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EFFECT OF ASPARAGUS CHITOSAN-RUTIN COATING ON LOSSES AND WASTE REDUCTION DURING STORAGE

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ABSTRACT

Storage is a crucial component of a sustainable and efficient food supply system. Reduction of postharvest losses and waste is a vital strategy to improve efficiency, ensure product availability, and reduce environ-

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mental impact. Asparagus (*Asparagus officinalis* L.) boasts a high nutritional value and complex of phytonutrients. Yet, the storage period for fresh asparagus is quite short, leading to rapid quality deterioration. An effective method to extend storage periods involves postharvest treatments using the natural biopolymer chitosan. The aim of the research was to assess the effectiveness of applying sustainable postharvest treatments based on chitosan and rutin, with a focus on losses and waste reduction during asparagus storage. The impact of the applied storage technology on the visual appeal and sensory attributes of asparagus, along with its effects on respiratory metabolism, weight loss, soluble solids, soluble carbohydrates, chlorophylls, and carotenoids, was systematically assessed. The findings indicate that the post-harvest treatment using chitosan and rutin effectively preserves the visual characteristics of asparaguswhen the storage period is prolonged to a week. A major advantage of this technology is a substantial reduction in waste, achieving the levels of 1.0-1.5%. The proportion of standard products post-storage ranged from 94.4% to 96.0%. The treatment with chitosan and rutin efficiently reduces weight loss by half and suppresses the respiration rate, leading to decreased losses in soluble solids, carbohydrates, chlorophylls, and carotenoids during storage. These outcomes underscore the effectiveness of the applied coating in impeding metabolic processes, resulting in minimized quantitative and qualitative losses in the product quality during a prolonged storage.

Introduction

Food systems play a dual role, contributing to and being vulnerable to the continuous shifts in the climate and environment. By producing food products for the growing global population, humanity has contributed to the climate change, posing a threat to food security (Fanzo et al., 2021). Within the "Sustainable Development Goals" adopted by the UN Summit for the period until 2030, Goal 12 is "Ensure sustainable consumption and production patterns." Target 12.3 specifically aims to "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (United Nations, 2015). The reduction of food losses comes to the fore in the conditions of the threat of food shortages due to the war launched by Russia against Ukraine, the theft of grain by the aggressor state from the occupied territories, destruction of the agricultural infrastructure and blocking of Ukrainian seaports (Priss et al., 2023; Trusova et al., 2023; Tryhuba et al., 2022). In addition, up to 14% of the world's food is lost on the way from production to retail stage, and another 17% is lost between the retail and consumption stage (*Volunt. code Conduct food loss waste Reduct.*, 2022). Food production requires a large number of resources, such as water, soil, energy, and fertilizers. When some of the products are turned into waste, these resources are irretrievably lost and become an additional source of greenhouse gas emissions. Inefficient functioning of food systems causes losses and waste of food products (*Volunt. code Conduct food loss waste Reduct.*, 2022). The largest part of food wastes and losses (40–50% of their production) is formed by fruits and vegetables (Cassani and Gomez-Zavaglia, 2022). On the other hand, a healthier diet involves increasing the consumption of fruits and vegetables (Harris et al., 2023; Mason-D'Croz et al., 2019). In addition, plant products are a supplier of valuable phytonutrients to the human body, which help to combat "hidden hunger" (Gödecke et al., 2018; Hutsol et al., 2023). Fruits and vegetables are also very profitable, so they are a good source of income for small farmers, and the right marketing strategies will help increase their consumption (Dunn et al., 2018; Kalchenko et al., 2018). Storage is an essential component of a sustainable and efficient food supply system. Therefore, reducing losses and waste of fruits and vegetables can become a leading key for transforming the agro-food systems by increasing food availability, achieving sustainable food security, improving diets, and reducing the load on ecosystems.

High losses during storage of fruit and vegetable products are due to their biochemical composition. Fruits and vegetables are characterized by a high water content (75–95%), low resistance to mechanical damage, intensive gas exchange, and active post-harvest metabolism. Preventing the natural aging process and changes of fruits and vegetables during storage is a fundamental problem from a technical point of view. It is especially difficult to store perishable foods with a high level of metabolic processes.

The same processes are typical for asparagus. Asparagus (*Asparagus officinalis* L.) is one of the most popular vegetable crops in the world due to the presence of a complex of valuable biologically active compounds and important dietary properties. However, it is one of the most perishable products in the post-harvest period. First, this is due to the fact that asparagus is a young and immature plant organ, where the metabolic rate and the intensity of gas exchange are very high. This leads to aging acceleration and limitation of shelf life (Mastropasqua et al., 2016). The mechanisms of post-harvest aging and rapid quality loss are associated with the development of oxidative stress (Bata Gouda et al., 2020). Slowing down metabolic processes and the intensity of gas exchange, preventing the development of oxidative stress make asparagus storage effective. However, this is quite a difficult task.

Cooling is the main factor that slows down the metabolic processes, transpiration and tissue oxidation processes. At room temperature, asparagus retains an acceptable quality for 5 days (Irving and Hurst, 1993), but lowering the temperature to 2 °C extends the storage period to 14 days (Papoutsis, 2023). In general, the acceptable storage temperature for asparagus is below 4°C, but it should be above -0.8°C (ice crystallization temperature in asparagus) (Ando et al., 2019). Another way to reduce the intensity of exchange processes and gas exchange is the use of film materials. The use of polypropylene packaging is highly effective for storing asparagus for 30 days (Toscano et al., 2021). However, the issue of global environmental changes calls for careful attention to the eco-friendliness of substances or materials used. Therefore, polypropylene films are not an ideal solution, as they require proper disposal and recycling, and their use contradicts the principles of the European Green Deal.

Therefore, it is imperative to exclusively employ sustainable storage technologies. The sustainability of plant product storage technology is assessed based on its ecological soundness, reliability, adaptability, and effectiveness in minimizing waste and losses both quantitatively and qualitatively. This explains the number of studies related to the use of edible coatings (Iñiguez-Moreno et al., 2021). Such natural oligosaccharides as chitosan, alginates, and pectins demonstrate great potential for preserving the quality of fruit and vegetable products and effectively reduce weight loss and the content of secondary metabolites (Bose et al., 2021). Among biopolymers, chitosan is the most interesting for use as an edible coating, as it is non-toxic, biodegradable, and biocompatible (Narasagoudr et al., 2020). Chitosan is classified as generally recognized as safe (GRAS) by the United States Food and Drug Administration. It is used as an additive (E number E1619) and possesses thickening and stabilizing properties. The use of chitosan derivatives for post-harvest processing of green asparagus inhibits the growth of *Fusarium concentricum* at the concentration of 4 mg/ml, and completely inhibits the germination of spores at the concentration of 0.05 mg/ml. These coatings provide a good antimicrobial effect, but have significant disadvantages, such as low water resistance and unsatisfactory mechanical properties. Other biopolymers such as starch, lipids and proteins are used to improve the functional properties of chitosan coatings (Zhu et al., 2019). Casein-based coatings significantly affect moisture and gas exchange, slowing down the exchange processes, but do not have bactericidal properties. Such coatings require the use of antimicrobial substances and antioxidants (Khan et al., 2021). Exogenous antioxidants can inhibit oxidative damage to plant tissues during storage (Priss and Kalytka, 2015). Essential oils and phenolic compounds are often used for this purpose (Hasheminejad and Khodaiyan, 2020). The inclusion of essential oils in polysaccharide matrices increases not only their antimicrobial activity, but also their antioxidant properties. It was reported that the polysaccharide matrix adapts the release of essential oils and thus affects the extension of the shelf life of food products (Anis et al., 2021). However, these substances sometimes diffuse into food products, adding undesirable taste and aroma due to the presence of a mixture of volatile and non-volatile components in them, which limits their use (Nair et al., 2020). Natural phenolic compounds are known to have strong antioxidant properties. Several natural and synthetic phenolic compounds are used for storage of fruit and vegetable products. Exogenous phenolics improve the postharvest fruit quality by inhibiting diseases, preserving nutraceutical compounds, delaying aging processes and improving respiratory metabolism and energy status. They attach to targets in the cell walls and membranes of fungi, can inhibit the activity of protective enzymes and disrupt the synthesis of ergosterol, which is the main component of the cell membrane of the fungus (Liu et al., 2023). Among the natural antioxidants of phenolic nature that can be used to extend shelf life, rutin exhibits high antioxidant activity. Rutin, also known as vitamin P or rutoside, is a phytochemical flavonoid found abundantly in food plants. It possesses functional properties and offers significant health benefits, making it a valuable component of our diet (Frutos et al., 2019). It binds free radicals and inhibits the chain reaction process of forming new aggressive radicals (Gullón et al., 2017). Additionally, rutin induces bioactive chitosan/poly (vinyl alcohol) films for food products. Narasagoudr et al. (2020) clearly demonstrated that such films exhibit excellent antibacterial activity and can be used as bioactive packaging materials for food products to extend their shelf life (Narasagoudr et al., 2020). Thus, the combination of chitosan with rutin for external use can be an effective strategy to reduce losses and waste during storage of asparagus.

The aim of this study was to investigate the effectiveness of sustainable postharvest treatments based on chitosan and rutin, focusing on reducing losses and waste during storage of asparagus spears.

Materials and Methods

Materials

Asparagus (*Asparagus officinalis* L.) green variety Prius F1 and violet/green variety Rosalie F1 were used for research. The plants were collected at the end of the campaign (the third decade of June) in 2023 in the village of Chaichyntsi, Ternopil region, Ukraine (49.844719, 25.899841). Immediately after harvesting, the samples were quickly cooled and transported to the Analytical Research and Food Products Quality laboratory of the Institute of Food Resources (Kyiv, Ukraine), where the research was carried out. Asparagus leaves had closed bracts, without mechanical damage, of approximately the same diameter (at least 8 mm) and 23-25 cm long, according to the requirements of CODEX STAN 225-2001.

Chemicals

All chemical substances (AR grade) produced by Merck KGaA (Germany) were obtained from LLC Chemlaborreaktiv (Kyiv, Ukraine).

Samples pretreatment and processing

Low-molecular chitosan with a viscosity of 55 mPa·s and with a degree of deacetylation of 90% and rutin of 98.7% by weight were used to prepare the treatment solutions (both produced in China). A 1% solution of chitosan was prepared in a 1% solution of acetic acid (Ch coating). To produce a complex preparation of chitosan with rutin, rutin powder was dissolved in 96% ethanol (5% by weight), and then adjusted with a Ch solution to obtain a concentration of 1% rutin (Ch+R coating). Asparagus spears were randomly packed into bundles of approximately the same weight (~200 g) and completely immersed in the prepared coating solutions. After removing from the solutions, the asparagus bunches were placed vertically on a grid with a tray for draining the remaining coating and dried for 1 hour under cooling conditions. Asparagus spears were cooled in forced-air cooling chambers with cold air at the speed of 3.0 $m \cdot s^{-1}$ (air exchange rate of 90 volumes per hour). The temperature in the forced-air cooling chambers was 2°C ± 0.5. The relative humidity was 90±1%. Samples of asparagus without coating were taken as control. Treated and untreated asparagus spears were stored at a temperature of 2°C ± 0.5 and a relative humidity of 95% ± 1.

Quality assessment and sensory indicators

The commodity indicators of asparagus were determined in accordance with the requirements CODEX STAN 225-200. Spears that lost turgor and those with open bracts (the so-called "artichoke") and with signs of yellowing were considered non-standard. Products that showed signs of rotting and damage by microorganisms were classified as waste. Storage was stopped when losses and waste reached 10%. A group of 5 experts with special knowledge evaluated the sensory characteristics of asparagus during storage. Experts evaluated the turgidity (from a fresh appearance to severe loss of turgor), the presence of longitudinal striation (from the absence of striations to strong striation), the desiccation of the bases (from no drying to strong drying), color changes (bright green or violet/green normal for variety, up to yellowing), the presence of extraneous odors (from the absence of odors to noticeable odors) and the absence of microbiological spoilage (Villanueva et al., 2005). A four-point scale was used (4 – very good; 3 – good; 2 – acceptable; 1 – unacceptable). Coefficients of the importance of indicators were also used: 0.3 - turgidity; 0.2 – the presence of extraneous odors and the absence of microbiological spoilage; 0.1 for other indicators.

Respiration rate and weight loss

The intensity of respiration was determined by the amount of released carbon dioxide and its absorption by the alkali solution (Wang and Fan, 2019). The determination was carried out in a refrigerator, starting from the next day after the storage, when the temperature of asparagus spears reached the storage temperature (2°C). A natural weight loss was determined by weighing the same samples throughout the storage period.

Total soluble solids and soluble carbohydrates content

The total soluble solids content was determined by the refractometric method. The soluble carbohydrates content was determined by high-performance liquid chromatography (HPLC) using Shimadzu CTO-20AC liquid chromatography system and HC-75 Hamilton column with water as a mobile phase.

Chlorophylls and carotenoids

The method of determination of chlorophylls and carotenoids was described earlier (Burdina and Priss, 2016). Briefly, the content of chlorophylls and carotenoids was determined by extracting pigments with undiluted acetone followed by determination of their absorbance at wavelengths of 440.5, 644, and 662 nm.

Data analysis

All experiments were repeated three times, and each treatment was repeated three times in each experiment. Data from the experiments were subjected to analysis of variance, and the least significant difference was calculated at the 5% significance level. The obtained results were presented as mean ± standard deviation.

Results and Discussion

Storage duration, marketability, and sensory indicators

The advancement of conservation strategies with a stronger focus on sustainability and the adoption of environmentally responsible treatment are poised to make a substantial impact on preserving product quality for extended periods. According to our data, the duration of storage of control samples of asparagus spears was no more than 14 days for both varieties. After 14 days of storage, the amount of waste in the control samples reached 5.5-7.4%, depending on the variety (Fig. 1).

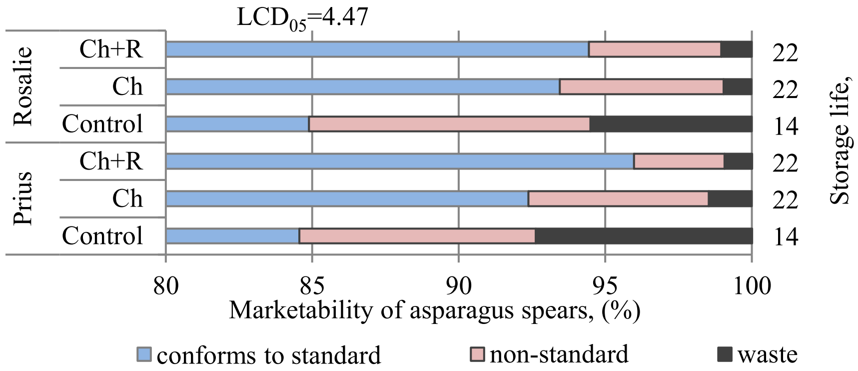


Figure 1. Marketability of asparagus spears after storage.

The number of products that met the requirements of the standard was about 85%. During further storage, the control samples of asparagus spears quickly lost quality and rotted. According to our data, treated samples of asparagus spears of both varieties were stored without visible quality deterioration for up to 22 days. With further storage, weight loss and waste increased by more than 10%, and storage became economically inefficient. Tran et al. studied the preservation of asparagus spears with a protective coating based on chitosan and alginate. They showed that such a coating extends the shelf life by 3 days (Tran et al., 2020). In contrast, Qiu et al. stored chitosan-coated asparagus spears at 2°C for 28 days (Qiu et al., 2014). The authors indicated that chitosan prevents *Fusarium concentricum* damage. However, the marketability of products after storage was not investigated. Sergio et al. studied the storage of four different varieties of asparagus spears in a modified atmosphere. The limit of marketability was reached after 21 days storage, for all treatments (Sergio et al., 2019).

The number of standard products reached 92.4–93.4% in asparagus spears with Ch coating, depending on the variety. In asparagus spears covered with Ch+R solution, the number of standard products was slightly higher – 94.4–96.0%. To establish the reliability of the effect of the coating on the increase in marketability after storage, a two-factor variance analysis was performed.

The marketability indicators of control samples on the 14th day of storage and processed asparagus spears on the 22nd day of storage were compared. The results show that the influence of the variety (factor A) on the marketability of asparagus spears is insignificant (influence of 0.08%), but the use of a coating based on chitosan (factor B) has a decisive influence – 85.2%. The main advantage of using Ch and Ch+R coatings was reducing the amount of waste to 1.0–1.5% while increasing the storage period by a week. Also, the number of non-standard products decreases, as can be seen from Fig. 1. A sensory quality attribute of a product is decisive for its choice by consumers. As our results show, covering asparagus spears with chitosan significantly increases the overall evaluation of products even after the prolonged storage (Fig. 2).

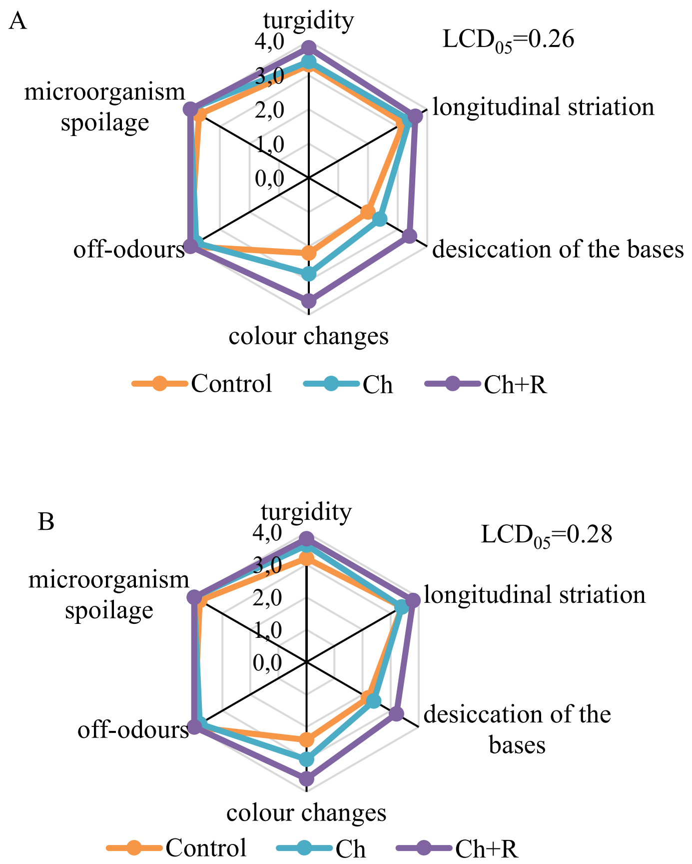


Figure 2. Sensory characteristics of asparagus spears: control after 14 days of storage; with coating after 22 days of storage: A – Prius, B – Rosalie

The control sample of the Prius variety received 3.2 points in the end, and the Rosalie variety after 14 days of storage received 3.3 points. Asparagus samples coated with Ch after 22 days of storage had a 0.2 point higher score than the control after 14 days. Even with an extended storage period of 8 days, we did not observe the development of microbiological spoilage. This can be explained by the antimicrobial properties of chitosan, which are enhanced by the action of flavonoids, including rutin, as described by Sousa et al. (2009). Asparagus coated with Ch+R showed the best results with the total score of 3.8 points for both varieties. A higher overall visual quality of asparagus when using 0.5% low molecular weight chitosan is also noted by Qiu et al. (2013). Asparagus samples covered with Ch+R have a larger area of the sensory profilogram. The overall sensory score was mainly reduced due to desiccation of the bases, changes in the main color, and longitudinal striation in all samples. The desiccation of the bases has the greatest effect on the reduction of the sensory evaluation. But the desiccation of the bases of asparagus coated with Ch+R was significantly less than that of the control samples. Similar results were obtained by Villanueva et al. (2005), when storing asparagus at 2°C. These authors show that bases desiccation was reduced when asparagus was stored in a modified atmosphere. Longitudinal striation is another parameter that limits sensory evaluation. According to Palma et al. (2015), the main changes found in unpackaged samples were longitudinal striation, indicating weight loss.

Weight loss and respiration rate

Quantitative losses during storage occur due to the spoilage of products, as well as due to weight losses caused by transpiration and respiration. Weight losses of asparagus spears during storage in different conditions are not the same. Albanese et al. (2007) observed 27.2% weight loss in unpackaged samples during 21 days of storage. Asparagus packed in semi-permeable film lost about 6.8% and 5.2% if the asparagus was pre-treated with an ascorbic acid solution. In contrast, Wang et al. (2017) reported that during 30 days of storage, the weight loss of untreated asparagus was 7.7%, while cholesterol-treated samples lost 4.8%. According to our data, untreated asparagus spears lose 8.3-8.8% of its mass in 14 days of storage (Fig. 3).

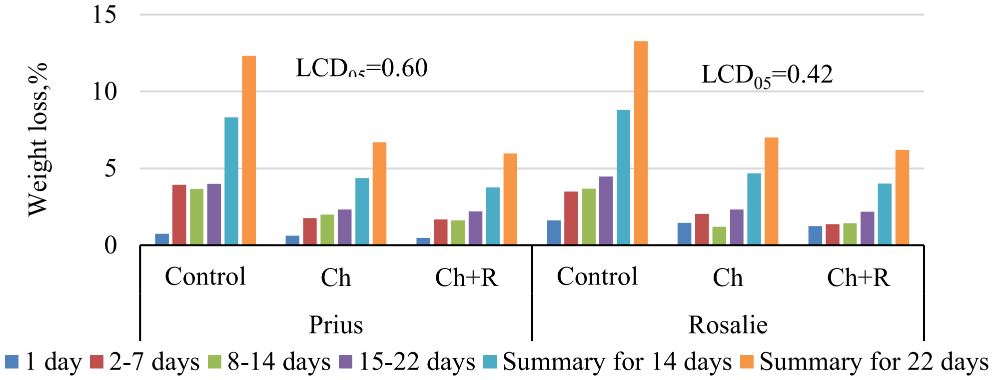


Figure 3. Changes of asparagus spears weight loss during storage.

The average daily weight loss is greatest during the first day of storage. These losses differ greatly depending on the variety. Mass loss in Rosalie during the first day of storage was 2.2 times higher than in Prius. This trend was also true for treated asparagus spears. However, during further storage, this varietal specificity was eliminated. A two-way analysis of the effect of variety (factor A) and treatment (factor B) on the weight loss showed that factor A was significant, but its effect was only 0.7%. The influence of factor B is 98.1%, the interaction of factors AB is insignificant. Asparagus with Ch coating had losses 1.8-1.9 times lower than in the control sample. We observed a two times reduction in the weight loss for asparagus coated with Ch+R. The obtained results coincide with the findings of Divya et al.

(2018) that chitosan-based films show high efficiency in mass loss reduction (Divya et al., 2018). Weight loss is also related to the process of breathing. Sugars and acids are involved in the respiratory process, and as a result of their consumption, mass decreases. These losses are determined by the level of respiratory activity. The pattern of changes in respiration intensity in both varieties of asparagus spears is similar. Immediately after cooling, the intensity of breathing decreases in all variants (Fig. 4).

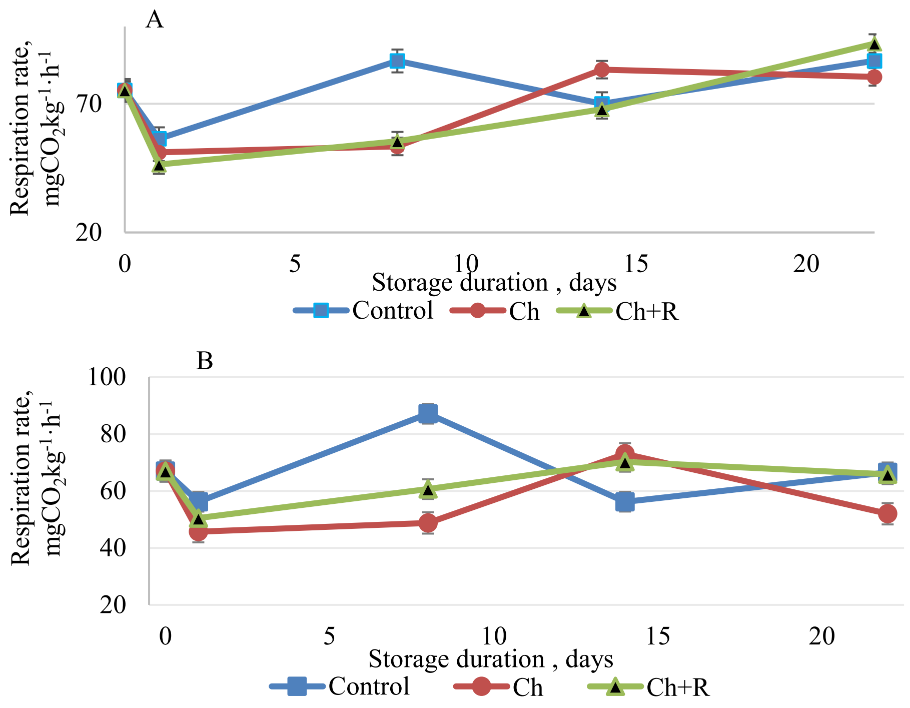


Figure 4. Respiration rate of asparagus spears: A – Prius, B – Rosalie

The intensity of respiration of untreated asparagus spears increases maximally on the 7th day of storage, then decreases on the 14th day and then slowly increases. A similar pattern of respiration during storage of asparagus spears was described by Zhang et al. (2012), Park (2016). In contrast, other researchers did not record an increase in respiratory activity at the final stage of asparagus spears storage (Wang and Fan, 2019; Wang et al., 2022). And Verlinden et al. (2014) showed that the respiration intensity of different segments of asparagus spear can be different.

The use of edible coatings based on chitosan can lead to a decrease in the respiratory rate (Duan et al., 2019). According to our data, in addition to a decrease in the intensity of breathing, the moment of maximum growth is postponed to a later period when using the coating Ch. In asparagus spears covered with Ch+R, there was no pronounced increase in respiration, which may indicate a more uniform course of metabolic processes.

Total soluble solids and soluble carbohydrates content

As per the FAO definition, food losses encompass not just the decrease in product weight but also the diminution of their nutritional value (State Food Agric., 2019). Aligned with the principles of the European Green Deal, enhanced storage techniques focused on nutrient preservation should guarantee that the produce received by consumers retains elevated nutritional value. A decrease in the nutritional value of products during storage is natural since soluble solids are constantly consumed to support metabolism. The tendency of decreasing the soluble solids content is also observed in asparagus and was described by many authors (Wang and Fan, 2019; Wang et al., 2022). However, we observed a statistically significant decrease in the level of soluble solids of asparagus spears only in the control samples (Fig. 5).

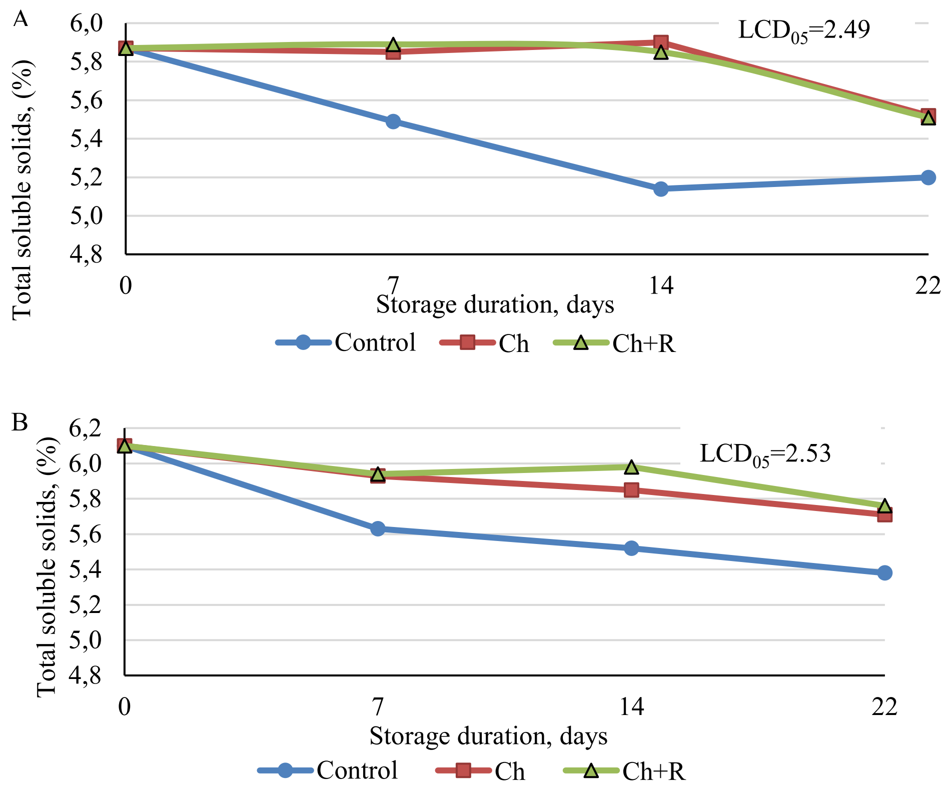
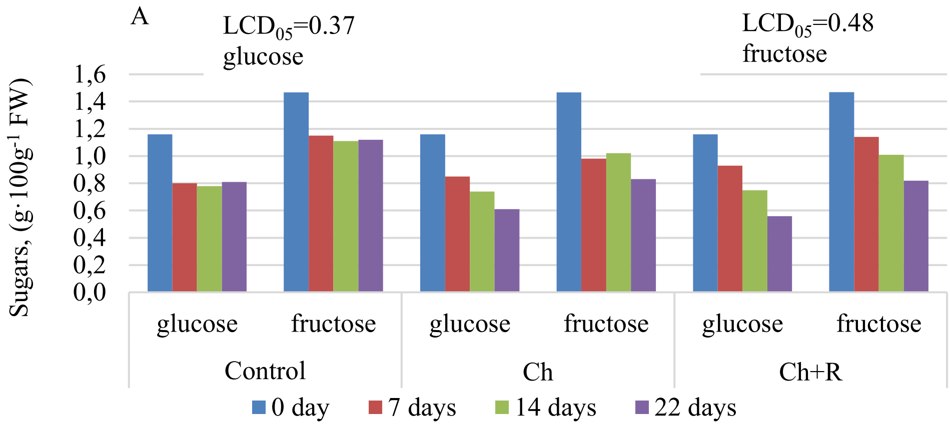


Figure 5. Total soluble solids content of asparagus spears during storage: A – Prius, B – Rosalie

Lower consumption of soluble solids in samples with Ch and Ch+R coatings is associated with a decrease in the intensity of respiration and transpiration, which is evidenced by a decrease in mass loss.

The content of soluble saccharides in asparagus spears can vary depending on growing conditions and variety. Asparagus spears mainly contains glucose, fructose and sucrose (Soteriou et al., 2021). However, Slatnar et al. identified only glucose and fructose in six green and two purple varieties of asparagus (Slatnar et al., 2018). We also did not identify sucrose in the studied varieties of asparagus spears. Our studies confirm the presence of only glucose and fructose (Fig. 6).



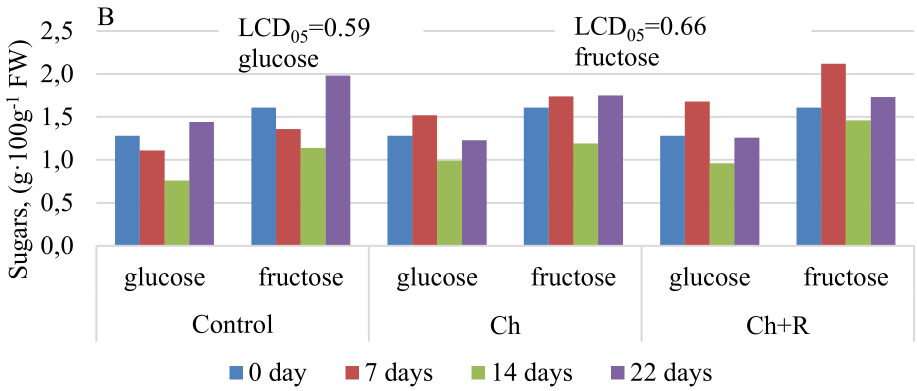


Figure 6. Soluble carbohydrates of asparagus spears during storage: A – Prius, B – Rosalie.

The researched varieties of asparagus differ significantly in the content of soluble carbohydrates. Soteriu et al. also showed that the content of fructose, glucose and total sugar in asparagus tissues depends on the variety and harvest period (Soteriou et al., 2021). In addition, according to our data, the nature of changes in sugar content during storage of asparagus of different varieties is not the same. If the content of glucose and fructose decreases in Prius asparagus during storage, then sugars increase in Rosalie asparagus at the end of storage. Most literary sources generally describe a constant decrease in sugars during storage (Techavuthiporn and Boonyaritthongchai, 2016; Verlinden et al., 2014). However, Japanese researchers describe a tendency of increase in glucose and fructose content when storing asparagus at 4°C (Shiomi et al., 2007). Sergio et al. showed that when purple asparagus "Purple Passion" was stored at 4°C after 14 days, the content of glucose and fructose decreased, and sucrose increased by approximately 40% (Sergio et al., 2019). Anastasiadi et al. demonstrated an increase in sucrose during storage of asparagus at 7°C (Anastasiadi et al., 2020). They concluded that the differentiation of sugar profiles during storage may be related to differences in light and temperature. In addition, varietal differences can be a significant factor affecting sugar metabolism. Our results confirm the opinion about the varietal specificity of changes in the content of soluble carbohydrates during storage.

Asparagus spears coated with Ch and Ch+R of the Prius variety had a higher glucose and fructose recovery rate than the control samples. Perhaps, for the control samples, this is due to the participation of complex polysaccharides in metabolic processes, and along with the use of soluble sugars for respiration, they are formed again, for example, from starch. Mastropasqua et al. believe that the recovery of sugar levels after six days of storage of asparagus in the dark may be related, at least in part, to the hydrolysis of starch, which actually decreases over long periods (Mastropasqua et al., 2016). Therefore, the restructuring of the nature of consumption of sugars as substrates of respiration could become the realization of the mechanism of preservation of other metabolites.

Total chlorophyll and total carotenoids contents.

The green color of asparagus spears is due to the pigment chlorophyll. The latest data show that chlorophylls and their decomposition products pheophytin are antioxidants which prevent oxidative DNA damage and lipid peroxidation, perform physiological roles of signaling molecules and contribute to the protection of plant tissues from damage due to pathogenic infections (Hsu et al., 2013; Jockusch et al., 2014; Solymosi and Mysliwa-Kurdziel, 2017). In addition to antioxidant functions, the amount of chlorophyll is an objective sensory indicator of vegetables preservation, because the degradation of chlorophyll during storage is a natural process. Low temperature, use of a controlled and modified atmosphere, 1-Methylcyclopropene treatment slow down the degradation of chlorophylls in the post-harvest period (Li and Zhang, 2015; Wang et al., 2023). Plant carotenoids belong to the group of lipophilic antioxidants and are capable of neutralizing various forms of reactive oxygen species (Young and Lowe, 2018). It is noted that at the stage of post-harvest storage of mature vegetables, the synthesis of carotenoids stops and their gradual degradation occurs (Ngamwonglumlert et al., 2020). The influence of edible coatings on the rate of degradation of chlorophylls and carotenoids is shown in Fig. 7.

The number of chlorophylls and carotenoids is a variety-specific characteristic of asparagus. A large difference in the initial concentration of chlorophylls in different varieties is associated with differences in the color of asparagus. At the beginning of storage, Rosalie variety contains a 40% higher concentration of chlorophylls and 17% more carotenoids than Prius. However, the rate of pigment degradation was higher in Rosalie variety. After 22 days, Rosalie variety lost 66% of chlorophylls and 59% of carotenoids from their initial content. For the Prius variety, these results were 53% and 42%, respectively.

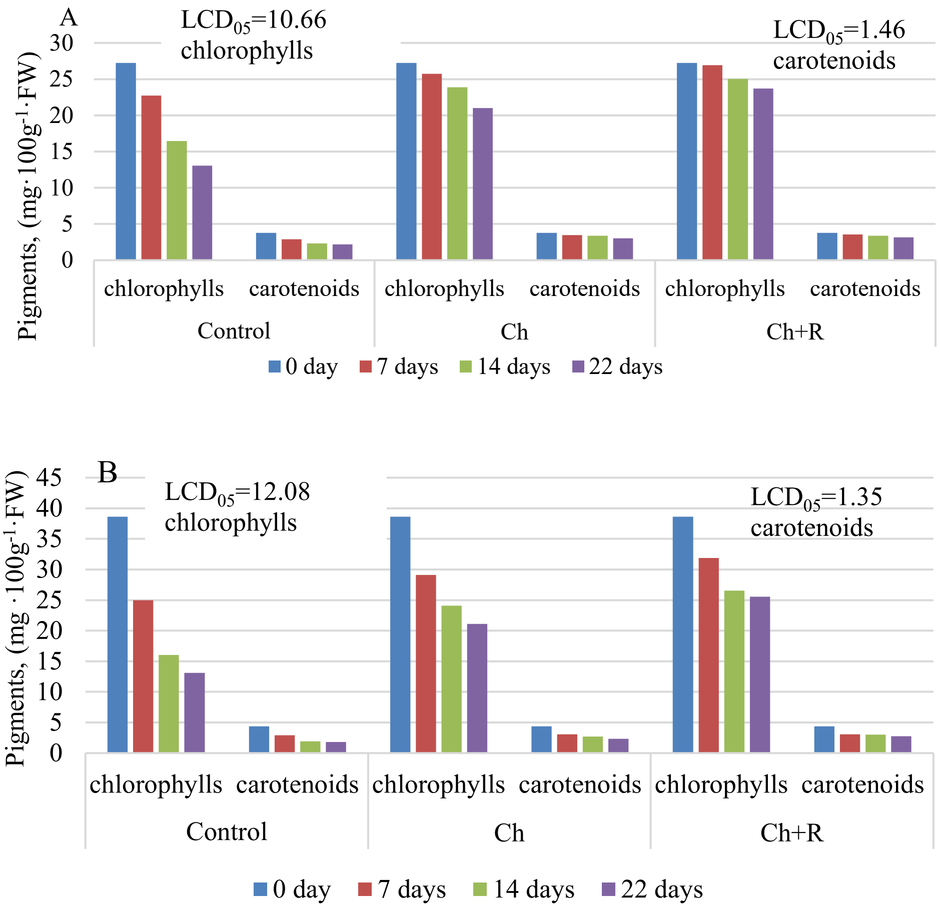


Figure 7. Chlorophylls and carotenoids content of asparagus spears during storage: A – Prius, B – Rosalie

In general, the use of the Ch coating slows down the rate of chlorophyll degradation by the average of 60%, and the Ch+R coating by 88%, respectively, relative to the control sample. Inhibition of the degree of degradation of chlorophylls during the application of chitosan-based coatings is described in other works (Tran et al., 2020). According to the literature available for analysis, we did not find any results regarding the content of carotenoids in asparagus spears during storage. According to our data, the degree of inhibition of carotenoids in Ch-coated asparagus spears is 33% and 48% for Ch+R-coated asparagus spears, respectively.

Such results indicate the inhibition of maturation processes in asparagus spears covered with Ch and Ch+R coatings.

Conclusions

In the context of food preservation, the efficiency of storage varies greatly depending on the storage conditions, type and variety of products and their characteristics. Despite the proven effectiveness of various treatments to reduce losses of fruit and vegetable products, the mechanism of influence of such coatings on the endogenous processes underlying fruit preservation is still little studied. Understanding these mechanisms will allow developing the composition of edible coatings which will inhibit the post-harvest physiological processes in plant products to the maximum degree. It also requires a coordinated action along the entire chain from cultivation, primary processing, storage and distribution to maintain the quality and reduce loss and waste. This is consistent with the goals of sustainable development which aims at creating sustainable and environmentally responsible food systems.

It was shown that the use of edible coatings based on chitosan and rutin allows extension of the shelf life by a week and preservation of the visual quality of asparagus spears. What is very important, this coating allows reduction of waste during storage to 1.5%. The number of standard products increases after the storage, and the weight losses are reduced by half. A decrease in transpiration and the activity of respiratory processes leads to the inhibition of the consumption of soluble solids. This makes it possible to reduce quality losses of asparagus, and therefore to preserve a greater amount of biologically active substances in product after storage.

Author Contributions

Conceptualization, O.P. and T.H.; methodology O.P., N.O. and I.H; software, S.G. and I.H.; validation, S.G. and T.N.; formal analysis, L.M.; investigation, P.B. and O.P.; resources, K.B.; writing-original draft preparation, O.P.; writing-review and editing, O.P. and N.O; visualization, K.B. and L.V.; project administration, S.G.; Supervision, T.H. All authors have read and agreed to the published version of the manuscript. Authorship must be limited to those who have contributed substantially to the work reported.

Conflicts of Interest

The authors declare no conflict of interest.

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WPŁYW POWŁOKI CHITOZANOWO-RUTYNOWEJ NA STRATY I REDUKCJĘ ODPADÓW PODCZAS PRZECHOWYWANIA SZPARAGÓW

Streszczenie. Przechowywanie jest istotnym elementem zrównoważonego i skutecznego łańcucha dostaw żywności. Redukcja strat i odpadów po zbiorze stanowi ważną strategię, której celem jest ulepszenie skuteczności, zapewnienie dostępności produktów oraz zmniejszenie wpływu na środowisko. Szparaga (*Asparagus officinalis* L.) posiada wysokie wartości odżywcze oraz kompleks fitozwiązków. Jednak okres przechowywania świeżej szparagi jest dosyć krótki, za czym idzie gwałtowne pogorszenie jakości. Skuteczna metoda wydłużająca okres przechowywania polega na zastosowaniu po zbiorze zabiegów z użyciem naturalnego chitozanu polimerowego. Niniejsze badanie miało na celu ocenę skuteczności stosowania zrównoważonych zabiegów po zbiorze z zastosowaniem chitozanu i rutyny skupiając się na redukcji strat i odpadów podczas przechowywania szparagi. Systematycznie oceniano wpływ zastosowanej technologii przechowywania na wygląd zewnętrzny i cechy sensoryczne szparagi razem z wpływem na metabolizm oddechowy, straty wagi, rozpuszczalnych cząstek stałych, rozpuszczalnych węglowodanów, chlorofilu i karotenoidów. Wyniki wskazują na to, że zabiegi przeprowadzone po zbiorze z użyciem chitozanu i rutyny skutecznie podtrzymują charakterystykę wizualną szparagi podczas gdy okres przechowywania wydłużony jest o tydzień. Główną korzyścią tej technologii jest widoczna redukcja odpadów na poziomie 1-1-5%. Proporcja standardowych produktów po przechowywaniu wahała się między 94,4 a 96%. Użycie chitozanu i rutyny skutecznie zmniejsza stratę wagi o połowę i hamuje tempo zmniejszając w ten sposób straty rozpuszczalnych części stałych, węglowodanów, chlorofilu i karotenoidów podczas przechowywania. Niniejsze wyniki potwierdzają skuteczność zastosowanej powłoki w blokowaniu procesu metabolicznego, co skutkuje zmniejszonymi stratami ilościowymi i jakościowymi produktu podczas przedłużonego przechowywania.

Słowa kluczowe: dopuszczalny okres przechowywania, chitozan, rutyna metabolizm oddechowy, straty wagi, rozpuszczalne cząstki stałe, karotenoidy, chlorofil