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Fruit packaging with edible chitosan wrappers

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Abstract

With the sharp increase in food safety issues and the lasting effects of the pandemic, consumers are paying more attention to food safety and healthy eating. Plastic waste is a serious environmental problem due to its long degradation period, which is a reason to seek biodegradable alternatives. Multifunctional films based on natural macromolecules are being studied to observe their mechanical properties, degradability, antibacterial and antioxidant activities. Edible film packaging has attracted the attention of manufacturers due to their functions of maintaining the freshness and quality of foods, they are bio-based macromolecules, which contributes to environmental protection and have good mechanical properties, degradability, antibacterial and antioxidant activities. A number of packaging methods have been used to observe the shelf life and changes in fruits, vegetables and local products when covered with packaging film. In our study, we used cherries and packaging made of chitosan and calcium lactate and chitosan and alginate. Edible packaging reduces changes in fruit texture and color during storage at 4^0 C, with two-layer packaging with chitosan/alginate film performing better.

Key words: edible packaging, biopolymers, biodegradable, chitosan, quality and safety preservation, physical properties, barrier properties

Introduction

The excessive use of synthetic waxes such as polyethylene, petroleum-based synthetic plastics or synthetic fungicides as coatings, controlling postharvest decay of fruits and vegetables poses negative impact on human and environmental health (Iniguez-Moreno et al., 2021).

Pollution with plastic waste is a serious environmental problem, as they degrade slowly in the environment after their use, the effects and damages of this pollution are being studied and investigated (Mitova et al., 2019).

The harmful effects of non-biodegradable plastics on ecosystems have intensified social awareness of the need to develop biodegradable alternatives. Development of innovative biodegradable materials with desirable properties of synthetic plastics continue to be sought for food packaging.

New ones are being studied preservation methods based on renewable, cost effective, and biodegradable alternatives for achieving healthy and fresh food which has the least environmental impact (Kumar et al., 2020).

Developing green and eco-friendly alternative strategies for effectively preserving fruits, vegetables, cereals, roots, and tubers is essential.

Ideal biodegradable packaging materials, most often biopolymers, are derived from renewable biological resources, possess good mechanical and barrier properties, and are biodegradable at the end of their life. Biopolymers are a potential environmentally friendly alternative to non-biodegradable and non-renewable plastic packaging materials.

Bio-based materials are considered safe and can play an important role in coating and packaging, decreasing the rate of respiration, ripening, ethylene, controlling moisture loss, and eliminating microbial activities (Basumatary et al., 2022).

Chitosan, alginate, starch, gelatin, cellulose, pectin, soy protein, dextran, and gums are the most common biopolymers utilized for the fabrication of food films and coatings to prolong postharvest shelf-life (Kumar et al., 2020; Basumatary et al., 2021; Basumatary et al., 2022; Riseh et al., 2023).

Multifunctional films protect food from microorganisms, oxygen and ultraviolet rays which worsen food quality (Nilsuwan et al., 2021).

Chitosan is a suitable biopolymer for inclusion in coatings, possessing suitable characteristics and film-forming abilities (Nuraje et al., 2011).

Experiments have been conducted on a composite coating of modified chitosan and polyvinyl alcohol and a multilayer coating of chitosan/alginate dialdehyde for packaging fresh produce, but there are some limitations when considering them that need to be studied more thoroughly (Nuraje et al., 2011; Li et al., 2020).

Chitin is synthesized by many living organisms, mainly waste from the seafood industry, therefore its use will limit their disposal (Younes and Rinaudo, 2015; Cazon and Vazquez, 2019). Therefore, chitosan is a cheap, environmentally friendly and commercially available polysaccharide.

New food packaging techniques should aim to reduce waste, limit the use of non-biodegradable packaging and its accumulation and disposal in nature, and ensure greater food safety. In this way, packaging will extend the shelf life of foods, and biopolymers will contribute to sustainable resource management (Wyrwa and Barska, 2017).

Composite films composed of chitosan and sodium alginate significantly improved mechanical properties and reduced hydrophilicity compared to pure chitosan film (Lan et al., 2018).

Composite films based on chitosan, polyvinyl alcohol and citric acid have been used for cherry packaging. It was found that the chitosan-based composite film effectively reduced water loss in cherries, increased their shelf life and had good potential for fruit packaging and preservation (Jiang et al., 2023).

After conducting studies on fruits packaged by dipping and spraying different edible coatings (Zsivanovits et al., 2022a; Zsivanovits et al., 2022b; Sabeva et al., 2024), we developed an edible film for fruit packaging.

Materials and methods

Materials and reagents:

-Chitosan - low molecular weight water-soluble hydrochloride, fungal origin (10-120 cps, Glentham life sciences, UK);

-calcium lactate ($C_6H_{10}CaO_6$), ≥ 98.0% (Sigma-Aldrich, Germany);

-alginate ($C_6H_7NaO_6$), CPM (Sigma-Aldrich, Germany);

-glycerol ($C_3H_8O_3$), ≥ 99.5%, h.z.a, (Valerus OOD, Sofia);

-emulsifier: Tween 20 (Sigma-Aldrich, Germany).

-Cherry fruits (*Prunus avium, var. "Regina"*) were supplied by the Fruit Growing Institute - Plovdiv, Bulgaria. The cherries are large, dark red, uniformly colored, firm, aromatic, with very good taste, the flesh is sweet. They have a low sensitivity to fungal and bacterial diseases, are stable during storage and transportation, have good handling durability and resistance to cracking.

Experimental series:

K: washed, unpackaged fruit, also examined on the first day of storage.

Ch/$CaCl_2$: fruits were wrapped with films of chitosan (1%), $CaCl_2$ (1%) and glycerol (0.15%), the series was studied only on storage time, after removal of the film.

Ch/Al: fruits were wrapped with a two-layer film of chitosan (1%), sodium alginate (1%) and glycerol (0.15%), the series were studied only on storage time, after removing the film.

Fruit packing:

The research was carried out on fresh cherries wrapped with cast and dried edible films based on low molecular weight water-soluble chitosan.

The films were cast in petri dishes (d=70 mm), dried for 3 days at room temperature until an equilibrium dry phase was reached.

Fresh cherries were wrapped with a film of chitosan (1%), $CaCl_2$ (1%) and glycerol (0.15%) and a two-layer film of chitosan (1%), sodium alginate (1%) and glycerol (0.15%).

The packaged fruits were stored in a refrigerator (at 4±0.5° C) for 21 days.

Characterizations of packed with edible wrappers cherries

Visual impact of packaging and changes in fruit quality during storage

Healthy, intact fruits are selected. A comparison was made between unpackaged (control) samples and cherries with packaging

Textural characteristics of cherries

Researched by TA.XT2 Texture Analyzer (Stable Micro Systems, Surrey, UK) in puncture test.

A cylindrical sensor with a diameter of 5 mm, strain rate 1 $mm.s^{-1}$, strain 5 mm.

In this test, brittleness, hardness and Young's modulus were determined on the cherries.

Color characteristics of cherries

Color parameters were determined using a colorimeter (PCE-CSM 5 portable colorimeter). The CIELAB color parameters L*, a*, b*, and c* were measured (Measuring geometry 8°/d, Ø 8 mm, light source D65) and ISO yellowness indexes were calculated by the Color Quality Controller System 3 software. A white control plate (L* = 94.3; a* = -0.92; b* = -0.67) was used as a calibration plate.

Results and discussion

Visual impact of packaging and changes in fruit quality during storage

Changes in the appearance of the two different edible packages were observed prior packaging.

The film with calcium chloride and chitosan (multicomponent) is thinner, white in color and rough in surface.

The two-layer film of chitosan and alginate is thicker, transparent with a pale yellow shade of color and a smooth surface.

Wrapping the fruit with the edible wrappers significantly changes their appearance (fig. 1).

From the figure, a change in the characteristic appearance of the fruits is evident. Cherries cannot be packed tightly with these film variants. In the case of calcium packaging, a tighter adhesion is obtained, but the packaging itself does not remain glued to the end of the fruit. With alginate packaging, there is a better general adhesion to the fruit, but there are areas not covered by the packaging.

The double-layered alginate coating is easier

Fig. 1. Cherries with edible packaging of chitosan and calcium lactate and chitosan and alginate

to handle, and the two-layer film is denser and more elastic. For the calcium coating, crumbling occurs at the end of the package, which may be due to the calcium ions contained in it.

Similar results for color change during packaging have been observed in experiments by other teams working with different foods packaged with edible film (fish, bread, fruits and vegetables) and in all of them it was found that the color of the samples was preserved longer when stored compared to the unpackaged samples (Li et al., 2024).

Textural characteristics of cherries

The changes in texture have a complex nature, which is due to the drying of the fruits in there and on the other hand to the bursting of the cell wall and destruction of the cells (Ghasemnezhad et al., 2011). The textural indicators show the different sensitivity of the fruits to the composition of the package and the changes during the cold storage time.

To determine textural changes of cherries, textural parameters: hardness, friability and modulus of elasticity are considered. Analyzes were made of fruit under cold storage at 4° C for 21 days, with samples checked weekly.

During storage, unpackaged fruits become harder because they lose water content and volume, which makes it difficult to measure the firmness of the fruit.

Edible films limit water loss and thus reduce change in friability and hardness. The modulus of elasticity at the beginning of storage increases, but with prolonged storage of the fruits in cold (4° C) the elasticity decreases dramatically in both packaged variants (table 1).

In the first week of the hardness test, the packages had a significant decrease compared to the unwrapped fruit, indicating the maintenance of the initial results and the influence of the packages on the hardness of the samples.

The results obtained prove the better firmness of the packaged fruits using chitosan packaging, which is in line with the research of Jiao et al., (2019) and Abdipour et al., (2020).

The improved firmness of the packaged fruits is due to the better density of the stable polyelectrolyte complex that occurs between chitosan and alginate in the bilayer packaging (Ch/Al), (Speranza et al., 2018) and the delay in the hydrolysis of the cell wall by calcium chloride and the formation of calcium complex in the multilayer packing (Ch/$CaCl_2$), (Shalan et al., 2020).

No statistically significant differences were found on the 7th day for the packaged fruit in the

Table 1. Textural characteristics of packed and unpackaged cherries

Variants	Time, days	Hardness, N	Fragility, N	Module of elasticity, N/mm
K	1	7.18±0.97a	2.93±0.45a	1.41±0.22a
	7	8.29±1.56b	2.95±0.54a	1.89±0.30b
	14	7.93±1.13a	3.28±0.49a	1.41±0.24a
	21	11.44±2.05c	4.36±0.82c	1.10±0.10b
Ch/$CaCl_2$	7	7.06±1.12a	2.94±0.52a	1.81±0.26c
	14	9.52±1.64b	3.81±0.67b	1.37±0.24b
	21	6.9±0.99a	2.81±0.48a	1.09±0.20a
Ch/Al	7	7.11±1.12a	2.89±0.52a	1.70±0.32c
	14	7.32±0.64a	2.99±0.34a	1.56±0.25b
	21	7.43±1.32a	2.99±0.56a	1.16±0.19a

Table 2. Color characteristics of packed and unpackaged cherries

Variants	Time, days	L*	a*	b*	c*	h°
K	1	24.32±1.40b	17.39±0.67c	5.91±0.31c	18.38±0.73c	18.20±1.96c
	7	23.68±1.53b	12.79±0.74b	4.14±0.30b	13.45±0.79b	17.45±1.53b
	14	23.23±1.14b	10.23±0.51a	3.07±0.19a	10.68±0.54a	16.39±1.42a
	21	19.51±1.77a	12.10±1.05b	3.88±0.21b	12.71±0.57b	17.83±2.15c
Ch/$CaCl_2$	7	23.05±1.31b	16.82±0.57c	5.58±0.25c	17.73±0.62c	17.91±1.77b
	14	23.68±1.29b	13.52±0.52b	4.32±0.21b	14.20±0.56b	17.47±1.27b
	21	21.45±1.02a	8.17±0.50a	2.37±0.10a	8.51±0.52a	16.10±1.34a
Ch/Al	7	22.62±1.96b	17.34±0.74c	5.95±0.39c	18.57±0.83c	18.17±2.19b
	14	23.61±1.10c	12.57±0.51b	3.93±0.20b	13.17±0.54b	17.10±1.35a
	21	21.40±1.53a	9.25±0.67a	2.90±0.12a	9.71±0.70a	17.54±1.95a

Where L*, a*, b* c* and h° are the color parameters of the CIELab system.
L* - brightness or luminance of the samples; between 0 and 100, corresponding to black and white respectively.
a* and b* vary from −120 to +120,
The positive a* axis shows red color, the negative a* axis shows green color.
The positive b* axis has yellow color, the negative b* axis shows a shift towards blue color.
c * - saturation, degree of dilution of the color tone with white color (white saturation=0)
h° - color tone, higher values indicate less darkening of the product and vice versa

next indicator - fragility.

In 14 days of refrigerated storage, unpackaged cherries decrease their hardness. There was an increase in packaged fruit, but it was significant only for packaged fruit Ch/$CaCl_2$.

After 21 days, control fruits (K) increased their scores for this indicator.

For the packaged samples with Ch/$CaCl_2$ there is a significant decrease in values, indicating that the packaging fails to preserve the fruit well enough for 21 days.

Ch/Al - wrapped fruits have no significant changes for 21 days of storage, the packaging preserves the cherries well during refrigerated storage.

The next indicator - friability, had no significant changes in the unpackaged and control samples until the 7th day.

On the second week, an increase was observed for all fruits, but it was significant only for the package with Ch/$CaCl_2$.

At the end of storage (21 days) for the control fruits there are the highest values for this indicator, the packages manage to maintain better friability during storage.

The modulus of elasticity has a significant decrease in the alginate packaging on the 7th day.

After 14 days of storage, the decrease was for all samples and this was maintained until day 21 with no significant differences in results.

Changes in firmness and elasticity indicate loss of freshness and reduce the sensory perception of the fruit.

The results obtained show preservation of cherries for a longer period of time by packaging them in edible packaging.

Color characteristics of cherries

Changes in color characteristics depend on packaging and storage time, the results are presented in table 2.

The first indicator of the color characteristics of the fruits is Brightness, L. When packing the fruit, the brightness changes, and during storage it decreases for all samples.

In the case of the control - unpackaged fruit, after the first week of storage there is a significant decrease in the result from the beginning of the test, and there are no significant differences between the control and the packaged fruit, which is preserved until the 14th day.

After 21 days of storage, there was a significant decrease in the results for all samples, with the lowest values for the control.

The next quantitative indicators considered for cherries are a* and b*.

The a* values decreased during storage for all samples, the difference between unpackaged and packaged cherries being insignificant during the first week of the test, and after the two-week period the unpackaged sample had significant differences with the packaged.

This shows that the packs tend to keep this indicator better for 14 days, but on the 21st day the effect of the packs changes.

The b* index also decreased during refrigerated storage, with the packages maintaining higher values until day 14, but then decreasing their results.

After the quantitative indicators, the qualitative indicators of color are considered: saturation (C*) and color tone (h°).

Saturation (C* value) indicates a brighter color of the fruit skin and a higher market value.

The type of packaging and storage time showed the same influence on fruit saturation, until day 14 all packaged fruits had higher values than cherries without packaging.

According to the literature, color changes are the result of enzymatic reactions that are related to the intensity of respiration (Tsaniklidis et al., 2017). Investigating these enzymatic changes and their dependence on packaging components requires further study in the future.

The influence of packaging and storage time for the color tone (h*) is the least, the values are almost constant throughout the period of the test conducted (21 days).

The results obtained show that the packaging better preserves the color of the fruit up to the 14th day, with the chitosan/alginate film giving the best results of the variants tested, due to the strong polyelectrolyte complex occurring in the coating, which is a better barrier to oxygen and slows down the enzymatic darkening process.

Similar color change results were observed after the 15th day in other groups packing cherries with polyvinyl alcohol chitosan wrapping, proving weaker changes in wrapped fruit compared to unwrapped (Jiang et al., 2023).

These results prove the positive impact of biodegradable packaging during fruit storage in terms of their color characteristics.

Conclusion

In summary, chitosan-based multicomponent films are environmentally friendly, biodegradable and do not pollute the environment. Their use helps in sustainable resource management and reduces the use of plastic and synthetic packaging that pollute the soil and the environment.

Edible packaging helps in preserving fruits in refrigerated storage for a longer period of time.

It is important to note that for each packaging there is an appropriate storage time for the samples, which allows them to remain without significant changes in the main indicators regarding their quality.

In our study, it was found that alginate packaging helps in preserving cherries for up to 14 days.

The composition, quantity of packaging and the method of packaging are essential.

There is a difference in the storage time of fruits with different packaging methods, which should be examined in more detail in the future to determine the most suitable methods for specific products.

It is also important to conduct more studies on the degradation time of packaging and the impact on the environment.

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