use in ice cream (Aljewicz et al., 2020b; Tomczyńska-Mleko et al., 2024).

Research methods

The viscosity of ice cream mixes was determined using an IKA ROTAVISC lo-vi Complete viscometer (IKA, Staufen, Germany) (Nazarewicz et al., 2022). For the measurement, a T-SP-2 spindle was used, which was immersed in the prepared sample at 18±1 °C and a shear rate of 200 rpm. Viscosity values were read after 2 min. A power law model was used to determine the flow behavior index (n) and the consistency coefficient (K). The flow behavior index shows how close the mix is to Newtonian. The consistency coefficient gives an idea of the flow properties of the mix (Muse and Hartel, 2004).

Analysis of the texture profile. Ice cream texture parameters were determined using a Brookfield CT-3 texture analyzer (Middleboro, Massachusetts, USA). Measurements were performed using Pro CT V1.6 software (Brookfield Engineering Laboratories Inc., ABD, Middleboro, MA, USA). For the analysis, a TA27 conical probe (on the first day of storage) and a TA 15/1000 (on the 1th month of storage) were used. The speed was 2 mm/s, the distance was 15 mm, the trigger load was 1.08 H, the length was 40 mm and the diameter was 60 mm.

Determination of overrun. Ice cream overrun was determined by the weight method by the difference in weight of samples of the same volume of the mix and ice cream, expressed as a percentage (Sofjan and Hartel, 2004).

Determination of the melting rate. The ice cream samples were stored at –22±1 °C, selected and placed on a special melting grid at room temperature of 19±1 °C. The weight of the melted ice cream was recorded after one hour every 10 min for 2 h. The melting rate (R, %) was calculated using the formula (Yeon et al., 2017):

$$R = (\text{weight of melted ice cream}) / (\text{weight of ice cream before melting}) \times 100,$$

Analysis of structural elements. The process of free water recrystallization and air bubbles in ice cream were studied using an Olympus BX53 microscope with a Linkam LTS420 cooling system (measuring temperature range from –196 °C to –420 °C) and an Olympus SC50 digital camera. For each sample, 300 to 500 crystals were labeled and the area, equivalent diameter, and standard deviation were calculated using NIS Elements D Imaging software (version 5.30.00, Nikon). The method has been reported in works related to the study of ice cream (Kamińska-Dwórznička et al., 2022; Kamińska-Dwórznička et al., 2020).

Sensory evaluation. The sensory evaluation of the ice cream was carried out on a five-point scale for such indicators as creaminess, milk taste, sweet taste, cold taste, stickiness, and hardness. Based on the results of the evaluation, profilograms were made.

Statistical processing. The significance of the test was set at $\alpha = 0.05$. The data are expressed as mean values with standard deviations (\pm SD).

Results and discussion

Determination of rheological parameters of ice cream mixes

Viscosity is a critical parameter in ice cream formulations that affects texture and flavor. The obtained viscosity values indicate significant differences between the ice cream mixes (Table 2).

Table 2

Rheological parameters of ice cream mixes ($p \leq 0.05$, $n = 3$)

| Indicator | Control | 0.5% OBG | 0.5% YBG |
|--|----------------------------|----------------------------|-----------------------------|
| Viscosity, mPa·s | 372.14 ^a ±10.54 | 623.07 ^b ±29.87 | 542.14 ^{ab} ±15.40 |
| Consistency coefficient (K), dynes/cm ² | 102.03 ^a ±2.56 | 155.98 ^b ±5.21 | 137.19 ^{ab} ±3.68 |
| Flow behavior index (n) | 0.214 ^a ±0.01 | 0.244 ^b ± 0.02 | 0.236 ^{ab} ±0.02 |

Due to their ability to interact with water and form viscous solutions, β -glucans can significantly increase the viscosity of foods with a high water content, with oat β -glucan being the most effective. On the contrary, β -glucan from yeast increases the viscosity of mixes less pronounced, which is associated with differences in molecular weight and structure (Frank et al., 2004; Sammalisto et al., 2024). Studies indicate that addition of yeast β -glucan can increase the viscosity of beverages and some dairy products, although to a lesser extent than oat β -glucan (Chiozzi et al., 2021; Rose et al., 2023).

The values of the consistency coefficient (K) show statistically significant differences between the groups. The 0.5%OBG sample has a significantly higher K value (155.98±5.21) than the control group (102.03±2.56), indicating an increase in viscosity with the addition of 0.5% oat β -glucan. The 0.5%YBG sample also exhibits a higher K value (137.19±3.68) compared to the control. The flow behavior index (n) for the samples with β -glucans indicates a significant change in flowability compared to the control.

The observed differences in viscosity between the samples demonstrate how the choice of β -glucan additive and its concentration can affect the rheological properties of ice cream.

Study of texture parameters of whey ice cream

To understand the changes in ice cream texture in the presence of β -glucans, a comparative analysis of the texture parameters of the control and experimental samples was conducted (Table 3).

Table 3

Texture parameters of whey ice cream ($p \leq 0.05$, $n = 3$)

| Indicator | Control | 0.5% OBG | 0.5% YBG |
|-----------------------------|------------|-----------|-----------|
| 1 day | | | |
| Hardness, N | 9.79±0.24 | 7.13±0.15 | 3.43±0.10 |
| Adhesiveness, mJ | 1.70±0.05 | 1.02±0.08 | 1.67±0.04 |
| Adhesive Force, N | 0.75±0.02 | 0.48±0.02 | 0.45±0.01 |
| Stringiness, mm | 1.22±0.02 | 0.80±0.04 | 1.61±0.07 |
| Stringiness Work Done, mJ | 0.70±0.01 | 0.30±0.01 | 0.50±0.02 |
| Recoverable Deformation, mm | 0.60±0.01 | 0.41±0.02 | 0.82±0.02 |
| 1 month | | | |
| Hardness, N | 14.46±0.24 | 9.98±0.27 | 5.63±0.19 |
| Adhesiveness, mJ | 1.02±0.01 | 2.30±0.08 | 0.91±0.02 |
| Adhesive Force, N | 0.47±0.02 | 0.79±0.01 | 0.32±0.01 |
| Stringiness, mm | 1.41±0.01 | 1.81±0.02 | 1.86±0.04 |
| Stringiness Work Done, mJ | 0.57±0.02 | 1.05±0.01 | 0.30±0.01 |
| Recoverable Deformation, mm | 1.23±0.03 | 1.01±0.04 | 1.43±0.01 |

The presence of β -glucans in ice cream mixes leads to noticeable changes in several key texture parameters. Both β -glucans generally soften ice cream, consistent with the demonstrated ability of polysaccharides as structural modifiers to reduce the force required to penetrate the ice cream matrix (Tolve et al., 2024). In particular, ice cream with 0.5% yeast β -glucan showed a significant reduction in hardness on day one compared to the control, indicating the ability of this polysaccharide to effectively reduce the textural stiffness of the product. Oat β -glucan also reduces the hardness of ice cream, but this effect is less pronounced.

With regard to adhesion and adhesive force, which refer to the stickiness and the force required to separate the ice cream from the surface, both parameters showed trends consistent with the softening effect observed for hardness. The decrease in stickiness and adhesion in ice cream with β -glucans indicates a possible change in the way the ice cream interacts with surfaces, which will certainly affect the organoleptic perception of the product by consumers.

The elasticity, which measures the tendency of ice cream to exhibit elastic behavior when stretched, shows quite different results. On the first day, the ice cream with oat β -glucan showed less elasticity than the control and the sample with yeast β -glucan. This suggests that oat β -glucan may affect the elasticity and extensibility of the ice cream matrix in a different way than yeast β -glucan. This phenomenon may be because oat β -glucan typically exhibits pseudoplastic behavior in dairy food systems (Aljewicz et al., 2021; Li et al., 2023), while yeast β -glucan provides a less robust gel network (Tomczyńska-Mleko et al., 2024).

The recoverable deformation, which measures the ability of ice cream to return to its original shape after deformation, indicates that β -glucans influence the recovery process, with oat β -glucan showing a more pronounced effect on day 1 compared to yeast β -glucan. The observed pattern confirms that oat β -glucan can improve the elastic properties of ice cream, potentially contributing to improved structure and shape retention during storage, which requires further research.

Analysis of the overrun of the ice cream indicates that β -glucans affect the distribution of the air phase in the product. The control sample had an overrun of 75.25%, while the oat and yeast β -glucan samples had overrun of 83.12% and 77.39%, respectively (Figure 1).

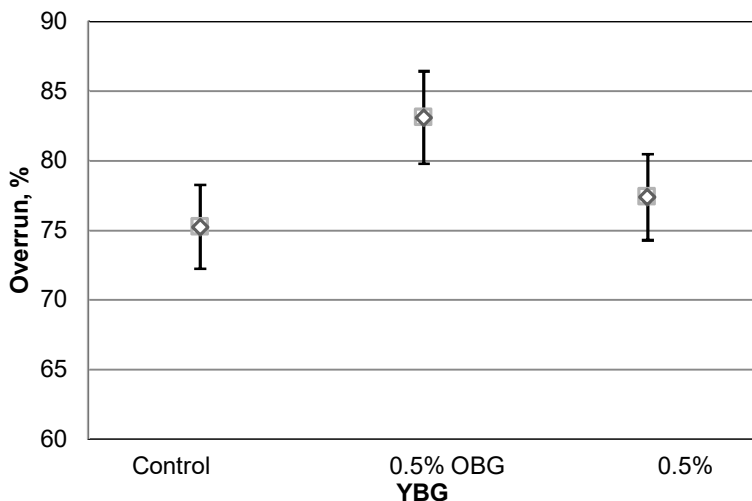


Figure 1. Overrun of whey ice cream

Oat β -glucan has been demonstrated to be more effective than yeast β -glucan in stabilizing air bubbles. Akal (2023) reported that the incorporation of soluble fibers, such as inulin and oat β -glucan, into ice cream formulations results in an increased rate of overrun. This phenomenon may be attributed to the stabilizing effect of soluble fibers, which enhance foam stability by trapping air within the ice cream matrix (Burkus and Temelli, 2000).

While yeast β -glucan also demonstrated an increase in overrun compared to the control sample, its ability to stabilize the air phase was less pronounced than that of oat β -glucan. These findings align with those of other researchers (Aljewicz et al., 2020b; Sadiq and Mousa, 2024) who have observed that different types of β -glucans exert varying effects on the physicochemical properties of dairy products, including the capacity to stabilize emulsions and air bubbles.

The incorporation of β -glucans markedly influenced the melting behavior of ice cream (Figure 2). The sample containing 0.5% oat β -glucan exhibited the lowest melting rate, with only 55% of the thawed mass melting after 120 minutes, indicating enhanced stability and resistance to melting. The sample with 0.25% yeast β -glucan also slowed the melting of ice cream by up to 64%.

The findings demonstrate that oat β -glucan is more efficacious in impeding the melting process of ice cream in comparison to yeast β -glucan. The higher water-binding and gel-forming ability of oat β -glucan contributes to the formation of a more stable ice cream matrix. Similarly, Aljewicz et al. (2020b) reached a comparable conclusion, indicating that the incorporation of hydrocolloids, particularly oat β -glucan, enhances the melting resistance of ice cream due to its stabilizing properties.

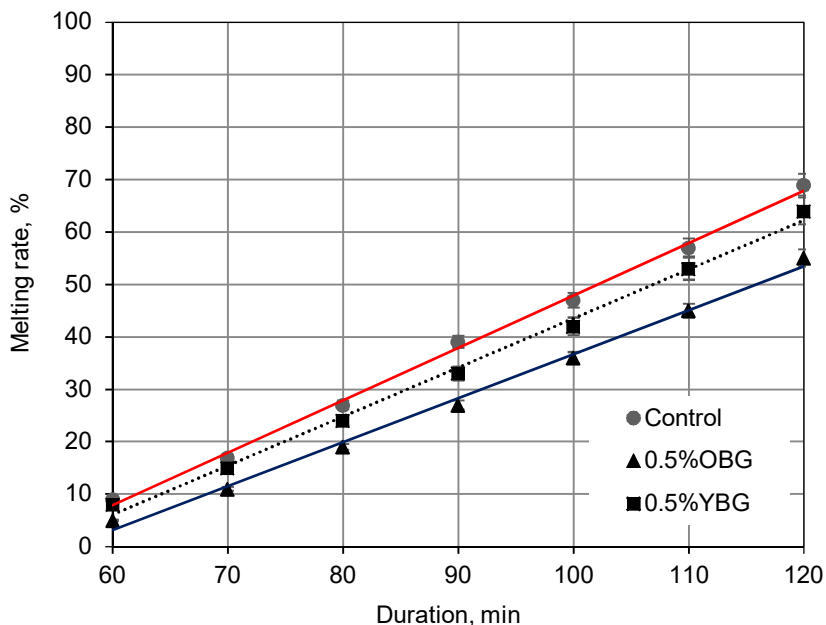


Figure 2. Melting rate of whey ice cream

In order to identify patterns of change in the dispersed crystalline and air phases of ice cream during storage, the dynamics of ice crystals and air bubbles growth in the tested samples were studied (Table 4).

Table 4

Structural elements of the dispersion phase of whey ice cream
($p \leq 0.05$, $n = 3$)

| Sample | Average diameter of air bubbles, μm | Average diameter of ice crystals, μm |
|----------|--|---|
| 1 day | | |
| Control | 6.60±0.03 | 15.80±0.67 |
| 0.5% OBG | 11.51±0.21 | 11.38±0.17 |
| 0.5% YBG | 8.56±0.18 | 8.49±0.37 |
| 1 month | | |
| Control | 14.92±0.10 | 32.15±1.18 |
| 0.5% OBG | 13.54±0.55 | 16.31±0.15 |
| 0.5% YBG | 10.47±0.12 | 9.52±0.16 |

The average diameter of air bubbles on the first day of storage was the smallest in the control sample (6.60 μm). In the samples with yeast and oat β -glucan, it was 8.56 μm and 11.51 μm , respectively. After 1 month, an increase in the size of air bubbles was observed in all samples, in particular, the largest bubble diameter was in the control sample (14.92 μm). This indicates that β -glucans stabilize the air phase more effectively over a long period in

contrast to the sample with a commercial stabilization system (Santipanichwong and Supphantharika, 2009). This is in line with the findings of Izydorczyk and McMillan (2019), who reported that dietary fiber, such as β -glucans, can stabilize air bubbles, improving the overall texture of the product.

Analyzing the process of free water recrystallization in ice cream it can be noted that significant differences were observed between the samples. On the first day, the control sample had the largest ice crystals (15.80 μm), while the smallest were found when using β -glucan from yeast. After 1 month, the control sample showed a significant increase in ice crystal size – up to 32.15 microns. In contrast, the sample with 0.5% oat β -glucan showed significantly smaller ice crystals (16.31 μm), and the sample with 0.5% yeast β -glucan had the smallest ice crystals at 9.52 μm). Yeast β -glucan is the most effective in inhibiting the growth of ice crystals during long-term storage. In a study of Soukoulis et al. (2014), it was found that the inclusion of hydrocolloids and dietary fiber in ice cream reduces the growth of ice crystals, which improves the texture and sensory characteristics of the product. Similar conclusions were reported by Ng et al. (2022), where hydrocolloids helped to soften the texture of ice cream and reduce the rate of recrystallization.

At the last stage of the study, a sensory evaluation of ice cream samples was performed (Figure 3).

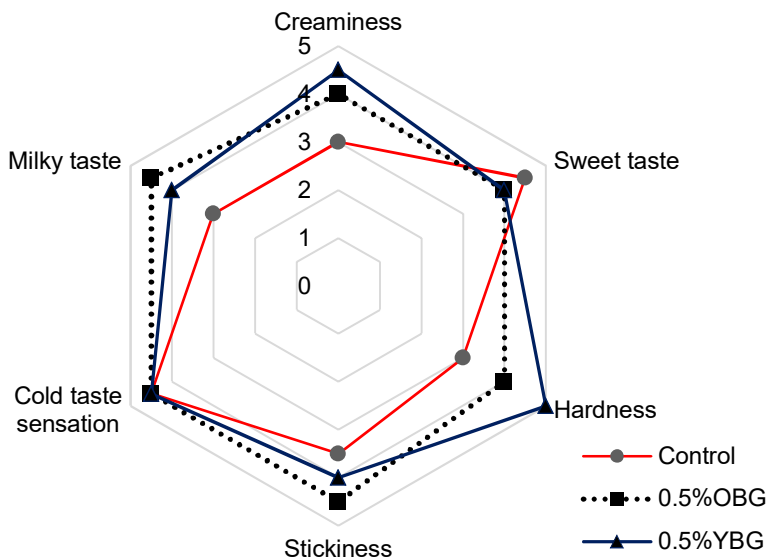


Figure 3. Sensory evaluation of whey ice cream

Samples with β -glucans received higher scores than the control sample for their more pronounced milk flavor. The presence of β -glucans effectively mimics milk fat in ice cream, which is likely due to their ability to improve texture by forming a more stable and homogeneous ice cream matrix. Other scientists who have established the ability of polysaccharides to improve the taste of low-fat products (Bealer et al., 2020; Kaur and Riar, 2020) have drawn similar conclusions.

The control sample received the highest score for its sweet taste, which is typical for ice cream. The decrease in sweetness perception in samples with β -glucans may be due to

their specific interaction with monosaccharides (Aljewicz et al., 2020a) present in the product.

The ice cream firmness score correlates with the measured firmness value in the texture analysis. Thus, β -glucans reduce the hardness of ice cream, which improves the perception of the product. β -Glucans also increase the stickiness of ice cream, possibly due to their gelling properties, which improve the cohesion of the product. Aljewicz et al. (2020b), studying ice cream with 1% oat β -glucan, found that it led to a sticky mouthfeel due to excessive viscosity. However, we did not observe such an effect, which can be explained by the lower mass fraction of the additive (0.5%) used in this study.

In terms of cold taste, all samples received an equally high score of 4.5, indicating that the addition of β -glucans did not affect this characteristic. The inclusion of oat and yeast β -glucans in ice cream improves several sensory characteristics, including creaminess, stickiness, and milky flavor, while maintaining the desired level of sweetness and cold taste. Such properties could potentially lead to the development of ice cream that consumers would prefer in further commercial testing.

Overall, the differences found between oat and yeast β -glucans emphasize the importance of understanding the specific structural and functional properties of each additive in the development of new ice cream formulations. The results of the experiment emphasize the significant influence of β -glucans, primarily on the parameters of ice cream texture. This makes it possible to rationally use β -glucans to control the characteristics of new types of ice cream.

Conclusions

The substantial impact of β -glucans on the rheological and physicochemical attributes of whey ice cream has been demonstrated. The addition of oat β -glucan (0.5%) to mixes has the effect of increasing their viscosity, as well as improving overrun and melting resistance, thus enhancing the quality of the resulting ice cream. β -Glucan from yeast (0.5%) has a less pronounced effect on these indicators, but it provides long-term stabilization of the crystalline and air phases of ice cream. Specifically, in the presence of β -glucan from yeast, after one month of ice cream storage, the diameter of air bubbles in the ice cream did not exceed 10.47 μm , and ice crystals did not exceed 9.52 μm . In contrast, the ice cream sample containing 0.5% oat β -glucan exhibited a significantly higher ice crystal size of 16.31 microns after one month of storage.

β -Glucans of disparate origins typically result in a softer ice cream, but oat β -glucan markedly enhances the elastic properties of ice cream, which has a beneficial impact on the structure of the product. The incorporation of oat and yeast β -glucan into ice cream formulations has been demonstrated to enhance the creaminess, stickiness, and milky flavor of the product, while maintaining the desired level of sweetness and cold taste.

Further research is needed to elucidate the long-term effects of β -glucans on ice cream quality.

Acknowledgments. The work was carried out within the framework of state-funded R&D projects of the Problem Research Laboratory of the National University of Food Technologies: "Development of technology for the reuse of secondary dairy resources for the production of new products and reduction of food waste" (state registration number 0124U000965) and "Scientific substantiation and development of resource-efficient technologies for food products for specific purposes as an imperative of food security of Ukraine" (registration number 0123U102060).

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Cite:

UFJ Style

Mykhalevych A., Moiseeva L., Polishchuk G., Bandura U., Buniowska-Olejnik M. (2024), Comparative analysis of functional and technological properties of β -glucans from oats and yeast in whey ice cream, *Ukrainian Food Journal*, 13(3), pp. 507–519, <https://doi.org/10.24263/2304-974X-2024-13-3-6>

APA Style

Mykhalevych, A., Moiseeva, L., Polishchuk, G., Bandura, U., & Buniowska-Olejnik, M. (2024). Comparative analysis of functional and technological properties of β -glucans from oats and yeast in whey ice cream. *Ukrainian Food Journal*, 13(3), 507–519. <https://doi.org/10.24263/2304-974X-2024-13-3-6>
