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A.M. Muratbayev¹ – main author, ©
K.S. Bekbayev², B. Kalemshariv³,
A.A. Melissova⁴, A.D. Daiyrbekova⁵



¹PhD, ²Doctor of Technical Sciences, Associate Professor, ^{3,5}MSc, ⁴PhD student

ORCID

¹<https://orcid.org/0000-0002-0830-5007> ²<https://orcid.org/0000-0001-9591-0370>

³<https://orcid.org/0000-0002-8036-9718> ⁴<https://orcid.org/0009-0002-8215-2595>

⁵<https://orcid.org/0009-0004-8622-0609>



^{1,2,4,5}Shakarim University, Semey, Kazakhstan

³S.Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan



¹aknurmelisova@gmail.com

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EFFECT OF MOLECULAR HYDROGEN ON THE QUALITY AND STABILITY OF COTTAGE CHEESE CURD WITH ENCAPSULATED BIOACTIVE ADDITIVE

Abstract. This paper presents the results of a study on the effect of molecular hydrogen (H₂) treatment on the quality and stability of functional cottage cheese curd enriched with an encapsulated bioactive additive based on a composite extract from three types of plant raw materials: purple coneflower (*Echinacea purpurea*), maral root (*Rhaponticum carthamoides*), and rose hips (*Rosa canina*). The study was conducted on four groups of samples over 12 days of storage at 4°C. Organoleptic, physicochemical (pH, oxidation-reduction potential, L*a*b* color parameters), and microbiological parameters (lactic acid bacteria, total mesophilic aerobic bacteria, yeasts and molds) were evaluated. It was found that the combined use of the encapsulated bioactive additive and molecular hydrogen treatment provides a synergistic effect, manifested in a reduction of the oxidation-reduction potential to negative values, pH stabilization, preservation of color characteristics and organoleptic properties of the product, as well as inhibition of spoilage microorganisms and stimulation of lactic acid bacteria growth. The obtained results indicate the promising potential of using molecular hydrogen as a safe antioxidant and preservative factor to enhance microbiological safety and extend the shelf life of functional cottage cheese products without the use of synthetic preservatives.

Keywords: cottage cheese curd, molecular hydrogen, encapsulated bioactive additive, *Echinacea purpurea*, *Rhaponticum carthamoides*, rose hips, oxidation-reduction potential, antioxidant activity, microbiological stability, functional food products.



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Introduction. In recent years, one of the priority directions in the development of the food industry has been the creation of functional food products with high biological value and the ability to provide the body with additional physiologically active components. Dairy products, which are a source of complete protein, essential amino acids, vitamins, and minerals, are of particular interest. Among them, cottage cheese products occupy a significant place due to their high

digestibility and the possibility of being used as a basis for introducing various functional ingredients [1].

Cottage cheese curd is a promising food matrix for the development of functional products. The use of biologically active additives makes it possible to increase the content of valuable components and expand the range of dairy products with targeted properties. It was previously shown that the introduction of natural components into cottage cheese curd contributes to the enrichment of the product with biologically active substances and the improvement of its functional characteristics [2]. However, the addition of functional components may affect the stability of the food system, which requires studying changes in product quality during storage.

In the present work, an encapsulated composite extract obtained from three types of plant raw materials was used as a functional additive: purple coneflower herb (*Echinacea purpurea*), maral root (*Rhaponticum carthamoides*), and rose hips (*Rosa canina*). The choice of these components is due to their proven biologically active properties and synergistic potential. Purple coneflower is one of the most studied immunostimulating plants; its key biologically active compounds, including alkamides, caffeic acid derivatives, flavonoids, and polysaccharides, have the ability to modulate both innate and adaptive immunity [3]. Studies show that echinacea extracts enhance the activity of macrophages and natural killer (NK) cells, stimulate the production of pro-inflammatory cytokines, and may promote the activation of T-helper cells, which confirms its potential as an effective immunomodulator [4]. Rose hips, rich in vitamin C, flavonoids, and other polyphenolic compounds, exhibit pronounced antioxidant and anti-inflammatory activity [5]. Maral root (*Rhaponticum carthamoides*) contains ecdysteroids, primarily 20-hydroxyecdysone, which have pronounced adaptogenic and anabolic properties, increasing the body's resistance to physical and chemical stress [6]. In combination with each other, these components contribute to maintaining the functional state of the immune system, increasing the body's adaptive capabilities, and protecting against adverse environmental factors [7]. A composition of plants containing different classes of phytochemical compounds can have a synergistic effect on the regulation of immune processes, affecting key signaling pathways, including NF- κ B, MAPKs, and JAK/STAT [8]. Such a complex composition provides a multifaceted physiological effect, making it promising for the enrichment of dairy products.

One of the modern technological approaches to increasing the effectiveness of functional ingredients is the encapsulation of biologically active substances. This technology allows protecting active compounds from the effects of oxygen, temperature, light, and other environmental factors, as well as promoting their uniform distribution in the product structure and controlled release [9]. The use of encapsulated biologically active additives in dairy systems makes it possible to preserve the activity of functional components and improve the consumer properties of the finished product.

Despite their high nutritional value, cottage cheese products are perishable food systems. During storage, their quality is limited by the development of microorganisms, changes in acidity, and the occurrence of oxidative processes, especially in the lipid and protein fractions of the product. Oxidative reactions can lead to changes in organoleptic characteristics, a decrease in nutritional value, and a reduction in the product's shelf life [10]. In this regard, the search for safe methods of stabilizing the quality of dairy products without the use of synthetic preservatives is relevant.

In recent years, the attention of researchers has been attracted by the use of molecular hydrogen (H_2) as a natural antioxidant factor. Molecular hydrogen is capable of exhibiting reducing properties due to the regulation of redox processes and the reduction of the activity of the most reactive free radicals [11]. Due to its small molecular size, high penetrating ability, and the absence of toxic reaction products, H_2 is considered a promising component for use in food technologies [12].

Studies show that the use of molecular hydrogen in dairy products contributes to a reduction in the oxidation-reduction potential, a slowdown in lipid oxidation processes, and the stabilization of quality indicators during storage [13]. In particular, the use of a hydrogen-enriched environment in the production of dairy products makes it possible to maintain stable pH values, water activity, and microbiological indicators, which confirms the promise of this approach for increasing product stability [14].

One of the methods for introducing molecular hydrogen is bubbling with gaseous H_2 , which allows saturating the product with molecular hydrogen without changing the recipe composition and introducing additional chemical compounds. However, the effect of this treatment method on the quality of cottage cheese curd with encapsulated biologically active additives has not been sufficiently studied.

In this regard, the aim of this study was to investigate the effect of molecular hydrogen on the quality and stability of cottage cheese curd with encapsulated biologically active additives during storage.

Materials and methods. *Object of study.* The object of the study was cottage cheese curd with a mass fraction of fat of 9%, intended for functional nutrition. The study was conducted to assess the effect of molecular hydrogen treatment on the quality indicators and stability during storage of cottage cheese curd enriched with an encapsulated biologically active additive (BAA).

Experimental design. To evaluate the effectiveness of the use of molecular hydrogen and the functional component, four groups of samples were formed:

- A – control group (cottage cheese curd without additives and without H_2 treatment);
- B – cottage cheese curd with encapsulated BAA (without H_2 treatment);
- C – cottage cheese curd treated with molecular hydrogen (without capsules);
- D – cottage cheese curd with encapsulated BAA treated with molecular hydrogen.

Raw materials and recipe. As the main raw material, cottage cheese with a mass fraction of fat of 9%, produced in accordance with the requirements of the technical regulations, was used. The recipe for cottage cheese curd per 1 kg of finished product is presented in Table 1.

Table 1

Recipe for cottage cheese curd with encapsulated BAA

Component	Amount per 1 kg of product, g
Cottage cheese 9%	869.0
Granulated sugar	100.0
Vanillin	1.0
Encapsulated BAA	30.0
Total	1000.0

Characteristics of the encapsulated biologically active additive. As a functional ingredient, an encapsulated biologically active additive containing a composite extract from three types of plant raw materials was used:

- purple coneflower herb (*Echinacea purpurea*);
- maral root (*Rhaponticum carthamoides*);
- rose hips (*Rosa canina*).

The choice of these components is due to their biologically active properties: rose hips are rich in vitamin C and natural antioxidants, while purple coneflower and maral root contribute to maintaining the functional state of the immune system, increasing the body's adaptive capabilities, and protecting against adverse environmental factors.

The encapsulated BAA was introduced in an amount of 30 g/kg of product at the final stage of preparing the cottage cheese curd. The additive was added with gentle stirring to preserve the integrity of the capsules and prevent the destruction of functional components.

Technology for the production of cottage cheese curd. The technological process included the preparation of dairy raw materials, the production of cottage cheese, the introduction of recipe components, the addition of encapsulated BAA, treatment with molecular hydrogen (for the relevant groups), packaging, and subsequent storage.

Production of cottage cheese. Dairy raw materials were received and evaluated for organoleptic and physicochemical parameters. For production, fresh milk with an acidity of no more than 20°T and a quality not lower than grade II was used. The milk was purified using a separator-cleaner, pasteurized at a temperature of $80 \pm 2^\circ\text{C}$ for 15–20 seconds, and cooled to $4 \pm 2^\circ\text{C}$.

If necessary, normalization by mass fraction of fat was carried out. The mixture was homogenized at a temperature of $60 \pm 5^\circ\text{C}$ and a pressure of 15.0 ± 2.5 MPa, after which it was re-pasteurized at $80 \pm 2^\circ\text{C}$ for 20 seconds and cooled to the fermentation temperature of $30 \pm 2^\circ\text{C}$.

Mesophilic lactic acid streptococci were used as a starter culture. Fermentation was carried out at a temperature of $30 \pm 2^\circ\text{C}$ for 8–10 hours until a dense curd formed and a pH of no more than 4.69 was reached.

The resulting curd was processed: cut, heated, and held to separate the whey. The separation of whey was carried out by self-pressing and pressing until the standard mass fraction of moisture was achieved. The finished cottage cheese was immediately cooled to a temperature of $3\text{--}8^\circ\text{C}$ to stop lactic acid fermentation.

Preparation of cottage cheese curd. The cooled cottage cheese was ground until a homogeneous structure was obtained and sent to a mixing machine. Granulated sugar was pre-sieved, and vanillin was mixed with a portion of sugar to ensure uniform distribution. Mixing of components was carried out at a cottage cheese temperature not exceeding 15°C until a homogeneous consistency was obtained.

The encapsulated BAA was introduced at the final stage of mixing at a low speed (0.5–1.5 minutes) to preserve the integrity of the microcapsules.

Treatment with molecular hydrogen. Samples of groups C and D were subjected to treatment by bubbling with gaseous molecular hydrogen. Hydrogen (H_2) with a purity of 99.99% was used, which was supplied directly to the cottage cheese curd through a bubbling device.

The bubbling process was carried out for 5 minutes at a hydrogen flow rate of 70.9 ± 1.2 ml/min. The treatment was carried out with the aim of uniformly

saturation of the cottage cheese curd with molecular hydrogen and forming a reducing environment without changing the main recipe composition of the product.

Packaging and storage. After treatment, all samples were packaged in sterile polyethylene packaging (50 g each) and stored at a temperature of $4\pm 2^{\circ}\text{C}$ for 12 days. Sampling for analysis was carried out on days 0, 4, 8, and 12 of storage.

Organoleptic analysis. Organoleptic evaluation of the cottage cheese curd samples was carried out at the Scientific and Experimental Center "Valorization of Agro-Industrial Complex Products" (NAO "Shakarim University", Semey) in accordance with the requirements of GOST 3622-68 "Milk and dairy products. Organoleptic methods for determining taste and smell" and GOST 31680-2012 "Curd mass 'Special'. Technical conditions."

Seven qualified experts with experience in the field of food technology participated in the tasting. The evaluation was carried out on a five-point scale according to the following indicators: appearance, color, smell, taste, and consistency. Each sample was coded with three-digit numbers and presented in random order. The results were recorded in tasting sheets and expressed as the mean $\pm$ standard deviation ($M \pm SD$).

Determination of physicochemical parameters.

pH determination. The pH value was measured using a digital pH meter (model HI 2211, Hanna Instruments, USA) with a glass electrode. The electrode was calibrated using standard buffer solutions with pH 4.01 and 7.00 before each measurement. Measurements were performed in triplicate for each sample. Results were expressed as mean $\pm$ standard error (SE).

Determination of oxidation-reduction potential (ORP). The oxidation-reduction potential (Eh) was measured using a pH-millivoltmeter (model HI 2211, Hanna Instruments, USA) with a platinum combination electrode. The electrode was calibrated using standard ORP solutions (225 mV and 468 mV) before each use. ORP was recorded in millivolts (mV) at a temperature of $25\pm 1^{\circ}\text{C}$. Measurements were performed in triplicate.

Determination of color characteristics (L , a , b^*). Color parameters (L^* – lightness, a^* – red-green component, b^* – yellow-blue component) were determined using a colorimeter (model CR-400, Konica Minolta, Japan). The device was calibrated using a standard white plate before each measurement. Samples were placed in a quartz cuvette, and measurements were taken at three different points on the sample surface. Results were expressed as mean $\pm$ standard error (SE).

Microbiological studies. Microbiological analyses were performed on days 0, 4, 8, and 12 of storage. Under aseptic conditions, 5 g of each cottage cheese curd sample was homogenized with 45 ml of sterile buffered peptone water (BPW) in a stomacher bag for 2 minutes. Decimal dilutions (10^{-2} – 10^{-5}) were prepared in sterile BPW, and 0.1 ml aliquots were plated on selective agar media in Petri dishes (in duplicate).

For the enumeration of the following groups of microorganisms, the following were used:

- Lactic acid bacteria (LAB) – on MRS medium (De Man, Rogosa and Sharpe, Merck, Germany), incubated at 37°C for 48 hours;
- Total mesophilic aerobic bacteria (TMAB) – on PCA medium (Plate Count Agar, Merck, Germany), incubated at 37°C for 72 hours under aerobic conditions;
- Yeasts and molds – on PDA medium (Potato Dextrose Agar, Merck, Germany), incubated at 25°C for 5 days.

After incubation, the number of colonies was counted and expressed in logarithmic units (log CFU/g). The actual number of microorganisms was calculated using the formula:

Actual number (CFU/g) = (number of colonies on the plate) $\times$ (dilution factor) $\times$ (BPW volume) / (sample weight)

All analyses were performed in two independent replicates for each sample. Results were expressed as mean $\pm$ standard error (SE).

Research results. *Organoleptic Indicators.* The results of the tasting evaluation of cottage cheese curd samples are presented in Table 2. All samples received high scores on a five-point scale. Appearance, color, and odor of all groups were rated at 5.0 points.

Table 2

Organoleptic evaluation of cottage cheese curd samples (M $\pm$ SD, points)

Parameter	A	B	C	D
Appearance	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00
Color	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00
Odor	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00
Taste	5.0 $\pm$ 0.00	4.9 $\pm$ 0.10	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00
Consistency	4.8 $\pm$ 0.12	4.9 $\pm$ 0.08	5.0 $\pm$ 0.00	5.0 $\pm$ 0.00
Average score	4.96 $\pm$ 0.05	4.96 $\pm$ 0.04	5.00 $\pm$ 0.00	5.00 $\pm$ 0.00

Note: A – control (no additives, no H₂); B – with encapsulated bioactive additive; C – H₂-treated; D – with encapsulated bioactive additive + H₂. Evaluation was performed on a five-point scale by seven experts.

The greatest differences between groups were recorded for “taste” and “consistency”. Group B (with encapsulated BAA) received 4.9 $\pm$ 0.10 points for taste, which is 0.1 points lower than groups A, C, and D (5.0 points each). The lower score is due to a slight herbal aftertaste caused by the release of plant extracts from the capsules.

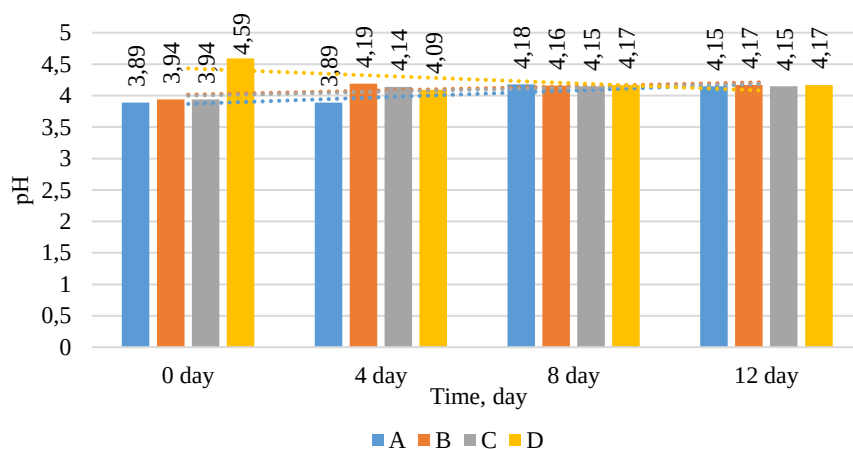
For consistency, group A scored 4.8 $\pm$ 0.12 points, group B – 4.9 $\pm$ 0.08 points, groups C and D – 5.0 points each. The increase in consistency scores in groups C and D correlates with the reduction of oxidation-reduction potential (ORP) to negative values (group D: –368.2 mV on day 0 and –24.3 mV on day 4), indicating stabilization of the protein matrix and reduced aggregation of protein particles in the reducing environment. In group C, despite H₂ treatment, ORP remained positive (+287.1 to +204.0 mV) throughout storage; however, consistency was rated at 5.0 points, which is attributed to the mechanical effect of sparging, promoting more uniform distribution of the fat phase.

The average organoleptic score for groups A and B was 4.96 points, and for groups C and D – 5.00 points. Samples from groups C and D retain traditional organoleptic properties and demonstrate improved consistency compared to the control.

pH Dynamics. The pH dynamics of cottage cheese curd samples during 12-day storage at 4°C are presented in Figure 1. The pH values of all samples ranged from 3.89 to 4.59.

Group A (control) showed pH values in the range of 3.89–4.18, increasing from 3.89 on day 0 to 4.15 on day 12. Group B exhibited similar dynamics with pH in the range of 3.94–4.19. Group C maintained stable pH values (3.94–4.15) without significant fluctuations. Group D showed the highest initial pH (4.59),

which decreased to 4.09 by day 4 and then stabilized at 4.17 ± 0.02 until the end of storage.

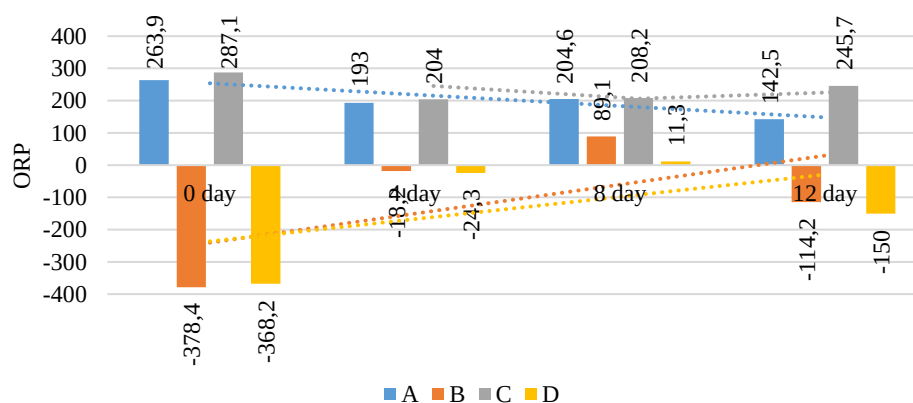


A – control group (no additives, no H_2); B – cottage cheese curd with encapsulated BAA; C – cottage cheese curd treated with H_2 ; D – cottage cheese curd with encapsulated BAA, treated with H_2 .

Fig. 1. Changes in pH of cottage cheese curd samples during storage at $4^\circ C$ for 12 days

The standard deviation of pH in group D after day 4 was ± 0.02 , whereas in group A it was ± 0.05 – 0.07 , indicating a stabilizing effect of the combined use of encapsulated BAA and molecular hydrogen treatment. The increase in pH during storage in all groups is attributed to protein proteolysis and the formation of basic compounds (ammonia, amines) in fermented dairy products. The higher initial pH value in group D (4.59) is due to the reducing environment created by molecular hydrogen, which shifts the acid-base equilibrium in the product matrix.

Oxidation-Reduction Potential (ORP). Changes in ORP during storage are presented in Figure 2.



A – control group (no additives, no H_2); B – cottage cheese curd with encapsulated BAA; C – cottage cheese curd treated with H_2 ; D – cottage cheese curd with encapsulated BAA, treated with H_2 .

Figure 2. Changes in ORP (mV) of cottage cheese curd samples during storage at $4^\circ C$ for 12 days

Group A maintained positive ORP values in the range of +142.5 to +287.1 mV throughout the entire 12-day period, corresponding to an oxidizing environment. Group C also showed positive ORP values (+287.1 mV on day 0, +204.0 mV on day 12). The absence of a reducing effect in group C is explained by rapid diffusion of molecular hydrogen from the open food system into the gas phase within the first hours after sparging. Without barrier packaging or a capsule matrix, H₂ is not retained in the product, and consequently the reducing effect is not recorded.

Group D demonstrated negative ORP values on day 0 (–368.2 mV) and day 4 (–24.3 mV), with a subsequent increase to +11.3 mV on day 8 and a decrease to –150.0 mV on day 12. Group B showed a negative initial ORP (–378.4 mV), which increased to +89.1 mV by day 8 and decreased to –114.2 mV by day 12.

The most pronounced reducing effect was recorded in groups containing capsules (B and D): ORP values reached –378.4 mV and –368.2 mV, respectively. This is due to the release of reducing compounds (polyphenols, flavonoids, ascorbic acid) from plant raw materials (echinacea, leuzea, rose hips) and the synergistic enhancement of their antioxidant action by the reducing environment created by H₂. Encapsulation creates a microenvironment in which hydrogen is retained for a longer period, providing a prolonged reducing effect. In group D, ORP remains negative on day 12 (–150.0 mV), whereas in group B, ORP on day 12 is –114.2 mV, indicating an additional contribution of H₂ to maintaining the reducing potential.

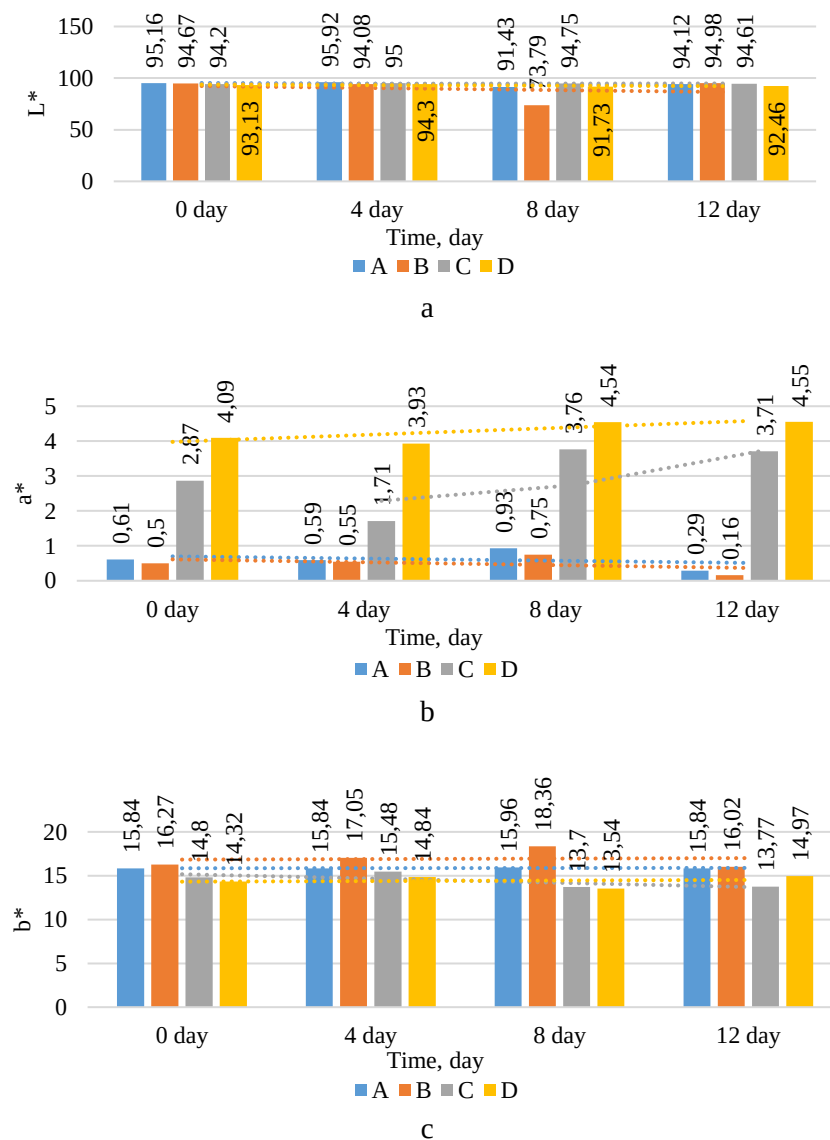
Color Characteristics (L, a, b).* Color is a critical quality indicator for dairy products, affecting consumer acceptability and perception of freshness. Changes in color parameters (L*, a*, b*) of cottage cheese curd samples during storage are presented in Figures 3A–3C.

Lightness (L).* L* values ranged from 73.79 to 95.92 across all groups (Figure 3A). Group A showed L* values in the range of 95.16–95.92 with a slight decrease to 91.43 on day 8 and recovery to 94.12 by day 12. Group B exhibited a similar trend with an anomalous value of 73.79 on day 8, which is considered a measurement error (outlier). H₂-treated groups showed lower L* values compared to A: group C – in the range of 94.20–95.00, group D – in the range of 91.73–94.30. The decrease in L* by 1–3 units in groups C and D compared to the control is attributed to changes in the redox state of carotenoids and riboflavin under the influence of the reducing environment. Group D demonstrated more stable L* dynamics (standard deviation ±0.15–0.44) compared to group B (±0.64–6.53), indicating a stabilizing effect of the combination of encapsulated BAA and hydrogen treatment.

**a* (red-green).* *a* values ranged from 0.16 to 4.55 across all groups (Figure 3B). Group A showed a* values in the range of 0.29–0.93, corresponding to a slight greenish tint typical of dairy products. Group B showed a* values in the range of 0.16–0.75, indicating a slight whitening effect of the capsule material. H₂-treated groups demonstrated significantly higher a* values: group C – in the range of 1.71–3.76, group D – in the range of 3.93–4.55. The increase in a* in groups C and D (by 4–12 times compared to the control) is attributed to the reduction of carotenoids and riboflavin under the action of molecular hydrogen, which is confirmed by negative ORP values in these samples. Changes in the colloidal structure of the protein matrix under the influence of H₂ also affect light scattering and contribute to the increase in reddish tint.

**b* (yellow-blue).* *b* values ranged from 13.54 to 18.36 across all groups (Figure 3C). Group A showed stable b* values in the range of 15.84–15.96. Group

B showed an increase from 16.27 to 18.36 by day 8, followed by a decrease to 16.02 by day 12, which is attributed to the release of yellow pigments from the plant extract. H₂-treated groups showed lower b* values compared to A: group C – in the range of 13.70–15.48, group D – in the range of 13.54–14.97. The decrease in b* in groups C and D by 1.5–2.4 units compared to the control is attributed to the reducing action of H₂ on flavonoids and other yellow pigments of the plant extract, as well as changes in the optical properties of the matrix due to the dispersion of hydrogen microbubbles.



A – control group (no additives, no H₂); B – cottage cheese curd with encapsulated BAA; C – cottage cheese curd treated with H₂; D – cottage cheese curd with encapsulated BAA, treated with H₂.

Figure 3. Changes in color parameters of cottage cheese curd samples during storage at 4°C for 12 days

In all groups, L , a , b^* values remained within acceptable limits for fermented dairy products during the 12-day storage period. The observed changes do not affect the visual quality of the product.

Microbiological Indicators. The microbiological quality of cottage cheese curd samples was assessed by monitoring lactic acid bacteria (MRS), total mesophilic aerobic bacteria (PCA), and yeasts and molds (PDA) during 12 days of storage at 4°C (Table 3).

Table 3

Microbiological indicators (log CFU/g) of cottage cheese curd samples during storage at 4°C for 12 days

Microorganism	Group	Day 0	Day 4	Day 8	Day 12
MRS (LAB)	A	5.33 ± 0.68	5.67 ± 0.34	6.11 ± 0.45	6.46 ± 0.23
	B	5.08 ± 0.52	5.29 ± 0.41	5.72 ± 0.38	6.27 ± 0.31
	C	4.95 ± 0.30	5.11 ± 0.15	5.56 ± 0.21	6.53 ± 0.20
	D	4.87 ± 0.28	5.03 ± 0.22	5.48 ± 0.19	6.41 ± 0.18
PCA (TMAB)	A	4.72 ± 0.43	5.12 ± 0.28	5.84 ± 0.36	6.45 ± 0.22
	B	4.51 ± 0.39	4.89 ± 0.33	5.41 ± 0.29	6.18 ± 0.27
	C	4.45 ± 0.28	4.89 ± 0.19	5.21 ± 0.18	6.52 ± 0.21
	D	4.32 ± 0.25	4.76 ± 0.22	5.09 ± 0.20	6.33 ± 0.19
PDA (Yeasts and molds)	A	5.87 ± 0.39	6.27 ± 0.31	6.68 ± 0.33	6.55 ± 0.29
	B	5.52 ± 0.44	5.98 ± 0.36	6.34 ± 0.28	6.41 ± 0.34
	C	5.61 ± 0.29	5.92 ± 0.27	6.22 ± 0.26	6.44 ± 0.22
	D	5.43 ± 0.34	5.71 ± 0.30	6.01 ± 0.25	6.28 ± 0.24

Note: A – control group (no additives, no H_2); B – cottage cheese curd with encapsulated BAA; C – cottage cheese curd treated with H_2 ; D – cottage cheese curd with encapsulated BAA, treated with H_2 . Values are presented as mean $\pm$ standard error ($n = 2-5$).

Lactic acid bacteria (LAB). Initial LAB values ranged from 4.87 to 5.33 log CFU/g. Group A showed the highest initial value (5.33 ± 0.68 log CFU/g), group D – the lowest (4.87 ± 0.28 log CFU/g). During storage, LAB counts increased in all samples, reaching by day 12: group A – 6.46 ± 0.23 , group B – 6.27 ± 0.31 , group C – 6.53 ± 0.20 , group D – 6.41 ± 0.18 log CFU/g. Group C showed the highest LAB increase ($\Delta = +1.58$ log CFU/g), group D – the smallest increase among H_2 -treated samples ($\Delta = +1.54$ log CFU/g). H_2 treatment stimulates LAB growth, as evidenced by the higher final value in group C (6.53) compared to the control (6.46). The presence of capsules moderates this effect, which is explained by competition for nutrients between released plant compounds and LAB.

Total mesophilic aerobic bacteria (TMAB). Initial TMAB values ranged from 4.32 to 4.72 log CFU/g. Group A had the highest initial value (4.72 ± 0.43 log CFU/g), group D – the lowest (4.32 ± 0.25 log CFU/g). By day 12, TMAB counts reached: group A – 6.45 ± 0.22 , group B – 6.18 ± 0.27 , group C – 6.52 ± 0.21 , group D – 6.33 ± 0.19 log CFU/g. The most pronounced inhibitory effect was recorded in group D, which maintained consistently lower values compared to A at all storage stages: on day 12, the difference was 0.12 log CFU/g. In group C, by contrast, a higher final value (6.52) was recorded than in the control (6.45), indicating the absence of an inhibitory effect of H_2 in the absence of a capsule matrix.

Yeasts and molds. Initial values ranged from 5.43 to 5.87 log CFU/g: group A – 5.87 ± 0.39 , group D – 5.43 ± 0.34 log CFU/g. By day 12: group A – 6.55 ± 0.29 , group B – 6.41 ± 0.34 , group C – 6.44 ± 0.22 , group D – 6.28 ± 0.24 log CFU/g. Group D showed the lowest final value, which is 0.27 log CFU/g lower than the control. H₂-treated groups consistently demonstrated lower yeast and mold counts compared to their non-H₂-treated counterparts. On day 8, group C showed 6.22 ± 0.26 versus 6.68 ± 0.33 log CFU/g in group A (difference of 0.46 log CFU/g). The combination of capsules and H₂ treatment (group D) provided the most effective inhibition at all storage stages.

The reduction in TMAB counts in group D compared to the control (6.33 ± 0.19 vs. 6.45 ± 0.22 log CFU/g on day 12) and yeasts and molds (6.28 ± 0.24 vs. 6.55 ± 0.29 log CFU/g) is explained by two factors: 1) the reducing environment (ORP –368.2 mV) suppresses the development of aerobic spoilage microflora; 2) the capsule matrix limits oxygen access and creates microzones with reduced oxidative stress, which additionally inhibits the growth of undesirable microorganisms. LAB growth is simultaneously stimulated (6.41 ± 0.18 log CFU/g in group D vs. 6.46 ± 0.23 in the control), indicating the selectivity of H₂ action in favor of beneficial microflora. The absence of an inhibitory effect in group C (TMAB 6.52 vs. 6.45 in the control) confirms that without the capsule matrix, H₂ is not retained in the product and does not exert a prolonged antimicrobial effect.

Conclusion. A recipe and technology for functional cottage cheese curd with an encapsulated biologically active additive based on purple coneflower, maral root, and rose hips have been developed. It has been established that treatment with molecular hydrogen in combination with encapsulated BAA ensures the stabilization of physicochemical parameters, the creation of a reducing environment, a reduction in microbiological load, stimulation of lactic acid bacteria growth, and the preservation of color and organoleptic characteristics of the product. The synergistic effect of the combined use of BAA and molecular hydrogen has been proven, due to the mutual enhancement of the antioxidant action of plant polyphenols and the reducing properties of hydrogen. The developed method makes it possible to increase microbiological safety and maintain the quality of cottage cheese curd without the use of synthetic preservatives, which opens up prospects for the industrial implementation of the technology for the production of functional dairy products with improved consumer properties and an extended shelf life.

References

1. Pilipenko T.V., Florinskaya E.E., Nikolaeva S.L. Microbiological research aspects of cottage cheese, obtained by the use of ultrafiltration while producing and storing // Bulletin of the South Ural State University. – 2016. – Vol. 4, No. 4. – P. 64–72.
2. Ginoyan R.V., Krylova D.S. Comparative evaluation of experimental samples of curd mass with various plant additives // Vestnik Vostochno-Sibirskogo gosudarstvennogo universiteta tekhnologii i upravleniya (Vestnik VSGUTU). – 2020. – Vol. 3, No. 78.
3. Barnes J. et al. Echinacea species (*Echinacea angustifolia* (DC.) Hell., *Echinacea pallida* (Nutt.) Nutt., *Echinacea purpurea* (L.) Moench): a review of their chemistry, pharmacology and clinical properties // Journal of Pharmacy and Pharmacology. – 2005. – Vol. 57, No. 8. – P. 929–954.
4. Zhai Z. et al. Enhancement of innate and adaptive immune functions by multiple *Echinacea* species // Journal of Medicinal Food. – 2007. – Vol. 10, No. 3. – P. 423–434.

5. Chrubasik C. et al. A systematic review on the Rosa canina effect and efficacy profiles // *Phytotherapy Research*. – 2008. – Vol. 22, No. 6. – P. 725–733.
6. Kokoska L., Janovska D. Chemistry and pharmacology of Rhaponticum carthamoides: a review // *Phytochemistry*. – 2009. – Vol. 70, No. 7. – P. 842–855.
7. Патент БАД 2026 [Текст].
8. Alesci A. et al. Resveratrol and immune cells: a link to improve human health // *Molecules*. – 2022. – Vol. 27, No. 2. – Art. 424.
9. Nedovic V. et al. An overview of encapsulation technologies for food applications // *Procedia Food Science*. – 2011. – Vol. 1. – P. 1806–1815.
10. Deeth H.C., Fitz-Gerald C.H. Lipolytic enzymes and hydrolytic rancidity // *Advanced Dairy Chemistry. Volume 2: Lipids*. – Boston, MA : Springer US. – P. 481–556.
11. Ohsawa I. et al. Hydrogen acts as a therapeutic antioxidant by selectively reducing cytotoxic oxygen radicals // *Nature Medicine*. – 2007. – Vol. 13, No. 6. – P. 688–694.
12. Russell G., Nenov A., Hancock J.T. How hydrogen (H₂) can support food security: From farm to fork // *Applied Sciences*. – 2024. – Vol. 14, No. 7. – Art. 2877.
13. Alwazeer D. Reducing atmosphere packaging technique for extending the shelf-life of food products // *Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi*. – 2019. – Vol. 9, No. 4. – P. 2117–2123.
14. Kyrykbaeva Sh.T. et al. The effect of molecular hydrogen on the quality and shelf life of soft brined cheese // *The Journal of Almaty Technological University*. – 2026. – Vol. 152, No. 2. – P. 68–76.

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**А.М. Муратбаев¹, К.С. Бекбаев¹, Б. Калемшариев²,
А.А. Мелісова¹, А.Д. Дайырбекова¹**

¹*Шәкәрім Университеті, Семей, Қазақстан*

²*С. Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті,
Астана, Қазақстан*

КАПСУЛАЛАНҒАН БИОЛОГИЯЛЫҚ БЕЛСЕНДІ ҚОСПАСЫ БАР СҮЗБЕ МАССАСЫНЫҢ САПАСЫ МЕН ТҰРАҚТЫЛЫҒЫНА МОЛЕКУЛАЛЫҚ СҮТЕГІНІҢ ӘСЕРІ

Аңдатпа. Бұл жұмыста молекулалық сүтегімен (H₂) өңдеудің үш түрлі өсімдік шикізатынан (үлкен гүлді эхинацея, марал тамыры және итмұрын) алынған инкапсуляцияланған биоактивті қоспамен байытылған функционалды сүзбе өнімінің сапасы мен тұрақтылығына әсері зерттелді. Төрт топ үлгісі 12 күн бойы 4°C температурада сақталды. Зерттеу барысында органолептикалық, физика-химиялық (рН, тотығу-тотықсыздану потенциалы, L*a*b* түс көрсеткіштері) және микробиологиялық көрсеткіштер (сүт қышқылды бактериялар, мезофильді аэробты бактериялар, ашытқылар мен көгеру саңырауқұлақтары) бағаланды. Инкапсуляцияланған қоспа мен H₂ өңдеуін бірге қолдану синергиялық әсер беріп, тотығу-тотықсыздану потенциалының теріс мәндерге төмендеуіне, рН тұрақтануына, түс пен дәмнің сақталуына, сондай-ақ бұзылу микроорганизмдерінің тежелуіне және сүт қышқылды бактериялардың өсуіне ықпал етті. Алынған нәтижелер молекулалық сүтегіні синтетикалық консерванттарсыз сүзбе өнімдерінің микробиологиялық

қауіпсіздігі мен жарамдылық мерзімін ұзарту үшін тиімді антиоксидант және табиғи консервант ретінде пайдалануға болатындығын көрсетеді.

Тірек сөздер: сүзбе массасы, молекулалық сүтегі, капсулаланған биологиялық белсенді қоспа, ақ эхинацея, левзея, итмұрын, тотығу-тотықсыздану потенциалы, антиоксиданттық белсенділік, микробиологиялық тұрақтылық, функционалдық тағам өнімдері.

**А.М. Муратбаев¹, К.С. Бекбаев¹, Б. Калемшариев²,
А.А. Мелісова¹, А.Д. Дайырбекова¹**

¹Шәкәрім Университет, Семей, Қазақстан

²Қазақский агротехнический исследовательский университет им. С. Сейфуллина,
Астана, Қазақстан

ВЛИЯНИЕ МОЛЕКУЛЯРНОГО ВОДОРОДА НА КАЧЕСТВО И СТАБИЛЬНОСТЬ ТВОРОЖНОЙ МАССЫ С КАПСУЛИРОВАННОЙ БИОЛОГИЧЕСКИ АКТИВНОЙ ДОБАВКОЙ

Аннотация. В данной работе представлены результаты исследования влияния обработки молекулярным водородом (H₂) на качество и стабильность функционального творожного продукта, обогащенного инкапсулированной биоактивной добавкой на основе композитного экстракта из трех видов растительного сырья: эхинацеи пурпурной, маральего корня и шиповника. Исследование проводилось на четырех группах образцов в течение 12 дней хранения при 4°C. Оценивались органолептические, физико-химические (pH, окислительно-восстановительный потенциал, цветовые параметры L*a*b*) и микробиологические показатели (молочнокислые бактерии, общее количество мезофильных аэробных бактерий, дрожжи и плесени). Установлено, что совместное применение инкапсулированной добавки и обработки H₂ обеспечивает синергетический эффект, проявляющийся в снижении окислительно-восстановительного потенциала до отрицательных значений, стабилизации pH, сохранении цветовых и органолептических свойств продукта, а также в ингибировании микроорганизмов порчи и стимуляции роста молочнокислых бактерий. Полученные результаты свидетельствуют о перспективности использования молекулярного водорода в качестве безопасного антиоксидантного и консервирующего фактора для повышения микробиологической безопасности и продления срока годности функциональных творожных продуктов без применения синтетических консервантов.

Ключевые слова: творожная масса, молекулярный водород, капсулированная биологически активная добавка, эхинацея пурпурная, левзея, шиповник, окислительно-восстановительный потенциал, антиоксидантная активность, микробиологическая стабильность, функциональные продукты питания.