IRSTI 61.01.90

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https://doi.org/10.55956/XXTR7517

DEVELOPMENT OF CHEMICAL TECHNOLOGIES FOR NEW BIODEGRADABLE HYDROGELS BASED ON CHITOSAN

Abstract. The primary objective of this study was to develop novel biodegradable hydrogels based on chitosan and alginate with controlled moisture-release properties for smart packaging applications. The research comprehensively investigated the physicochemical properties of the hydrogels, including their mechanical strength, biodegradability, and effects on the shelf life of model products (carrots and ascorbic acid tablets). The hydrogels were synthesized using chitosan, sodium alginate, glutaraldehyde, and calcium chloride. Experimental methods encompassed swelling degree determination, mechanical property analysis, biodegradability assessment, and the evaluation of the hydrogels' effects on product moisture content, color stability, and microbial contamination. Key findings revealed the exceptional swelling capacity of chitosan-alginate hydrogels (1500% in distilled water), making them highly effective for moisture regulation. The mechanical properties were found to be equally impressive, with a tensile strength of 1.2 MPa and an elongation at break of 180%. Biodegradability reached 70% after 28 days, confirming their environmental compatibility. The hydrogels maintained carrot moisture at 68% after 28 days, limited color change (ΔE=14.2), and reduced microbial contamination to 10^5 CFU/g. In pharmaceutical applications, the hydrogels preserved 84% of ascorbic acid content in tablets over the same period. Future research directions include optimizing hydrogel composition to enhance mechanical strength and biodegradability and conducting real-world storage condition trials. It is also necessary to develop modified hydrogel variants with additional functionalities, such as antimicrobial protection and controlled release of active compounds. These advancements will broaden the hydrogels' application potential across food processing, agriculture, and pharmaceutical industries.

Keywords: biodegradable hydrogels, chitosan, alginate, controlled moisture release, environmentally friendly materials.

Azimov A., Bolysbek A.A., Iztleuov G.M. Development of chemical technologies for new biodegradable hydrogels based on chitosan //Mechanics and Technology / Scientific journal. – 2025. – No.3(89). – P.146-158. https://doi.org/10.55956/XXTR7517

Introduction. Biodegradable hydrogels based on natural polymers like chitosan and alginate offer a promising solution to this problem. These materials degrade under natural conditions and can be employed to develop smart packaging systems that regulate moisture and extend product shelf life [1-3]. Furthermore, hydrogels can be modified to perform specific functions, such as antimicrobial protection or controlled release of active compounds. Recent years have seen extensive research on the development and application of biodegradable hydrogels. A key focus has been the utilization of natural polymers, such as chitosan and alginate, which provide high biocompatibility and biodegradability. Chitosan, which is derived from chitin, ranks among the most extensively studied natural polymers due to its unique properties, including antimicrobial activity, biocompatibility, and hydrogel-forming capacity. Alginate is extracted from seaweed and is similarly valued for its ability to form gels in the presence of calcium ions. Chitosan-alginate hydrogels show particular promise for developing moisture-regulating packaging materials. Studies have demonstrated that a combination of these polymers results in an optimal balance between mechanical strength and swelling capacity, rendering them suitable for food industry applications. Moreover, such hydrogels have proven effective in slowing moisture loss from fresh produce like fruits and vegetables.

Another critical research direction involves hydrogel applications for controlled release of active substances. Researchers have developed chitosan-alginate hydrogels capable of gradual antimicrobial agent release. These materials can be incorporated into packaging systems that suppress pathogenic microorganism growth and extend product shelf life – a crucial consideration for the food industry, where microbiological safety remains paramount [4-6].

The primary goal of this study was to develop novel biodegradable hydrogels based on chitosan and alginate with controlled moisture release properties for smart packaging.

The research encompassed the following specific tasks:

1) to investigate physicochemical and functional properties of hydrogels, including swelling degree, mechanical strength, and biodegradability;

2) to evaluate hydrogel effects on the shelf life of model products (carrots and ascorbic acid in the form of tablets);

3) to examine the potential of hydrogels for the development of packaging materials with antimicrobial properties;

4) to conduct a comparative analysis of the effectiveness of chitosan-based, alginate-based, and composite hydrogels.

Materials and methods. Figure 1 presents a research flowchart outlining the development and characterization of biodegradable chitosan-based and alginate-based hydrogels for smart packaging. The flowchart illustrates key research stages, including material preparation, hydrogel synthesis, physicochemical characterization, and functional property evaluation.

The initial stage involved the selection and preparation of raw components: chitosan, sodium alginate, glutaraldehyde, and calcium chloride. This stage was followed by hydrogel fabrication using crosslinking agents to control structural and functional properties. Critical analytical steps included determining the hydrogels' swelling degree, mechanical properties (tensile strength and elongation at break), and biodegradability in soil. The final stage focused on evaluating hydrogel effects on moisture retention, color stability, and microbial contamination in model products (carrots and ascorbic acid in the form of tablets) during a 28-day storage period.

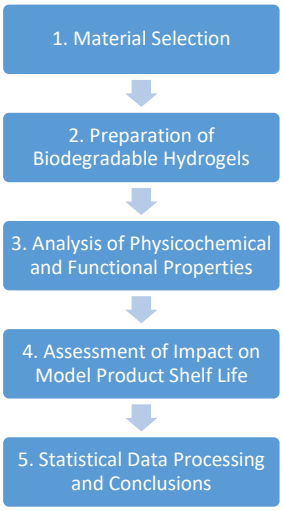

Fig. 1. Research flowchart

Materials

The biodegradable hydrogels were developed using the following materials: chitosan, sodium alginate, glutaraldehyde, and calcium chloride. Table 1 presents the characteristics and quality parameters of these materials.

Table 1

Characteristics and quality parameters

Material	Molecular weight (kDa)	Degree of deacetylation (%)	Solution concentration (%)	Dissolution conditions
Chitosan	100-300	85	1 (in acetic acid)	Room temperature
Sodium alginate	200-400	-	1 (in distilled water)	Heating to 60°C
Glutaraldehyde	-	-	0.5	Room temperature
Calcium chloride ($CaCL_2$)	-	-	2	Room temperature

Chitosan with a molecular weight of 100-300 kDa and a deacetylation degree of 85% was dissolved in a 1% acetic acid solution at room temperature. Sodium alginate with a molecular weight of 200-400 kDa was dissolved in distilled water with heating to 60°C. For polymer crosslinking, a 0.5% glutaraldehyde solution and a 2% calcium chloride solution were used. The crosslinking process was carried out at room temperature for 24 hours. These materials were selected due to their biodegradability, hydrophilic properties, and capacity for modification, making them suitable for developing hydrogels with controlled moisture release.

Methods

Analysis of physicochemical and functional properties of hydrogels. Swelling degree determination. The swelling degree (S_w) was calculated using the formula:

$$S_w = \frac{W_s - W_d}{W_d} \times 100\% \quad (1)$$

where: W_s – the mass of the swollen hydrogel (after immersion in liquid); W_d – the mass of the dry hydrogel (before immersion).

This formula (1) was used to determinev the percentage increase in hydrogel mass upon liquid absorption. The swelling process was studied under different conditions: distilled water, physiological saline (0.9% NaCl), and pH 4.0 and 7.4 buffer solutions.

Mechanical properties. Mechanical properties were evaluated using an Instron 5566 universal testing machine equipped with a 10 kN load cell and a digital data acquisition system. Samples were tested at room temperature with a tensile speed of 10 mm/min.

Tensile strength (σ) was determined as:

$$\sigma = \frac{F_{max}}{A} \quad (2)$$

where: F_{max} – the maximum load before rupture (N); A – the cross-sectional area of the sample (mm²).

Elastic modulus (E) was calculated as the tangent of the slope in the linear part of the stress-strain curve:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (3)$$

where: $\Delta\sigma$ – the change in stress (MPa); $\Delta\varepsilon$ – the corresponding change in strain.

Elongation at break (ε) was computed as:

$$\varepsilon = \frac{L_f - L_0}{L_0} \times 100\% \quad (4)$$

where: L_f – the final sample length after testing (mm); L_0 – the initial length (mm).

Biodegradability assessment. The biodegradability of the hydrogels was evaluated by mass loss during soil burial. Samples were placed in containers with moist soil at 25°C and 60% moisture. After 7, 14, 21, and 28 days, the hydrogels were retrieved, rinsed with distilled water, dried at 40°C to constant weight, and weighed.

The degradation degree (D, %) was calculated as:

$$D = \frac{m_0 - m_t}{m_0} \times 100\% \quad (5)$$

where: m_0 – the initial sample mass (g) and m_t – the mass after t days (g).

The degradation rate (R, %/ day) was determined by:

$$R = \frac{D}{t} \quad (6)$$

where, t – the degradation time (days).

Effect on shelf life of model products. Carrots and ascorbic acid in the form of tablets were used as model products to study the effects of hydrogels on shelf life. The products were stored at 25°C and 60% relative moisture for 28 days. The following parameters were evaluated: moisture loss, color change, and microbial contamination during biodegradation.

Moisture loss (W, %) was assessed by changes in weight using Formula:

$$W = \frac{m_i - m_f}{m_i} \times 100\ \% \quad (7)$$

where: m_i – the initial product mass (g); m_f – the mass after storage (g).

Color change was evaluated using the color difference indicator ΔE:

$$\Delta E = \sqrt{(L_f - L_0)^2 + (a_f - a_0)^2 + (b_f - b_0)^2} \quad (8)$$

where, L, a, b – CIE Lab color coordinates before (0) and after (f) storage.

Microbial contamination (CFU/g) was quantified via the serial dilution agar plate procedure.

Statistical analysis. All experiments were conducted three times. Data were processed using Statistica 10.0 software. Student's t-test was applied for mean comparisons, with a significance level of $p < 0.05$.

Research results. *Physicochemical properties of hydrogels*. *swelling degree*. Table 2 presents the swelling degree values of chitosan-based, alginate-based, and composite hydrogels in four different conditions: distilled water, physiological saline (0.9% NaCl), and pH 4.0 and 7.4 buffer solutions.

Table 2

Swelling degree of hydrogels

Hydrogel composition	Distilled water, %	Physiological saline, %	pH 4.0, %	pH 7.4, %
Chitosan	1200 ± 50	800 ± 30	950 ± 40	1100 ± 50
Alginate	1000 ± 40	700 ± 25	850 ± 35	900 ± 40
Chitosan-alginate	1500 ± 60	1000 ± 40	1300 ± 50	1400 ± 60

The results demonstrate that hydrogels exhibit the highest swelling capacity in distilled water. This occurs because the absence of ions in the water facilitates maximum moisture absorption through the hydrophilic groups of the polymers. The composite hydrogel achieved the highest swelling degree (1500 ± 60%) due to the synergistic effect of chitosan's amino groups and alginate's carboxyl groups, which enhance water absorption. In physiological saline, swelling was reduced as NaCl ions screened the polar groups, decreasing their water absorption capacity. The lowest values were observed at pH 4.0, which can be attributed to the reduced ionization of alginate's carboxyl groups, limiting their interaction with water. Overall, the data confirm that the hydrogel composition and medium strongly influence the properties of hydrogels. The combination of chitosan and alginate showed superior swelling properties, making it promising for moisture regulation in packaging materials.

Mechanical properties. Table 3 presents the tensile strength, elastic modulus, and elongation at break of chitosan-based, alginate-based, and composite hydrogels.

Table 3

Mechanical properties of hydrogels

Composition	Tensile strength, MPa	Elastic modulus, MPa	Elongation at break, %
Chitosan	0.8 ± 0.1	1.2 ± 0.2	150 ± 10
Alginate	0.6 ± 0.1	1.0 ± 0.2	130 ± 10
Chitosan-alginate	1.2 ± 0.2	1.5 ± 0.3	180 ± 15

Tensile strength reflects a material's ability to withstand mechanical load. The highest values (1.2 ± 0.2 MPa) were observed for the composite hydrogel due to the synergistic effect of the two polymers. Pure chitosan and alginate hydrogels exhibited lower tensile strengths (0.8 ± 0.1 MPa for chitosan and 0.6 ± 0.1 MPa for alginate). The elastic modulus characterizes a material's stiffness. The composite hydrogel also showed the highest values (1.5 ± 0.3 MPa), resulting from enhanced intermolecular interactions. Elongation at break indicates a material's ability to stretch before rupture. The composite hydrogel achieved the greatest elasticity (180 ± 15%), while pure chitosan and alginate samples exhibited lower deformation capacity (150 ± 10% and 130 ± 10%, respectively). Thus, composite (chitosan-alginate) hydrogels possess an optimal balance of strength and elasticity, making them promising for applications in packaging materials and biomedical devices.

Biodegradability of hydrogels. Table 4 presents the biodegradation parameters of hydrogels during soil burial testing.

Table 4

Biodegradability of hydrogels

Hydrogel composition	Day	Mass, %	Degradation degree, %	Degradation rate, %/day
Chitosan	7	85 ± 3	15 ± 3	2.14 ± 0.43
	14	70 ± 2	30 ± 2	2.14 ± 0.14
	21	55 ± 2	45 ± 2	2.14 ± 0.10
	28	40 ± 2	60 ± 2	2.14 ± 0.70
Alginate	7	90 ± 3	10 ± 3	1.43 ± 0.43
	14	80 ± 3	20 ± 3	1.43 ± 0.21
	21	65 ± 3	35 ± 3	1.67 ± 0.14
	28	50 ± 3	50 ± 3	1.79 ± 0.11
Chitosan-alginate	7	80 ± 2	20 ± 2	2.86 ± 0.29
	14	60 ± 2	40 ± 2	2.86 ± 0.14
	21	45 ± 2	55 ± 2	2.62 ± 0.10
	28	30 ± 2	70 ± 2	2.50 ± 0.07

The results indicate that chitosan hydrogels degrade most rapidly, reaching 15 ± 3% degradation after 7 days and 60 ± 2% after 28 days. The degradation rate of the chitosan hydrogel remained stable throughout the experimental period: 2.14 ± 0.43%/day. The alginate hydrogel exhibited slower degradation (10 ± 3% after 7 days, 50 ± 3% after 28 days), with the rate increasing from 1.43 ± 0.43%/day to 1.79 ± 0.11%/day. The chitosan-alginate composite showed intermediate indicators, achieving 20 ± 2% degradation at 7 days and 70 ± 2% at 28 days. The degradation rate of composite hydrogels decreased from 2.86 ± 0.29%/day to 2.50 ± 0.07%/day. The findings suggest that composite hydrogels have a higher degradation degree than pure alginate alternatives but exhibit a slower degradation rate than chitosan hydrogels. These properties make the composite compositions suitable for applications requiring a balance between biodegradability and durability.

Effect of hydrogels on model product shelf life. Moisture in products. Figure 2 illustrates the moisture retention in carrots during storage (for 7, 14, 21, and 28 days) with the application of different hydrogels.

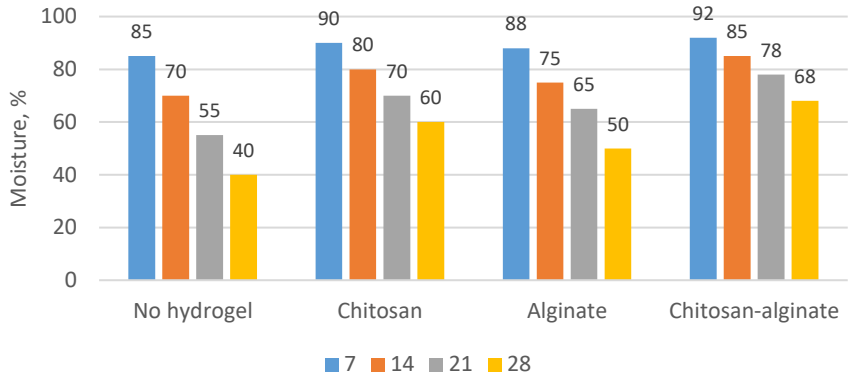

Fig. 2. Carrot moisture content during storage with hydrogels

According to the results, samples without hydrogel application exhibited the most rapid moisture loss: moisture decreasing to 40 ± 2% after 28 days indicated significant product dehydration. The chitosan hydrogel markedly improved moisture retention, maintaining 60 ± 2% moisture over the same period. This enhanced performance can be attributed to the excellent water-holding capacity of chitosan. The alginate-based hydrogel showed moderate moisture retention, preserving carrot moisture at 50 ± 2% after 28 days (gradual moisture release). The chitosan-alginate composite hydrogel demonstrated superior performance, minimizing moisture loss – 68 ± 2% after 28 days. These findings position chitosan-alginate composite hydrogels as highly promising materials for food packaging applications that protect fresh products from drying.

Product color stability. Table 5 presents the color change of carrots during storage with different hydrogels for 7, 14, 21, and 28 days. The ΔE indicator was used to evaluate the color change over time. It was calculated by measuring the color changes in CIE Lab color coordinates. Higher ΔE values indicate greater color deviation.

Table 5

Color change of carrots during storage

Hydrogel composition	ΔE after 7 days	ΔE after 14 days	ΔE after 21 days	ΔE after 28 days
No hydrogel	5.2 ± 0.3	10.8 ± 0.5	18.5 ± 0.7	25.2 ± 1.0
Chitosan	3.1 ± 0.2	7.5 ± 0.4	12.0 ± 0.6	17.3 ± 0.8
Alginate	4.0 ± 0.3	8.9 ± 0.5	14.7 ± 0.7	20.5 ± 0.9
Chitosan-alginate	2.5 ± 0.2	5.9 ± 0.3	9.8 ± 0.5	14.2 ± 0.7

The samples without hydrogel application exhibited the most rapid color deterioration: ΔE reached 25.2 after 28 days, indicating severe browning and visible defects. The chitosan-based hydrogel reduced the rate of color change. After 28 days of storage, ΔE was 17.3, which indicates a moderate change in color. The alginate-based hydrogel, on the other hand, showed lower efficacy, with a ΔE of 20.5 signaling a more pronounced color change after 28 days. The composite hydrogel proved to be the most effective, providing the least amount of color change (ΔE = 14.2 after 28 days). Thus, chitosan-alginate hydrogels represent a promising option for preserving the freshness and quality of vegetables for longer periods.

Microbial contamination. Table 6 presents changes in the microbial contamination of carrots (in colony-forming units per gram, CFU/g) during storage over 7, 14, 21, and 28 days with different types of hydrogels.

Table 6

Microbial contamination of carrots

Hydrogel composition	CFU/g at 7 days	CFU/g at 14 days	CFU/g at 21 days	CFU/g at 28 days
No hydrogel	$10^5 \pm 10^3$	$10^6 \pm 10^4$	$10^7 \pm 10^5$	$10^8 \pm 10^6$
Chitosan	$10^3 \pm 10^2$	$10^4 \pm 10^3$	$10^5 \pm 10^3$	$10^6 \pm 10^4$
Alginate	$10^4 \pm 10^3$	$10^5 \pm 10^4$	$10^6 \pm 10^4$	$10^7 \pm 10^5$
Chitosan-alginate	$10^2 \pm 10^1$	$10^3 \pm 10^2$	$10^4 \pm 10^3$	$10^5 \pm 10^3$

In the absence of hydrogels, rapid microbial proliferation was observed, with contamination reaching 10^8 CFU/g by day 28. This result suggests a serious deterioration in product quality. The chitosan-based hydrogel effectively suppressed bacterial growth, yet microbial load still reached 10^6 CFU/g by day 28 – several times lower than in no-hydrogel samples. The alginate hydrogel exhibited moderate antimicrobial activity, but bacterial levels increased to 10^7 CFU/g by day 28, demonstrating lower efficacy compared to chitosan. The composite hydrogel proved most effective, substantially slowing bacterial growth – after 28 days, the CFU count was only 10^5, resulting in a substantial extension of shelf life. Thus, composite hydrogels represent a promising material for fresh product packaging, reducing microbial contamination and prolonging freshness.

Effects of hydrogels on pharmaceutical products. Figure 3 illustrates changes in the ascorbic acid content of tablets stored for 7, 14, 21, and 28 days in different types of hydrogel packaging.

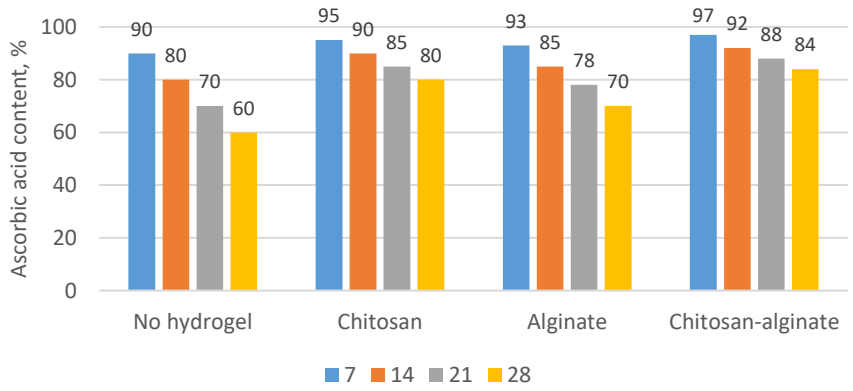

Fig. 3. Ascorbic acid content in tablets

Without hydrogel packaging, the degradation rate of ascorbic acid was highest – after 28 days, its content decreased to 60 ± 2%, which could considerably reduce the drug's effectiveness. The chitosan hydrogel slowed decomposition, maintaining 80 ± 2% of vitamin C after 28 days, confirming its protective properties. The alginate hydrogel also delayed degradation but was less effective than chitosan, retaining 70 ± 2% of vitamin C after 28 days. The chitosan-alginate composite hydrogel delivered the best results – after 28 days, ascorbic acid content remained at 84 ± 2%, demonstrating optimal barrier properties. Thus, composite hydrogel packaging provides the highest level of protection for active

pharmaceutical ingredients, making it a promising solution for pharmaceutical packaging applications.

Discussion. This study developed and characterized biodegradable hydrogels based on chitosan and alginate with controlled moisture release properties. The results reveal that composite hydrogels exhibit enhanced moisture retention, high mechanical strength, and significant biodegradability, making them promising alternatives for smart packaging applications. For comparison with the existing literature, Table 7 presents key findings from similar studies.

Table 7

Comparative analysis of research findings

Study	Hydrogel Type	Swelling Degree (%)	Tensile Strength (MPa)	Biodegradability (28 days, %)	Effect on Product Shelf Life
Present study	Chitosan-alginate	1500	1.2	70	68% moisture retention, ΔE = 14.2
Bahndral et al. (2024)	Chitosan	1200	0.8	60	Moderate evaporation reduction
Wang et al. (2025)	Alginate	1000	0.6	50	Limited dehydration protection
Kumar et al. (2024)	Polysaccharide	1300	1.0	65	Good freshness preservation
Nath et al. (2023)	Biodegradable composite	1400	1.1	68	High dehydration protection

Our findings indicate that chitosan-alginate hydrogels demonstrate superior sorption capacity compared to pure chitosan or alginate hydrogels [5-7]. This enhancement stems from synergistic interactions between chitosan's amino groups and alginate's carboxyl groups, which collectively foster water absorption. Similar conclusions were drawn by Nath et al. [2], who reported that incorporating natural polysaccharides into hydrogels enhances moisture retention and extends product shelf life. Regarding the mechanical properties, our results align with those reported by Kumar et al. [4] and Lang et al. [8]. These studies noted that chitosan-based hydrogels typically exhibit tensile strengths of 0.8-1.0 MPa, while composite hydrogels (e.g., chitosan-alginate) can achieve 1.2 MPa or higher. This conclusion confirms the effectiveness of composite approaches for improving the mechanical performance of packaging materials. Biodegradability is a critical factor for eco-friendly packaging applications. Our results (70% over 28 days) support findings from studies by Kumar and Gupta [5] and Kumar et al. [4], where natural polymer-based hydrogels showed 50-80% degradation within similar timeframes. The data obtained by Nath et al. [2] additionally demonstrate that incorporating supplementary natural components such as cellulose may slow degradation while contributing to mechanical stability – an important consideration for packaging design [9,10].

The positive impact of hydrogels on food preservation is further supported by Nath et al. [2] and Mondéjar-López, et al. [1]. In our study, chitosan-alginate hydrogels achieved optimal performance in moisture retention (68% after 28 days) and color stability (ΔE = 14.2), making them particularly suitable for extending the shelf life of fresh products. Nath et al. [2] also highlighted chitosan's inherent antimicrobial properties, which may inhibit food spoilage mechanisms. Another advantage of chitosan-alginate hydrogels lies in their capacity for controlled release of active compounds. Wang et al. [3] found that hydrogels containing bioactive

substances can gradually release these components, creating antibacterial effects. Our study corroborates this functionality, pointing to the potential of such materials for active packaging systems that enhance product preservation.

Despite the promising results, this study has several limitations. The experiments were conducted in a controlled laboratory environment, which may not fully replicate real-world storage conditions where variable temperature, humidity, and microbial exposure could alter hydrogel performance. Furthermore, biodegradability was assessed over a 28-day period, whereas longer-term studies would be required to understand degradation behavior in natural environments [11,12]. The research employed carrots as a model food product, necessitating additional testing with diverse food categories – including meats, fruits, and dairy products – to evaluate the hydrogels' universal applicability. Another critical consideration is the long-term mechanical stability of the hydrogels under repeated wetting-drying cycles, as such conditions could accelerate their degradation. Finally, this study did not include an economic analysis of production costs, which is essential for assessing the commercial viability and potential industrial adoption of these packaging materials.

Conclusion. The primary objective of this study was to develop novel biodegradable hydrogels based on chitosan and alginate with controlled moisture release properties for smart packaging applications. The research comprehensively investigated the physicochemical properties of the hydrogels, including their mechanical strength, biodegradability, and effects on the shelf life of model products (carrots and ascorbic acid tablets). The hydrogels were synthesized using chitosan, sodium alginate, glutaraldehyde, and calcium chloride. Experimental methods encompassed swelling degree determination, mechanical property analysis, biodegradability assessment, and the evaluation of the hydrogels' effects on product moisture content, color stability, and microbial contamination.

Key findings revealed the exceptional swelling capacity of chitosan-alginate hydrogels (1500% in distilled water), making them highly effective for moisture regulation. The mechanical properties were found to be equally impressive, with a tensile strength of 1.2 MPa and an elongation at break of 180%. Biodegradability reached 70% after 28 days, confirming their environmental compatibility. The hydrogels maintained carrot moisture at 68% after 28 days, limited color change ($\Delta E = 14.2$), and reduced microbial contamination to 10^5 CFU/g. In pharmaceutical applications, the hydrogels preserved 84% of ascorbic acid content in tablets over the same period.

However, the study has certain limitations. The experiments were conducted under controlled laboratory conditions, which may not fully replicate real-world storage environments. Additional testing across diverse food categories (meats, fruits, dairy products) is necessary to verify the universal applicability of our findings. Furthermore, long-term mechanical stability under repeated wetting-drying cycles requires investigation.

Future research directions include optimizing hydrogel composition to enhance mechanical strength and biodegradability and conducting real-world storage condition trials. It is also necessary to develop modified hydrogel variants with additional functionalities, such as antimicrobial protection and controlled release of active compounds. These advancements will broaden the hydrogels' application potential across food processing, agriculture, and pharmaceutical industries.

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This research is funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR24993129).

Received: 20 July 2025
Accepted: 15 September 2025

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ХИТОЗАН НЕГІЗІНДЕГІ ЖАҢА БИОЛОГИЯЛЫҚ ЫДЫРАЙТЫН ГИДРОГЕЛЬДЕРДІҢ ХИМИЯЛЫҚ ТЕХНОЛОГИЯЛАРЫН ЖАСАУ

Аңдатпа. Осы зерттеудің негізгі мақсаты – ақылды орауыштарға арналған ылғалдылықты реттеп тұратын қасиеттері бар хитозан мен альгинат негізінде биожетімді жаңа гидрогелдер әзірлеу болды. Зерттеу барысында гидрогелдердің физика-химиялық қасиеттері жан-жақты қарастырылды, оның ішінде механикалық беріктігі, биожетімділігі және модель өнімдердің (сәбіз бен аскорбин қышқылы таблеткалары) сақтау мерзіміне әсері зерттелді. Гидрогелдер хитозан, натрий альгинаты, глутарльдегид және кальций хлориді қолданылып синтезделді. Эксперименттік әдістерге ісіну дәрежесін анықтау, механикалық қасиеттерін талдау, биожетімділігін бағалау және гидрогелдердің өнімдегі ылғал мөлшеріне, түсінің тұрақтылығына және микробтық ластануына әсерін зерттеу кірді. Негізгі нәтижелер көрсеткендей, хитозан-альгинат гидрогелдерінің ісіну қабілеті ерекше жоғары болды (дистилденген суда 1500%), бұл оларды ылғалдылықты реттеуде өте тиімді етеді. Механикалық қасиеттері де жоғары деңгейде – созылу беріктігі 1,2 МПа және үзілу кезіндегі ұзаруы 180%. Биожетімділік деңгейі 28 күннен кейін 70%-ға жетіп, олардың экологиялық тұрғыдан қауіпсіздігін дәлелдеді. Гидрогелдер 28 күн ішінде сәбіздің ылғалдылығын 68% деңгейінде сақтап, түсінің өзгеруін шектеді (ΔE = 14,2) және микробтық ластануды 10^5 КОЕ/г дейін азайтты. Фармацевтикалық қолдануда гидрогелдер 28 күн ішінде таблеткалардағы аскорбин қышқылының 84% мөлшерін сақтап қалды. Болашақ зерттеулер гидрогелдердің құрамын жетілдіруге, олардың механикалық беріктігі мен биожетімділігін арттыруға және нақты сақтау жағдайларында сынақтар жүргізуге бағытталуы тиіс. Сонымен қатар, микробқа қарсы қорғаныс пен белсенді қосылыстарды бақыланатын түрде шығару сияқты қосымша функциялары бар гидрогелдердің модификацияланған түрлерін әзірлеу қажет. Бұл жетілдірулер гидрогелдердің азық-түлік өнеркәсібінде, ауыл шаруашылығында және фармацевтика саласында қолдану аясын кеңейтеді.

Тірек сөздер: биологиялық ыдырайтын гидрогельдер, хитозан, альгинат, бақыланатын ылғалдың бөлінуі, экологиялық таза материалдар.

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РАЗРАБОТКА ХИМИЧЕСКИХ ТЕХНОЛОГИЙ ПОЛУЧЕНИЯ НОВЫХ БИОРАЗЛАГАЕМЫХ ГИДРОГЕЛЕЙ НА ОСНОВЕ ХИТОЗАНА

Аннотация. Основной целью данного исследования было разработать новые биоразлагаемые гидрогели на основе хитозана и альгината с контролируемыми свойствами высвобождения влаги для применения в «умной» упаковке. В рамках исследования были всесторонне изучены физико-химические свойства гидрогелей, включая их механическую прочность, биоразлагаемость и влияние на срок хранения модельных продуктов (морковь и таблетки с аскорбиновой кислотой). Гидрогели синтезированы с использованием хитозана, альгината натрия, глутарового альдегида и хлорида кальция. Экспериментальные методы включали определение степени набухания, анализ механических свойств, оценку биоразлагаемости, а также изучение влияния гидрогелей на содержание влаги в продуктах, устойчивость цвета и микробное загрязнение. Ключевые результаты показали, что гидрогели на основе

хитозана и альгината обладают исключительно высокой способностью к набуханию (1500% в дистиллированной воде), что делает их эффективными регуляторами влаги. Механические свойства также оказались высокими: прочность на растяжение составила 1,2 МПа, а удлинение при разрыве – 180%. Биоразлагаемость достигла 70% через 28 дней, что подтверждает их экологическую безопасность. Гидрогели сохраняли уровень влаги в моркови на уровне 68% через 28 дней, ограничивали изменение цвета (ΔE = 14,2) и снижали микробное загрязнение до 10^5 КОЕ/г. В фармацевтическом применении гидрогели сохраняли 84% содержания аскорбиновой кислоты в таблетках за тот же период. Будущие направления исследований включают оптимизацию состава гидрогелей для улучшения их механической прочности и биоразлагаемости, а также проведение испытаний в реальных условиях хранения. Также необходимо разработать модифицированные варианты гидрогелей с дополнительными функциями, такими как антимикробная защита и контролируемое высвобождение активных соединений. Эти усовершенствования расширят потенциал применения гидрогелей в пищевой промышленности, сельском хозяйстве и фармацевтике.

Ключевые слова: биоразлагаемые гидрогели, хитозан, альгинат, контролируемое выделение влаги, экологически чистые материалы.