Article

Enhancing the shelf life of postharvest fruits and vegetables using starch-based edible coatings and natural antioxidants

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Abstract

Post-harvest losses account for an estimated 30–50% of global fruit and vegetable production, driven primarily by physiological processes (respiration, transpiration) and microbiological spoilage. To address this critical challenge, sustainable and safe preservation technologies are urgently needed. Edible coatings based on starch matrices fortified with natural antioxidants have emerged as a promising green and bioactive strategy. This article provides a comprehensive review of their role and efficacy in extending the shelf life of fresh produce, synthesizing peer reviewed literature from the last decade. Starch, sourced from materials like cassava, corn, or sago, forms a semi permeable film that acts as a selective barrier to gases and water vapor, thereby modulating respiration and minimizing weight loss. The incorporation of natural antioxidants provides complementary biochemical protection by inhibiting oxidative damage and enzymatic browning. This synergistic mechanism, where the starch matrix offers physical protection and antioxidants counteract biochemical degradation, overcomes the inherent limitations of pure starch films. The result is significantly enhanced retention of nutrients, preserved sensory quality, and extended shelf life. In conclusion, starch antioxidant edible coatings represent an effective, sustainable solution for post-harvest management. Their adoption can substantially reduce global post-harvest losses while simultaneously improving food safety, quality, and sustainability.

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1. Introduction

Fruits and vegetables play a central role in global food security and nutrition, providing essential nutrients that support the health and well-being of communities. However, efforts to ensure a stable and high-quality supply continue to be hindered by the significant issue of post-harvest losses (PHL) (1). Globally, losses in fresh commodities are extremely high, ranging from 30–50% of total production. The primary causes of these losses include high respiration rates, transpiration, and microbiological damage (2). These factors accelerate aging, leading to water loss, weight reduction, wilting, and decay. In addition, oxidative damage that triggers enzymatic browning and the degradation of bioactive compounds further reduces the sensory and nutritional quality of product. These challenges have driven innovations aimed at extending the shelf life of fruits and vegetables, particularly in the areas of packaging and storage (3). Conventional packaging materials are typically made from non-biodegradable synthetic polymers, which pose environmental concerns. Consequently, current research increasingly focuses on developing environmentally friendly and effective packaging solutions. One promising innovation for improving storage is the application of edible coatings on fruits and vegetables).

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Edible coatings have emerged as innovative, effective, and environmentally friendly post-harvest treatment strategies. An edible coating is a thin layer of biopolymer applied to the surface of fresh produce, functioning as a semi-permeable barrier that modifies the microenvironment surrounding the product (4). This barrier slows respiration and transpiration rates and provides protection against microbial contamination. Edible coatings are generally formulated from polymers such as polysaccharides, proteins, and lipids (5). Among these, starch is widely used because it is abundant, biodegradable, and capable of forming coherent films. Starch-based films can limit gas exchange and reduce water vapor permeability, thereby minimizing moisture loss and weight reduction (6). However, native starch films exhibit certain limitations, particularly their sensitivity to high humidity and their lack of inherent bioactive properties to counteract oxidative and microbial deterioration (7).

To address the functional limitations of starch-based films, recent studies have focused on their fortification with natural bioactive agents, with natural antioxidants being key components (8). The incorporation of antioxidant compounds, such as extracts rich in carotenoids, phenolics, or ascorbic acid has been shown to significantly reduce oxidative damage, inhibit enzymatic browning, and preserve essential nutrients (1). The synergistic interaction between the starch matrix and antioxidant constituents enhances the film's biochemical protective capacity, resulting in an effective preservation system that maintains sensory quality, extends shelf life, and improves the nutritional value of fresh produce.

Research on the combined use of edible coatings and antioxidants has been widely conducted, including the application of cassava starch incorporated with red ginger extract as an antioxidant to prevent oxidative damage in tomatoes (9). Other studies have also explored edible coatings enriched with compounds that exhibit both antimicrobial and antioxidant activities, such as lemongrass essential oil (10,11), kecombrang flower extract (12), and turmeric extract (13). In addition, several review articles have examined specific components of edible coating technology, such as Puspitasari's review on alginate-based edible coatings (14) and Rosyadi's review on cassava starch-based edible films (15). However, no comprehensive literature review has specifically addressed the effectiveness of edible coatings that integrate starch-based matrices with natural antioxidant fortification. Therefore, this review aims to critically synthesize current findings to evaluate the role, effectiveness, and potential of starch-based edible coating formulations enriched with natural antioxidants as a sustainable and bioactive post-harvest management strategy to support food security.

2. Materials and Methods

The search for articles (original or review) was performed using the Google Scholar and Scopus electronic databases until May 2025. The main keywords used were: "edible coating,"; "biopolymer coating,"; "starch-based coating,"; "natural antioxidant,"; "enzymatic browning inhibition," and "bioactive packaging," among others. All the included references were manually selected and reviewed by the authors.

3. Results and Discussion

3.1. Post-Harvest Physical and Chemical Changes

Post-harvest horticultural produce continues to undergo active physiological and biochemical processes that determine its physical and chemical characteristics. The deterioration and challenges encountered during this period are closely linked to the sustained cellular metabolic activity that persists after detachment from the parent plant (16). This continued metabolism drives progressive changes in the produce's physical, chemical, and biological properties, which are the primary determinants of quality degradation, loss, and spoilage (1). The key metabolic reactions governing these changes during storage are respiration and transpiration. Water vapor loss through transpiration, coupled with the respiratory process, constitutes the principal physiological mechanism leading to moisture loss (hydric degradation) in fresh horticultural commodities. This reduction in water content is a major factor accelerating quality decline, manifesting as visible defects such as wilting, shriveling, and textural breakdown, for instance, softening (17).

Various internal and external factors can induce stress in fruit, triggering a series of physiological, biochemical, and biophysical changes that influence the respiration rate. Key external factors include temperature, atmospheric composition, water content, lighting, and mechanical injury (18). Among these, temperature is the most influential. Extreme temperatures can lead to enzyme denaturation or physical damage, which drastically accelerates respiration in horticultural produce (19). Notably, the metabolic rate typically doubles with every 10°C increase in temperature (20). Consequently, reducing temperature is an effective strategy to suppress the respiration rate of fruit. However, this approach has limitations; many horticultural commodities are sensitive to chilling injury and therefore cannot be stored at low temperatures for extended periods (21).

Relative humidity (RH) is another key factor influencing the respiration rate of fruit. RH is defined as the ratio of the actual water vapor pressure to the saturated water vapor pressure at a given temperature (22). Research indicates that maintaining high RH levels can effectively mitigate damage from low-temperature storage, such as chilling injury. For instance, storing peppers at high RH significantly reduces calyx browning. This effect is attributed to the prevention of water loss from the calyx, a primary site of transpiration. The browning is likely a consequence of mechanical stress induced by the shrinkage of the calyx surface as it dehydrates (23).

Cold storage is a widely adopted post-harvest strategy to inhibit spoilage. Its efficacy relies on the principle that reducing temperature slows the biochemical reactions responsible for degradation and quality loss in fresh produce (24). However, the significant limitation of this method is that many fruits and vegetables, including those harvested unripe are susceptible to chilling injury. This physiological disorder results from prolonged exposure to low, non-freezing temperatures, typically between 0°C and 8°C (21). The visual symptoms of chilling injury are often delayed, becoming apparent only after the produce is transferred to a warmer environment. Commodities with high sensitivity include citrus varieties such as lemons, oranges, and pigmented mandarins (16). At the cellular level, the disorder is initiated by the disorganization of membrane structure, which disrupts metabolic homeostasis. This leads to ion leakage and elevated production of reactive oxygen species (ROS). ROS accumulation induces cellular apoptosis, which manifests macroscopically as skin lesions or pitting (25).

3.2. Edible Coating

Fruits and vegetables are quintessential perishable horticultural commodities. Their post-harvest shelf life is inherently limited by ongoing respiration and transpiration, which drive detrimental changes such as significant weight loss, unattractive shriveling, texture softening, and nutrient depletion, including the loss of vitamins. Consequently, these products require careful post-harvest handling to extend their marketable life and prevent quality deterioration (7).

The primary strategy for mitigating post-harvest losses and extending the shelf life of horticultural produce involves interventions that suppress the rates of respiration and transpiration. The objective of this physiological inhibition is to minimize the degradation of nutritional quality. Practically, this can be effectively achieved by applying edible coatings to the surface of fresh commodities (26). Coating technology involves depositing a thin, safe-to-consume layer on the produce surface. This layer functions as a semi-permeable barrier, modulating the exchange of gases (O_2 and CO_2) and water vapor. By limiting the direct exposure of the commodity surface to atmospheric oxygen, the coating slows the ripening rate and inhibits enzymatic browning reactions (27). Furthermore, edible coatings are semipermeable, regulating not only gas exchange but also the transfer of water-soluble components that can contribute to nutrient degradation in fruit (28). To enhance food safety and environmental sustainability, current research recommends formulating these coatings from safe, natural materials. Consequently, edible coating formulations are predominantly based on easily sourced agricultural biopolymers, such as hydrocolloids (e.g., polysaccharides, proteins) and lipids (29). The use of these natural components provides an effective alternative to synthetic fungicides and chemical preservatives. This shift significantly reduces potential toxicity, making EC technology a safer and more environmentally sustainable post-harvest solution (30).

3.3. Starch-based Edible Coating

The utilization of starch as the primary matrix polymer in edible coating formulations is a major focus in post-harvest research, owing to its abundance, biodegradability, and economic viability. Structurally, starch is a carbohydrate biopolymer composed of two main fractions: linear amylose and branched amylopectin (31). The ratio of these fractions, which varies with botanical source (e.g., cassava, corn, or sago), dictates the functional properties of the resultant film. Generally, a higher amylose content favors the formation of a stronger, more crystalline film network, imparting greater structural integrity and mechanical strength to the coating (32). This cohesive network, formed via hydrogen bonding between starch chains, enables the applied and dried EC to function effectively as a semi-permeable barrier on the surface of fresh produce (33).

The primary mechanism of starch-based edible coatings to extend shelf life involves modifying the internal atmosphere and controlling moisture loss. Acting as a selective barrier, the starch-based layer significantly reduces the diffusion of oxygen (O_2) into the produce tissue while concurrently restricting the outward diffusion of carbon dioxide (CO_2). This modification creates an internal atmosphere characterized by low O_2 and elevated CO_2 levels, which effectively suppresses the commodity's respiration rate (34). Reducing metabolic activity is crucial for delaying the depletion of energy reserves, senescence, and excessive ripening. Furthermore, the starch film functions as a water vapor barrier by partially sealing surface pores (stomata, lenticels), thereby markedly reducing transpiration water loss. This action is vital for minimizing weight loss and maintaining the firmness and texture of the produce, which are key indicators of sensory quality (11).

Table 1. Amylose Content and Film Properties of Various Starch Sources

Starch Source	Amylose Content (%)	Film Characteristics	Ref.
Cassava	15–20	Flexible but poor water resistance	(35)
Corn	25–28	Strong and relatively stable	(36)
Sago	27–30	Good gas barrier properties	(37)
Sweet Potato	15–20	Flexible films	(38)
High-Amylose Corn Starch	50–70	Stronger with excellent gas barrier proper	(39)

Although starch's general function as a gas and water vapor barrier is well established, the specific performance and properties of edible coatings are highly dependent on the botanical source of the starch (Table 1). This variation is due to differences in the fundamental ratio of its two constituents: amylose and amylopectin. A higher amylose content generally contributes to greater film strength and crystallinity, whereas amylopectin enhances flexibility and extensibility. The characteristic amylose-amylopectin ratio of starches from sources like cassava, corn, and sago directly governs the resultant film's mechanical strength and its permeability to gases and water vapor (40). To provide a detailed overview of the relationship between starch source, composition, and film functionality.

Despite their significant potential, pure starch-based edible coatings possess inherent weaknesses that must be addressed for optimal industrial application. A primary limitation is their high hydrophilicity, resulting from the abundance of hydroxyl groups in the glucose polymer structure (31). This property results in films with poor water vapor barrier capacity. Under high relative humidity, the hydrophilic film matrix swells by absorbing water, leading to a loss of structural integrity and a drastic decline in its barrier function (9). A second major drawback is the inherently brittle mechanical properties of pure starch films, particularly those with high amylose content. Such films exhibit low elasticity and are prone to cracking, rendering them unable to accommodate the natural dimensional changes of produce or withstand mechanical stress during handling (41). Consequently, formulation strategies such as incorporating plasticizers, hydrophobic agents, and bioactive compounds such as natural antioxidants are essential to optimize the performance of starch-based edible coatings (42).

3.4. Bioactive Compounds as Natural Antioxidant

While starch-based films can effectively modulate respiration and transpiration, pure starch matrices possess functional limitations, particularly in mitigating oxidative damage and ongoing biochemical degradation in post-harvest produce. Consequently, fortifying starch-based edible coating with natural antioxidants is a key strategy for developing a more comprehensive preservation system (43). Various natural antioxidant compounds are under investigation for their ability to neutralize reactive oxygen species (ROS), thereby slowing quality deterioration. Commonly explored compounds include phenolic compounds extracted from secondary sources such as fruit peels, tea leaves, and spices. Ascorbic acid is also frequently incorporated due to its potent antioxidant activity and water solubility (44). Furthermore, fat-soluble antioxidants like carotenoids (lycopene and beta-carotene) and tocopherols (vitamin E) are utilized; these compounds offer nutritional benefits, pigmentation, and effective protection against lipid oxidation (40,45). Antioxidant source and mechanism are shown in the Table 2.

Table 2. Antioxidant Compounds Source and Its Mechanism

Antioxidant Compound	Source	Solubility	Antioxidant Mechanism	Ref.
Phenolic (Quercetin, Catechine)	Fruit peel extract, grape seeds, green tea, spices.	Polar	Inhibition of PPO/POD (anti-browning); Neutralization of free radicals (ROS).	(46–48)
Ascorbic Acid (Vitamin C)	Pure acid, citrus fruit extract.	Polar	Strong reducing agent; Regenerates other antioxidants (e.g., α-tocopherol); Prevents browning	(49)
Carotenoids (β-carotene, Lycopene)	Tomato, carrot, algae, and paprika extracts.	Non-polar	*Singlet Oxygen Quenching; Protects pigments and lipids from photo-oxidation.*	(50,51)
Tocopherol (Vitamin E)	Vegetable oil (soybean, grains).	Non-polar	Lipid Oxidation Inhibitor; Highly effective in composite starch films containing lipids.	(52,53)

The incorporation of natural antioxidants functions through two primary biochemical mechanisms to maintain product quality. First, they directly inhibit oxidative damage to cellular components, particularly lipids and pigments (54). Lipid oxidation triggers rancidity and the formation of unpleasant volatiles, while pigment oxidation causes discoloration and loss of bright color. By donating hydrogen atoms, natural antioxidants stabilize free radicals, terminate oxidative chain reactions, and protect cellular membrane integrity (55). Secondly, phenolic antioxidants and ascorbate are critical for inhibiting enzymatic browning mediated by enzymes such as polyphenol oxidase (PPO) and peroxidase (POD) (44). For instance, ascorbic acid acts as a reducing agent, converting brown-colored quinones back into colorless phenolic precursors, thereby delaying the appearance of unsightly brown spots (49). When integrated into a starch-based edible coating, these antioxidants exhibit a synergistic effect: the starch matrix provides a physical and gas barrier, while the antioxidants offer complementary biochemical protection. This combined action significantly enhances the retention of oxidation-sensitive nutrients, such as vitamin C and carotenoids (33).

Determining the appropriate dosage and selecting an effective encapsulation method are critical for maximizing antioxidant efficacy within edible coatings. Research often focuses on identifying the optimal concentration of bioactive agents that provides protective effects without compromising the film's physical or sensory properties. Furthermore, to overcome challenges related to volatility, thermal degradation, or rapid release, encapsulation techniques are employed. In this approach, antioxidant compounds are entrapped within protective matrices, such as nano capsules, liposomes, or biopolymer complexes prior to their incorporation into the coating formulation (27). This strategy enhances antioxidant stability during processing and application while enabling a controlled, slow release of the bioactive compounds onto the produce surface. This ensures sustained protection throughout the storage period (56).

3.5. Effectiveness of Starch-Based Edible Coatings with Natural Antioxidants

The efficacy of edible coating formulations combining starch matrices with natural antioxidants is well-documented for extending shelf life and maintaining quality in both climacteric and non-climacteric fruits, as well as in various vegetables. Fundamentally, applying starch-based edible coatings fortified with antioxidants such as phenolic extracts or ascorbic acid provides dual-layer protection. The physical barrier formed by the starch layer effectively reduces respiration and transpiration rates, evidenced by significantly lower weight loss and delayed textural softening (30). For instance, in climacteric fruits like bananas, such coatings delay the respiratory climacteric and ethylene production peak, thereby slowing the ripening process (57). Concurrently, antioxidant fortification provides biochemical protection at the cellular level. In oxidation-sensitive commodities like apple slices or strawberries, natural antioxidants effectively inhibit enzymatic browning, preserving color and visual appearance (58). Quantitative analyses confirm the superiority of this approach for nutrient retention, showing significantly higher levels of preserved vitamin C and carotenoids compared to uncoated controls, as the antioxidants mitigate degradation from oxygen and enzymatic activity (59). In summary, data synthesis confirms that starch-antioxidant EC treatment is a versatile and effective strategy for maintaining the physical, chemical, and sensory quality of fresh produce over extended storage periods (1).

4. Conclusions

Edible coating formulations based on starch matrices fortified with natural antioxidants represent a green, bioactive, and effective strategy for sustainable post-harvest management. Their efficacy arises from a synergistic mechanism: the starch matrix functions as a physical barrier that modulates respiration and minimizes water loss, while incorporated natural antioxidants provide complementary biochemical protection by inhibiting oxidative damage and enzymatic browning. This synergy overcomes the inherent limitations of hydrophilic starch films, resulting in significantly enhanced nutrient retention and extended shelf life. The adoption of this technology is a crucial step toward reducing global post-harvest losses while simultaneously enhancing food safety, quality, and sustainability.

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Available data are presented in the manuscript.

Conflicts of Interest

The author declares no conflict of interest.

References

1. Tamamiya NU. Aplikasi Edible Coating Pati Jagung Dengan Penambahan Minyak Jintan Hitam (HABBATUSSAUDA) Terhadap Kualitas Fisikokimia Fisikokimia Jeruk Siam Madu (Citrus nobilis) Pascapanen. Vol. 4, universitas Maulana Malik Ibrahim. 2024. 9–15 p.
2. Rajput S, Rajput AS, Jain V. Effect of pre-cooling of fresh vegetables in low cost zero energy cool chamber at farmers field in Janjgir-Champa District of Chhattisgarh. J Pharmacogn Phytochem. 2020;9(5):1041–3.
3. Rukhana IS. Pengaruh Lama Pencelupan Dan Penambahan Bahan Pengawet Alami Dalam Pembuatan Edible Coating Berbahan Dasar Pati Kulit Singkong Terhadap Kualitas Pasca Panen Cabai Merah (Capsicum annum L). Universitas Islam Negeri Maulana Malik Ibrahim. 2017. 634 p.
4. Sen M, Singh HP. Edible Food Coatings are Biopolymers. In: Food Coatings and Preservation Technologies [Internet]. 2024. p. 1–25. Available from: https://doi.org/10.1002/9781394237623.ch1
5. Shit SC, Shah PM. Edible Polymers: Challenges and Opportunities. J Polym [Internet]. 2014 Jan 1;2014(1):427259. Available from: https://doi.org/10.1155/2014/427259
6. Putri CI, Warkoyo W, Siskawardani DD. Karakteristik Edible Film Berbasis Pati Bentul (Colacasia Esculenta (L) Schoott) dengan Penambahan Gliserol dan Filtrat Kunyit Putih (Curcuma zedoaria Rosc). Food Technol Halal Sci J [Internet]. 2022 Jan 29;5(1 SE-Articles):109–24. Available from: https://doi.org/10.22219/fths.v5i1.18785
7. Arsyadita T, Susiyanti S, Yenny RF, Imas Rohmawati IR. Pengaruh Edible Coating berbasis Pati Singkong dan Suhu Penyimpanan terhadap Masa Simpan Tomat (Lycopersicum esculentum Mill.). J Ilm Membangun Desa dan Pertan. 2025;10(2):177–93.
8. Ariviani S, Kusumawati M. Potensi chitosan dan essential oil bawang putih (Allium sativum) yang diinkorporasikan pada edible coating sebagai pengawet bakso. Agrointek J Teknol Ind Pertan [Internet]. 2021;15(1):324–35. Available from: https://doi.org/10.21107/agrointek.v15i1.7898
9. Johannes E, Tuwo M, Katappanan N, Henra H, Wirianti G. Edible Coating Berbasis Pati Ubi Kayu Manihot esculenta Crantz dan Jahe Merah Zingiber officinale var. rubrum Memperpanjang Umur Simpan Buah Tomat Solanum lycopersicum L. J Agric Sci [Internet]. 2022;12(2):204. Available from: https://doi.org/10.24843/AJoAS.2022.v12.i02.p03
10. Retnaningtyas SM, Khasanah LU, Sari AM. The Application of Edible Coating Based on Natrium Alginate Enrich With Lemongrass Oil (Cymbopogon citratus) on Tilapia Fish

Fillet (Oreochromis niloticus) For Inhibited Microbiological and Oxidative Damage During Cold Storage. JITIPARI (Jurnal Ilm Teknol dan Ind Pangan UNISRI). 2021;6(1):1–16.

11. Sholekhah NN, Anggreini RA. Potensi Edible coating Kombinasi Pati Suweg dan Minyak Atsiri Sereh serta Aplikasinya pada Cabai. In: Prosiding Seminar Nasional Teknologi Pangan. 2023. p. 82–97.
12. Indratmi D, Septia ED, Hidayat YA, Malikah RA. Potensi Ekstrak Bunga Kecombrang (Etlingera elatior) dan Tanaman Mimosa pudica L. sebagai Edible Coating untuk Memperpanjang Masa Simpan pada Buah Apel. J Hortik Indones [Internet]. 2025;16(1):58–69. Available from: https://doi.org/10.29244/jhi.16.1.58-69
13. Prasasty EA, Anggreini RA. Aplikasi edible coating dari kitosan dan kunyit sebagai antimikroba terhadap komoditas ikan. In: Prosiding Seminar Nasional Teknologi Pangan. 2023. p. 49–58.
14. Puspitasari AM, Seftiono H. Pengaruh Alginat Sebagai Edible Coating Terhadap Kualitas Buah Potong Klimakterik: Kajian Pustaka. J Teknol. 2023 Aug 31;15(2 SE-Articles):305–14.
15. Rosyadi ASAI. Film Antioksidan Berbasis Pati Singkong: Review Sistematis: Cassava Starch-based Antioxidant Film: A Systematic Review. Nac (National Conf Innov Agric. 2024 Dec 8;2(1 SE-Articles):181–7.
16. Ihsan T, Derosya V. Tinjauan Strategi Pengemasan Buah dan Sayur dalam Memerangi Food Loss dalam Rantai Pasokan Pascapanen di Indonesia. J Ilmu Lingkung. 2024;22(4):1078–87.
17. Gidado MJ, Gunny AAN, Gopinath SCB, Ali A, Wongs-Aree C, Salleh NHM. Challenges of postharvest water loss in fruits: Mechanisms, influencing factors, and effective control strategies – A comprehensive review. J Agric Food Res. 2024;17:101249.
18. Utami R, Annisa RR, Praseptiangga D, Nursiwi A, Sari AM, Ashari H, et al. Effect of edible coating sodium alginate with addition of siam pontianak tangerine peel essential oil (Citrus suhuinensis cv Pontianak) on the physical quality of strawberries (Fragaria ananassa) during refrigeration temperature storage. IOP Conf Ser Earth Environ Sci [Internet]. 2023;1200(1):12058. Available from: https://doi.org/10.1088/1755-1315/1200/1/012058
19. Pérez-López A, Ramírez-Guzmán ME, Espinosa-Solares T, Aguirre-Mandujano E, Villaseñor-Perea CA. Postharvest respiration of fruits and environmental factors interaction: An approach by dynamic regression models. Sci Agropecu. 2020;11(1):23–9.
20. Yolanda N, Khamidah N, Rizali A. Teknologi Edible Coating Menggunakan Lilin Lebah (Beeswax) Dan Kitosan Terhadap Mutu Buah Jambu Kristal (Psidium guajava L. VAR. KRISTAL). Agroekotek View [Internet]. 2021;4(2):114–24. Available from: https://doi.org/10.20527/agtview.v4i2.2848
21. Valenzuela JL, Manzano S, Palma F, Carvajal F, Garrido D, Jamilena M. Oxidative stress associated with chilling injury in immature fruit: Postharvest technological and biotechnological solutions. Int J Mol Sci. 2017;18(7).
22. Astutiningsih A, Noertjahyani N, Mulya H, Aisyah I. Pengaruh Aplikasi Edible Coating Gel Lidah Buaya dan Kitosan terhadap Mutu Buah Stroberi pada Penyimpanan Suhu Ruang dan Suhu Rendah. Paspalum J Ilm Pertan [Internet]. 2024 Sep 30;12(2 SE-):353–66. Available from: https://doi.org/10.35138/paspalum.v12i2.765

23. Afolabi AS, Choi IL, Lee JH, Kwon YB, Kang HM. High-Relative-Humidity Storage Reduces the Chilling Injury Symptoms of Red Sweet Peppers in the Breaker Stage. Horticulturae. 2023;9(1):1–13.
24. Sugianti C, Hasbullah R, Purwanto YA, Setyabudi DA. Kajian Pengaruh Iradiasi Dosis 0.75 Kgy Terhadap Kerusakan Dingin (Chilling Injury) Pada Buah Mangga Gedong Selama Penyimpanan Study Effect Of Irradiation 0.75 Kgy Dose On Chilling Injury Symptoms Of Mango Cv Gedong During Stored. J Tek Pertan LampungVol. 2014;3(2):195–204.
25. Strano MC, Altieri G, Allegra M, Renzo GC Di, Paterna G, Matera A, et al. Postharvest Technologies of Fresh Citrus Fruit: Advances and Recent Developments for the Loss Reduction during Handling and Storage. Horticulturae. 2022;8(7).
26. Rosita D, Zaenab S, Budiyanto MAK. Analisis Kandungan Klorin Pada Beras Yang Beredar Di Pasar Besar Kota Malang Sebagai Sumber Belajar Biologi. J Pendidik Biol Indones. 2016;2(1):88–93.
27. Sapper M, Chiralt A. Starch-based coatings for preservation of fruits and vegetables. Coatings. 2018;8(5).
28. Novita M, Sugiyono S, Suyatma NE, Yuliani S. Pemanfaatan Pelapis Edibel Untuk Mempertahankan Kualitas Buah Dan Sayur Segar / Utilization of Edible Coatings to Maintain the Quality of Fresh Fruits and Vegetables. J Penelit dan Pengemb Pertan. 2022;41(2):65.
29. Santoso H, Utama NA, Prabasari I. Aplikasi edible coating kitosan dan cincau hitam untuk memperpanjang kualitas buah salak pondoh (Sallaca edulis Reinw) kupas. Semin Nas KEDAULATAN Pertan 2 TAHUN 2025. 2025;2(2019):289–95.
30. Catarina Nunes, Mafalda Silva, Diana Farinha, Hélia Sales RP and JN. Edible Coatings and Future Trends in Active Food Life Increasing. Foods. 2023;12(3308):3–4.
31. Sondari D, Restu WK, Sampora Y, Devy YA, Yosta TD, Muawanah A, et al. The characteristics of amylose fraction of sago starch-based edible films. AIP Conf Proc [Internet]. 2022 Dec 5;2493(1):70011. Available from: https://doi.org/10.1063/5.0110002
32. Mudaffar RA. Karakteristik edible film dari limbah kulit singkong dengan penambahan kombinasi plasticizer serta aplikasinya pada buah nanas terolah minimal. J TABARO Agric Sci. 2020;4(2):473-â.
33. Winarti C, Miskiyah, Widaningrum. Teknologi dan Aplikasi Pengemas Edible Antimikroba Berbasis Pati. Jurnal Litbang Pertanian. J Litbang Pertan. 2012;31(3):85–93.
34. Leonard V. Karakteristik dan Aplikasi Edible Coating pada Buah dan Sayur. Zigma. 2023;38(2):120–32.
35. Dewi SR, Widyasanti A, Putri SH. Pengaruh Konsentrasi Pati Singkong Terhadap Karakteristik Edible Film Berbahan Pati Singkong dengan Penambahan Ekstrak Daun Belimbing Wuluh. J Trop Agric Eng Biosyst Keteknikan Pertan Trop dan Biosist. 2023;11(2):158–67.
36. Zheng F, Yang Q, Yuan C, Guo L, Li Z, Zhang J, et al. Characterizations of corn starch edible films reinforced with whey protein isolate fibrils. Food Hydrocoll [Internet]. 2024;147:109412. Available from: https://doi.org/10.1016/j.foodhyd.2023.109412
37. Prasetyo HA, Laia F. Pemanfaatan gliserol dan pati sagu sebagai edible coating pada penyimpanan jeruk siam madu (Citrus nobilis). J Agroteknosains [Internet]. 2018;2(1).

Available from: http://dx.doi.org/10.36764/ja.v2i1.140
38. Ghoshal G, Kaur M. Optimization of extraction of starch from sweet potato and its application in making edible film. Food Chem Adv [Internet]. 2023;3:100356. Available from: https://doi.org/10.1016/j.focha.2023.100356
39. Calderón-Castro A, Vega-García MO, de Jesús Zazueta-Morales J, Fitch-Vargas PR, Carrillo-López A, Gutiérrez-Dorado R, et al. Effect of extrusion process on the functional properties of high amylose corn starch edible films and its application in mango (Mangifera indica L.) cv. Tommy Atkins. J Food Sci Technol [Internet]. 2018;55(3):905–14. Available from: https://doi.org/10.1007/s13197-017-2997-6
40. Kusumawati DH, Dwi W, Putri R, Koresponsdensi P. Karakteristik Fisik Dan Kimia Edible Film Pati Jagung Yang Diinkorporasi Dengan Perasan Temu Hitam Physical and Chemical Characteristic of Corn Starch Edible Film that Incorporated with Pink and Blue Ginger Extract. J Pangan dan Agroindustri. 2013;1(1):90–100.
41. Moeini A, Pedram P, Fattahi E, Cerruti P, Santagata G. Edible Polymers and Secondary Bioactive Compounds for Food Packaging Applications: Antimicrobial, Mechanical, and Gas Barrier Properties. Vol. 14, Polymers. 2022. p. 2395.
42. Fendriansah, Tamrin, Oktafri. Pengaruh Media Penyimpanan (Biji Plastik) Terhadap Umur Simpan Wortel Segar (Daucus carrota L.) [The Effect Of Storage Media (Plastic Seed) To Keep Long Fresh Carrot (Daucus carota L.)]. J Tek Pertan Lampung. 2014;3(2):111–8.
43. Nilasari N, Hasri H, Putri SE, Genisa MU. Penambahan Ekstrak Daun Kelor Sebagai Antioksidan Pada Karakteristik Edible Film Pati Talas (Colocasia esculenta). Anal Anal Environ Chem [Internet]. 2025 Feb 28;8(1 SE-Articles):100–10. Available from: https://doi.org/10.23960/aec.v8i1.2023.p100-110
44. Syahputra MI. Pengembangan Edible Coating Berbasis Pati Sagu Termodifikasi untuk Menghambat Pencoklatan Buah Potong. J Teknol dan Ilmu Pertan [Internet]. 2024;2(01):6–10. Available from: https://doi.org/10.54209/tip.v2i01.386
45. Assis RQ, Pagno CH, Costa TMH, Flôres SH, Rios A de O. Synthesis of biodegradable films based on cassava starch containing free and nanoencapsulated β-carotene. Packag Technol Sci [Internet]. 2018 Mar 1;31(3):157–66. Available from: https://doi.org/10.1002/pts.2364
46. Chalob KK, Abdul-Rahman SM. Mechanical, barrier and antioxidant properties of edible films made from whey protein isolate incorporated with green tea extract. Iraqi J Agric Sci. 2018;49(4).
47. Munir S, Hu Y, Liu Y, Xiong S. Enhanced properties of silver carp surimi-based edible films incorporated with pomegranate peel and grape seed extracts under acidic condition. Food Packag Shelf Life. 2019;19:114–20.
48. Huri D, Nisa FC. Pengaruh Konsentrasi Gliserol dan Ekstrak Ampas Kulit Apel Terhadap Karakteristik Fisik dan Kimia Edible Film. J Pangan dan Agroindustri. 2014 Feb 9;2(4 SE-Articles):29–40.
49. Najafi Marghmaleki S, Mortazavi SMH, Saei H, Mostaan A. The Effect of Alginate-Based Edible Coating Enriched with Citric Acid and Ascorbic Acid on Texture, Appearance and Eating Quality of Apple Fresh-Cut. Int J Fruit Sci [Internet]. 2021 Jan 1;21(1):40–51. Available from: https://doi.org/10.1080/15538362.2020.1856018
50. Ozvural EB, Huang Q. Quality differences of hamburger patties incorporated with encapsulated β carotene both as an additive and edible coating. J Food Process

Preserv [Internet]. 2018 Jan 1;42(1):e13353. Available from: https://doi.org/10.1111/jfpp.13353
51. Hari N, Francis S, Rajendran Nair AG, Nair AJ. Synthesis, characterization and biological evaluation of chitosan film incorporated with β-Carotene loaded starch nanocrystals. Food Packag Shelf Life [Internet]. 2018;16:69–76. Available from: https://www.sciencedirect.com/science/article/pii/S221428941730340X
52. Zhang L, Liu Z, Sun Y, Wang X, Li L. Effect of α-tocopherol antioxidant on rheological and physicochemical properties of chitosan/zein edible films. LWT. 2020;118:108799.
53. Dias MV, de Azevedo VM, Ferreira LF, de Oliveira ACS, Borges SV, de Fátima Ferreira Soares N, et al. Chitosan-nanocomposites as a food active packaging: Effect of addition of tocopherol and modified montmorillonite. J Food Process Eng [Internet]. 2021 Nov 1;44(11):e13843. Available from: https://doi.org/10.1111/jfpe.13843
54. Ribeiro AM, Estevinho BN, Rocha F. Preparation and Incorporation of Functional Ingredients in Edible Films and Coatings. Food Bioprocess Technol [Internet]. 2021;14(2):209–31. Available from: https://doi.org/10.1007/s11947-020-02528-4
55. Inats A, Dewi EN, Purnamayati L. Penghambatan Oksidasi Lemak Bakso Ikan Lele (Clarias batracus) dengan Edible Coating Karagenan yang Diperkaya Minyak Wijen. J Ilmu dan Teknol Perikanan; Vol 2, No 1 (2020)DO - 1014710/jitpi20208087 [Internet]. 2020 Jun 8; Available from: https://doi.org/10.14710/jitpi.2020.8087
56. Vasile C, Baican M. Progresses in Food Packaging, Food Quality, and Safety—Controlled-Release Antioxidant and/or Antimicrobial Packaging [Internet]. Vol. 26, Molecules. 2021. p. 1263. Available from: https://doi.org/10.3390/molecules26051263
57. Thakur R, Pristijono P, Bowyer M, Singh SP, Scarlett CJ, Stathopoulos CE, et al. A starch edible surface coating delays banana fruit ripening. LWT. 2019;100:341–7.
58. Ma X, Feng J, Zhou Y, Wang L, He Y, Zhang H. Application of antioxidant peptide-based coating on fresh-cut apple. Int J Food Sci Technol [Internet]. 2024 Dec 1;59(12):9051–9. Available from: https://doi.org/10.1111/ijfs.17455
59. Feng L, Jiang X, Kitazawa H, Wang X, Guo Y, Li L, et al. Characterization of bioactive films loaded with melatonin and regulation of postharvest ROS scavenging and ascorbate-glutathione cycle in Agaricus bisporus. Postharvest Biol Technol. 2022;194:112107.