University "St. Kliment Ohridski" - Bitola, Republic of North Macedonia
Faculty of Technology and Technical Sciences - Veles

Book of proceedings of the 1st International Scientific Conference - Food Science, Nutrition, Innovative Technologies and Sustainability

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NATURAL ANTIMICROBIAL AND ANTIOXIDANT ADDITIVES IN EDIBLE PACKAGING FOR IMPROVED MICROBIOLOGICAL STABILITY OF FOOD

Aneta Stajikj[1], Daniela Nikolovska Nedelkoska[1], Anka Trajkovska Petkoska[1,2]

[1]St. Kliment Ohridski University-Bitola, Faculty of Technology and Technical Sciences, Dimitar Vlahov 57, 1400 Veles, North Macedonia
[2]Korea University, Department of Materials Science and Engineering, 145 Anam-no, Seongbuk-gu, Seoul, South Korea

Abstract
The increasing demand for sustainable food packaging has driven research toward bio-based edible films and coatings enriched with natural antimicrobial and antioxidant additives, aiming to replace conventional plastics and enhance food safety. This study addresses the global trend of reducing synthetic preservatives by integrating plant-derived bioactive compounds into edible packaging systems. The research question focuses on how natural additives, such as essential oils, phenolic compounds, and other plant extracts influence the functional and protective properties of edible packaging. The purpose of this research is to evaluate their role in improving microbiological stability, extending shelf life, and ensuring environmental sustainability. A comprehensive literature review was conducted, analyzing recent studies and case reports on edible packaging systems, their structural matrices based on polysaccharides, proteins, lipids and their combination, and bioactive compounds incorporated into these matrices. Data were synthesized regarding preparation methods, release mechanisms, and interactions between biopolymers and bioactive agents. Results indicate that natural additives significantly enhance antimicrobial and/or antioxidant properties, reduce moisture and oxygen permeability, and improve mechanical stability. Advanced approaches such as micro- or nano-encapsulation further optimize the stability and controlled release of active agents. Additionally, plant-based extracts could positively affect sensory attributes, contributing to consumer acceptance. The findings highlight the dual benefits of natural additives: ensuring food quality and safety while reducing environmental impact through biobased and biodegradable packaging solutions. Future research should focus on scaling up production, optimizing formulations, and applying emerging technologies to maximize efficacy. Overall, edible packaging with natural bioactive compounds represents a promising direction for food preservation as well as it is well aligned with global sustainable trends.

Keywords: edible packaging, antioxidant, antimicrobial, natural additives, microbiological stability, sustainability.

Literature Review/Broader Research Context

The use of natural antimicrobial and antioxidant additives in edible packaging has emerged as an innovative and sustainable approach to enhance food quality, safety, and shelf life. Edible films and coatings, primarily formulated from biodegradable biopolymers such as starch, chitosan, and bacterial cellulose, serve as carriers of bioactive compounds that create multifunctional barriers against microbial contamination, oxidative degradation, and moisture loss (Yanti et al., 2023; Yıldırım & Ateş, 2022). This concept responds to the increasing consumer demand for clean-label products and addresses safety concerns associated with synthetic preservatives, which may cause chemical migration and toxicological issues.

Extensive research confirms that natural antimicrobials, including essential oils from plants, as well as phenolic extracts and bacteriocins, effectively inhibit spoilage and pathogenic microorganisms (Al-Hilifi et al., 2022; Cesca et al., 2024; Mutlu-Ingök et al., 2020). Their antimicrobial action is mainly attributed to disruption of microbial cell membranes and inhibition of enzymatic activity, which reduces the risk of foodborne illnesses and spoilage (Shukla et al., 2020). At the same time, natural antioxidants such as polyphenols, carotenoids, curcumin, and vitamins have proven effective in delaying lipid oxidation and enzymatic browning, thereby maintaining color, texture, and nutritional properties of packaged food (Wang et al., 2021). These dual functionalities make edible packaging a promising alternative to conventional plastic-based materials.

Another critical factor influencing the effectiveness of edible packaging systems is the method of incorporation and release of active compounds. Controlled release ensures prolonged antimicrobial and antioxidant activity throughout storage, which can be achieved through matrix modification, crosslinking, and advanced techniques such as nanoencapsulation (Trajkovska Petkoska et al., 2025; Li et al., 2021). Nanoencapsulation not only stabilizes sensitive bioactive compounds against environmental degradation but also minimizes negative sensory impacts on the food product (Trajkovska Petkoska et al., 2025; Cesca et al., 2024). Incorporation of plant-based additives further enhances the sensory attributes of edible packaging by introducing desirable flavors, aromas, and natural colors, improving consumer acceptance (Nikhanj, 2023). However, balancing bioactivity and organoleptic quality remains a key challenge, requiring optimized formulations and sensory evaluations.

From a technological and environmental perspective, the development of edible films and coatings enriched with natural additives offers several advantages. These materials are biodegradable, reducing reliance on petroleum-based plastics and contributing to the mitigation of plastic pollution (Moeini et al., 2022). Additionally, sourcing bioactive compounds from agricultural by-products and food waste supports circular economy principles, adding value to underutilized resources (Yanti et al., 2023). Safety considerations also favor natural additives, as most plant-derived compounds and essential oils are recognized as safe (GRAS) by regulatory agencies and have a long history of use in food preservation (Majdi et al., 2024; Cesca et al., 2024).

Overall, the integration of natural antimicrobial and antioxidant additives into edible packaging systems represents a holistic approach that combines food preservation, consumer safety, and environmental sustainability. Continuous innovations in material formulation, active compound delivery systems, and processing technologies, further enhance the performance of these packaging solutions (Kumar et al., 2023; Sani et al., 2023). This multi-functional concept provides a strong foundation for the development of next-generation packaging solutions aligned with global trends toward sustainable, safe and high-quality food systems.

Methods and Materials

This research is primarily based on a qualitative synthesis of existing scientific literature, aiming to identify the role of natural antimicrobial and antioxidant additives in edible packaging and their impact on food safety, quality, and shelf life . The main research question addressed is: How do natural antimicrobial and antioxidant additives incorporated into edible films / coatings improve the microbiological stability and quality of food products as well as extending the shelf life while promoting environmental sustainability?

For this purpose, published scientific articles, review papers, and experimental studies that investigate edible packaging systems enriched with bioactive compounds are taking in the observation; namely, a sample of 60 peer-reviewed studies published between 2020 and 2025 was analyzed, selected based on relevance, methodological rigor, and focus on antimicrobial and antioxidant additives in edible films and coatings. They encompass applications of biopolymer-based packaging such as chitosan, starch, and bacterial cellulose combined with natural extracts like essential oils, phenolic compounds, plant-derived bioactive materials in various food matrices.

The literature review was conducted following a structured and transparent selection approach to ensure relevance and scientific rigor. Articles published between 2020 and 2025 were identified through ScienceDirect, SpringerLink, and Google Scholar using predefined keywords related to edible packaging, antimicrobial and antioxidant additives, and biodegradable materials. Studies were screened based on their relevance to edible films and coatings incorporating natural bioactive compounds, with emphasis on experimental evaluation of antimicrobial, antioxidant, functional, and sensory properties. Articles focusing exclusively on synthetic additives or lacking quantitative assessment were excluded. This selection strategy ensured a focused and up-to-date synthesis of the most relevant research in the field.

The theoretical foundation of the analysis integrates principles from active packaging theory alongside the concept of functional food packaging systems (Petkoska et al., 2021; Kumar et al., 2023; Daniloski et al., 2021).

Results and Discussion

The analysis of the reviewed literature confirms that the incorporation of natural bioactive compounds into edible packaging is an effective and sustainable strategy for enhancing food quality, safety, and shelf life. Biopolymers such as chitosan, starch, and bacterial cellulose, when enriched with plant-based bioactive compounds, create films and coatings that function as physical and biochemical barriers. These systems limit oxygen and moisture transfer, inhibit microbial growth, and delay oxidative processes, thus ensuring prolonged product stability (Yanti et al., 2023; Kumar et al., 2023). Moreover, these findings address growing concerns over synthetic preservatives and align with consumer preferences for clean-label and eco-friendly solutions.

Regarding antimicrobial synergy, chitosan exhibits strong antimicrobial activity due to its cationic nature and ability to disrupt microbial cell membranes. When combined with essential oils, chitosan composite films show enhanced inhibition of pathogens such as *E. coli* and *S. aureus* (Li et al., 2021; Shukla et al., 2020, Al-Hilifi et al., 2022, Kumar et al., 2021). Starch-based matrices display moderate antimicrobial effects that largely depend on essential oil incorporation and are generally less effective than chitosan systems (Araujo et al., 2021; Cesca et al., 2024). Protein-based matrices show variable bacteriostatic activity depending on protein type and additive, with compounds such as curcumin providing measurable but typically weaker effects (Yanti et al., 2023; Bhatia et al., 2023).

In terms of barrier properties, chitosan films provide superior resistance to moisture and gas transmission, supporting extended shelf life and reduced oxidation (Moeini et al., 2022; Majdi et al., 2024). Starch-based films generally exhibit higher moisture permeability, and although lipid addition can improve performance, their barrier stability remains lower than that of chitosan (Hernández-Carranza et al., 2024; Renur et al., 2022). Protein-based matrices show formulation-dependent barrier behavior, often offering good oxygen barriers but limited moisture resistance (Yıldırım & Ateş, 2022; Thamarsha et al., 2024).

Release kinetics also differ among matrices. Chitosan films typically enable controlled and sustained release of antimicrobial agents due to polymer–additive interactions, maintaining prolonged efficacy (Cai et al., 2020; Mirhosseini et al., 2023). Essential oils incorporated into chitosan systems exhibit improved stability and regulated diffusion (Al-Hilifi et al., 2022). In contrast, starch-based films often show rapid additive release, reducing long-term effectiveness (Shukla et al., 2020; Araujo et al., 2021), while protein-based matrices display variable and sometimes unpredictable release behavior (Juliyarsi et al., 2023; Alkan & Yemenicioğlu, 2020).

The encapsulation of hydrophobic additives such as essential oils is most effective in chitosan matrices, which enable uniform dispersion and retention within the film structure (Li et al., 2021; Shukla et al., 2020). Starch matrices can be modified with emulsifiers to improve compatibility but generally show lower encapsulation efficiency (Hernández-Carranza et al., 2024; Renur et al., 2022). Protein-based matrices also face limitations due to protein–water interactions, although cross-linking strategies can enhance hydrophobic compound retention (Juliyarsi et al., 2023; Yıldırım & Ateş, 2022).

Research highlights the strong antimicrobial potential of essential oils derived from clove, cinnamon, oregano, and ginger, as well as phenolic extracts and bacteriocins. These compounds exhibit inhibitory effects against a wide spectrum of foodborne pathogens and spoilage microorganisms by disrupting cell membrane integrity and interfering with microbial metabolism (Cesca et al., 2024; Shukla et al., 2020; Utama-ang et al., 2021). For example, edible films enriched with ginger extract inhibited *Streptococcus mutans*, while coatings with clove essential oil significantly delayed microbial growth in poultry meat, extending its shelf life up to 30 days under refrigeration (Utama-ang et al., 2021; Shukla et al., 2020). Similarly, natural antioxidants such as polyphenols, carotenoids, curcumin, and vitamins demonstrated strong free-radical scavenging activity, reducing lipid peroxidation and enzymatic browning in packaged foods (Wang et al., 2021; Yanti et al., 2023). The inclusion of these compounds not only preserves color, aroma, and texture but also maintains the nutritional value of foods during storage.

A notable trend is the synergistic effect observed when antimicrobial and antioxidant agents are combined in a single system, resulting in enhanced protective functionality (Kumar et al., 2023). To achieve sustained activity, the reviewed studies emphasize the importance of incorporation and release mechanisms. Techniques such as matrix modification, crosslinking, and nanoencapsulation are commonly employed to stabilize bioactive compounds and enable controlled release during storage (Li et al., 2021; Cesca et al., 2024). Nanoencapsulation, in particular, has proven effective in minimizing volatility and degradation of essential oils, ensuring uniform distribution within the polymer matrix and reducing undesirable sensory impacts (Li et al., 2021; Mutlu-Ingök et al., 2020).

Environmental benefits of edible packaging systems enriched with natural additives are significant. These materials are biodegradable and help reduce plastic waste while promoting the principles of the circular economy through the use of agricultural by-products and food waste as raw materials (Moeini et al., 2022; Yanti et al., 2023). This dual function-enhancing food preservation and reducing environmental footprint-addresses two major global challenges simultaneously. Additionally, most of these natural additives, including essential oils and plant extracts, are generally recognized as safe (GRAS), reducing health risks associated with synthetic preservatives (Majdi et al., 2024; Cesca et al., 2024; Mutlu-Ingök et al., 2020).

Despite these advantages, some limitations still remain. There is a need to optimize formulations to maintain a balance between strong bioactivity and desirable sensory properties of packaged foods (Nikhanj, 2023). High concentrations of essential oils and plant extracts may negatively affect sensory attributes. Other challenges include ensuring compound stability during processing, standardizing industrial-scale production, and reducing costs to make these systems economically viable (Renur et al., 2022). Future research should also explore advanced encapsulation techniques, long-term storage performance, and regulatory compliance. Regulatory approval, labeling requirements, and migration limits vary across regions, creating further barriers to commercialization. Additionally, consumer acceptance studies and sensory evaluations are crucial for successful commercialization of edible packaging technologies (Nikhanj, 2023; Thamarsha et al., 2024). From an industrial perspective, scaling up production while maintaining consistent quality, controlled release behavior, and cost efficiency remains a significant challenge that must be addressed to enable real-world application of these technologies.

Table 1 summarizes the findings from case studies that experimentally demonstrate the antimicrobial and antioxidative effects in prolonging the shelf life of various food products.

Table 1: Selected studies investigating various natural additives in edible packaging

Used additives	Title of the paper	Shown results	Reference
Ginger, garlic, cinnamon, turmeric	Antimicrobial and antioxidant activity of bacterial cellulose-based edible film from sago liquid waste incorporated with spices	Results showed that edible film based on bacterial cellulose enriched with spices can increase antimicrobial and antioxidant activity.	Yanti et al., (2023)
Extract from *Portulaca oleracea* (succulent)	Application of edible film incorporated with *Portulaca oleracea* extract to inhibit microbiological and oxidative damage in sausages	Addition of Portulaca extract significantly inhibited microbial growth and oxidative damage in sausages.	Qoeroti et al., (2021)
Ginger extract	Edible Thai rice film incorporated with ginger extract by microwave extraction: optimization of bioactive compounds and functional properties for antimicrobials	Dried ginger extract showed antimicrobial activity against Streptococcus mutans DMST 18777.	Utama-ang et al., (2021)
Beta carotene, hesperidin and propolis	Antimicrobial Edible Cellulose-Based (CB) Films and Coatings for Enhancing Microbial Safety of White Cheese During Storage	Films sprayed with hesperidin showed an antimicrobial effect against E. coli growth, while carotene films inhibited S. aureus growth.	Yıldırım, S. C., & Ateş, F. (2022)
Clove essential oil	Development of antibacterial edible films for food packaging using tragacanth gum, carrageenan, and clove essential oil	Films containing 30% clove essential oil showed a strong inhibitory effect against Escherichia coli and Bacillus.	Tabassum, A., Babu, R., Ahmed, H. S., Naik, T. R., Bhumika, K. P., & Reddy, D. J. (2024)
Syzygium aromaticum	Effects of Chitosan Coating Enriched With *Syzygium Aromaticum* Essential Oil on Quality and Shelf-life of Chicken Patties	Chicken meat dipped in the edible coating with clove essential oil had significantly improved quality parameters compared to other treatments.	Shukla, V., Mendiratta, S. K., Zende, R. J., Agrawal, R. K., & Jaiswal, R. K. (2020)
Nanochitosan–nisin	Characterization and Antibacterial Activity	Peaches coated with the obtained solution	Mirhosseini, M., Afzali, M., &

	of Nanochitosan - Nisin Biocomposite Film Prepared from Shrimp Shells	showed significantly reduced microbial growth and had a markedly extended shelf life compared to uncoated peaches.	Ghotbuddini, S. G. (2023)
Phenolic compounds	Potential application of natural phenolic antimicrobials and edible film technology against bacterial plant pathogens	Films containing phenolic compounds became more porous, more flexible and lost their brittleness.	Alkan, D., & Yemenicioğlu, A. (2020)
Hibiscus extract	Edible Film from Whey: The Impact of the Addition of Rosella Extract (*Hibiscus sabdariffa L*)	Increasing the concentration of hibiscus in the film increased antioxidant activity.	Juliyarsi, I., Melia, S., Setiawan, R. D., Novia, D., Anshor, L., & Susanto, T. (2023)
Ginger essential oil	The Physiochemical and Preservation Properties of Fish Sarcoplasmic Protein/Chitosan Composite Films Containing Ginger Essential Oil Emulsions	The antioxidant and antimicrobial activity of the films depended on ginger concentration.	Cai, L., Wang, Y., & Cao, A. (2020)
Whey, mango solution	Development and Application of Bioactive Bi-Layer Edible Films Based on Starch and LAB-Fermented Whey and/or Mango Solution	Bilayer edible films based on fermented whey and mango solutions with lactic acid bacteria (LAB) contained higher amounts of phenolic compounds and had higher antioxidant activity.	Hernández-Carranza, P., Mendoza-Gutiérrez, B. A., & Estévez-Salas, K. H. (2024)
Black pepper and Brazilian pepper tree extracts	Comparison of biopolymer-based edible coatings incorporating *Piper nigrum* and *Schinus terebinthifolia* applied on minimally processed pineapple	Essential oils from Piper nigrum and Schinus terebinthifolia improved the durability of minimally processed pineapple.	de Araujo, C. I. M., Bonato, L. B., Mangucci, C. B., & others. (2021)
Peppermint essential oil	A Comparative Study of the Properties of Gelatin (Porcine and Bovine)-Based Edible Films Loaded with Spearmint Essential Oil	Antioxidant properties significantly increased with essential oil incorporation compared with control films.	Bhatia, S., Al-Harrasi, A., Jawad, M., Shah, Y. A., & Al-Amodi, M. S. (2023)

Licorice extract	Preparation and Characterization of Licorice-Chitosan Coatings for Postharvest Treatment of Fresh Strawberries	Strawberries coated with chitosan and licorice extract retained good parameters during storage and showed the best microbiological protection compared with controls.	Quintana, S. E., Llalla, O., García-Zapateiro, L. A., & García-Morales, M. R. (2020)
Turmeric extract (*Curcuma domestica*)	Characterization of Edible Film Whey with Addition of Curcuma Extract (*Curcuma domestica val.*) on Moisture, Water Vapor Absorption, Solubility Time, and Antioxidant Activity	The results showed that the whey-based edible film with added turmeric extract had a significant effect on antioxidant activity.	Juliyarsi, I., Tanifal, M., Melia, S., Arief, & Djamaan, A. (2020)

Conclusion

Rather than representing an endpoint, edible packaging systems enriched with natural antimicrobial and antioxidant compounds should be viewed as a versatile platform technology with significant potential for further innovation. Future research should address key knowledge gaps related to the long-term stability of bioactive compounds, their performance in real food systems under commercial storage conditions, and consumer perception of sensory and functional attributes. Innovation pathways are expected to focus on the development of smart and multi-functional edible packaging, combining antimicrobial, antioxidant, and sensing capabilities, as well as on the valorization of waste-derived bioactive compounds in line with circular economy principles. From a practical perspective, these advancements could facilitate clean-label reformulation strategies, reduce reliance on synthetic preservatives, and accelerate industrial adoption of sustainable packaging solutions. Continued interdisciplinary research bridging material science, food technology, and regulatory frameworks will be essential to translate these promising systems from laboratory research to scalable, market-ready applications.

References

A. K. A. N. W. M. R. K. Thamarsha, Kumar, N., Pratibha, N. A., Mor, K., Upadhyay, A., Sudhani, H. P., & Pamu, V. S. (2024). A Review of Functional Properties and Applications of Legume-Based Edible Coatings. Legume Science, 6(4). https://doi.org/10.1002/leg3.70004

Al-Hilifi, S. A., Al-Ali, R. M., & Petkoska, A. T. (2022). Ginger Essential Oil as an Active Addition to Composite Chitosan Films: Development and Characterization. Gels, 8(6), 327. https://doi.org/10.3390/gels8060327

Alkan, D. & Yemenicioğlu, A. (2020). Potential application of natural phenolic antimicrobials and edible film technology in food preservation. International Society for Horticultural Science (ISHS), 1292, 103-110. DOI: 10.17660/actahortic.2020.1292.14

Bhatia, S., Al-Harrasi, A., Jawad, M., Shah, Y. A., Al-Azri, M. S., Ullah, S., Anwer, M. K., Aldawsari, M. F., Koca, E., & Aydemir, L. Y. (2023). A Comparative Study of the Properties of Gelatin (Porcine and Bovine)-Based Edible Films Loaded with Spearmint Essential Oil. Biomimetics, 8(2), 172. https://doi.org/10.3390/biomimetics8020172

Cai, L., Wang, Y., & Cao, A. (2020). The Physiochemical and Preservation Properties of Fish Sarcoplasmic Protein/Chitosan Composite Films Containing Ginger Essential Oil Emulsions. Journal of Food Process Engineering, 43(10). https://doi.org/10.1111/jfpe.13495

Cesca, R. S., Fonseca, G. G., Paz, M. F. d., & Cortez-Vega, W. R. (2024). Advances and Perspectives on the Application of Essential Oils in Food Packaging Films, Coatings, and Nanoencapsulated Materials. Bragantia, 83. https://doi.org/10.1590/1678-4499.20230132

Daniloski, D., Petkoska, A. T., Lee, N. A., Bekhit, A. E. A., Carne, A., Vaskoska, R., & Vasiljevic, T. (2021). Active Edible Packaging Based on Milk Proteins: A Route to Carry and Deliver Nutraceuticals. Trends in Food Science & Technology, 111, 688–705. https://doi.org/10.1016/j.tifs.2021.03.024

De Araujo, C. I. M., Bonato, L. B., Mangucci, C. B., Malpass, G. R. P., Okura, M. H., & Granato, A. C. (2022). Comparison of biopolymer-based edible coatings incorporating Piper nigrum and Schinus terebinthifolia applied on minimally processed pineapple. British Food Journal, 124(4), 1274–1284. https://doi.org/10.1108/BFJ-04-2021-0453

Hernández-Carranza, P., Mendoza-Gutiérrez, B.A. & Estévez-Sánchez, K.H. (2024). Development and Application of Bioactive Bi-Layer Edible Films Based on Starch and Gelatin. MDPI AG. 10, 2, 105. DOI: 10.3390/fermentation10020105

Juliyarsi, I., Melia, S., Dwi Setiawan, R., Novia, D., Anshor, L., & Candra, T. (2023). Edible Film from Whey: The Impact of the Addition of Rosella Extract (Hibiscus sabdariffa L). Advances in Animal and Veterinary Sciences, 11(7). https://doi.org/10.17582/journal.aavs/2023/11.7.1105.1111

Juliyarsi, I., Tanifal, M., Melia, S., Arief, Djamaan, A. & Purwati, E. (2020). Characterization of Edible Film Whey with Addition of Curcuma Extract (Curcuma domestica Val.). IOP Publishing. 515, 1, 012050. DOI: 10.1088/1755-1315/515/1/012050

Kumar, N., Pratibha, N. A., Prasad, J., Yadav, A., Upadhyay, A., Phogat, N., Shukla, S., Petkoska, A. T., Heena, Suri, S., Gniewosz, M., & Kieliszek, M. (2023). Recent Trends in Edible Packaging for Food Applications—Perspective for the Future. *Food Engineering Reviews*, *15*(4), 718–747https://doi.org/10.1007/s12393-023-09358-y

Kumar, N.; Pratibha; Trajkovska Petkoska, A.; Khojah, E.; Sami, R.; Al-Mushhin, A.A.M. Chitosan Edible Films Enhanced with Pomegranate Peel Extract: Study on Physical, Biological, Thermal, and Barrier Properties. Materials 2021, 14, 3305. https://doi.org/10.3390/ ma14123305

Li, Y., Zhou, Y., Wang, Z., Cai, R., Yue, T., & Cui, L. (2021). Preparation and Characterization of Chitosan–Nano-ZnO Composite Films for Preservation of Cherry Tomatoes. Foods, 10(12), 3135. https://doi.org/10.3390/foods10123135

Majdi, F., Behbahani, B. A., Barzegar, H., Mehrnia, M. A., & Taki, M. (2024). Active Packaging Coating Based on Lepidium Sativum Seed Mucilage and Propolis Extract: Preparation, Characterization, Application and Modeling the Preservation of Buffalo Meat. Plos One, 19(10), e0311802. https://doi.org/10.1371/journal.pone.0311802

Mirhosseini, M., Afzali, M. & Ghotbuddini, S.G. (2023). Characterization and Antibacterial Activity of Nanochitosan-Nisin Biocomposite Edible Film. CMV Verlag. 25, 2, 341-354. DOI: 10.52547/jast.25.2.341

Moeini, A., Pedram, P., Fattahi, E., Cerruti, P., & Santagata, G. (2022). Edible Polymers and Secondary Bioactive Compounds for Food Packaging Applications: Antimicrobial, Mechanical, and Gas Barrier Properties. Polymers, 14(12), 2395. https://doi.org/10.3390/polym14122395

Mutlu-Ingök, A., Devecioğlu, D., Dikmetaş, D. N., Karbancıoğlu-Güler, F., & Çapanoğlu, E. (2020). Antibacterial, Antifungal, Antimycotoxigenic, and Antioxidant Activities of Essential Oils: An Updated Review. Molecules, 25(20), 4711.

https://doi.org/10.3390/molecules25204711

Nikhanj, P. (2023). Edible Coatings: A Novel Technique for Shelf Life Extension of Fresh Cut Vegetables. World J Food Nutr, 3(1), 1–2. https://doi.org/10.54026/wjfn/1015

Petkoska, A. T., Daniloski, D., D'Cunha, N. M., Naumovski, N., & Trajkovska-Broach, A. (2021). Edible Packaging: Sustainable Solutions and Novel Trends in Food Packaging. *Food Research International*, *140*, 109981. https://doi.org/10.1016/j.foodres.2020.109981

Qoeroti, B., Pangastuti, A., & Susilowati, A. (2021). Application of edible film incorporated with Portulaca oleracea extract to inhibit microbiological and oxidative damage in sausages. Biodiversitas Journal of Biological Diversity, 22(8). https://doi.org/10.13057/biodiv/d220856

Quintana, S. E., Llalla, O., García-Zapateiro, L. A., García-Risco, M. R., & Fornari, T. (2020). Preparation and Characterization of Licorice-Chitosan Coatings for Postharvest Treatment of Fresh Strawberries. Applied Sciences, 10(23), 8431. https://doi.org/10.3390/app10238431

Renur, N., Sutrisno, S., Darmawati, E., & Nurjanah, N. (2022). Applications of Edible Coating Made From Sago Starchwith Essential Oil Additives on Tatihu Fish Fillet (Thunnus Albacares). Iop Conference Series Earth and Environmental Science, 1033(1), 012047. https://doi.org/10.1088/1755-1315/1033/1/012047

Sani, I. K., Aminoleslami, L., Mirtalebi, S. S., Sani, M. A., Mansouri, E., Eghbaljoo, H., Jalil, A. T., Thanoon, R. D., Khodaei, S. M., Mohammadi, F., & Kazemzadeh, B. (2023). Cold Plasma Technology: Applications in Improving Edible Films and Food Packaging. *Food Packaging and Shelf Life*, *37*, 101087. https://doi.org/10.1016/j.fpsl.2023.101087

Shukla, V., Mendiratta, S. K., Zende, R. J., Agrawal, R. K., & Jaiswal, R. K. (2020). Effects of Chitosan Coating Enriched With Syzygium Aromaticum Essential Oil on Quality and Shelf-life of Chicken Patties. Journal of Food Processing and Preservation, 44(11). https://doi.org/10.1111/jfpp.14870

Tabassum, Babu, A.R., Ahmed, H.S., Naik, T.R., Bhumika, K.P. & Jeevan, D. (2024). Development of antibacterial edible films for food packaging using tragacanth gum. Wiley. 141, 24, [No pages]. DOI: 10.1002/app.55495

Trajkovska Petkoska, A., Kumar, N., Pratibha, Koraqi, H., Ali-Haliti, S., & T.-Broach, A. (2025). Bionanocomposites in food packaging and preservation. In Sustainable Materials for Food Packaging and Preservation (pp. 149–170). Elsevier. https://doi.org/10.1016/B978-0-443-13567-5.00007-1

Utama-ang, N., Sida, S., Wanachantararak, P., & Kawee-ai, A. (2021). Edible Thai Rice Film Incorporated With Ginger Extract by Microwave Extraction: Optimization of Bioactive Compounds and Functional Properties for Antimicrobials. https://doi.org/10.21203/rs.3.rs-379250/v1

Wang, G., Liu, Y., Yong, H., Zong, S., Jin, C., & Liu, J. (2021). Effect of Ferulic Acid-Grafted-Chitosan Coating on the Quality of Pork During Refrigerated Storage. Foods, 10(6), 1374. https://doi.org/10.3390/foods10061374

Yanti, N. A., Ahmad, S. W., La Ode Ahmad Nur Ramadhan, & Walhidayah, T. (2023). Antimicrobial and Antioxidant Activity of Bacterial Cellulose-Based Edible Film From Sago Liquid Waste Incorporated With Spices. Iop Conference Series Earth and Environmental Science, 1271(1), 012061. https://doi.org/10.1088/1755-1315/1271/1/012061

Yıldırım, S. C., & Ateş, F. (2022). Antimicrobial Edible Cellulose-Based (CB) Films and Coatings for Enhancing Microbial Safety of White Cheese During Storage. Emirates Journal of Food and Agriculture. https://doi.org/10.9755/ejfa.2022.v34.i12.2954