CHAPTER 10

Effect of a combined biopolymer coating on the quality of asparagus spears during storage

Olesia Priss
Liudmyla Kiurcheva
Pavlo Bulhakov
Iryna Taraymovich
Larysa Chepurda
Sergii Stepanenko

Abstract

The chapter is devoted to the study of the influence of a biopolymer coating based on sodium alginate and the antioxidant rutin on the quality of asparagus spears of Prius and Rosalie varieties during storage under refrigerated conditions.

The influence of the coating on the preservation of marketable, physiological and organoleptic characteristics of asparagus was considered.

It was found that the most pronounced effect was obtained when using a combined coating (1% sodium alginate +1% rutin), which combines the barrier properties of the biopolymer and the antioxidant activity of rutin.

The use of such a composition allows to extend the shelf life of spears of both varieties by 7 days compared to the control, reduce mass loss by 1.9 times for the Prius variety and by 2.2 times for the Rosalie variety and increase the yield of standard products to 88.14–91.79% depending on the variety, despite the increased storage time.

The use of the studied biopolymer made it possible to slow down respiratory metabolism, degradation of chlorophylls and carotenoids and stabilize the organoleptic characteristics of the product.

Keywords

Asparagus, biopolymer coating, sodium alginate, rutin, weight loss, yield of marketable products, pigments, respiratory rate, postharvest treatment.

 DOI: 10.21303/978-9908-845-03-6.ch10

10.1 Introduction

Modern world vegetable growing is developing in conditions of aggravation of food security. This fact emphasizes the importance of developing technologies for the production and storage of fruit and vegetable products that minimize their losses at all stages of the logistics chain connecting the producer and the end consumer. This is especially important for crops that have high market potential, but are characterized by limited shelf life. Asparagus (*Asparagus officinalis* L.), which is characterized by high biological value and growing demand among consumers, has good prospects in this aspect. Asparagus belongs to valuable vegetable crops, characterized by high taste properties and significant nutritional value. The crop is gradually gaining popularity due to trends in expanding the range of plant crops in human nutrition and the globalization of gastronomic preferences. Despite the availability of processed products (canned, quick-frozen), the main direction of asparagus use remains fresh sale. The active growth in demand for asparagus, especially in the HoReCa segment, as well as its relatively high profitability, also cause increased interest among agricultural producers in expanding the area under this crop [1]. At the same time, the economic efficiency of its production largely depends not only on the yield, but also on the ability to preserve the marketable quality of the product in the post-harvest period. This places increased demands on the preservation of its natural properties during transportation and refrigerated storage. Therefore, the segment of fresh asparagus production requires the improvement of technological solutions aimed at minimizing post-harvest losses and extending the period of sale without deterioration in quality.

The season for the sale of fresh asparagus in Ukraine is limited and lasts from the end of April to the beginning of June, which additionally makes the issue of extending its storage period relevant. Asparagus spears 15–22 cm long and up to 2 cm thick are used in food. The plant is in a phase of active growth and, accordingly, with a particularly active tissue metabolism. Asparagus spears are extremely sensitive to the conditions of the post-harvest period, which is due to the high intensity of respiration, intensive gas exchange and transpiration. This leads to rapid weight loss, a decrease in turgidity, deterioration of the texture and general marketable appearance of the product. After cutting, the respiratory rate increases even more due to wound stress, which is accompanied by increased transpiration and biochemical transformations [2]. As a result, the harvested spears extremely quickly lose mass, turgidity, consumer properties, and their nutritional value decreases. At the same time, the amount of waste, non-marketable products that cannot be sold, increases. Therefore, extending the storage period of asparagus and minimizing quantitative and qualitative losses in the post-harvest period have not only economic, but also socio-ecological significance. Reducing waste volumes will contribute to increasing the profitability of production, stabilizing supplies to the market and extending the period of consumption of fresh products. In addition, preserving the marketable quality and nutritional value of asparagus during storage ensures greater accessibility of this functionally valuable vegetable for consumers, which has a positive effect on the formation of balanced diets [3].

Therefore, the above makes it necessary to find effective technological solutions aimed at slowing down physiological processes, reducing mass losses and preserving the quality of asparagus for a longer period of sale.

10.2 Changes in asparagus quality during storage

Product losses during storage and a decrease in quality indicators are caused by a number of factors, including natural (loss of mass, overripening, aging, etc.), phytopathological (disease damage), technological (non-compliance with storage conditions), mechanical (damage to products during transportation and primary processing), which significantly accelerate degradation processes.

The main goal of effective product storage is to ensure conditions for its vital activity for a long period, inhibit the processes of overripening and aging without reducing marketable quality while maintaining sufficient resistance to microbiological and functional diseases. Extending the period of receipt of fresh vegetables is achieved mainly by refrigerated storage, sometimes in combination with other methods aimed at slowing down the metabolism of vegetables [4].

During refrigerated storage, however, microbiological, biochemical and physical transformations occur in fresh plant products, which cause changes in their quality and marketability. Asparagus spears are characterized by a high metabolic rate, which leads to accelerated overripening and aging processes, and accordingly, limits the duration of storage. External quality indicators, such as the diameter and color of the spears, the shape of the top and the peculiarity of the fit of the leaf scales, are considered the main ones for assessing the commercial quality according to the requirements of the standards. The group of organoleptic indicators (consistency of the pulp, taste, level of bitterness) is a priority for consumers. During storage, the spears discolor as a result of the decomposition of chlorophylls, the loss of nutrients and organic acids, the accumulation of asparagine, and changes in texture. The latter is due to lignification and an increase in fiber content (by 72% according to [4]). The fit of the leaf scales also changes significantly during storage of some varieties (due to loose fit to the spear, the so-called "pluminess" develops).

Moisture evaporation is a natural process caused by water migration from asparagus spear tissues. Due to their relatively rapid turgidity loss, asparagus spears become wilted and more susceptible to physiological disorders and microbiological diseases. The intensity of water loss depends on the hydrophilicity of cellular colloids, as well as on the structure and properties of the protective tissues. Spear sections with a larger surface area-to-mass ratio exhibit higher moisture loss rates, as do shorter spears [5].

The dynamics of asparagus spears aging are influenced by their structural heterogeneity: the bud contains parenchymal meristematic cells, which active division drives spear growth. These cells are small, densely packed, have thin walls composed of hemicellulose and pectin compounds, and exhibit high metabolic rates, requiring a constant supply of water and nutrients. In contrast, the lower parts of the spears consist primarily of mature tissue where cell elongation has ceased. Respiratory activity in the buds is high (about 60 mg $CO_2 \times kg^{-1} \times h^{-1}$ at 5°C), exceeding that in the lower spear parts by an average of 4 times at the start of storage and by 2 times after 3 weeks [6]. Immediately after harvest, respiratory processes slow down and stabilizing after 12–24 hours.

Pigments are an important visual indicator used to assess the quality of asparagus spears. The chlorophyll content of green spears varies depending on the part of the spears, ranging from about 10 mg/ml in the upper part to about 8 mg/ml in the middle. During storage, chlorophyll levels gradually decrease, accompanied by yellowing of the spears. Several factors can slow down the degradation of chlorophyll during storage, including low temperature, the use of polypropylene packaging, elevated CO_2 levels, and treatment with a cholesterol solution [7]. Color changes in white and purple asparagus varieties are mainly due to the gradual synthesis and accumulation of flavones (which cause yellowing) and anthocyanins (which cause reddening).

Understanding the nature of the changes that occur in asparagus spears after harvest and initiate the aging process allows to predict the quality of asparagus during storage and manage technological regimes to improve quality indicators.

10.3 Asparagus storage technologies

At room temperature, the storage life of asparagus averages only 3–5 days, whereas under refrigerated conditions it extends to approximately 14–15 days [8]. Refrigerated storage is the standard method for preserving fruits and vegetables, as it significantly reduces the respiratory metabolism of plant products. However, under conventional cold storage conditions, lignification processes in asparagus spears also begin relatively quickly. To slow these processes, refrigeration should be combined with additional methods of preliminary chemical or physical treatment.

Postharvest heat treatment prior to storage involves exposing the produce to elevated temperatures (immersion in hot water, heating with saturated steam, or treatment with hot dry air). According to a study conducted by Taiwanese researchers [9], preliminary hot-water treatment of asparagus (immersion in water at 48°C for 4 min) increases storage efficiency both when applied alone and when combined with subsequent refrigerated storage and film packaging. Currently, postharvest heat treatment is used mainly for the storage of organic produce.

To inhibit vegetable ripening processes, hypobaric storage – storage under reduced atmospheric pressure – is increasingly applied. According to literature data [10], hypobaric storage of asparagus significantly suppresses the respiratory activity of the spears, promotes the preservation of chlorophylls, antioxidants, and soluble solids, and reduces the accumulation of malondialdehyde. As a result, overripening processes are delayed, allowing the storage period to be extended up to 50 days. However, this storage method requires expensive specialized equipment.

To extend the shelf life of asparagus, refrigerated storage is often supplemented by the use of various films, vacuum packaging, and modified atmosphere packaging (MAP) [11]. The use of synthetic polymer materials to maintain modified atmosphere conditions during storage has been shown to be highly effective. However, one drawback of MAP storage is the accumulation of excessive condensate on the inner surface of the packaging, which stimulates the development of microflora and leads to premature spoilage of the product.

Nevertheless, the large volumes of waste generated after the use of polymer packaging materials worsen the global environmental situation, which stimulates the search for more environmentally friendly alternatives.

To preserve the post-harvest quality of asparagus, treatment of spears with 1-methylcyclopropene (1-MCP), which is an ethylene inhibitor and is able to delay the ripening and senescence processes, is widely used. Treatment with a 4 ml/l solution of 1-MCP effectively delays the lignification process when asparagus is stored at 4°C and 80% relative humidity, allowing to extend the storage period up to 37 days [12]. The decrease in ethylene concentration in 1-MCP-treated samples was also confirmed in [13], although this study did not reveal a significant effect of 1-MCP on the quality and preservation of asparagus spears under MAP conditions and in perforated film.

Given the growing demand for the use of environmentally friendly and safe substances for human health for post-harvest processing, research into the development of edible food coatings is becoming increasingly relevant. It has been shown that such coatings extend the shelf life and maintain the quality of various fresh vegetables, such as carrots, potatoes, eggplants, tomatoes, and bell peppers [14].

Edible coatings are thin external layers applied to the surface of fresh fruits and vegetables to improve their appearance, reinforce the natural waxy cuticle, minimize moisture loss during storage, protect against mechanical damage, and create an individual modified atmosphere. Edible coatings have several advantages, including ease of application, energy efficiency, and scalability of production, as well as proven safety (classified as GRAS by the FDA) due to their origin from food-grade materials [15].

Edible coatings act as barriers to gases and moisture, thereby not only limiting respiratory metabolism but also enhancing the antioxidant properties of the produce by restricting oxygen access. In addition, they serve as carriers of functional or biologically active compounds incorporated into the formulation to preserve or improve product quality.

Polysaccharides such as chitosan, sodium alginate, carboxymethylcellulose, and pectins have good film-forming properties, thus demonstrating the potential for use as food coatings. Forming a dense framework, polysaccharide films completely cover the fruits and effectively delay weight loss, a decrease in the content of anthocyanins, and secondary metabolites [16]. Alginates are hydrophilic colloidal carbohydrates extracted from various species of brown seaweeds belonging to the class Phaeophyceae. Films formed with sodium alginate are uniform, transparent, and act as good oxygen barriers, but due to their hydrophilic nature, they are not waterproof [17]. Glycerol is used to improve the plasticity of alginate films, which improves the flexibility of the film but increases the permeability of water vapor [18]. Sodium alginate-based films can help maintain the quality of fruits during storage, especially in combination with antioxidants [19]. Alginate films successfully act as carriers of bioactive substances. Phenolic compounds are often used as antioxidants. However, these substances sometimes diffuse into food products, imparting undesirable taste and aroma due to the presence of a mixture of volatile and non-volatile components, which limits their application [16]. The use of many polyphenols (quercetin, other flavonoids) in alginate films has been described, emphasizing that such a strategy is universal for flavonoid antioxidants [20]. Rutin, which is contained in asparagus in significant quantities and, when used exogenously, will not change the taste and aroma of the product, also belongs to this group. It can be assumed that the introduction of the natural antioxidant rutin into the alginate composition will allow extending the shelf life of asparagus processed in this way. Therefore, the aim of the work was to confirm the possibility of extending the shelf life of asparagus spears and stabilizing their quality indicators by using a combined biopolymer coating based on alginate and rutin.

10.4 Research methodology

In the study, asparagus spears (*Asparagus officinalis* L.) of two hybrids with different coloration were used – Prius F1 (green) and Rosalie F1 (purple-green). For the experiment, uniform, straight, and undamaged spears with a diameter of 1.6–2.0 cm and a length of approximately 25 cm were selected. The spears had closed bracts and showed no signs of wilting or mechanical damage, in accordance with the requirements of the standard for fresh asparagus CODEX STAN 225-2001, which defines the criteria for sizing, appearance, freshness, and permissible defects of the product (**Fig. 10.1**).

a *b*

Fig. 10.1 Asparagus variety Prius: *a* – calibrated; *b* – after commercial processing

The research program involved a stepwise substantiation of the combined biopolymer coating composition. Initially, the effects of sodium alginate biopolymer (A) and the sodium alginate-glycerol combination (A + G) were evaluated on asparagus storage duration, natural mass loss during storage, and organoleptic indicators.

Asparagus spears (of both varieties) were treated with the following biopolymer coating variants:

– A – 1% aqueous sodium alginate solution (dry substance gradually dissolved in hot water at ($t = 45$°C));

– G – 1% aqueous glycerol solution;

– A + G – 1% aqueous sodium alginate solution combined with 1% glycerol solution;

– C – untreated (control).

Parallel evaluations assessed the antioxidant rutin's (R) effects on the same indicators. Asparagus spears were treated with aqueous rutin solutions at concentrations of: 0.5% (R0.5), 1% (R1), 1.5% (R1.5) or left untreated (C, control). Rutin solutions were prepared by dissolving dry powder in 96% ethanol (5% by mass) and diluting to the required concentration with water.

For coating application, asparagus spears were fully immersed in cooled solutions. After removal, spears were placed vertically on a rack over a drip tray to drain excess solution and air-dry for 1 hour under cooling conditions. Treated and untreated samples were then placed in refrigerated storage. Storage was considered complete when losses and waste reached 10%, with waste including rotten produce and items showing microbial damage signs. Marketable and physiological indicators of asparagus spears were assessed at the start and end of storage. Storage durations for experimental samples were extended relative to controls until spear damage appeared.

At the next stage, the effectiveness of the combined coating was investigated. Asparagus spears were treated with the combined biopolymer coating A + R – a 1% aqueous sodium alginate solution combined with a 1% rutin solution (alginate was added to the preheated 1% rutin solution and left for cooling and uniform gel formation for 20 min). Coating application and subsequent storage followed the scheme described above.

Organoleptic characteristics were assessed according to the following parameters: turgidity (from a fresh appearance to severe loss of turgidity), longitudinal striation (from absence of striations to pronounced striation), desiccation of the bases (from no desiccation to severe desiccation), color changes (from bright green or purple-green typical for the variety to yellowing), off-odors (from absence of odors to noticeable off-odors), and microorganism spoilage (from absence of visible microbial damage to clear signs of spoilage).

A four-point scale was used for evaluation: 4 – very good; 3 – good; 2 – acceptable; 1 – unacceptable.

In addition, an importance coefficient was introduced for the overall assessment, considering the critical influence of each parameter on consumer satisfaction: 0.3 for turgidity; 0.2 for off-odors and microorganism spoilage; and 0.1 for the other indicators.

To determine the effect of biopolymer coatings on respiratory metabolism, the respiration rate was assessed by measuring the absorption of carbon dioxide (CO_2) by an alkali solution [21]. The chlorophyll and carotenoid contents were determined by extracting the pigments with acetone followed by spectrophotometric analysis [22].

The experiments were carried out with replication in accordance with the applied methodology. Data were processed using standard statistical methods, with calculation of mean values and standard deviations.

10.5 Effect of biopolymer coating on the preservation of asparagus quality during storage

Control samples of both varieties stored in refrigerated conditions maintained acceptable quality for no more than 14 days. Further storage was accompanied by yellowing of the spears, loss of firmness and lignification of tissues, which was confirmed by the results of organoleptic evaluation (**Fig. 10.2**).

In this case, the Prius variety demonstrated a higher number of non-marketable products after 14 days of storage (**Fig. 10.3**).

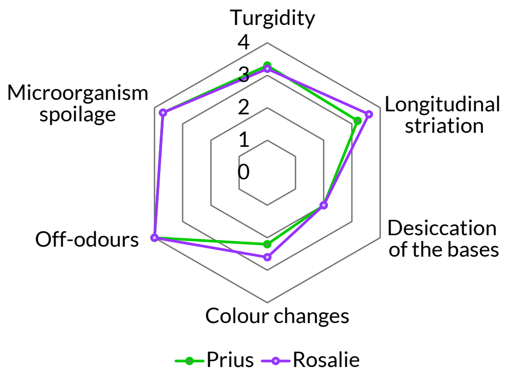


Fig. 10.2 Organoleptic evaluation of raw asparagus spears after 14 days of storage

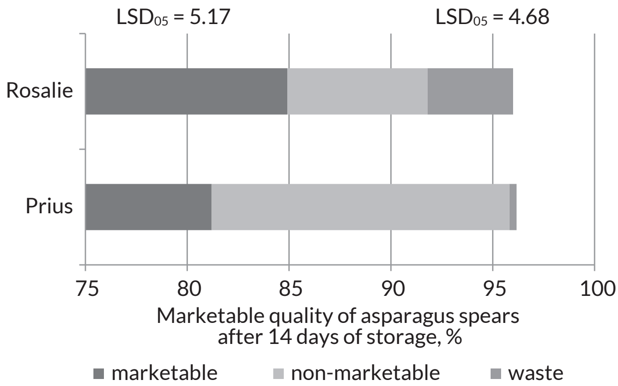


Fig. 10.3 Marketability of asparagus spears after 14 days of storage. The indicators are presented taking into account natural weight losses

This can be explained by the greater tendency of green spears to open bracts during storage, which is one of the key parameters for determining marketable quality. As can be seen from **Table 10.1**, the use of biopolymer coatings allowed to extend the shelf life of asparagus to 18 days compared to control samples (14 days).

Table 10.1 Marketable quality of asparagus spears after storage with biopolymer coatings, %, $M \pm m$, $n = 5$

Variety	Treat-ment	Storage time, days	Products, %		
			marketable	non-marketable	waste
Prius	A	18	88.69 ± 1.57*	5.85 ± 0.80*	2.97 ± 0.92*
	G	14	82.25 ± 0.63	10.55 ± 0.42	3.35 ± 0.39*
	A + G	18	84.32 ± 1.29*	7.93 ± 0.96*	4.07 ± 0.88*
	C	14	81.20 ± 1.16	14.62 ± 0.98	0.35 ± 0.19
Rosalie	A	18	88.14 ± 0.82*	4.98 ± 0.38*	3.91 ± 0.53
	G	14	84.48 ± 0.99	6.23 ± 0.51	2.15 ± 0.47
	A + G	18	85.72 ± 1.25	4.74 ± 0.66*	2.30 ± 0.45
	C	14	84.91 ± 1.53	6.89 ± 0.41	4.20 ± 1.64

*Note: marketable indicators were calculated at the end of storage, taking into account natural weight losses. * – significant difference compared with the control on the day of measurement ($p \leq 0.05$)*

This effect was observed for both varieties, although the indicators of product losses and the amount of marketable products differed somewhat between Prius and Rosalie. The obtained data are consistent with observations [22], which indicated a reduction in mass losses and an extension of the storage period of spears treated with compositions based on alginate, chitosan and carrageenan by 3 days compared to control samples.

Treatment with alginate reduced weight loss by 1.4 times compared with the control and improved the yield of marketable produce. A decrease in the number of non-marketable spears was also observed, especially noticeable in the example of the Prius variety, which indicates the stabilizing effect of biopolymer coatings on the marketable quality of asparagus during storage.

Additionally, the experimental samples showed a larger area of the profilogram compared to the controls in terms of organoleptic indicators (**Fig. 10.4**).

The most noticeable positive effect of the treatment was on such indicators as turgidity and color changes. Maintaining turgidity at a constant level for a longer time, which also correlates with a decrease in mass loss, seems natural given the expected effect of the coating on the intensity of respiration and transpiration due to the formation of a film over the stomata. The improvement in the color index may also be associated with the slowing down of chlorophyll decomposition in conditions of a general slowdown in metabolism. To improve the plasticizing properties of the coating, the possibility of introducing glycerol into the composition of the biopolymer was investigated. The introduction of glycerol into the sodium alginate solution (A + G), although it contributed to the formation of films of more uniform thickness, did not significantly affect the marketable quality of the samples and their organoleptic indicators compared to treatment with a separate sodium alginate solution. The control treatment of spears with glycerol also did not have a significant effect on the quality of asparagus. In the case of the Rosalie variety, weight losses during such treatment were even higher than in untreated samples. Given the lack of a positive effect of mixtures with glycerol on the dynamics of asparagus respiration intensity (**Table 10.2**), the inclusion of glycerol was not further considered as a promising option for post-harvest treatment of asparagus.

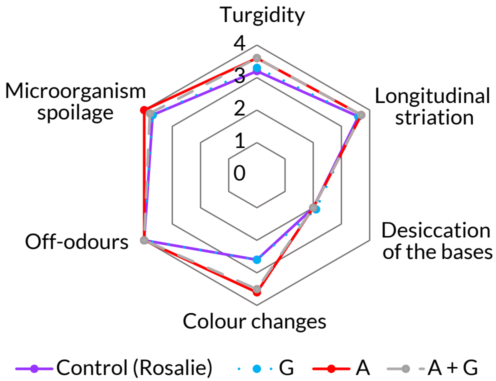


Fig. 10.4 Organoleptic evaluation of asparagus at the end of storage after treatment with biopolymer coatings: *a* – Prius; *b* – Rosalie

Table 10.2 Respiration rate ($mgCO_2 \times kg^{-1} \times h^{-1}$) of asparagus treated with glycerol-based compositions

Day of storage	Rosalie				Prius			
	Control	G	A + G	LSD_{05}	Control	G	A + G	LSD_{05}
0	106.2	106.2	106.2	–	94.9	94.9	94.9	–
1	65.2	118.6	167.3	17.99	55.4	65.9	59.5	10.82
7	94.6	83.0	134.2	25.30	81.4	98.6	80.0	13.47
12	98.2	114.2	83.9	14.25	94.5	89.9	78.6	12.01
21	117.7	85.7	69.9	12.62	128.4	52.2	71.0	10.60
37	–	–	–	–	80.0	92.6	121.6	17.42

Given that the main action of biopolymer coatings is primarily aimed at limiting physical moisture losses from plant raw materials, for effective inhibition of post-harvest metabolism it is advisable to use biologically active compounds with antioxidant properties, which are able to additionally stabilize cell structures and slow down oxidative processes.

10.6 The effect of rutin on the marketable quality and organoleptic characteristics of asparagus spears

Rutin, which is naturally found in asparagus in significant quantities, is a powerful antioxidant and participates in processes related to pigment metabolism. This makes it advisable to use it as a functional component of a coating for processing spears. Our previous studies prove the high efficiency of rutin in chitosan-based coatings for extending shelf life [23]. However, it is necessary to determine its optimal concentration for post-harvest processing of asparagus.

The results obtained indicate that the use of rutin (R) solutions in low concentrations, similar to biopolymer coatings, contributes to the extension of the shelf life of asparagus spears compared to untreated control samples (**Table 10.3**).

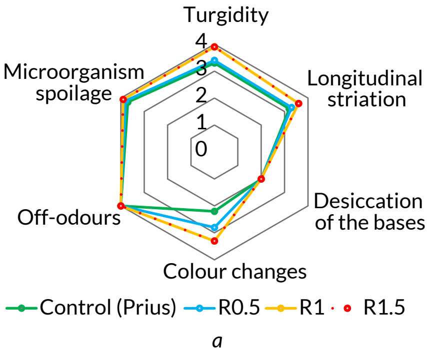
Table 10.3 Marketable quality of asparagus spears after storage with rutin treatment, %, $M \pm m$, $n = 5$

Variety	Treatment	Storage time, days	Products, %		
			marketable	non-marketable	waste
Prius	R0.5	18	87.98 ± 1.48*	6.17 ± 0.54*	2.49 ± 0.76*
	R1	18	88.00 ± 1.31*	5.27 ± 0.32*	2.69 ± 1.05*
	R1.5	18	88.5 ± 1.28*	5.11 ± 0.46*	3.18 ± 0.89*
	Control	14	81.20 ± 1.16	14.62 ± 0.98	0.35 ± 0.19
Rosalie	R0.5	18	86.38 ± 0.86	4.79 ± 0.68*	6.10 ± 1.31
	R1	18	87.14 ± 0.78	4.24 ± 0.52*	5.2 ± 1.18
	R1.5	18	87.26 ± 1.32	4.68 ± 0.97*	4.98 ± 0.44
	Control	14	84.91 ± 1.53	6.89 ± 0.41	4.20 ± 1.64

*Note: marketable indicators were calculated at the end of storage, taking into account natural weight losses. * – significant difference compared with the control on the day of measurement ($p \leq 0.05$)*

In control samples, the proportion of standard-quality products ranged from 81.2–84.9% depending on the variety, whereas rutin treatment increased this to 87.2–88.5%. The Rosalie variety proved more responsive to rutin than Prius, showing both greater increases in standard product yield and relatively lower mass loss during storage.

Analysis of organoleptic characteristics (**Fig. 10.5**) revealed rutin's most pronounced effects on maintaining spears and color intensity. Treatments with 1% and 1.5% rutin solutions significantly delayed turgidity loss even during extended storage, while the 0.5% solution provided benefits but did not achieve maximum quality preservation.



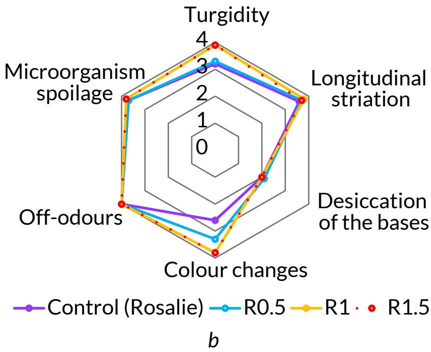


Fig. 10.5 Organoleptic evaluation of asparagus at the end of storage when treated with rutin: *a* – Prius; *b* – Rosalie

Significant differences were also observed in the dynamics of color changes. In the control samples of the Prius variety, the color score decreased to 2.2 points by the end of storage, whereas treatment with rutin allowed this parameter to be maintained at 2.8–3.3 points, depending on the concentration used. For the Rosalie variety, where the control value was 2.6 points, rutin treatment increased this parameter to 3.3–3.8 points by the end of storage.

The positive effect can be explained by the antioxidant properties of rutin, which contribute to the stabilization of plant pigments – primarily chlorophylls and carotenoids – and slow down their oxidative degradation. This likely results in a slower loss of the characteristic color of asparagus spears.

The results of determining the chlorophyll content (**Fig. 10.6**) and carotenoid content (**Fig. 10.7**) at the beginning and at the end of storage confirm this trend. In particular, the application of 1% and 1.5% rutin solutions made it possible to maintain chlorophyll levels 1.8–2 times higher (depending on the variety) compared with the control samples.

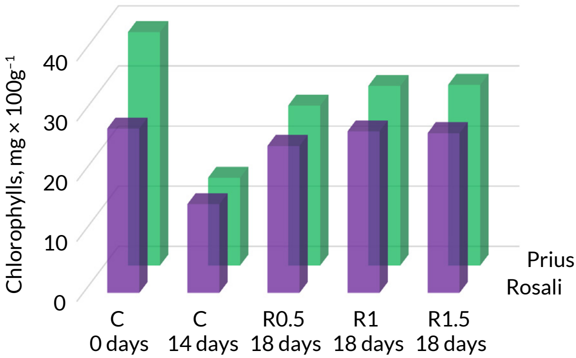


Fig. 10.6 Chlorophyll content in asparagus spears treated with rutin

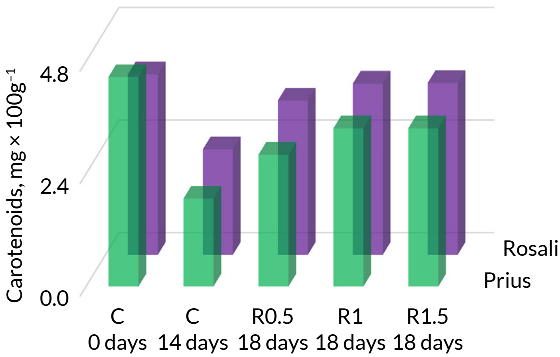


Fig. 10.7 Carotenoid content in asparagus spears treated with rutin

Similarly, carotenoids in samples treated with 1% and 1.5% rutin solutions were preserved 1.6–1.8 times better than in untreated samples.

According to the obtained data, treatment with a 1.5% rutin solution did not result in a significant improvement in the marketable and organoleptic quality parameters of asparagus compared with treatment with a 1% solution, and maintained pigment content at a level similar to that observed for the 1% treatment. At the same time, treatment of asparagus (regardless of variety) with 1% and 1.5% rutin solutions produced better results than treatment with a 0.5% solution. Thus, for further investigation of synergistic effects in the combined coating, a 1% rutin concentration was selected as optimal.

10.7 Effect of the combined biopolymer coating on the marketable quality and organoleptic characteristics of asparagus spears

Based on the results of the previous stage of the study, a composition based on sodium alginate with the addition of 1% rutin (A + R) was tested for a more detailed evaluation of the effect of biopolymer coatings on asparagus storage. The inclusion of rutin in the coating composition provided an additional positive effect regardless of variety, manifested in an extension of storage duration by 7 days compared with the control and by 4 days compared with treatments using sodium alginate alone. After storage, the yield of marketable produce in samples treated with the alginate-rutin composition ranged from 88.14 to 91.79%, depending on the variety, despite the extended storage period (**Fig. 10.8**).

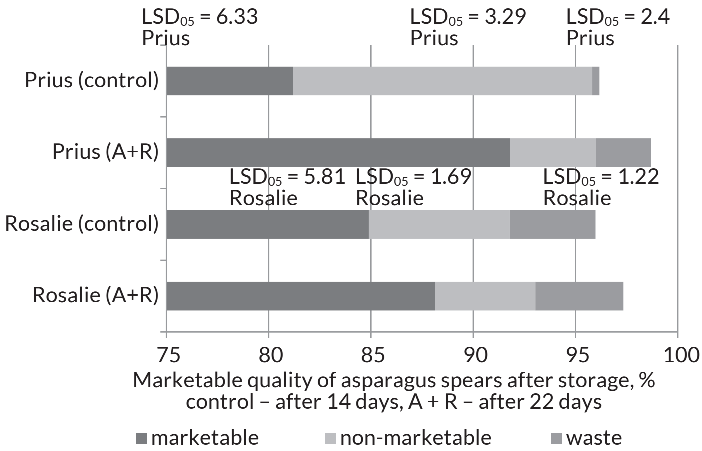


Fig. 10.8 Marketable quality of asparagus spears treated with a combined coating. The indicators are presented taking into account natural weight losses

In addition, these samples showed a reduction in the proportion of non-marketable produce, while the amount of waste under prolonged storage conditions did not increase statistically significantly, indicating the high efficiency of the combined coating.

Regarding organoleptic characteristics, all experimental samples, similarly to the effect observed for simple coatings, demonstrated a larger profilogram area compared with the controls (**Fig. 10.9**).

The application of the studied treatment methods made it possible to almost completely prevent the appearance of longitudinal striation, which is characteristic of spears of the Prius variety. At the same time, no deviations in odor were detected in any treatment, and it remained typical of fresh asparagus.

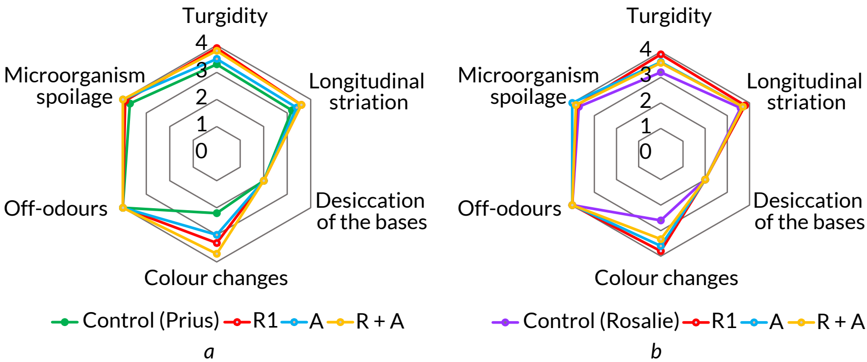


Fig. 10.9 Organoleptic evaluation of asparagus treated with a biopolymer coating based on alginate and rutin at the end of storage: *a* – Prius; *b* – Rosalie

The use of combined biopolymer edible coatings ensured effective preservation of spear turgidity even under extended storage conditions. In addition, such coatings contributed to the stabilization of color, demonstrating a positive effect similar to that of rutin, which confirms the feasibility of their use for maintaining the marketable quality of the product.

One of the key approaches to minimizing losses during the storage of fruit and vegetable products is the reduction of natural weight loss by slowing down respiration and transpiration processes. Transpiration occurs due to the gradient of water vapor partial pressure between the shoot tissues and the surrounding environment. Asparagus is characterized by a high rate of moisture evaporation, which determines its increased sensitivity to dehydration.

The gas exchange of asparagus spears at the beginning of storage, as well as the subsequent dynamics of respiratory processes, shows pronounced variety-specific characteristics. According to the literature, the trends may vary depending on the variety; however, most researchers report a similar pattern of changes at the initial stages of storage. In particular, immediately after cooling, a decrease in respiration intensity is usually observed as a response to the reduction in temperature. After several days, respiration intensity may increase, followed by a subsequent decline. Some studies also describe patterns characterized by a gradual increase in respiratory activity during storage, which highlights the complex and multifactorial nature of the postharvest metabolism of asparagus [24].

According to our results, green asparagus of the Prius variety exhibited a higher respiration rate throughout the entire storage period. Our data regarding the treatment of asparagus spears with sodium alginate-based coatings confirm their effect in reducing the intensity of respiratory metabolism compared with the control samples (**Table 10.4**).

Table 10.4 Respiration rate ($mgCO_2 \times kg^{-1} \times h^{-1}$) of asparagus treated with coatings based on sodium alginate and rutin

Day of storage	Rosalie					Prius				
	Control	R1	A	A + R	LSD_{05}	Control	R1	A	A + R	LSD_{05}
0	106.2	106.2	106.2	106.2	–	94.9	94.9	94.9	94.9	–
1	65.2	72.7	57.0	86.2	5.88	55.4	66.8	55.4	88.7	5.54
7	94.6	82.5	69.7	105.6	7.97	81.4	88.3	91.9	76.9	6.62
12	98.2	113.7	88.4	98.4	8.79	94.5	102.1	75.3	117.3	9.38
21	117.7	87.9	82.1	85.3	10.78	128.4	112.1	67.9	106.6	11.73
37	–	–	–	–		80.0	79.8	115.0	132.0	–

Applying a film coating, which partially isolates the stomata, limits transpiration and creates a barrier to gas exchange, naturally reduces mass loss. Thus, the use of a 1% sodium alginate solution reduced mass loss on the 14th day of storage by 1.8 times for the Rosalie cultivar and by 1.5 times for the Prius cultivar compared with the control. Even higher efficiency was observed for the combined coating based on sodium alginate with the addition of rutin (A+R): mass losses were reduced by 1.9 times for the Prius cultivar and by 2.2 times for the Rosalie cultivar.

The reduction in mass losses in the treated samples was positively reflected in an increase in the yield of marketable produce after storage. Thus, the use of coatings based on sodium alginate and rutin contributes to the extension of the storage life of asparagus spears and the maintenance of their quality attributes.

10.8 Conclusions

It was established that the use of a biopolymer coating based on 1% sodium alginate is an effective method for preserving the quality of asparagus spears of the Prius and Rosalie variety during refrigerated storage. The formation of a semipermeable film on the surface of the spears contributes to a reduction in the intensity of respiration and transpiration, resulting in a decrease in natural mass losses by an average of 1.5 times compared with the control and an increase in the yield of marketable produce.

Adding glycerol at a concentration of 1% to the coating composition did not significantly affect the yield of marketable produce or the reduction of respiratory metabolism.

Treatment of spears with a 1% rutin solution extended the storage duration, reduced the rate of pigment degradation, and helped maintain turgidity and tissue firmness. It was established that a 1% concentration is sufficient to achieve the maximum technological effect without deterioration of organoleptic characteristics.

The most pronounced effect was obtained when using a combined coating (1% sodium alginate + 1% rutin), which combines the barrier properties of the biopolymer with the antioxidant activity of rutin. The use of this composition allowed the shelf life of asparagus spears of both cultivars to be extended by 7 days compared with the control, while minimizing weight loss and ensuring a consistently high yield of marketable produce.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper.

Financing

The research was funded by the Ministry of Education of Ukraine within the framework of the project "Scientific justification and development of storage technology for fruit and vegetable products and mushrooms to reduce losses and waste" state registration number 0125U001919.

Data availability

Manuscript has no associated data.

Use of artificial intelligence statement

The authors used the AI assistant Perplexity (Grok 4.1, Perplexity AI) for translation and literature source selection. The authors bear full responsibility for the final manuscript. Generative AI tools are not credited and are not responsible for the final results.

Authors' contributions

Olesia Priss: Supervision, Conceptualization, Methodology, Writing – original draft, Investigation, Project administration.

Liudmyla Kiurcheva: Methodology, Writing – original draft, Writing – review & editing, Investigation.

Pavlo Bulhakov: Methodology, Writing – original draft, Investigation, Visualization, Validation.

Iryna Taraymovich: Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Validation.

Larysa Chepurda: Writing – original draft, Writing – review & editing, Formal analysis.

Sergii Stepanenko: Writing – original draft, Resources, Formal analysis, Visualization.

References

1. Papoutsis, K. (2023). Sustainable Postharvest Treatments for Prolonging Asparagus (Asparagus officinalis L.) Shelf Life by Minimizing the Development of Physiological Disorders. ACS Food Science & Technology, 3 (10), 1617–1631. https://doi.org/10.1021/acsfoodscitech.3c00319
2. Papadopoulou, P., Siomos, A., Dogras, C. (2001). Metabolism of etiolated and green asparagus before and after harvest. The Journal of Horticultural Science and Biotechnology, 76 (4), 497–500. https://doi.org/10.1080/14620316.2001.11511399
3. Priss, O., Glowacki, S. (2024). Strategies for reducing postharvest losses of vegetablesthrough integral assessment of antioxidant status. Food Technology Progressive Solutions. Tallinn: Scientific Route OÜ, 4–27. https://doi.org/10.21303/978-9916-9850-4-5.ch1
4. Toscano, S., Rizzo, V., Licciardello, F., Romano, D., Muratore, G. (2021). Packaging Solutions to Extend the Shelf Life of Green Asparagus (Asparagus officinalis L.) Vegalim. Foods, 10 (2), 478. https://doi.org/10.3390/foods10020478
5. Schäfer, J., Wagner, S., Trierweiler, B., Bunzel, M. (2016). Characterization of Cell Wall Components and Their Modifications during Postharvest Storage of Asparagus officinalis L.: Storage-Related Changes in Dietary Fiber Composition. Journal of Agricultural and Food Chemistry, 64 (2), 478–486. https://doi.org/10.1021/acs.jafc.5b05575

6. Verlinden, S., Silva, S. M., Herner, R. C., Beaudry, R. M. (2014). Time-dependent Changes in the Longitudinal Sugar and Respiratory Profiles of Asparagus Spears During Storage at 0°C. Journal of the American Society for Horticultural Science, 139 (4), 339–348. https://doi.org/10.21273/jashs.139.4.339
7. Wang, X., Gu, S., Chen, B. (2017). Effect of Cholesterol Dipped Treatment on Green Asparagus Spear during Low Temperature Storage. Journal of Chinese Institute of Food Science and Technology, 17 (8), 177–182. https://doi.org/10.16429/j.1009-7848.2017.08.024
8. Simón, A., Gonzalez-Fandos, E. (2011). Influence of modified atmosphere packaging and storage temperature on the sensory and microbiological quality of fresh peeled white asparagus. Food Control, 22 (3–4), 369–374. https://doi.org/10.1016/j.foodcont.2010.09.002
9. Kai, Y. C., Jih, M. S. (2013). Quality of low temperature heat-shocked green asparagus spears during short-term storage. African Journal of Agricultural Research, 8 (28), 3849–3856. https://doi.org/10.5897/ajar2012.6697
10. Li, W., Zhang, M., Yu, H. (2006). Study on hypobaric storage of green asparagus. Journal of Food Engineering, 73 (3), 225–230. https://doi.org/10.1016/j.jfoodeng.2005.01.024
11. Gantner, M., Król, K., Kopczyńska, K. (2020). Application of MAP and ethylene-vinyl alcohol copolymer (EVOH) to extend the shelf-life of green and white asparagus (Asparagus officinalis L.) spears. Journal of Food Measurement and Characterization, 14 (4), 2030–2039. https://doi.org/10.1007/s11694-020-00449-6
12. Zhang, P., Zhang, M., Wang, S., Wu, Z. (2012). Effect of 1-methylcyclopropene treatment on green asparagus quality during cold storage. International Agrophysics, 26 (4), 407–411. https://doi.org/10.2478/v10247-012-0057-z
13. Yoon, H. S., Choi, I.-L., Baek, J. P., Kang, H.-M. (2016). Effects of 1-MCP and MA Storage Treatments for Long-Term Storage of Asparagus Spears. Protected Horticulture and Plant Factory, 25 (2), 118–122. https://doi.org/10.12791/ksbec.2016.25.2.118
14. Matloob, A., Ayub, H., Mohsin, M., Ambreen, S., Khan, F. A., Oranab, S. et al. (2023). A Review on Edible Coatings and Films: Advances, Composition, Production Methods, and Safety Concerns. ACS Omega, 8 (32), 28932–28944. https://doi.org/10.1021/acsomega.3c03459
15. Firdous, N., Moradinezhad, F., Farooq, F., Dorostkar, M. (2023). Advances in formulation, functionality, and application of edible coatings on fresh produce and fresh-cut products: A review. Food Chemistry, 407, 135186. https://doi.org/10.1016/j.foodchem.2022.135186

16. Nair, M. S., Tomar, M., Punia, S., Kukula-Koch, W., Kumar, M. (2020). Enhancing the functionality of chitosan- and alginate-based active edible coatings/films for the preservation of fruits and vegetables: A review. International Journal of Biological Macromolecules, 164, 304–320. https://doi.org/10.1016/j.ijbiomac.2020.07.083
17. Costa, M. J., Marques, A. M., Pastrana, L. M., Teixeira, J. A., Sillankorva, S. M., Cerqueira, M. A. (2018). Physicochemical properties of alginate-based films: Effect of ionic crosslinking and mannuronic and guluronic acid ratio. Food Hydrocolloids, 81, 442–448. https://doi.org/10.1016/j.foodhyd.2018.03.014
18. Sharma, A., Singh, A. (2025). Sodium Alginate: A Green Biopolymer Resource-Based Antimicrobial Edible Coating to Enhance Fruit Shelf-Life: A Review. Colloids and Interfaces, 9 (3), 32. https://doi.org/10.3390/colloids9030032
19. Ramana Rao, T. V., Baraiya, N. S., Vyas, P. B., Patel, D. M. (2016). Composite coating of alginate-olive oil enriched with antioxidants enhances postharvest quality and shelf life of Ber fruit (Ziziphus mauritiana Lamk. Var. Gola). Journal of Food Science and Technology, 53 (1), 748–756. https://doi.org/10.1007/s13197-015-2045-3
20. Luo, Y., Liu, H., Yang, S., Zeng, J., Wu, Z. (2019). Sodium Alginate-Based Green Packaging Films Functionalized by Guava Leaf Extracts and Their Bioactivities. Materials, 12 (18), 2923. https://doi.org/10.3390/ma12182923
21. Wang, J., Fan, L. (2019). Effect of ultrasound treatment on microbial inhibition and quality maintenance of green asparagus during cold storage. Ultrasonics Sonochemistry, 58, 104631. https://doi.org/10.1016/j.ultsonch.2019.104631
22. Tran, Y. T. N., Nguyen, A. T. T., Bui, A. N. N. (2020). A Study of Asparagus Preservation Capacity of Chitosan-Alginate and Chitosan-Carrageenan Biofilms. Journal of Food Engineering and Technology, 9 (2), 89–94. https://doi.org/10.32732/jfet.2020.9.2.89
23. Priss, O., Hutsol, T., Glowacki, S., Bulhakov, P., Bakhlukova, K., Osokina, N. et al. (2024). Effect of Asparagus Chitosan-Rutin Coating on Losses and Waste Reduction During Storage. Agricultural Engineering, 28 (1), 99–118. https://doi.org/10.2478/agriceng-2024-0008
24. Park, M.-H. (2016). Sucrose delays senescence and preserves functional compounds in Asparagus officinalis L. Biochemical and Biophysical Research Communications, 480 (2), 241–247. https://doi.org/10.1016/j.bbrc.2016.10.036