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Nanocoating-konjac enriched natural antimicrobials to maintain the quality of Siam Kintamani oranges at various ripeness

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Abstract

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Siam Kintamani oranges (*Citrus nobilis* Tan) are gaining popularity among consumers due to their nutritional content and health benefits. However, their quality deteriorates rapidly postharvest, necessitating effective postharvest handling techniques. This study explores using konjac nanocoating enriched with natural antimicrobial agents to maintain the fruit's quality at various ripeness stages. The konjac nanocoating, made from konjac glucomannan and infused with essential oils such as thyme, clove, and cinnamon bark, was tested using a dipping method. The research comprised characterizing the fruit based on ripeness, applying the konjac nanocoating, and analyzing the structure and properties of the coating using a scanning electron microscope. Observed variables included water content, degree of acidity, vitamin C, total dissolved solids, total microbes, color, and texture. Results indicated that applying konjac nanocoating enriched with antimicrobial agents significantly extended the shelf life and preserved the quality of Siam Kintamani oranges. The findings suggest that konjac-based nanocoating enriched with natural antimicrobial clove oil can serve as an innovative solution for enhancing the quality and shelf life of Siam Kintamani oranges, considering the critical maturity stage of 28 weeks. This research provides new insights into natural preservation methods that can reduce reliance on synthetic preservatives, thereby supporting sustainability in the agricultural and food industries. The success of the konjac nanocoating application is highly dependent on the fruit's ripeness stage, which affects its effectiveness in minimizing damage and maintaining quality during storage.

*Keywords***:** Siamese orange; Kintamani; shelf life; nanocoating; konjac

Introduction

Siam Kintamani oranges (*Citrus nobilis* Tan) are a high-value fruit commodity and are currently very popular. According to Siam Kintamani, oranges contain bioactive components such as organic acids, vitamin C, phenolics, carotenoids, and fiber, which are beneficial for health. In addition to having a sweet and delicious taste, Siam oranges can aid digestion, combat obesity, boost immunity, and prevent cancer and premature aging (Strano et al., 2021). The distinctive characteristics of Siam Kintamani oranges include their thick and rough skin, with a slightly wrinkled surface (±2 mm). The base of the fruit has a short neck and a profoundly indented apex. The fruit's flesh is soft, with a sweet and fragrant flavor. The stage of ripeness determines the bioactive components it contains, which influences its shelf life (Alshallash et al., 2022). Public awareness of health issues has increased demand for high-quality oranges with a long shelf life. Simple postharvest technology innovations are crucial in maintaining quality, extending shelf life, and enhancing overall consumer appeal (Habibi et al., 2020).

The production of Siam Kintamani oranges continues to increase. However, this is accompanied by postharvest losses due to inadequate handling during distribution and storage. The decline in the quality of Siam oranges due to mechanical damage is estimated at 15–20%. Damage such as skin cracking and rot from microbial infection or contamination by fungi, molds, and bacteria often determines consumer preference. According to Khefifi et al. (2020), oranges stored indoors only last for 4 days, making the application of natural coatings highly recommended. Proper postharvest handling is necessary to reduce the deterioration of Siam Kintamani oranges (Mohammed et al., 2024). The application of nanocoating on Siam Kintamani oranges after harvest is essential to ensure that the product remains fresh for consumers(Chinchkar et al., 2025). Nanocoating is a coating application at a scale of 0.1–100 nm (Suriati et al., 2021). It can be applied to the surface of fresh fruit to maintain its quality and shelf life (Ghosh et al., 2021). The advantages of nanocoating include: *1*) Antimicrobial properties; *2*) Enhanced mechanical properties (flexibility, durability, temperature, and humidity resistance); *3*) Improved emulsion systems; and *4*) Bioavailability to enhance the absorption of bioactive components. Nanocoating functions as a carrier for additives and as a barrier against chemical, physical, and biological changes (Dini, 2022). According to Basaglia et al. (2021), nanocoating helps maintain quality and extend the shelf life of fruits. The effectiveness of nanocoating on the surface of fruits is optimized by the addition of antimicrobial materials (Suarez-Barreiro et al., 2024). Previous research indicates that konjac nanocoating is highly promising for addressing postharvest issues in Siam Kintamani oranges (Suriati, 2023). Konjac nanocoating is made from konjac glucomannan, which can be enriched with active additives such as antimicrobials, and possesses biodegradable properties, low toxicity, is cost-effective, and easy to apply (Butler et al., 2024; Xiao et al., 2022).

One way to enhance the effectiveness of konjac nanocoating is to incorporate natural additives with hydrophobic properties (Díaz-Montes and Castro-Muñoz, 2021; Dini, 2022). Currently, natural antimicrobials are increasingly preferred due to their safety, availability, and non-harmful effects on health. Antimicrobial agents used in food applications can include essential oils, bacteriocins, enzymes, diterpenes, and fatty acids (Hu et al., 2020; Perdana et al., 2021). Essential oils from several plants exhibit biological activity as antibacterial and antifungal agents (Reyes et al., 2021). Among the essential oils with a broad spectrum of antimicrobial efficacy are thymol from thyme, cinnamon bark oil from cinnamon, and clove oil from clove. Research has shown that thyme oil (Ochoa-Velasco et al., 2021), cinnamon bark oil (Gao et al., 2018), and clove oil (Pernin et al., 2019) possess antimicrobial activity. Clove oil, cinnamon bark oil, and thyme oil demonstrate antimicrobial capabilities against bacteria, molds, and yeasts (Li et al., 2021; Lu et al., 2021; Mousavian et al., 2021). The emulsion of essential oils with water can be optimized by adding glycerol, which contains both polar and non-polar groups (Perdana et al., 2021).

The formulation of konjac nanocoating enriched with natural antimicrobial agents shows significant effects on various quality parameters of Siam Kintamani oranges. This research is essential to investigate the impact of different types of natural antimicrobial agents, specifically essential oils, on the effectiveness of konjac nanocoating in preserving the quality of Siam Kintamani oranges. The ripeness stage of Siam Kintamani oranges not only determines their flavor and quality, but also influences the effectiveness of konjac nanocoating in extending shelf life (Ha et al., 2023). Oranges that are either too young or too ripe exhibit different surface characteristics (Lon Kan et al., 2019). Younger fruit tends to be more challenging and has a higher natural wax content, whereas ripe fruit has a softer and smoother surface. These differences affect the adhesion properties of the coating (Strano et al., 2021). Younger fruit typically contains more natural wax, which can create a barrier layer between the coating and the fruit surface, thereby reducing the coating's adhesive strength (Zacarías-García et al., 2022). The sugar content in the fruit can influence the acidity. Changes in pH can affect the performance of specific coatings (Mohammed et al., 2024). Fruit harvested too young or too ripe may require special handling during postharvest processes (Alshallash et al., 2022). Improper handling can damage the fruit's surface and reduce the effectiveness of the coating (Butler et al., 2024). The ripeness stage also affects the rate of fruit maturation during storage. Fruit that is too ripe at harvest will spoil quickly, thereby reducing the time available for coating application (Mohammed et al., 2024).

This research is significant because the success of the konjac nanocoating application is influenced by the ripening rate of the fruit during storage; thus, the ripeness stage of Siam Kintamani oranges also affects their quality. According to Suhag et al. (2020), the accuracy of the application process can preserve product quality. The most common method for applying nanocoating is dipping, in which the oranges are immersed in a solution containing the nanocoating material for several minutes. Kumar et al. (2021) state that the properties of the nanocoating that maintain the quality of the coated product are determined by the surface topography of the fruit, thickness, structure, and uniformity of the desired layer. Based on this, research should be conducted to optimize the dipping method for Siam Kintamani oranges at different ripeness stages into a konjac nanocoating solution enriched with natural antimicrobial agents. The novelty of this research lies in the effectiveness of the konjac nanocoating solution, enhanced with natural antimicrobial agents, in preserving the quality of Siam Kintamani oranges at specific ripeness stages. This study aims to determine the impact of the konjac nanocoating enriched with natural antimicrobial agents on maintaining the quality of Siam Kintamani oranges at particular ripeness stages.

Materials and Methods

Tools and materials

The tools used include scissors, stirring spoons, plastic gloves, masks, knives, blowers, and blenders. The analytical equipment consists of dropper pipettes, volumetric pipettes, beakers, measuring flasks, Petri dishes, graduated cylinders, Erlenmeyer flasks, incubators (Memmert, Germany), texture analyzers (TA.XTplus), colorimeters (Cs-280, Zhejiang), pH meters (Hanna HI 8424, Europe), hand refractometers (950.032 B-ATC, France), UV-Vis spectrophotometers (Libra S60, USA), test tubes (Pyrex), funnels, analytical balances (Ohaus, USA), viscometers (Fluid meter NDJ8S), magnetic stirrers (VWR IKA VMS-C7, USA), Scanning Electron Microscopes (SEM) (JSM-651OLA, Cambridge), and sonicates (Q Sonica Sonicate Q125), as well as electric stoves. The primary materials include Siam Kintamani oranges (*Citrus nobilis* Lour.), sourced from farmers in Bayung Gede Village, Kintamani District, Bangli Regency, Bali Province, at ripeness stages of 24, 28, and 32 weeks after flowering. Konjac glucomannan powder, derived from konjac tubers (*Amorphophallus muelleri*), and natural antimicrobial agents such as clove essential oil, cinnamaldehyde, and thyme are also used. The analytical substances include distilled water, PCA media, NaCl dilution solutions (Oxoid, UK), sulfuric acid, sodium phosphate, and ammonium molybdate (Merck, Germany).

Research Implementation

The stages of this research begin with the characterization of Siam Kintamani oranges. The fruit's characteristics are tested before applying konjac nanocoating, prepared intact, and sorted based on ripeness levels precisely 24, 28, and 32 weeks after flowering. Each research unit consists of 60 fruits. The observed variables include weight loss, color (Ahmad et al., 2024), texture (Mohammed et al., 2024), moisture content (Ismael and Hadi, 2024), pH (Zia et al., 2025), vitamin C content (Zia et al., 2025), total soluble solids (Mohammed et al., 2024), and total microbial count (Suriati et al., 2021). The application of konjac nanocoating enriched with antimicrobial agents on the surface of Siam Kintamani oranges is conducted using the dipping method. This research employs a randomized block factorial design. The first factor is the ripeness stage: 24, 28, and 32 weeks. The second factor is the type of natural antimicrobial agents, which include thymol, clove oil, and cinnamon bark. During this phase, analyses are performed on weight loss, color (Ahmad et al., 2024), texture (Mohammed et al., 2024), moisture content (Ismael and Hadi, 2024), pH (Zia et al., 2025), vitamin C content (Zia et al., 2025), total soluble solids (Mohammed et al., 2024), and total microbial count (Suriati et al., 2021). The subsequent research focuses on examining the topographical structure and thickness of the konjac nanocoating on the surface of Siam Kintamani oranges, selected from the best treatments using a Scanning Electron Microscope (SEM) (Lu et al., 2021).

Data Analysis

The data obtained were analyzed using Analysis of Variance. The ANOVA results indicated significant to highly significant interaction effects, followed by the Duncan Multiple Range Test. Single treatments that showed significant to highly significant effects were further analyzed using the Honestly Significant Difference test.

Result and Discussion

Characteristics of Siam Kintamani oranges without konjac nanocoating application

Siam Kintamani oranges grow in mountainous areas with a cool climate and possess several distinct characteristics, including a sweet and fresh flavor. The fruit is typically medium to large, with a round or oval shape. Its skin is thick and rough, with a slightly wrinkled surface. The flesh is bright orange, juicy, and contains many seeds, with a soft and easy-to-chew texture. This orange is rich in vitamin C, fiber, and antioxidants, making it a healthy choice for consumption. The shelf life of Siam Kintamani oranges tends to be limited, and they spoil quickly if not stored properly. The skin color of the fruit is generally yellowish-green when immature and changes to bright orange when ripe (maturity stages: 24 weeks green, 28 weeks yellow-green, and 32 weeks bright orange). Characterization of Siam Kintamani oranges before the application of konjac nanocoating is essential to obtain baseline data that will aid in evaluating the effects of the nanocoating application. Several parameters analyzed at this stage can be seen in Table 1.

Weight loss in food science

Weight loss refers to the decrease in the mass of stored food materials (Nunes et al., 2023). Analysis of variance (ANOVA) on weight loss indicates that the type of essential oil applied results in significant differences, while maturity stages and their interactions show no significant differences. For instance, Kintamani Siam oranges treated with nanocoating containing eugenol oil exhibit the lowest weight loss. Coatings enriched with essential oils significantly enhance the quality of oranges by reducing weight loss compared to control treatments, effectively extending shelf life without negatively impacting sensory attributes (Radi et al., 2018). Edible coatings that incorporate eugenol present a commercially viable method to prevent spoilage and maintain the quality of oranges (Pham et al., 2023). Environmental conditions, such as temperature and physiological processes, can affect the weight loss of oranges (Garcıá-Pastor et al., 2024). Weight loss of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Table 2.

Water content

Water content refers to the amount of moisture present in food products. It is a critical parameter for determining the quality and shelf life of food materials (Bintoro et al., 2024). Analysis of variance (ANOVA) on water content reveals that the type of essential oil, maturity stages, and their interactions show no significant differences. For example, Kintamani Siam oranges at 28 weeks of maturity, treated with konjac nanocoating enriched with eugenol oil, demonstrate the highest levels of bioactive components. The maturity stage of the fruit significantly influences its water content. During the early maturity stage, the water content in the fruit is relatively high, making it fresh and crisp with a juicier texture. As the fruit reaches full maturity, water content peaks, optimizing flavor and sweetness. However, once the maturity phase is surpassed, water content begins to decline. This process can be attributed to evaporation, spoilage, or ongoing metabolism (Alshallash et al., 2022; Mohammed et al., 2024). Overall, understanding the relationship between maturity stages and water content is crucial in agriculture and the food industry to ensure optimal fruit quality (Garcıá-Pastor et al., 2024). Essential oils can form a protective layer on the fruit's surface, helping to reduce water evaporation and maintain stable water content in oranges (Gu et al., 2024). Moreover, essential oils possess antimicrobial properties that can inhibit microorganism growth, thereby reducing spoilage and helping to preserve the fruit's water content (Dong et al., 2023). The suitability of essential oils for coating oranges and their ability to maintain moisture while preventing oxidative damage are significant factors in enhancing fruit quality (Kowalewska and Majewska-smolarek, 2023). Water content of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Table 3.Table 3:

Table 1. Average water content values, degree of acidity, vitamin C, total dissolved solids, and total microbes, color, and texture of Siam Kintamani oranges

Component	Maturity stage (week)		
	24	28	32
Water content (%)	89.31	90.45	89.22
Degree of acidity	3.06	3.56	4.41
Vitamin C (μg/g)	61.78	73.78	65.80
Total Dissolved Solids (ºbrix)	14.75	15.35	15.05
Total Microbes (log cfu/g)	2.58±0.14	2.12±0.73	2.57±1.62
Color	75.86	78.76	94.57
Texture (N)	20.79	21.92	23.41

Source: Authors' own elaboration

Table 2. Weight loss of Kintamani Siamese Oranges after nanocoating-konjac application

Type of Essential Oil	Maturity stage (week)			Average
	24	28	32	
Thyme	13.67±1.65	11.63±0.26	11.65±1.33	12.32±1.17
Clove	8.84±1.97	7.30±0.91	4.03±4.17	6.73±2.46
Cinnamon bark	10.49±1.78	10.30±1.38	8.19±1.13	9.66±1.28
Average	11.00±2.45	9.75±2.22	7.96±3.81	

Source: Authors' own elaboration

Acidity level

The acidity level is used to express the degree of acidity or alkalinity of a solution (Suriati and Gede Pasek Mangku, 2023). Analysis of variance on the acidity of Kintamani Siam oranges reveals significant differences based on the type of essential oil used and the maturity stages, while their interactions show no significant differences. As the oranges ripen, various quality parameters change, such as the acidity of the fruit, which indirectly influences water loss and sugar accumulation (Nasrin et al., 2020). Overall, the maturity of the oranges significantly affects their acidity level, impacting the taste and quality of the fruit itself (Zacarías-García et al., 2022). During the ripening process, the levels of citric acid and other acids typically increase in the early stages of maturity. However, as ripening progresses, these acid levels tend to decrease (Pham et al., 2023). The application of essential oils as a coating material on oranges can influence the acidity and overall quality of the fruit (Gu et al., 2024). Essential oils can inhibit the activity of enzymes involved in the ripening process, thereby slowing down changes in acidity (Díaz-Montes and Castro-Muñoz, 2021). Degree of acidity of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Table 4.

Vitamin C

Vitamin C is an essential nutrient crucial for overall health, commonly found in various fresh fruits, mainly citrus fruits (Chinchkar et al., 2025). Analysis of variance on vitamin C content indicates that the type of essential oil, maturity stages, and their interactions show no significant differences. Maturity also affects nutrient concentration. Ripe oranges tend to have higher levels of vitamin C and minerals, as well as bioactive components that can influence their acidity (Zacarías-García et al., 2022). Ripe fruits generally offer better taste and are more appealing to consumers. However, once fruits surpass full maturity, vitamin C levels begin to decline (Alshallash et al., 2022). Oxidation and spoilage processes can lead to nutrient loss, including vitamin C (Gu et al., 2024). Essential oils can form a protective layer that reduces direct contact with oxygen, helping to slow down the oxidation of vitamin C (Aini et al., 2022). Some essential oils possess antimicrobial properties that can help prevent the growth of microorganisms that may damage the fruit and decrease its nutrient content (Kowalewska and Majewska-smolarek, 2023). Essential oils can aid in maintaining fruit quality, contributing to the stability of vitamin C levels (Yang et al., 2021). The effectiveness of essential oils in preserving vitamin C is more significant in more mature fruits, as these fruits are more susceptible to damage (Shenbagam et al., 2023). According to Harsojuwono et al. (2022), coatings containing essential oils significantly improve the quality of orange slices by maintaining ascorbic acid levels, thus effectively extending shelf life. Vitamin C of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Table 5.

Total dissolved solids

Total dissolved solids (TDS) refer to the total amount of dissolved mineral elements or compounds in a solution. TDS is often associated with total sugar content, as the sweetness quality of fruit is measured by sugar concentration (Lugaresi et al., 2024). Analysis of variance on total dissolved solids indicates that the type of essential

Table 3. Water content of Kintamani Siamese oranges after nanocoating-konjac application

Type of essential oil	Maturity stage (week)			Average
	24	28	32	
Thyme	89.02±0.28	92.38±0.72	91.16±0.62	90.86±1.70
Clove	89.23±0.76	89.65±0.76	88.70±0.90	89.19±0.48
Cinnamon bark	89.96±16.42	88.14±0.27	87.59±1.58	91.90±6.99
Average	92.74±6.26	90.06±2.15	89.15±1.83	

Source: Authors' own elaboration

Table 4. Degree of acidity of Kintamani Siamese oranges after nanocoating-konjac application

Type of essential oil	Maturity stage (week)			Average
	24	28	32	
Thyme	3.40±0.00	3.30±0.13	3.58±0.04	3.43±0.14
Clove	3.11±0.25	3.31±0.22	3.73±0.02	3.38±0.32
Cinnamon bark	3.52±0.16	3.49±0.27	4.00±0.08	3.67±0.29
Average	3.34±0.21	3.37±0.10	3.77±0.22	

Source: Authors' own elaboration

Table 5. Vitamin C of Kintamani Siamese oranges after nanocoating-konjac application (μg/g)

Type of essential oil	Maturity stage (week)			Average
	24	28	32	
Thyme	70.22±14.49	157.61±123.36	50.48±3.51	92.77±57.01
Clove	51.58±3.41	44.55±14.03	70.58±19.10	55.57±13.47
Cinnamon bark	137.60±48.43	97.77±3.28	77.58±5.15	104.32±30.54
Average	86.47±45.26	99.97±56.56	66.21±14.07	

Source: Authors' own elaboration

oil, maturity stages, and their interactions show significant differences. The impact of maturity stages and types of essential oils in coatings on total dissolved solids (TDS) in immature fruit is usually relatively low (Aini et al., 2022; Alshallash et al., 2022). As the fruit reaches full maturity, the total dissolved solids increase due to higher concentrations of sugars and acids, contributing to sweetness (Nasrin et al., 2020). TDS decreases after surpassing full maturity due to spoilage processes or metabolic changes that reduce sugar and acid concentrations (Chinchkar et al., 2025). Coating with essential oils can help maintain moisture, keep the fruit fresh, and preserve the levels of sugars and acids, which contributes to the stability of TDS (Radi et al., 2018). The type of essential oil added to the nanocoating solution can affect TDS levels (Gu et al., 2024). Nanocoating enriched with essential oils can help retain or enhance total dissolved solids, as the fruit already possesses an optimal flavor (Dong et al., 2023). Konjac nanocoating enriched with clove oil tends to show stable increases as the fruit achieves optimal ripeness. Appropriate nanocoating can optimize flavor and nutrient content, including total dissolved solids (Hu et al., 2020). Total disolved solid of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Figure 1.

Total microbial count

Total microbial count refers to the total number of microorganisms (bacteria, fungi, and other microbes) present in a sample, such as food, water, or a specific environment (Perdana et al., 2021). This total microbial count is often used as an indicator of the cleanliness and safety of a product, particularly in the food industry (Dini, 2022). Analysis of variance on the total plate count (TPC) of Kintamani Siam oranges shows that the type of essential oil, maturity stages, and their interactions have significant effects. Kintamani Siam oranges stored at room temperature for 28 weeks of maturity, when treated with konjac nanocoating enriched with clove oil, demonstrate the lowest total microbial count. Immature fruit tends to have lower sugar content and higher acidity, which can inhibit the growth of certain types of microbes (Alshallash et al., 2022). Nanocoating applied to younger fruit is more effective in retaining moisture and reducing microbial contamination (Ngoc et al., 2022). When nanocoating is applied to overripe fruit, it helps extend shelf life and reduce total microbial count; however, its effectiveness depends on the type of essential oil used (Kowalewska and Majewska-smolarek, 2023). Essential oils such as clove oil, cinnamon bark oil, and thyme oil exhibit varying antimicrobial properties (Gu et al., 2024). Coatings combined

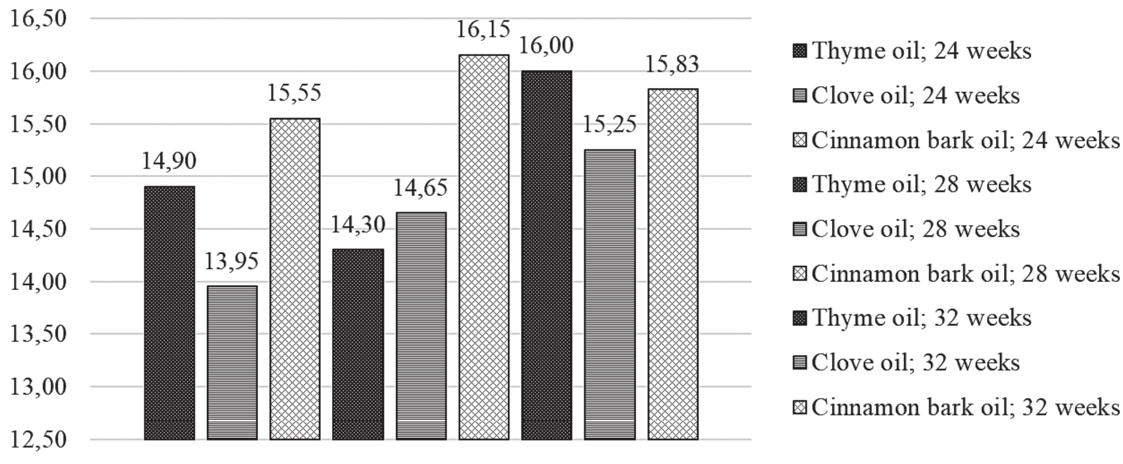

Fig. 1. Total dissolved solids of Siam Kintamani oranges after application of nanocoating-konjac

Source: Authors' own elaboration

with clove oil have shown effectiveness in inhibiting pathogens and slowing the growth of molds and yeasts on the fruit surface (Pham et al., 2023). Furthermore, clove oil enhances its function as a probiotic, thereby reducing pH decline, color changes, and acidity (Nunes et al., 2023). Bioactive compounds with antimicrobial activity, such as clove oil, can serve as alternatives to antibiotics against many pathogenic microbes, helping to reduce the increasing resistance of microorganisms to antibiotics (Kowalewska and Majewska-smolarek, 2023). The combination of appropriate maturity stages and effective types of essential oils can lead to better nanocoating for controlling total microbial count. Total Microbes of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Figure 2.

Color

Citrus fruits can exhibit colors other than orange. In some regions, some oranges are yellow or even green, which can occur due to the climatic conditions where the oranges are grown (Ahmad et al., 2024). Analysis of variance in the color of Kintamani Siam oranges indicates that the type of essential oil and its interactions have significant effects, while maturity stages show no significant differences. Applying konjac nanocoating to Kintamani Siam oranges postharvest results in no significant color changes, and the texture remains relatively stable, mainly when treated with konjac nanocoating and eugenol oil at 28 days of maturity, keeping the fruit in fresh quality. Early-stage fruit typically appears greener or less developed, indicating that the ripening process is not yet optimal. As fruit reaches full maturity, the color becomes brighter and more appealing (Baldassi et al., 2024). More intense colors often indicate higher nutrient content and improved flavor. Essential oils can help protect the fruit's color from oxidation and damage due to light exposure (Gu et al., 2024). By forming a protective layer, essential oils can preserve the fruit's color for a more extended period. The type of essential oil used can impart different colors depending on its chemical composition and aromatic properties (Ochoa-Velasco et al., 2021). Some oils can enhance the visual appearance of the fruit, making it more attractive to consumers. The use of essential oils on ripe fruit can help maintain or improve color, while on unripe fruit, essential oils may not have the same Effect (Shenbagam et al., 2023). Effective coatings can slow down color degradation that typically occurs during storage, ensuring that the fruit remains looking fresh and appealing for a longer time. Color of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Figure 3.

Texture

Ripe citrus fruits have the smoothest skin texture and the lowest firmness (Aini et al., 2022). Analysis of variance on the total plate count of Kintamani Siam oranges indicates that the type of essential oil and its interactions have no significant effect. In contrast, maturity stages have a highly significant impact. Early-stage fruit tends to have a firmer and more rigid texture. Typically, the fruit still contains a lot of starch that has not yet been converted to sugar, resulting in a less sweet taste and a less appealing texture. As the fruit reaches full maturity, the texture usually becomes softer and juicier (Garcıá-Pastor et al., 2024). The ripening process causes changes in the cell structure, where starch is broken down into sugars, providing better sweetness and a more pleasant texture (Ha et al., 2023). After surpassing full maturity, the fruit's texture may begin to decline. Spoilage or moisture loss can cause the fruit to become mushy or even rotten, which reduces overall quality (Zacarías-García et al., 2022). Essential oils can form a protective layer on the fruit's surface, helping to retain moisture. This is important for maintaining good texture, preventing

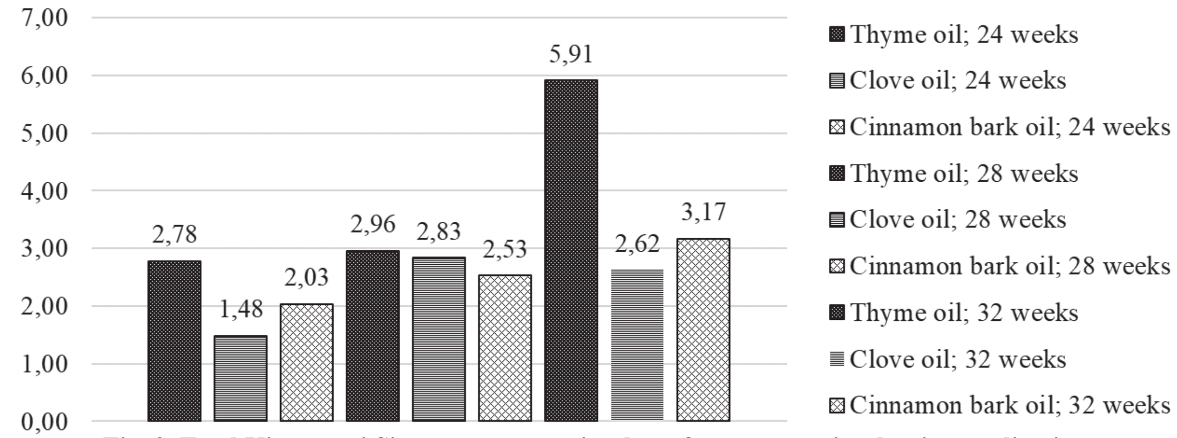

Fig. 2. Total Kintamani Siamese orange microbes after nanocoating-konjac application

Source: Authors' own elaboration

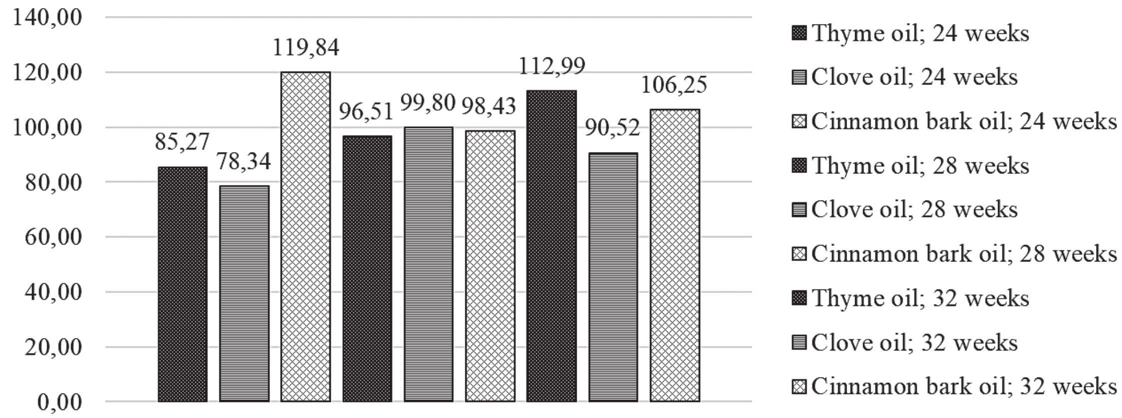

Fig. 3. Color of Kintamani Siamese oranges after nanocoating-konjac application
Source: Authors' own elaboration

dryness, and avoiding the loss of a crispy sensation (Dong et al., 2023). Some essential oils have antimicrobial properties that can prevent damage caused by microorganisms, thereby better preserving the fruit's texture during storage (De Bruno et al., 2023). Coating with essential oils on ripe fruit can help maintain optimal texture, while on unripe fruit, the effects may not be as significant (Chinchkar et al., 2025). Proper coatings can optimize the fruit's texture, providing a better sensory experience when consume. Texture of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in the Table 6

Structure and thickness of konjac nanocoating

The structure and thickness of konjac nanocoating significantly influence quality attributes such as adhesion, hardness, flexibility, and permeability (Zhang et al., 2020). The results of the study on the structure of konjac nanocoating enriched with clove oil can be seen in Figure 4, while the thickness of the konjac nanocoating is shown in Figure 5. The thickness of the konjac nanocoating is measured at 4.294 µm. This thickness provides optimal protection for Kintamani Siam oranges from environmental influences without adding excessive weight (Suriati et al., 2021). The maturity stage of the fruit can affect how essential oils are absorbed and how the coating layer is formed. Ripe fruit tends to have softer skin, which can influence the thickness and distribution of the coating (Suhag et al., 2020). In immature fruit, the skin may be more complicated to absorb essential oils, resulting in a thinner coating layer (Ha et al., 2023).

Conversely, in mature fruit, the coating layer can be more uniform and thicker. Overripe fruit may have a more fragile structure, which could make the coating layer easier to detach or damage, impacting its thickness and effectiveness (Ha et al., 2023). The type of essential oil used also affects the viscosity and flow characteristics of the coating. Oils with higher viscosity can produce a thicker coating layer (De Bruno et al., 2023). The chemical composition of the essential oils can also influence interactions with the fruit surface, affecting the strength and durability of the coating (Reyes et al., 2021). The maturity of the fruit and the type of essential oil used interact with each other. In more mature fruit, essential oils may spread more quickly and form a thicker, more uniform layer. The quality and method of coating application also have an impact (Mohammed et al., 2024). Even application on ripe fruit can lead to a more effective and longer-lasting coating. The effectiveness of konjac nanocoating can be enhanced by adding natural antimicrobial agents, such as essential oil from clove plants or eugenol oil. The appearance, the surface structure, the thickenes of Kintamani Siamese Orange after Nanocoating-konjac application can be seen in Figures 4, 5, and 6.

Table 6. Texture of Kintamani Siamese oranges after nanocoating-konjac application (n)

Type of essential oil	Maturity stage (week)			Average
	24	28	32	
Thyme	32,36±0,64	24,88±4,75	22,67±0,31	26,63±5,08
Clove	33,00±6,08	226,48±3,08	26,08±5,07	28,52±3,89
Cinnamon bark	34,90±2,51	25,11±0,70	26,38±2,94	28,41±5,74
Average	33,42±1,32	25,11±1,28	25,04±2,06	

Source: Authors' own elaboration

Fig. 4. The appearance of Kintamani Siam oranges before and after nanocoating-konjac application based on the maturity stage

Source: Authors' own elaboration

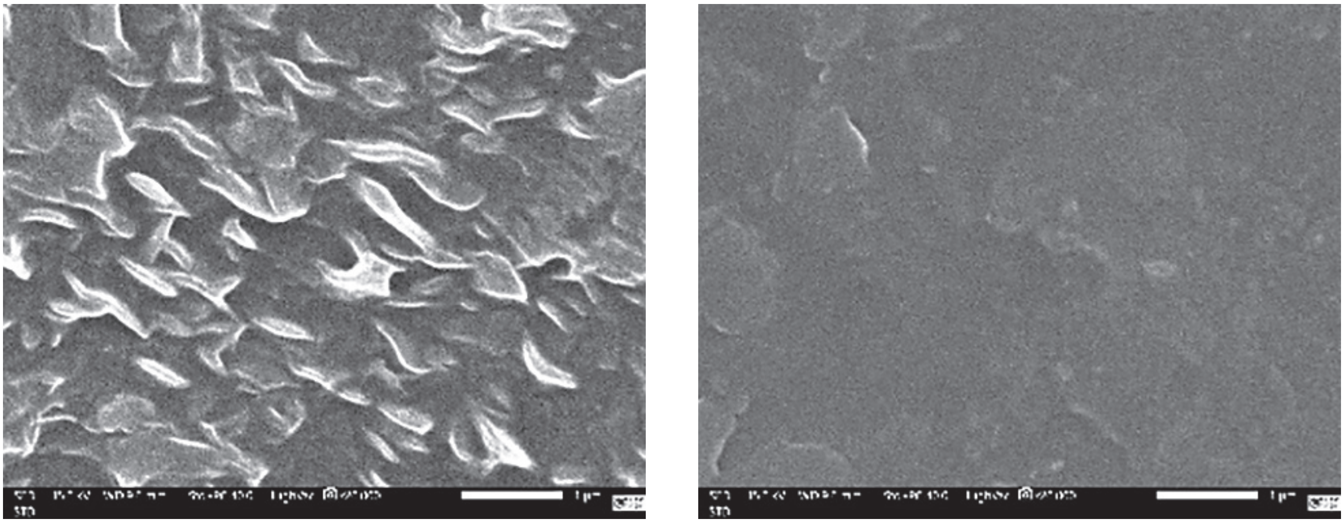

Fig. 5. The surface structure of Siam Kintamani orange peel before and after application nanocoating-konjac

Source: Authors' own elaboration

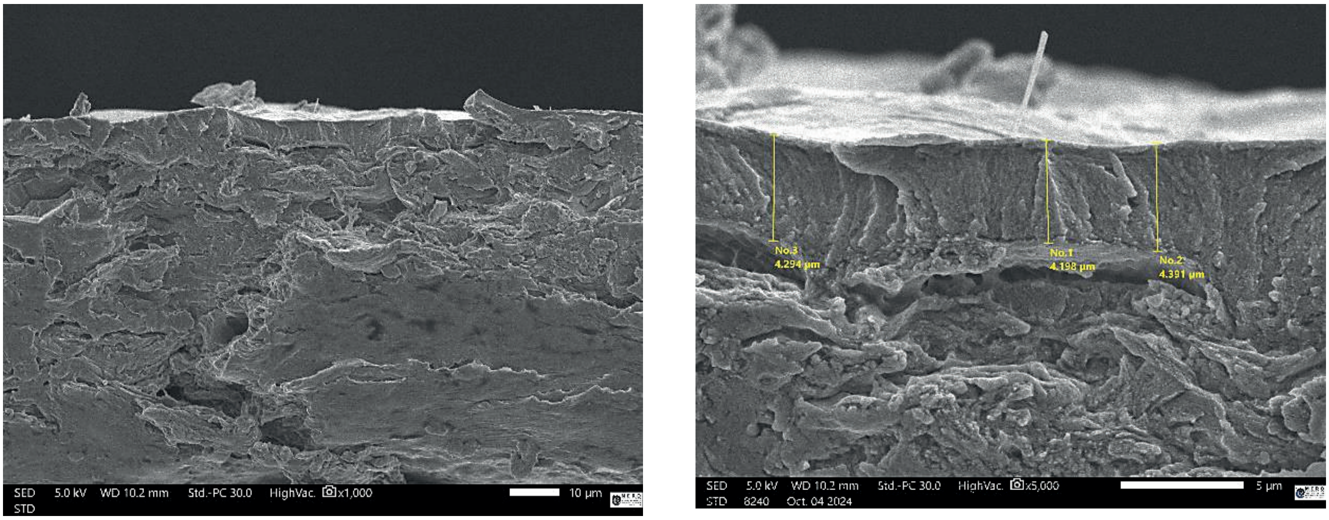

Fig. 6. The thickness of nanocoating-konjac on the surface of Siam Kintamani orange peel after nanocoating application enriched with clove oil

Source: Authors' own elaboration

Conclusion

Using konjac-based nanocoating enriched with natural antimicrobials significantly enhances the quality of Siam Kintamani oranges. Quality assessments across various maturity stages indicate that nanocoating is most effective on optimally ripe fruit, precisely at 28 weeks of maturity. Oranges treated with konjac nanocoating fortified with clove oil retain higher levels of nutrients and moisture than those treated with cinnamon bark oil and thyme oil. Compared to untreated controls, nanocoated oranges exhibit improvements in quality parameters, including vitamin C content, total soluble solids, and texture. The incorporation of natural ingredients in konjac nanocoating offers advantages in terms of sustainability and food safety, making it an appealing alternative for fruit preservation. This study recommends the commercial application of konjac nanocoating as an effective strategy for maintaining the quality of Siam Kintamani oranges, particularly at their optimal maturity stage for consumption. Overall, the findings suggest that konjac-based nanocoating enriched with natural antimicrobial clove oil can enhance the quality and shelf life of Siam Kintamani oranges, considering the critical maturity stage of 28 weeks.

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Conflict of interest

The authors declare no personal conflict of interest that would improperly influence the representation or interpretation of the reported research results. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in writing the manuscript, or in the decision to publish the results. All authors declare that they have no competing interests.

References

Ahmad, M. M., Qureshi, T. M., Zia, M., Mushtaq, M., Iqbal, M. W., Cacciotti, I., Esatbeyoglu, T. & Korma, S. A. (2024). Analytical study to measure the variability in quality factors attenuating the export of Kinnow/Mandarin fruit. *Measurement: Food, 1*4(November 2023), 100155. https://doi.org/10.1016/j.meafoo.2024.100155.

Aini, N., Dwiyanti, H., Setyawati, R., Handayani, I., Septiana, A. T., Sustriawan, B. & Aena, D. A. Q. (2022). Siam orange (*Citrus nobilis* L.) nectar characteristics with variations in stabilizer and sucrose level. *Food Research, 6*(3), 315 – 323. https://doi.org/10.26656/fr.2017.6(3).386.

Alshallash, K. S., Sharaf, M., Abdel-Aziz, H. F., Arif, M., Hamdy, A. E., Khalifa, S. M., Hassan, M. F., Abou ghazala, M. M., Bondok, A., Ibrahim, M. T. S., Alharbi, K. & Elkelish, A. (2022). Postharvest physiology and biochemistry of Valencia orange after coatings with chitosan nanoparticles as edible for green mold protection under room storage conditions. *Frontiers in Plant Science, 13*(November), 1 – 15. https://doi.org/10.3389/fpls.2022.1034535.

Baldassi, C., Lee, C., Dossett, M. & Castellarin, S. D. (2024). High-throughput color determination of red raspberry puree and correlation of color parameters with total anthocyanins. *Plant Methods, 20*(1), 1 – 13. https://doi.org/10.1186/s13007-024-01197-0.

Basaglia, R. R., Pizato, S., Santiago, N. G., Maciel de Almeida, M. M., Pinedo, R. A. & Cortez-Vega, W. R. (2021). Effect of edible chitosan and cinnamon essential oil coatings on the shelf life of minimally processed pineapple (Smooth cayenne). *Food Bioscience*, 41.

Bintoro, V. P., Dwiloka, B., Ekaputri, H. & Kamil, R. Z. (2024). The effect of gelatin and konjac glucomannan concentrations on moisture content, water activity, texture, density, and protein content in synbiotic marshmallows. *Food Research, 8*(4), 409 – 419. https://doi.org/10.26656/fr.2017.8(4).623.

Butler, J., Morgan, S., Jones, L., Upton, M. & Besinis, A. (2024). Evaluating the antibacterial efficacy of a silver nanocomposite surface coating against nosocomial pathogens as an antibiofilm strategy to prevent hospital infections. *Nanotoxicology, 18*(4), 410 – 436. https://doi.org/10.1080/17435390.2024.2379809.

Chinchkar, A. V., Singh, A., Singh, S. V., Mazumder, K., Bishnoi, M. & Kamble, M. G. (2025). Application and toxicological study of polyvinyl acetate (PVAc) coating on lemon (Citrus limon L.) fruit to extend the shelf life. *Journal of Future Foods, 5*(2), 145 – 152. https://doi.org/10.1016/j.jfutfo.2024.05.003.

De Bruno, A., Gattuso, A., Ritorto, D., Piscopo, A. & Poiana, M. (2023). Effect of Edible Coating Enriched with Natural Antioxidant Extract and Bergamot Essential Oil on the Shelf Life of Strawberries. *Foods, 12*(3). https://doi.org/10.3390/foods12030488.

Díaz-Montes, E. & Castro-Muñoz, R. (2021). Edible Films and Coatings as Food-Quality Preservers: An Overview. https://doi.org/10.3390/foods10020249.

Dini, I. (2022). Contribution of Nanoscience Research in Antioxidants Delivery Used in Nutricosmetic Sector. *Antioxidants, 11*(3), 563. https://doi.org/10.3390/antiox11030563.

Dong, Y., Wei, Z., Yang, R., Zhang, Y., Sun, M., Bai, H., Mo, M., Yao, C., Li, H. & Shi, L. (2023). Chemical Compositions of Essential Oil Extracted from Eight Thyme Species and Potential Biological Functions. *Plants, 12*(24). https://doi.org/10.3390/plants12244164.

Gao, Y., Kan, C., Wan, C., Chen, C., Chen, M. & Chen, J. (2018). Quality and biochemical changes of navel orange fruits during storage as affected by cinnamaldehyde -chitosan coating. *Scientia Horticulturae, 239*(May), 80 – 86. https://doi.org/10.1016/j.scienta.2018.05.012.

Garcıá-Pastor, M. E., Garrido-Auñón, F., Puente-Moreno, J., Valero, D. & Serrano, M. (2024). Characterization of maturity stages in blood oranges: external and internal parameters. *Acta Horticulturae, 1399*, 315 – 322. https://doi.org/10.17660/ActaHortic.2024.1399.39.

Ghosh, T., Nakano, K., Mulchandani, N. & Katiyar, V. (2021). Curcumin loaded iron functionalized biopolymeric nanofibre reinforced edible nanocoatings for improved shelf life of cut pineapples. *Food Packaging and Shelf Life, 28*(May 2020), 100658. https://doi.org/10.1016/j.fpsl.2021.100658.

Gu, X., Li, J., Yang, L., Liu, L., Li, T., Zhang, H., Gao, Y. & Xiao, L. (2024). Comparative study on the different edible coatings loaded with fennel essential oil/β-cyclodextrin microcapsules for blueberry preservation. *Journal of Horticultural Science and Biotechnology, 99*(5), 584 – 596. https://doi.org/10.1080/14620316.2024.2318569.

Ha, T. T. N., Pham, T. T., Dam, S. M. A. I., Mac, X. H. O. A., Nguyen, L. P. L., Hitka, G. & Zsom, T. (2023). Effect of 1-methylcyclopropene treatment on quality of 'Zebra' apricot harvested at different maturity stages. *Progress in Agricultural Engineering Sciences, 19*, 69 – 76. https://doi.org/10.1556/446.2023.00084.

Habibi, F., Ramezanian, A., Guillén, F., Castillo, S., Serrano, M. & Valero, D. (2020). Changes in bioactive compounds, antioxidant activity, and nutritional quality of blood orange cultivars at different storage temperatures. *Antioxidants, 9*(10), 1 – 15. https://doi.org/10.3390/antiox9101016.

Harsojuwono, B. A., Arnata, I. W., Hartiati, A., Setiyo, Y., Hatiningsih, S. & Suriati, L. (2022). The Improvement of the Modified Starch—Glucomannan—Polyvinyl Alcohol Biothermoplastic Composite Characteristics With Polycaprolactone and Anhydride Maleic Acid. *Frontiers in Sustainable Food Systems, 6*(March), 1 – 13. https://doi.org/10.3389/fsufs.2022.844485.

Hu, X., Saravanakumar, K., Sathiyaseelan, A. & Wang, M. H. (2020). Chitosan nanoparticles as edible surface coating agent to preserve the fresh-cut bell pepper (Capsicum annuum L. var. grossum (L.) Sendt). *International Journal of Biological Macromolecules, 165*, 948 – 957. https://doi.org/10.1016/J.IJBIOMAC.2020.09.176.

Ismael, F. N. & Hadi, S. T. (2024). The Effect of thyme, rosemary, and lemongrass oils on extension of the shelf life and qualitative characteristics of Iraqi soft cheese. *Functional Foods in Health and Disease, 14*(1), 1 – 13. https://doi.org/10.31989/ffhd.v14i1.1262.

Khefifi, H., Selmane, R., Mimoun, M. B., Tadeo, F., Morillon, R. & Luro, F. (2020). Abscission of Orange Fruit (Citrus sinensis (L.) Osb.) in the Mediterranean Basin Depends More on Environmental Conditions Than on Fruit Ripeness. *Agronomy, 10*(4). https://doi.org/10.3390/agronomy10040591.

Kowalewska, A. & Majewska-smolarek, K. (2023). Eugenol-Based Polymeric Materials — Antibacterial Activity doses for long periods of time. Therefore, a growing interest in eu Keywords : essential oils of cinnamon, bay and tulsi leaves, turmeric, nutm Syzygium aromaticum activities of this compound. *Antibiotics, 12*(11), 1570.

Kumar, N., Pratibha, Neeraj, Ojha, A., Upadhyay, A., Singh, R. & Kumar, S. (2021). Effect of active chitosan-pullulan composite edible coating enrich with pomegranate peel extract on the storage quality of green bell pepper. *LWT, 138*, 110435. https://doi.org/10.1016/J.LWT.2020.110435

Li, M., Yu, H., Xie, Y., Guo, Y., Cheng, Y., Qian, H. & Yao, W. (2021). Effects of double layer membrane loading eugenol on postharvest quality of cucumber. *LWT*, 145.

Lon Kan, E. E., Sargent, S. A., Cantliffe, D. J., Berry, A. D. &

Shaw, N. L. (2019). Harvest maturity and storage temperature affect postharvest quality of 'wanda' datil hot pepper grown under protected culture. *Hort Technology, 29*(4), 402 – 407. https://doi.org/10.21273/HORTTECH04328-19.

Lu, W., Chen, M., Cheng, M., Yan, X., Zhang, R., Kong, R., Wang, J. & Wang, X. (2021). Development of antioxidant and antimicrobial bioactive films based on Oregano essential oil/ mesoporous nano-silica/sodium alginate. *Food Packaging and Shelf Life*, 29.

Lugaresi, A., Steffens, C. A., Heinzen, A. S., Fenili, C. L., Brighenti, A. F., de Martin, M. S. & do Amarante, C. V. T. (2024). The influence of the summer pruning on 'Fuji' apples storage under controlled atmosphere. *Acta Scientiarum – Agronomy, 46*(1), 1 – 13. https://doi.org/10.4025/actasciagron.v46i1.63557.

Mohammed, M., Alqahtani, N. K. & Ali, S. A. (2024). Development, RSM-based modeling, and process optimization of an ultrasonic coating system for extending the storage life of fresh fruits. *Frontiers in Sustainable Food Systems, 8*(June). https://doi.org/10.3389/fsufs.2024.1403164.

Mousavian, D., Mohammadi Nafchi, A. & Nouri, L. (2021). Effect of active packaging based on polyethylene/propylene films containing thymol on the quality attributes and shelf life of season salad. *Journal of Food Science and Technology (Iran), 18*(116). https://doi.org/10.29252/FSCT.18.07.06.

Nasrin, T. A. A., Rahman, M. A., Arfin, M. S., Islam, M. N. & Ullah, M. A. (2020). Effect of novel coconut oil and beeswax edible coating on postharvest quality of lemon at ambient storage. *Journal of Agriculture and Food Research, 2*, 100019. https://doi.org/10.1016/J.JAFR.2019.100019.

Ngoc, L. S., Van, P. T. H., Nhi, T. T. Y., Dung, N. A. & Manh, T. D. (2022). Effects of dipping time in chitosan (CS) and polyvinyl alcohol (PVA) mixture to quality of orange fruits during storage. *Food Science and Technology (Brazil), 42*, 1 – 7. https://doi.org/10.1590/fst.114221.

Nunes, C., Silva, M., Farinha, D., Sales, H., Pontes, R. & Nunes, J. (2023). Edible coatings and future trends in active food packaging–fruits' and traditional sausages' shelf life increasing. *Foods, 12*(17), 3308.

Ochoa-Velasco, C. E., Pérez-Pérez, J. C., Varillas-Torres, J. M., Navarro-Cruz, A. R., Hernández-Carranza, P., Munguía-Pérez, R., Cid-Pérez, T. S. & Avila-Sosa, R. (2021). Starch edible films/coatings added with carvacrol and thymol: In vitro and in vivo evaluation against colletotrichum gloeosporioides. *Foods, 10*(1). https://doi.org/10.3390/foods10010175.

Perdana, M. I., Ruamcharoen, J., Panphon, S. & Leelakriangsak, M. (2021). Antimicrobial activity and physical properties of starch/chitosan film incorporated with lemongrass essential oil and its application. *LWT*, 141.

Pernin, A., Bosc, V., Maillard, M. N. & Dubois-Brissonnet, F. (2019). Ferulic acid and eugenol have different abilities to maintain their inhibitory activity against Listeria monocytogenes in emulsified systems. *Frontiers in Microbiology, 10*(FEB). https://doi.org/10.3389/FMICB.2019.00137.

Pham, T. T., Nguyen, L. L. P., Dam, M. S. & Baranyai, L. (2023). Application of Edible Coating in Extension of Fruit Shelf Life: Review. *AgriEngineering, 5*(1), 520 – 536. https://doi.org/10.3390/agriengineering5010034.

Radi, M., Akhavan-Darabi, S., Akhavan, H.-R. & Amiri, S. (2018). The use of orange peel essential oil microemulsion and nanoemulsion in pectin-based coating to extend the shelf life of fresh-cut orange. *Journal of Food Processing and Preservation, 42*(2). https://doi.org/10.1111/jfpp.13441.

Reyes, L. M., Landgraf, M. & Sobral, P. J. A. (2021). Gelatin-based films activated with red propolis ethanolic extract and essential oils. *Food Packaging and Shelf Life*, *27*, 100607.

Shenbagam, A., Kumar, N., Rahul, K., Upadhyay□, A., Gniewosz, M. & Kieliszek, M. (2023). Characterization of Aloe Vera Gel-Based Edible Coating with Orange Peel Essential Oil and Its Preservation Effects on Button Mushroom (Agaricus bisporus). *Food and Bioprocess Technology, 16*(12), 2877 – 2897. https://doi.org/10.1007/s11947-023-03107-z.

Strano, M. C., Restuccia, C., De Leo, R., Mangiameli, S., Bedin, E., Allegra, M., Quartieri, A., Cirvilleri, G. & Pulvirenti, A. (2021). Efficacy of an antifungal edible coating for the quality maintenance of Tarocco orange fruit during cold storage. *Crop Protection, 148*(May), 105719. https://doi.org/10.1016/j.cropro.2021.105719.

Suarez-Barreiro, J. M., Suarez, M. C., Calvo, M. A., Parada, F., Cortés, F., Tobón, F. & Toro, S. (2024). Screening of essential oils against oxacillin-resistant Staphylococcus aureus strains isolated from bovine mastitis. *Boletin Latinoamericano y Del Caribe de Plantas Medicinales y Aromaticas, 23*(3), 401 – 409. https://doi.org/10.37360/blacpma.24.23.3.28.

Suhag, R., Kumar, N., Petkoska, A. T. & Upadhyay, A. (2020). Film formation and deposition methods of edible coating on food products: A review. *Food Research International, 136*(March), 109582. https://doi.org/10.1016/j.foodres.2020.109582.

Suriati, L. (2023). Nanocoating-konjac application as postharvest handling to extend the shelf life of Siamese oranges. *Frontiers in Sustainable Food Systems, 7,* 1104498. https://doi.org/doi:10.3389/fsufs.2023.1104498.

Suriati, L. & Mangku, I. G. P. (2023). Application of coating-konjac to maintain the quality of Kintamani Siamese oranges during storage. *IOP Conference Series: Earth and Environmental Science, 1228*(1), 012009. https://doi.org/10.1088/1755-1315/1228/1/012009.

Suriati, L., Utama, I. M. S., Harsojuwono, B. A., Gunam, I. B. W., Adnyana, I. M. & Fudholi, A. (2021). Nano-ecogel to maintain the physicochemical characteristics of fresh-cut mangosteen. *AIMS Agriculture and Food, 6*(4), 988 – 999. https://doi.org/10.3934/agrfood.2021059.

Xiao, M., Luo, L., Tang, B., Qin, J., Wu, K. & Jiang, F. (2022). Physical, structural, and water barrier properties of emulsified blend film based on konjac glucomannan/agar/gum Arabic incorporating virgin coconut oil. *Lwt, 154*, 112683. https://doi.org/10.1016/j.lwt.2021.112683.

Yang, R., Miao, J., Shen, Y., Cai, N., Wan, C., Zou, L., Chen, C. & Chen, J. (2021). Antifungal effect of cinnamaldehyde, eugenol and carvacrol nanoemulsion against *Penicillium digitatum and application in postharvest preservation of citrus fruit, LWT*, 141.

Zacarías-García, J., Cronje, P. J., Diretto, G., Zacarías, L.

& Rodrigo, M. J. (2022). A comprehensive analysis of carotenoids metabolism in two red-fleshed mutants of Navel and Valencia sweet oranges (Citrus sinensis). *Frontiers in Plant Science, 13*(October), 1 – 24. https://doi.org/10.3389/fpls.2022.1034204.

Zhang, K., Yang, W., Ge, F., Xu, B., Chen, Y., Yin, X., Liu, Y. & Zuo, H. (2020). A self-curing konjac glucomannan/CaCO3 coating for corrosion protection of AA5052 aluminum alloy in NaCl solution. *International Journal of Biological Macromolecules, 151,* 691 – 701. https://doi.org/10.1016/j.ijbiomac.2020.02.223.

Zia, H., Murray, H., Hofsommer, M., Barreto, A. M., Pavon-vargas, D., Puzovic, A., Gędas, A., Rincon, S., Gössinger, M. & Slatnar, A. (2025). Comparing the impact of conventional and non-conventional processing technologies on water-soluble vitamins and color in strawberry nectar – a pilot scale study. *Food Chemistry, 463*(August 2024). https://doi.org/10.1016/j.foodchem.2024.141078.

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