

Citronella oil as additives in active carrageenan-based food packaging films : A Review

ABSTRACT

The natural degradation process of plastics is slow and harmful to the environment, making biodegradable films a more advantageous option. These films not only reduce environmental pollution but also have the potential to preserve food products and extend their shelf life. Utilization of Iota Carrageenan-based Films with Essential Oils for Food Packaging Applications. This study explores the potential of utilizing Iota Carrageenan-based films in combination with essential oils for food packaging applications. Iota Carrageenan, known for its high elasticity and thixotropic properties, serves as an ideal base material for film formation. Essential oils, with antioxidant and antimicrobial properties, are incorporated into the packaging material to enhance shelf life and prevent food spoilage. Citronella oil demonstrates effective antimicrobial and antioxidant activities for food preservation. The presence of essential oils acts as plasticizers in the film, improving flexibility but requiring careful consideration of concentration to maintain network strength.

Keywords: Citronella oil, Carrageenan, film

1. INTRODUCTION

Food packaging is defined as the wrapping of food to protect it from tampering or contamination from physical, chemical, and biological sources, with active packaging being the most commonly used packaging system to preserve food products [1]. In general, the natural degradation of plastics starts with photodegradation, which leads to thermo-oxidative degradation. Ultraviolet light from the sun provides the activation energy required to initiate the incorporation of oxygen atoms into the polymer. This causes the plastic to become brittle and break into smaller and smaller pieces, until the polymer chain reaches a low enough molecular weight to be metabolized by microorganisms. These microbes can convert the carbon in the polymer chains into carbon dioxide or combine them into biomolecules. However, this whole process is very slow, and plastics can take 50 years or more to degrade [2]. Due to the disadvantages of these plastics that are difficult to degrade naturally, a new solution is currently needed, namely packaging that is easy to degrade naturally, also known as biodegradable films. Biodegradable films have received attention due to their advantages over plastics. Besides reducing environmental pollution, biodegradable films can be used as carriers of active compounds, preservatives, and antimicrobial agents. In addition, by acting as a barrier to the transfer of water vapor, gas, lipids, and flavor components, biodegradable films can prevent quality deterioration and extend the shelf life of food products [3].

2. CHEMICAL STRUCTURE AND PROPERTIES OF CARRAGEENAN

Carrageenan is an advanced preparation of alkali treated cottonii (ATC) or semi-refined carrageenan (SRC). The purity level of SRC is lower than refined carrageenan because the sulfate content is still high, so the gel forming power is low [4]. Carrageenan is an anionic and sulfated polysaccharide consisting of long chains alternating linear chains of (1 → 3)-β-D-galactose and (1 → 4)-3, 6-anhydro-α-D-galactose (3, 6-AG) or (1 → 4)-α-D-galactose with sulfate esters (15-40%) [5]. It is a new renewable natural material that these polymers are derived from the marine red algae family. They can be sorted into six basic forms depending on their source, solubility, and sulfate content: kappa, iota, lambda, mu, nu, and

theta; among these, kappa, iota, and lambda. are commonly used as materials for hydrogel manufacturing due to their viscoelastic and gelling properties [6]. Currently, most carrageenans are extracted from *Kappaphycusalvarezii* and *Eucheuma denticulatum*[7] but some of them are still isolated from *Chondrus crispus* [8]. native carrageenan, also known as refined carrageenan and filtered carrageenan, is used as a material for hydrogel production.

3. SRIC PRODUCTION

The carrageenan production procedure starts with cooking raw red seaweed under alkaline conditions (e.g. sodium hydroxide) to increase the 3, 6-AG content, and then extracting the carrageenan. After extraction, the remaining seaweed is filtered to obtain a concentrated polysaccharide solution. This solution is then precipitated using isopropanol to obtain a fibrous coagulum, which is further separated, pressed, washed, dried, and ground. The alcohol precipitation method can be applied to all types of carrageenan, while the gel method involving potassium chloride is usually used for the extraction of kappa-carrageenan [9],[10],[11]. Carrageenan can also be extracted by environmentally friendly technologies, such as microwave-assisted extraction [12]. and eutectic solvent method in [10].

4. COMPOSITION AND FUNCTIONAL PROPERTIES OF CITRONELLA OIL (CO)

Essential oils (EOs) have gained attention as natural additives in active food packaging due to their antioxidant and antimicrobial properties [13]. These volatile compounds, extracted from various plant organs, can be incorporated into biodegradable materials like edible films to create active packaging systems [14]. The inclusion of EOs in packaging materials can extend food shelf-life by preventing spoilage and improving preservation properties [15]. EOs can be added as free or encapsulated molecules, with encapsulation showing promising results [9]. However, incorporating EOs may affect packaging properties and consumer acceptability [16]. The use of essential os extracted from agro-industrial by-products in biodegradable packaging can lead to a more sustainable food industry [9]. While ssential oil offer numerous benefits, further research is needed to standardize their use in the food industry and address potential allergic reactions in some individuals [16].

Citronella oil is a type of essential oil from the citronella plant (*Cymbopogon nardus*) that has been used in various industrial fields, such as the food industry, cosmetics, and also medicine. Just like other types of essential oils, lemongrass oil is volatile at room temperature without causing decomposition, light yellow to dark yellow in color, fragrant (according to the smell of the producing plant), and generally soluble in organic solvents and insoluble in water [17]. Lemongrass oil is also widely used as a well-known insect repellent and is also registered for use in the United States for human application in eradicating insects and mosquitoes [18]. Lemongrass oil contains natural compounds that are stimulant, anti-inflammatory, antimicrobial, and antioxidant [19].

Based on research conducted by [20], essential oil from citronella plants (*Cymbopogon nardus*) is quite effective in inhibiting mold growth, so it can be used as a preservative for food commodities. The chemical components contained in essential oils vary, but these components can be classified into large groups that are dominant in determining the properties of essential oils. One of these components is terpenes, which are related to iso-prene or iso-pentane elements, are benzene derivatives, do not contain branch chains, and are straight chain compounds. The chemical components in lemongrass oil are quite complex, but there are main compounds that play an important role, namely citronellal, geraniol, and citronellol. The three main components determine the intensity of the fragrant odor to the selling price of citronella oil [21].

Table 1.Review of Essential oil in food packaging

No	Main Findings	Source
1	Active packaging with essential oils can extend the shelf-life of food by interacting with the external environment.Essential oils can be incorporated into active packaging in the form of films and coatings.Active packaging with essential oils can help maintain temperature, moisture, and control microbial growth and food quality.	[15]
2	Essential oils contain bioactive compounds with antioxidative and antimicrobial properties.Essential oils are used as natural additives to extend the shelf-life of food	[22]

No	Main Findings	Source
	products. Essential oils can be incorporated into packaging materials to provide "active or smart packaging" with improved properties.	
3	Essential oils can be incorporated into biodegradable packaging materials like edible films to create active packaging systems with improved preservation properties. Encapsulating the essential oils in the packaging material is a particularly promising approach. The addition of essential oils to the packaging can provide bioactive properties that can extend the shelf-life of the packaged food products by preventing spoilage.	[9]
4	Essential oils have beneficial properties but are unstable and have limited applications. Nanoencapsulation of essential oils in biopolymeric nanocarriers can improve their stability and functionality. Essential Oil -loaded biopolymeric nanocarriers have shown promising antimicrobial and antioxidant effects in food products, but further studies are needed to explore their commercial exploitation.	[23]
5	There is an increasing demand for natural antioxidant active packaging due to its advantages over adding antioxidants directly to food. Various natural antioxidants like tocopherol, caffeic acid, catechin, etc. have been incorporated into food packaging in recent years. The paper reviews methods for determining the oxidation protection effect of antioxidant active films and quantifying natural antioxidants in food.	[24].
6	The paper provides an overview of the current knowledge on the antibacterial properties and mode of action of essential oils and their constituents. It identifies the main obstacle for using essential oil constituents as food preservatives, which is that they are not potent enough as single components and cause negative organoleptic effects. It suggests that exploiting synergies between several essential oil compounds could be a solution to this problem, and recommends that future research should focus on exploring the mode of action of individual constituents and investigating the mechanisms of synergy.	[25].
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5. SRIC-BASED FILMS CONTAINING CITRONELLA OIL

SRiC-based films containing citronella oil have been researched and developed for various applications. A novel active packaging film containing citronella oil was prepared and characterized [27]. The film exhibited antimicrobial activity and was applied in grape preservation [23]. A study characterized cassava starch-based edible films enriched with lemongrass oil. The film showed antimicrobial activity and potential applications in food preservation. Research on PLA films containing montmorillonite nanoclay-citronella essential oil hybrids was conducted. The hybrids showed potential for active film formulations, enhancing the antimicrobial properties of the films [29]. A study investigated the use of citronella oil in edible coatings to extend the shelf life and improve the quality of banana fruit. The results showed that the edible coating with citronella oil significantly reduced weight loss and microbial growth in bananas [30].

6. EFFECT OF CITRONELLA OIL ADDITION ON THE PROPERTIES OF SRIC-BASED FILMS

6.1 GENERAL PROPERTIES

The addition of citronella oil (CO) to SRiC-based films impacts various general properties. Citronella oil's incorporation tends to affect the mechanical properties, water content, and opacity of the films. Research indicates that films with added CO exhibit increased flexibility and reduced tensile strength compared to those without CO. Additionally, the water content in these films is generally higher due to the hydrophobic nature of CO, which influences the water absorption capacity and retention. Furthermore, the opacity of the films tends to increase with higher concentrations of CO, resulting in less transparent films. This change in opacity can be attributed to the distribution and size of CO droplets within the film matrix [31].

6.2 MORPHOLOGY

The morphology of SRiC-based films is notably altered by the addition of citronella oil. Microstructural analysis reveals that CO droplets undergo varying degrees of aggregation depending on the concentration of CO used. At lower concentrations, CO droplets are more uniformly dispersed within the polymer matrix, leading to a homogeneous film structure. However, as the concentration increases, CO droplets tend to coalesce, forming larger aggregates. This aggregation can create microvoids and heterogeneities within the film, potentially impacting the film's barrier properties and mechanical integrity [32].

Additionally, scanning electron microscopy (SEM) images typically show that the surface of SRiC-based films with CO is rougher and more irregular compared to control films. The roughness can be linked to the uneven distribution and partial migration of CO to the film's surface during the drying process. This phenomenon affects not only the film's mechanical properties but also its optical properties, such as gloss and clarity [33]. In conclusion, the addition of citronella oil to SRiC-based films significantly influences both their general properties and morphology. These changes are largely dependent on the concentration of CO used, affecting the films' mechanical strength, water content, opacity, and structural uniformity.

6.3 OPACITY OF SRIC FILM INCORPORATING CO

Semi-refined iota carrageenan (SRiC) films show promise as biodegradable food packaging materials. These films can be enhanced with various additives to improve their properties. Incorporating plasticizers like sorbitol or glycerol increases film flexibility and thermal stability [23]. Adding essential oils, such as cinnamon oil, can impart antimicrobial and antioxidant properties [23]. ZnO nanoparticles improve UV-screening, transparency, and water barrier properties [23]. α -tocopherol incorporation enhances antioxidant activity and can prolong food shelf life [19]. However, additives may affect mechanical properties, with some decreasing tensile strength while increasing elongation at break [19]. Overall, SRiC films demonstrate comparable properties to refined carrageenan films, suggesting their potential as cost-effective, sustainable packaging materials [19]. These studies highlight the versatility of SRiC films and their potential for various food packaging applications. CO affects light transmission, and light can scatter at the interface of CO droplets [23]. In general, antibacterial protein coatings effectively block UV light and visible light. These properties can delay the oxidative spoilage of food products [34].

6.4 WATER SOLUBILITY

Previous research reported that Citronella Oil increased the WVP of cuticle-chitosan composite films [35]. It is known that water vapor usually occurs in the hydrophilic part of the film network. Thus, the WVP also depends on the hydrophilic/hydrophobic ratio of the film composition [36]. In contrast, interfacial interactions between CO and the film substrate lead to reduced protein-water interactions, potentially allowing free passage of water molecules and thus increasing the WVP [37]. It has also been reported that the increase in WVP may be due to the plasticizing effect of CO on the film due to the weakening of protein-protein interactions in the film [34]. Other factors, such as film thickness and relative humidity, may also affect WVP. For hydrophilic films, studies have shown a positive positive correlation between WVP and film thickness [38].

6.5 MOISTURE AND SOLUBILITY OF FILMS

In [55] the moisture content of the films varied between 20% - 27.5%. this was due to the different drying treatments. Drying was carried out under the same conditions, and the moisture content of the film decreased with increasing CO concentration. Similar results were observed in oregano oil biocomposite films [36]. Due to the hydrophobic

nature of CO, CO-containing films are more soluble than SPI films. It is possible that protein-water partially replaces protein-water interactions [39]. Water solubility of films is an important characteristic of food packaging films, and potential commercial films should usually be insoluble or water-resistant. The low film solubility in this study may be because protein-CO interactions mainly occur through hydrogen hydrogen, which facilitates film development [40].

6.3 ANTIOXIDANT PROPERTIES

Carrageenan iota film (SRiC) is known for its antioxidant properties, which can be enhanced by incorporating natural antioxidants such as citronella oil. Citronella oil, which is derived from the leaves of the *Cymbopogon nardus* plant, is rich in antioxidants and has been shown to exhibit significant antioxidant activity. SRiC film with citronella oil has been shown to exhibit high antioxidant activity in the DPPH radical scavenging assay, indicating its ability to effectively neutralize free radicals and protect against oxidative damage. The antioxidant activity of SRiC films with citronella oil has also been evaluated using the β -carotene bleaching assay, which measures the ability of the film to inhibit β -carotene oxidation. The results showed that the film with citronella oil exhibited significant antioxidant activity, indicating its ability to protect against lipid peroxidation [41]. Antioxidant compounds in citronella oil come from terpenoid compounds and secondary metabolites such as phenolic groups, where phenol groups have an important role in antioxidant activity [42]. The mechanism of action of phenolic compounds as antioxidants is through the ability of the phenol group to bind a free radical by donating a hydrogen atom through an electron transfer process, so that phenol turns into a phenoxyl radical [3].

6.3 ANTIMICROBIAL PROPERTIES

The antibacterial activity of essential oils is determined by differences in chemical composition, one of which is terpenoid compounds. According to [43] citronella essential oil content consists of terpenoid metabolites, namely monoterpenes and sesquiterpenes. Terpenoids have antibacterial effects, and the mechanism of action of these compounds reacts with porins (transmembrane proteins) found in the outer membrane of the bacterial cell wall. This bond creates a strong polymeric bond that damages the porin. Damaged porins affect the entry and exit of cellular components contained in bacteria, reduce the permeability of the bacterial cell wall and bacterial cells experience nutrient deficiencies inhibit bacterial growth or die [44]. The chemical content contained in citronella plants (*Cymbopogon nardus* L.) that can inhibit bacterial growth are saponins and flavonoids. Saponins can cause microbial cells to lyse by disrupting the stability of their cell membranes [45]. Saponins are polar surfactants that will reduce the surface tension of the sterol membrane of the bacterial cell wall, causing disruption of membrane permeability which results in the entry of materials or substances needed to be disrupted eventually the cell swells and ruptures [25]. Flavonoids work by denaturing proteins, disrupting the lipid layer and causing cell wall damage. This can occur because flavonoids are lipophilic so that they will bind to phospholipids phospholipids in fungal cell membranes and disrupt cell membrane permeability [25].

6.3 CONCLUSION

The incorporation of citronella oil into carrageenan-based food packaging films offers a promising solution for sustainable and effective food preservation. Citronella oil, known for its antimicrobial and antioxidant properties, enhances the functional properties of these biodegradable films, making them suitable for extending the shelf life of food products. The addition of citronella oil increases the film's flexibility and water content, while reducing its tensile strength and transparency. The essential oil's chemical components, such as citronellal, geraniol, and citronellol, contribute to its effectiveness as a plasticizer and antimicrobial agent. These compounds disrupt bacterial cell membranes, preventing microbial growth and spoilage. Despite the potential sensory impacts and the need for further research to standardize its use, the application of citronella oil in food packaging represents a significant advancement in creating environmentally friendly and efficient preservation methods. This innovative approach not only addresses the hopkins issue of plastic pollution but also offers a natural means to maintain food quality and safety.

REFERENCES

- [1] V. García Ibarra, R. Sendón, J. Bustos, P. Paseiro Losada, and A. Rodríguez Bernaldo de Quirós, "Estimates of dietary exposure of Spanish population to packaging contaminants from cereal based foods contained in plastic materials," *Food Chem. Toxicol.*, vol. 128, no. April, pp. 180–192, 2019, doi: 10.1016/j.fct.2019.04.003.
- [2] Zeenat, A. Elahi, D. A. Bukhari, S. Shamim, and A. Rehman, "Plastics degradation by microbes: A sustainable approach," *J. King Saud Univ. - Sci.*, vol. 33, no. 6, p. 101538, 2021, doi: 10.1016/j.jksus.2021.101538.
- [3] M. Beigomi, M. Mohsenzadeh, and A. Salari, "Characterization of a novel biodegradable edible film obtained from *Dracocephalum moldavica* seed mucilage," *Int. J. Biol. Macromol.*, vol. 108, pp. 874–883, 2018, doi:

- 10.1016/j.ijbiomac.2017.10.184.
- [4] H. Hardan, W. Warsidah, and I. S. Nurdiansyah, "The growth rate of *Kappaphycus alvarezii* seaweed with different planting methods in the sea waters of Sepempang Village, Natuna Regency," *J. Laut Khatulistiwa*, vol. 3, no. 1, p. 14, 2020, doi: 10.26418/lkuntan.v3i1.35101.
- [5] V. L. Campo, D. F. Kawano, D. B. da Silva, and I. Carvalho, "Carrageenans: Biological Properties, Chemical Modifications and Structural Analysis - A Review," *Carbohydr. Polym.*, vol. 77, no. 2, pp. 167–180, 2009, doi: 10.1016/j.carbpol.2009.01.020.
- [6] H. S. Kiani *et al.*, "Phytochemical Composition and Pharmacological Potential of Lemongrass (*Cymbopogon*) and Impact on Gut Microbiota," *AppliedChem*, vol. 2, no. 4, pp. 229–246, 2022, doi: 10.3390/appliedchem2040016.
- [7] X. Y. Yap, L. T. Gew, M. Khalid, and Y. Y. Yow, "Algae-Based Bioplastic for Packaging: A Decade of Development and Challenges (2010–2020)," *J. Polym. Environ.*, vol. 31, no. 3, pp. 833–851, 2023, doi: 10.1007/s10924-022-02620-0.
- [8] S. Gerassimidou, O. V. Martin, G. Y. F. Diaz, C. Wan, D. Komilis, and E. Iacovidou, "Systematic Evidence Mapping to Assess the Sustainability of Bioplastics Derived from Food Waste: Do We Know Enough?," *Sustain.*, vol. 15, no. 1, 2023, doi: 10.3390/su15010611.
- [9] M. Carpena, B. Nuñez-Estevez, A. Soria-Lopez, P. Garcia-Oliveira, and M. A. Prieto, "Essential oils and their application on active packaging systems: A review," *Resources*, vol. 10, no. 1, pp. 1–20, 2021, doi: 10.3390/resources10010007.
- [10] A. K. Das, M. Sharma, D. Mondal, and K. Prasad, "Deep eutectic solvents as efficient solvent system for the extraction of κ -carrageenan from *Kappaphycus alvarezii*," *Carbohydr. Polym.*, vol. 136, pp. 930–935, 2016, doi: 10.1016/j.carbpol.2015.09.114.
- [11] M. Beaumont *et al.*, "Hydrogel-Forming Algae Polysaccharides: From Seaweed to Biomedical Applications," *Biomacromolecules*, vol. 22, no. 3, pp. 1027–1052, 2021, doi: 10.1021/acs.biomac.0c01406.
- [12] A. Bianchi, V. Sanz, H. Domínguez, and M. D. Torres, "Valorisation of the industrial hybrid carrageenan extraction wastes using eco-friendly treatments," *Food Hydrocoll.*, vol. 122, no. March 2021, p. 107070, 2022, doi: 10.1016/j.foodhyd.2021.107070.
- [13] P. Tongnuanchan and S. Benjakul, "Essential Oils: Extraction, Bioactivities, and Their Uses for Food Preservation," *J. Food Sci.*, vol. 79, no. 7, pp. 1231–1249, 2014, doi: 10.1111/1750-3841.12492.
- [14] X. Luo *et al.*, "Chitosan-based packaging films with an integrated antimicrobial peptide: Characterization, in vitro release and application to fresh pork preservation," *Int. J. Biol. Macromol.*, vol. 231, no. November 2022, p. 123209, 2023, doi: 10.1016/j.ijbiomac.2023.123209.
- [15] S. Sharma, S. Barkauskaite, A. K. Jaiswal, and S. Jaiswal, "Essential oils as additives in active food packaging," *Food Chem.*, vol. 343, no. July 2020, p. 128403, 2021, doi: 10.1016/j.foodchem.2020.128403.
- [16] M. Z. Akram, S. Yaman Fırıncıoğlu, H. Jalal, and S. Canoğulları Doğan, "The Use of Essential Oils in Active Food Packaging: A Review of Recent Studies," *Turkish J. Agric. - Food Sci. Technol.*, vol. 7, no. 11, pp. 1799–1804, 2019, doi: 10.24925/turjaf.v7i11.1799-1804.2640.
- [17] R. Ribeiro-Santos, M. Andrade, N. R. de Melo, and A. Sanches-Silva, "Use of essential oils in active food packaging: Recent advances and future trends," *Trends Food Sci. Technol.*, vol. 61, pp. 132–140, 2017, doi: 10.1016/j.tifs.2016.11.021.
- [18] R. S. Verma, S. K. Verma, S. Tandon, R. C. Padalia, and M. P. Darokar, "Chemical composition and antimicrobial activity of Java citronella (*Cymbopogon winterianus* Jowitt ex Bor) essential oil extracted by different methods," *J. Essent. Oil Res.*, vol. 00, no. 00, pp. 449–455, 2020, doi: 10.1080/10412905.2020.1787885.
- [19] V. Francisco *et al.*, "Cymbopogon citratus as source of new and safe anti-inflammatory drugs: Bio-guided assay using lipopolysaccharide-stimulated macrophages," *J. Ethnopharmacol.*, vol. 133, no. 2, pp. 818–827, 2011, doi: 10.1016/j.jep.2010.11.018.
- [20] M. A. Devi and T. B. Singh, "Composition of Essential Oil of Indigenous and Exotic Species of Lemongrass Growing in Manipur Materials and Methods," vol. 2, no. 2, pp. 58–64, 2023.
- [21] X. N. Yang and S. C. Kang, "Chemical composition, antioxidant and antibacterial activities of essential oil from Korean Citrus unshiu peel," *J. Agric. Chem. Environ.*, vol. 02, no. 03, pp. 42–49, 2013, doi: 10.4236/jacen.2013.23007.
- [22] P. Tongnuanchan, S. Benjakul, and T. Prodpran, "Properties and antioxidant activity of fish skin gelatin film incorporated with citrus essential oils," *Food Chem.*, vol. 134, no. 3, pp. 1571–1579, 2012, doi: 10.1016/j.foodchem.2012.03.094.
- [23] A. C. Souza, G. E. O. Goto, J. A. Mainardi, A. C. V. Coelho, and C. C. Tadini, "Cassava starch composite films incorporated with cinnamon essential oil: Antimicrobial activity, microstructure, mechanical and barrier properties," *Lwt*, vol. 54, no. 2, pp. 346–352, 2013, doi: 10.1016/j.lwt.2013.06.017.
- [24] A. Sanches-Silva *et al.*, "Trends in the use of natural antioxidants in active food packaging: a review," *Food Addit. Contam. - Part A*, vol. 31, no. 3, pp. 374–395, 2014, doi: 10.1080/19440049.2013.879215.
- [25] A. R. Mukurumbira, R. A. Shellie, R. Keast, E. A. Palombo, and S. R. Jadhav, "Encapsulation of essential oils and their application in antimicrobial active packaging," *Food Control*, vol. 136, no. October 2021, p. 108883, 2022, doi:

- 10.1016/j.foodcont.2022.108883.
- [26] M. Hyldgaard, T. Mygind, and R. L. Meyer, "Essential oils in food preservation: Mode of action, synergies, and interactions with food matrix components," *Front. Microbiol.*, vol. 3, no. JAN, pp. 1–24, 2012, doi: 10.3389/fmicb.2012.00012.
- [27] R. Zhao *et al.*, "Active chitosan/gum Arabic-based emulsion films reinforced with thyme oil encapsulating blood orange anthocyanins: Improving multi-functionality," *Food Hydrocoll.*, vol. 134, no. 866, p. 108094, 2023, doi: 10.1016/j.foodhyd.2022.108094.
- [29] R. R. Ferreira, M. C. Farina, A. Maia, and R. F. S. Torin, "PLA Films Containing Montmorillonite Nanoclay–Citronella Essential Oil Hybrids for Potential Active Film Formulation," *Macromol*, vol. 3, no. 2, pp. 200–210, 2023, doi: 10.3390/macromol3020012.
- [30] I. Kamar and D. Yuniharni, "Incorporating citronella oil into edible coating to extend the stable life and improve the quality of banana fruit," *J. Pijar Mipa*, vol. 18, no. 5, pp. 759–765, 2023, doi: 10.29303/jpm.v18i5.5593.
- [31] W. Zhao *et al.*, "A novel active packaging film containing citronella oil: Preparation, characterization, antimicrobial activity and application in grape preservation," *Food Packag. Shelf Life*, vol. 40, no. September, p. 101168, 2023, doi: 10.1016/j.fpsl.2023.101168.
- [32] M. Ji *et al.*, "A biodegradable chitosan-based composite film reinforced by ramie fibre and lignin for food packaging," *Carbohydr. Polym.*, vol. 281, no. August 2021, p. 119078, 2022, doi: 10.1016/j.carbpol.2021.119078.
- [33] C. Li, X. Liu, X. Du, T. Yang, Q. Li, and L. Jin, "Preparation and optical properties of nanostructure thin films," *Appl. Nanosci.*, vol. 11, no. 7, pp. 1967–1976, 2021, doi: 10.1007/s13204-021-01930-4.
- [34] K. Chauhan, R. Kaur, and I. Chauhan, "Sustainable bioplastic: a comprehensive review on sources, methods, advantages, and applications of bioplastics," *Polym. Technol. Mater.*, vol. 63, no. 8, pp. 913–938, 2024, doi: 10.1080/25740881.2024.2307369.
- [35] W. Song *et al.*, "Mulching Practices Improve Soil Moisture and Enzyme Activity in Drylands, Increasing Potato Yield," *Agronomy*, vol. 14, no. 5, 2024, doi: 10.3390/agronomy14051077.
- [36] S. F. Hosseini, M. Rezaei, M. Zandi, and F. Farahmandghavi, "Bio-based composite edible films containing *Origanum vulgare* L. essential oil," *Ind. Crops Prod.*, vol. 67, pp. 403–413, 2015, doi: 10.1016/j.indcrop.2015.01.062.
- [37] M. Maizura, A. Fazilah, M. H. Norziah, and A. A. Karim, "Antibacterial activity and mechanical properties of partially hydrolyzed sago starch-alginate edible film containing lemongrass oil," *J. Food Sci.*, vol. 72, no. 6, 2007, doi: 10.1111/j.1750-3841.2007.00427.x.
- [38] J. Tao *et al.*, "Significant impact of water-soluble organic matter on hygroscopicity of fine particles under low relative humidity condition," *Sci. Total Environ.*, vol. 907, no. October 2023, p. 167980, 2024, doi: 10.1016/j.scitotenv.2023.167980.
- [39] E. J. Hopkins, C. Chang, R. S. H. Lam, and M. T. Nickerson, "Effects of flaxseed oil concentration on the performance of a soy protein isolate-based emulsion-type film," *Food Res. Int.*, vol. 67, pp. 418–425, 2015, doi: 10.1016/J.FOODRES.2014.11.040Corpus.
- [40] S. Sivakanthan, S. Rajendran, A. Gamage, T. Madhujith, and S. Mani, "Antioxidant and antimicrobial applications of biopolymers: A review," *Food Res. Int.*, vol. 136, no. May, 2020, doi: 10.1016/j.foodres.2020.109327.
- [41] A. Farhan and N. M. Hani, "Characterization of edible packaging films based on semi-refined kappa-carrageenan plasticized with glycerol and sorbitol," *Food Hydrocoll.*, vol. 64, pp. 48–58, 2017, doi: 10.1016/j.foodhyd.2016.10.034.
- [42] "Journal of Nutrition College , 8 (4), 264-273.," vol. 8, pp. 4–5, 2019.
- [43] S. M. Evans and M. M. Cowan, "Plant products as antimicrobial agents," *Cosmet. Drug Microbiol.*, vol. 12, no. 4, pp. 205–231, 2016, doi: 10.3109/9781420019919-17.
- [44] N. M. Puspawati, I. W. Suirta, and S. Bahri, "Isolation, Identification, And Antibacterial Activity Tests On Citronella Essential Oil (*Cymbopogon winterianus* Jowitt)," *J. Kim.*, pp. 219–227, 2016, doi: 10.24843/jchem.2016.v10.i02.p08.
- [45] M. Raningsih, N. T. Wulansari, and N. K. Suarnadi, "Effectiveness of *Streptococcus thermophilus* Bacteriocins on the Growth of *Escherichia coli* and *Staphylococcus aureus*," *BIO-EDU J. Pendidik. Biol.*, vol. 6, no. 2, pp. 83–89, 2021, doi: 10.32938/jbe.v6i2.1038.