Application of protein-berry concentrates in sauce compositions

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Keywords:

Protein-berry concentrate
Sauce
Rheology
Sensory

Article history:

Received 12.01.2025
Received in revised form 16.06.2025
Accepted 30.06.2025

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DOI:
10.24263/2310-1008-2025-13-1-6

Abstract

Introduction. This study aimed to evaluate the effect of incorporating protein–berry concentrates, obtained by thermo-acid coagulation of milk proteins with the use of blueberry paste as a coagulant, into sauces on their structural, sensory, and physicochemical properties.

Materials and methods. In the sauce formulations, a part of the milk protein products was replaced with protein–berry concentrates, which were added at levels of 30–50%, with a variation step of 10 %. Structural and mechanical characteristics were assessed using deformation kinetics curves. Active acidity was measured potentiometrically; moisture content was determined using the thermogravimetric method.

Results and discussion. A sharp decrease in the effective viscosity of the sauces by 1.45–1.73 kPa·s was observed in the shear rate range of 1–3 s^{-1}. In the range of 3–5 s^{-1}, structural breakdown of the sauce matrix based on protein–berry concentrate (PBC) occurred, with partial structural recovery noted. At higher shear rates (5–9 s^{-1}), changes in effective viscosity were minimal (0.15–0.4 kPa·s), and the viscosity curves became linear.

The active acidity of the studied sauce samples decreased from 4.75 to 4.5 pH with the increase of protein-berry concentrate (PBC) content from 30 % to 50 %, showing values that were 0.05 to 0.25 pH units higher than those of the control sample.

The moisture content in sauces containing protein-berry concentrates was by 4.8–12.3% lower than in the control, decreasing from 57.2% to 49.7% as the content of PBC increased from 30% to 50%.

The highest effective viscosity (5.63 kPa·s) was observed in the sauce containing 50% protein–berry concentrate. This sample was characterized by a homogeneous, plastic, creamy consistency, a pronounced berry flavor, and a natural purple color.

Conclusions. The effectiveness of using protein–berry concentrates as a formulation component for developing sauces with improved sensory and rheological properties, as well as enhanced nutritional value, has been confirmed.

Introduction

The production of natural sauces enriched with beneficial compounds and featuring reduced caloric content aligns with modern consumer demands for healthier food products. Sauces are commonly used in cooking or served with dishes to enhance flavor, aroma, appearance, and nutritional value (Maoloni et al., 2022). They are characterized by specific structural and mechanical properties, which can be achieved through targeted technological processing of vegetable or dairy raw materials, in combination with the use of structure-forming agents and acidulants (Benderska et al., 2019). However, many commercially available sauces contain preservatives, artificial stabilizers, and emulsifiers (Lebedenko et al., 2021). Despite this, insufficient attention has been given to the development of new formulations and technologies for the industrial production of milk-based sauces.

When developing sauce formulations, particularly those based on protein-berry concentrates, attention must be paid to the consumer-relevant characteristics of the final product (Grek et al., 2020). To achieve the desired rheological properties, structure-forming agents are commonly employed (Lystopad et al., 2020). In berry sauce technologies, these structure formers typically include thickeners such as starches, gums, and similar ingredients, which influence the structural and mechanical characteristics of the product (Kim et al., 2014). However, these conventional structuring agents are often high in calories, poorly digestible, and do not contribute significantly to the nutritional value of the final product (Yalcinoz et al., 2016).

Most existing research focuses on the use of structuring agents and flavor enhancers, which complicate the technological process and increase production costs (Hernández-Carrión et al., 2015; Honchar and Gnitsevych, 2024; Shalaby et al., 2017; Zaouadi et al., 2015). Meanwhile, there is a lack of studies dedicated to the development of sauces based on milk concentrates, including protein-berry concentrates, with adjustable structural and mechanical properties, moisture content, active acidity, and natural color.

Dairy-plant products are widely developed and introduced into the human diet (Nascimento et al., 2023; Onopriichuk and Skuibida 2024; Skuibida et al., 2022). It is known that berry raw materials contain a significant amount of pectin substances, which have a structure-forming effect (Bélafi-Bakó et al., 2012). Blueberries are rich in vitamins, including vitamin C (14.1–26.4 mg%), pectic substances (0.32–0.45%), phenolic compounds (339–364 mg%), as well as macro- and microelements, and other biologically active substances essential for normal body function. These components also contribute to improved consumer properties of food products (Białoszycka et al., 2025). In addition, berries contain flavones, flavonols, catechins, oxycinnamic acids, which cause the natural purple colour of the product. It is known that the complex of phenolic compounds of blueberries is represented by chlorogenic acid; glycosides of kaempferol and quercetin; free, condensed catechins and proanthocyanidins (Guiné et al., 2018). Coloring substances of berry raw materials are low molecular weight phenolic compounds related to bioflavonoids, in particular anthocyanins, which are found in plants in the form of glycosides. It is the presence of anthocyanins in berries that enables their use as natural food colorants (Stabnikova et al., 2024).

The incorporation of protein–berry concentrates into sauce formulations could potentially eliminate the need for traditional thickeners and artificial colorants. The final product would be characterized by a natural composition, improved digestibility, enhanced biological value, and favorable rheological properties. The aim of the present research was to evaluate the effect of incorporating protein–berry concentrates, obtained by thermo-acid coagulation of milk proteins using blueberry paste as a coagulant, into sauces on their structural, sensory, and physicochemical properties.

Materials and methods

Materials

Protein–berry concentrates (PBC) were incorporated into the sauce formulations. The production of PBC involved thermo-acid coagulation of milk proteins using berry raw material as a coagulant, under classical conditions: a temperature of 93–95 °C with a 5-minute holding time. Homogenized blueberry paste with a pH of 2.6 ± 0.2 was used as the coagulant at a concentration of 8%, which adjusted the active acidity of the mixture to achieve an equilibrated isoelectric state of the milk proteins (pH 4.1–4.5), thereby promoting their effective coagulation (Grek et al., 2017).

Blueberry paste was obtained using the processes of hydrodynamic cavitation treatment of berry raw material on the units of TEK-SM type (Bessarab et al., 2014). The products of this process step are protein-blueberry concentrates and the coloured whey with the tint of blueberry coagulant introduced (Grek et al., 2020).

In the sauces composition containing traditional components (cream, hard rennet and processed cheeses, milk powder or whey, stabilising and flavouring additives) a part of milk-protein products was replaced by protein-berry concentrates, which were added in the amount of 30-50 %, with a variation step of 10 % of the component composition.

Methods for determining the quality indicators of sauces based on protein-berry concentrates

Structural and mechanical characteristics (effective viscosity, boundary shear stress) of sauces based on PBC were determined on a rotational viscometer by taking curves of deformation (flow) kinetics. The measurements were carried out in the 'a' mode set experimentally taking into account the structural and mechanical properties of the studied samples. The measuring cylinder was selected so that the gradient layer spreads over the entire thickness of the product layer in the annular gap of the viscometer measuring device. Shear stress τ (Pa) was measured at twelve values of shear rate gradient γ. For this purpose, readings were taken at the maximum angle of deflection of the arrow on the instrument scale. Dependences of effective viscosity (η, Pa·s) on the displacement rate (γ, s^{-1}) of sauces based on PBC were plotted on the basis of the obtained data.

The effective viscosity was determined at increasing values of cylinder speed. Tested samples of sauces based on PBC were placed in the gap between the working cylinders of the viscometer. The measurement was made at temperature (20±2) °C (Pshenychna et al., 2018).

Sensory parameters including product appearance, colour of sauces based on PBC were controlled visually; taste and smell, consistency – organoleptically at sauce temperature from 18°C to 20°C.

Active acidity of sauces based on PBC was determined potentiometrically on a universal pH-meter Sartorius PB-20. To determine the pH, 40 g of sauces was taken into the beaker, the electrodes are immersed in the beaker and after 10-15 seconds the readings of the device are recorded. The electrodes are rinsed with distilled water and wiped off with filter paper after each measurement.

The moisture content of sauces based on PBC was determined by the accelerated method (using a «Quartz» device). To determine the moisture content of the sauces, 150x150 mm newsprint bags (single or double layers) were rolled diagonally, the corners and edges were bent. The package was placed in a sheet of parchment slightly larger than the package,

without wrapping the edges. The finished bags were dried on a «Quartz» apparatus for 3 min at a temperature of 150–152 °C.

The prepared bag was weighed with 5 g of the test product to the nearest 0.01 g. The product was distributed evenly over the entire surface of the bag. The bag with the sample was closed and placed in the device between the plates heated to 150–152 °C for 5 min. The bags with dried samples were cooled in a desiccator for 3–5 min and weighed. The moisture content of the product was determined by the formula:

$$W = \frac{M - M_1}{5} \cdot 100,$$

where, W is the mass fraction of moisture, %; M is the mass of the bag with the sample before drying, g; M_1 is the mass of the bag with the sample after drying, g; 5 is the mass of the product, g. The difference between the parallel determinations did not exceed 0.5 %. The final result was the arithmetic mean of three parallel determinations (Onopriichuk et al., 2024).

Results and discussion

Structural and mechanical characteristics of sauces based on protein-berry concentrates

At the first stage, the primary raw materials directly influencing the structural–mechanical and organoleptic quality indicators of the final product were investigated. Depending on the formulation and technological purpose, pasty products must exhibit specific structural and mechanical characteristics. Structural and mechanical characteristics of sauces based on PBC were determined by the nature of bonds arising between protein particles during the structure formation. They can be classified as thixotropic structures in which the effective viscosity decreases with increasing shear rate, reversible bonds are restored after the mixture structure is disturbed. The rheological curves presented in Figure 1 describe the effect of shear rate on the effective viscosity of sauces based on PBC.

The character of curve changes indicates that the studied sauce samples are pseudoplastic in structure and flow as abnormal viscous liquids in the whole range of shear rates from 1 s^{-1} to 5 s^{-1}. The analysis of flow curves indicates that the effective viscosity of sauces under the same conditions decreases with decreasing mass fraction of protein-berry concentrate. Probably, it is connected with the change of their spatial structure, which is formed as a result of direct phase contacts of particles adhesion of the newly formed phase – caseinate calcium phosphate complex and constituents of berry coagulant. The latter are characterised by high strength. Pectin substances as surfactant compounds form a strong framework due to the convergence of hydrophobic methoxyl groups in aqueous medium, and free carboxyl groups dissociate into ions, which interact with NH_3^+ groups on the protein surface. The growth of contact strength between particles is accompanied by the appearance of crystallisation bridges. The sauce structure is elastic, dense, after mechanical breakage the bonds are slowly restored, as a consequence, the thixotropic properties are reduced in such systems.

The highest viscosity of 5.63 KPa·s was found in the sauce sample with a mass fraction of 50 % PBC. This may be due to the optimally selected amount of formulation components, which favours the formation of a compound of stable three-dimensional spatial structures and enhances the viscous characteristics of the product. When assessing organoleptic parameters of the samples under study, homogeneous, plastic, creamy consistency of sauces was noted.

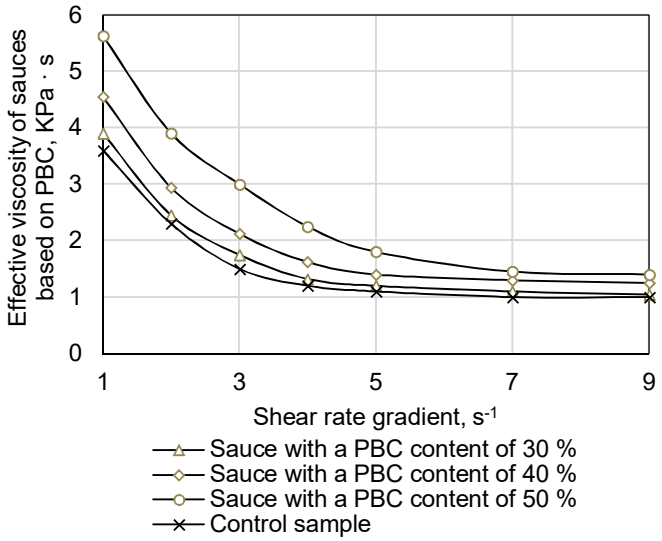

Figure 1. Effect of shear rate gradient on the effective viscosity of sauces depending on the amount of protein–berry concentrate (PBC)

Previous studies (Benderska et al., 2019) on the structural and mechanical characteristics of sauces confirm an increase in the effective viscosity values of sauces when the concentration of tomato seed paste is increased in the system. By increasing the amount of tomato paste added from 5 % to 11 %, the structural and mechanical properties of the finished product change significantly: its viscosity increases 2.46 times – from 147 Pa·s to 363 Pa·s. This can be attributed to the presence of significant content of proteins, pectin and hemicellulose in tomato seed paste with moisture-binding capacity.

There are 3 sections on the rheological curves (Figure 1). A sharp drop in effective viscosity by 1.5-2 times is observed in the range of displacement velocity (1-3) s^{-1}. This effect is due to the fact that protein-berry concentrates form a continuous three-dimensional coagulation structure under the action of Van-der-waals cohesive forces. The process occurs through the interaction between the protein globules of casein and whey proteins with the pectin substances of blueberry paste. The flow resistance in this case is insignificant, which causes a decrease in the effective viscosity of sauces by 1.45-1.73 KPa·s at shear rates up to 2 s^{-1}.

At the second section, in the range of shear rate (3-5) s^{-1}, the non-Newtonian fluidity of the viscous system of sauces based on concentrates and destruction of the partially recovering structure are observed. At the third section at high values of shear rate (5-9) s^{-1} the effective viscosity of sauces changes by 0.15-0.4 KPa·s, and the curves of effective viscosity have a linear character. The recovery process of the sample with a mass fraction of PBC 30 % is slower (deformation is greater and recovery is less pronounced), suggesting a less stable structure compared to samples with mass fraction of PBC 40 % and 50 %.

Other experimental data (Lebedenko et al., 2021) also confirm that the sauce with complete replacement of flour by a structuriser of polysaccharide nature had the highest viscosity, while the control sample had the lowest. Thus, at a shear rate of 0.3333 s^{-1}, the

viscosity of the control sample is 14.32 Pa·s, the samples with replacement of 50 % flour, 10 g fat and 100 % flour, 10 g fat are 16.49 and 19.6 Pa·s, respectively. Scientists have stated that the sauce with complete replacement of flour by plant polysaccharides has a thicker, more viscous consistency, affecting organoleptic properties.

The determining quality indicator for sauces is their consistency, so the obtained data of rheological parameters of experimental samples correlated with organoleptic perception. The type of product structure determines its qualitative and technological characteristics. Based on the obtained results, organoleptic evaluation of the developed samples of sauces based on PBC was carried out, which is presented in Table 1.

Table 1

Sensory characteristics of sauces based on protein-berry concentrates

Amount of protein-berry concentrate, %	Sensory characteristics		
	Consistency and appearance	Taste and smell	Colour
30	Homogeneous, mastic, slightly viscous	Clear, milky, with a slight blueberry flavour	Barely noticeable pale purple, uniform throughout the whole mass
40	Pasty, homogeneous, moderately thick	Moderately noticeable blueberry flavour and aroma	Light purple, uniform throughout the mass
50	Thick, homogeneous creamy consistency	Pronounced flavour and aroma of berry raw material	Pronounced purple, uniform throughout the mass

The visualization of the obtained sauce samples based on protein-berry concentrates is shown in Figure 2. The samples had a purple, uniform color, a noticeable berry taste and aroma, and a delicate, moderately mastic consistency with single inclusions of berry shells.

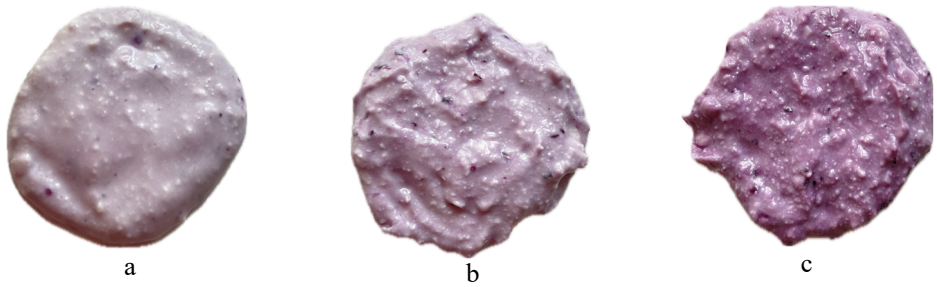

Figure 2. Sauces based on protein-berry concentrate (PBC): a, 30 % PBC; b, 40 % PBC; c, 50 % PBC

Physicochemical parameters of sauces based on protein-berry concentrate

Since PBC have a higher acidity compared to classical types of milk-protein concentrates, it is reasonable to determine the effect of different amounts of PBC on the acidity in the finished product and the mass moisture fraction (Figure 3).

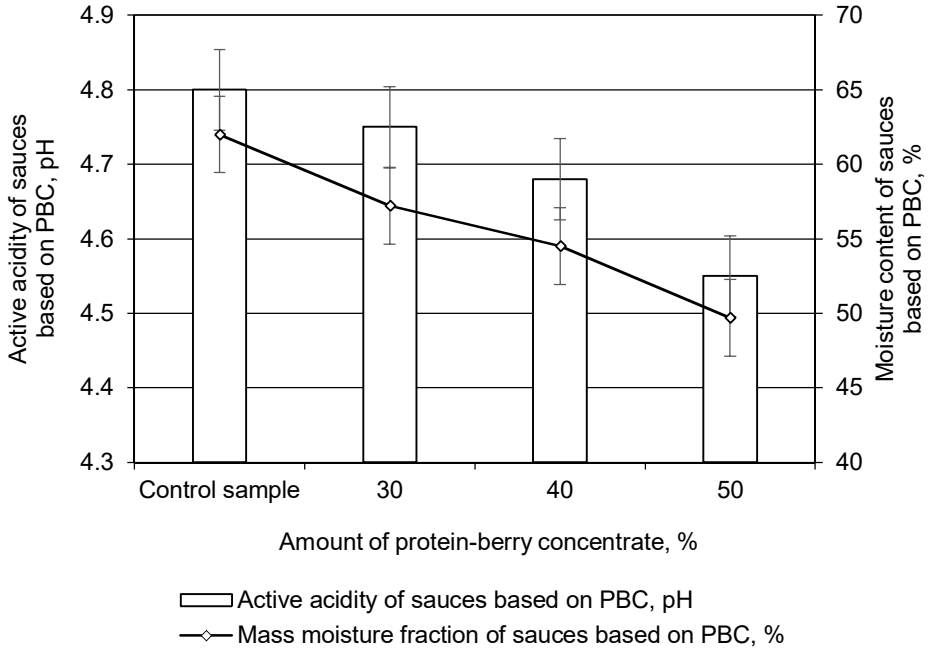

Figure 3. Change in active acidity and moisture content of sauces depending on the amount of protein-berry concentrate (PBC)

The active acidity of the sauce samples increased from 4.75 to 4.5 pH with increasing the amount of PBC used from 30 % to 50 % and was 0.05-0.25 pH units higher than in the control sample. For comparison, the active acidity values for functional sauces using whey and vegetable powders ranged from 3.50 to 4.45 pH (Khatko et al., 2021).

The obtained results confirm that protein-berry concentrates are characterized by an increased content of organic acids contained in the berry coagulant. When developing formulations, this will allow artificial citric acid to be replaced by natural organic acids, which are contained in significant amounts (2.0-4.3 %) in blueberry paste (Yavorska et al., 2020).

The mass fraction of moisture in sauces based on PBC was 4.8-12.3 % lower compared to the control sample and continued to decrease from 57.2 to 49.7 % with increasing concentrate use from 30 to 50 %. Probably, it is connected with transformation of the spatial structure, which is formed as a result of direct contacts of the adhesion of particles in the formed phase – caseinate calcium phosphate complex and carbohydrate components of blueberry paste.

The sauce is characterised by a high content of high-grade animal proteins due to the introduction of milk-protein concentrates with essential amino acids, which are of great importance in dietary, medical and preventive nutrition, and determines its high biological value.

The technology of sauces based on PBC can be realised on the equipment for production of pasty cheeses. Due to the use of a wide range of berry raw materials in the production of protein-berry concentrates, sauces can acquire a variety of taste, aroma and natural colouring, which significantly increases the possibility of their use in cooking.

Conclusions

1. By varying the amount of protein-berry concentrate (PBC) from 30% to 50% in the sauce formulation, it is possible to predict one of the key quality indicators—effective viscosity. The sauce containing 50% PBC demonstrated the highest effective viscosity (5.63 kPa·s) and was characterized by a homogeneous, plastic, creamy consistency, a pronounced berry flavor, and a natural purple color.

2. The active acidity of the studied sauce samples increased from 4.75 to 4.5 pH with the increase in the use of protein-berry concentrates from 30 % to 50 %, and the mass moisture fraction on the contrary decreased from 57.2 % to 49.7 % under the same manufacturing conditions.

3. The presence of natural berry flavor and color in sauces made with protein-berry concentrates eliminates the need for artificial flavors and colorants.

4. Based on the specific characteristics of sauces containing protein–berry concentrates, a sensory evaluation scale was developed according to the concentrate content, allowing for the production of sauces with predictable sensory properties. The obtained data also make it possible to forecast the influence of mechanical processing of the formulation components on the rheological characteristics of the final product.

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Cite:

UFJ Style

Grek O., Pshenychna T., Lisniuk V. (2025), Application of protein-berry concentrates in sauce compositions, *Ukrainian Journal of Food Science*, 13(1), pp. 45–54, https://doi.org/10.24263/2310-1008-2025-13-1-6

APA Style

Grek, O., Pshenychna, T., & Lisniuk, V. (2025). Application of protein-berry concentrates in sauce compositions. *Ukrainian Journal of Food Science, 13*(1), 45–54. https://doi.org/10.24263/2310-1008-2025-13-1-6