Journal of Applied Food Technology 12 (2) 182–188

Journal of Applied Food Technology

Home page: https://ejournal2.undip.ac.id/index.php/jaft

Development and Characterization of Calcium Lactate-Activated Sodium Alginate-Gum Arabic Edible Films

Sri Mulyani[1,2], Mohamad Rizky Dharmawan[1], Inish Chris P. Mesias[3], Yoga Pratama[1,2]*

[1]Department of Food Technology, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro, Jl. Prof. Jacub Rais, Tembalang, Semarang, Central Java 50275, Indonesia
[2]Food Research for Safety, Security, and Sustainability (FORC3S), Semarang, Indonesia
[3]Department of Food Science and Technology, College of Agriculture and Food Science, Visayas State University, 6521-A, Philippines

*Corresponding author (yogapratama@live.undip.ac.id)

Abstract

Indonesia generated approximately 12.87 million tons of plastic waste in 2023, highlighting the urgent need to develop biodegradable alternatives such as edible films. This study investigated the effect of sodium alginate - gum arabic ratios on the physical and mechanical properties of edible films, combined with a calcium lactate spray activation technique aimed at enhancing film crosslinking, fasten gelling speed and improve performance. A completely randomized design with four treatments (1:1, 2:1, 3:1, and 4:1 ratios of sodium alginate and gum arabic) and five replications was applied. Parameters evaluated included thickness, water vapor transmission rate (WVTR), tensile strength, elongation, and microscopic morphology. Results showed that higher sodium alginate concentrations significantly increased film thickness (0.023–0.094 mm) and significantly improved barrier properties, as indicated by lower WVTR values (69–94 g/m²/day). Tensile strength varied across treatments, reaching the highest value at the 1:1 ratio (8.24 MPa), while elongation peaked at the 2:1 ratio (30.94%), suggesting an optimal balance between flexibility and strength. Microscopic observation revealed fewer air bubbles and more homogeneous structures at higher sodium alginate levels. The introduction of calcium lactate spray activation, rather than conventional immersion or solution mixing, represents a novel crosslinking strategy that is suitable for edible film production. This method demonstrates a promising pathway toward the development of sustainable and high-performance biodegradable packaging materials.

Article information:
Received: 8 November 2025
Accepted: 1 December 2025
Available online: 3 December 2025

Keywords:
edible film
sodium alginate
gum arabic
calcium lactate
mechanical properties

doi: 10.17728/jaft.30001

Introduction

Plastic packaging waste has emerged as one of the most pressing environmental problems worldwide. In Indonesia alone, plastic waste reached 34.2 million tons in 2025, much of persist in ecosystems due to its non-biodegradable nature. This persistence contributes to soil, water, and air pollution, underscoring the urgent need for sustainable packaging alternatives. To address this issue, sustainable and biodegradable alternatives such as edible films have gained increasing attention. Edible films are thin, edible layers derived from biopolymers that function as food coatings or barriers, helping to extend shelf life, reduce moisture loss, and inhibit oxidation without altering the sensory properties of foods (Rahmawati et al., 2024).

The functionality of edible films is strongly influenced by the type of biopolymers used in their formulation. Carbohydrates such as starch and alginate provide film-forming ability, proteins like soy protein and casein contribute structural stability, and lipids improve resistance to water vapor (Oliveira et al., 2025). To achieve desirable characteristics, these polymers are often combined with additives such as plasticizer or antimicrobial agents.

Among carbohydrate-based biopolymers, sodium alginate is widely recognized for its favorable film-forming ability. Sodium alginate is an anionic polysaccharide composed of guluronic (G) and mannuronic (M) acid units, capable of forming three-dimensional gel network through ionic interactions with divalent cations like calcium (Li et al., 2025). This mechanism, described as the “egg-box model,” results in dense and compact structures with strong mechanical resistance (Cao et al., 2020). Furthermore, sodium

Table 1. Formulation of edible films for 100 ml film solution

Material	T1 (1:1)	T2 (2:1)	T3 (3:1)	T4 (4:1)
Sodium alginate	1 g	1.33 g	1.5 g	1.6 g
Gum arabic	1 g	0.67 g	0.5 g	0.4 g
Peppermint oil	1 g	1 g	1 g	1 g
Glycerol	1 g	1 g	1 g	1 g

alginate is water-soluble, biodegradable, biocompatible, and safe for food applications, making it one of the most promising polymers for edible film production.

However, application of sodium alginate as a single polymer source has some drawbacks. Films produced solely from alginate tend to be brittle, with limited flexibility, suboptimal mechanical strength, and relatively weak antimicrobial activity (Eslami *et al.*, 2023). These shortcomings restrict their industrial applicability and necessitate the incorporation of other natural polymer blends are frequently employed to enhance the strength, elasticity, and barrier properties of alginate-based films (Olivas & Barbosa-Cánovas, 2008).

One potential blending agent is gum arabic, a natural polysaccharide that is highly soluble in water and known for its molecular flexibility. Gum arabic acts as a natural plasticizer, reducing brittleness and improving the elasticity of films. Previous studies have demonstrated that the incorporation of gum arabic into alginate matrices enhances polymer compatibility, decreases pore size, and leads to more uniform microstructures (Kocira et al., 2021). This combination is expected to produce edible films that are more resistant to mechanical stress while maintaining desirable barrier properties.

Building on previous research, this study examines the effect of sodium alginate–gum arabic ratios on the physical and mechanical properties of edible films. In contrast to common practices where calcium lactate activation is applied through immersion techniques in edible coatings (Parreidt et al., 2018), this study introduces a spray application method during the film casting process. Immersion method is more common in the production of edible coating, whereas it is impractical in the preparation of edible film. Furthermore, the repeated use calcium lactate bath in the immersion method may affect its concentration and consequently the quality of crosslinking polymer (Parreidt et al., 2018; Jeong et al., 2020; Tordi et al., 2025). Our current approach represents an innovative adaptation aimed at simplifying the activation step and potentially improving process efficiency. The main objective is to optimize the formulation and activation method to achieve a desirable balance of thickness, water vapor transmission rate, tensile strength, elongation, and microstructural integrity for application in biodegradable food packaging.

Materials and Methods

Sodium alginate, gum arabic, and calcium lactate were obtained from Subur Kimia Jaya Semarang, Indonesia. Whereas glycerol, silica gel, and peppermint oil were sourced from CV. Indrasari Semarang, Indonesia.

Preparation of edible film in this study was based on (Pratama et al., 2019; Liah et al., 2023), with several modifications. Initially the required materials were weighed according to the concentration of each treatment (1:1, 2:1, 3:1, and 4:1 ratios of sodium alginate and gum arabic), with the solid content adjusted to 2% w/v (Table 1). Sodium alginate and gum arabic were dissolved in mineral water using an overhead stirrer (IKA, Germany) and heated simultaneously on a hot plate (Thermo Scientific, USA) at 80 °C for 15 minutes until reaching the gelatinization stage. After which, glycerol (1% v/v) and peppermint oil (0.5% v/v) were added and the mixture was homogenized (Ultraturrax, IKA, Germany) at 10,000 rpm for 15 minutes. A volume of 160 mL of the prepared film-forming solution was cast into each plastic tray. Calcium lactate (2.87% w/v) spray was applied five times (center and four corners) from a distance of ±20 cm. The trays containing the film solution were subsequently placed in a cabinet dryer (Maksindo, Indonesia) at 35 °C for 24 hours to obtain dried edible films.

Parameter Analysis

Thickness

The thickness of the edible film was determined following the method to Suhasini et al., 2023. Dried film samples were measured using a micrometer screw gauge with a precision of 0.01 mm. Measurements were taken at five different points on each film, and the average value was calculated to obtain the final thickness of the edible film.

Water Vapor Transmission Rate

The measurement of water vapor transmission rate (WVTR) was conducted following the method of Malaka et al., 2024 with slight modifications. The edible film samples were cut into circular shapes and used to cover the mouth of glass container (diameter 2.8 cm) filled with 3 g of silica gel. Vaseline was used to ensure no vapor transmission from the side. Each container was weighed and then stored in a desiccator with a relative humidity of approximately 55% for 24 hours. Weighing was performed at one-hour intervals. The WVTR was calculated using the following equation:

$$WVTR = {[\frac{G}{t}]}\Big/_{A}$$

Description:

$\frac{G}{t}$: Difference in weight gain of water absorbed by glass (g)

A : Film area (mm^2)

Tensile Strength

Tensile strength (TS) of the edible film was measured following the method described by Liu et al., 2023. Film samples were cut into pieces with dimensions of 5 × 5 cm and tested using a texture analyzer (CT3, Brookfield, USA). The initial grip separation was set at 50 mm with a probe speed of 1 mm/s. Each measurement was conducted five times on randomly selected samples, and the average value was recorded. The tensile strength was calculated using the following equation:

$$Tensile\ strength = \frac{P}{b \times d}$$

Description:
P : Maximum force (N)
b : Film thickness (mm)
d : Film width (mm)

Elongation at Break

Elongation at break (EAB) of the edible film was determined according to the method described by Liu et al., 2023. Film samples were cut into 5 × 5 cm pieces and tested using a texture analyzer (CT3, Brookfield, USA). The initial grip separation was set at 50 mm, with a probe speed of 1 mm/s. Measurements were conducted five times on randomly selected samples, and the average values were recorded. The EAB was calculated using the following equation:

$$EAB\ (\%) = \frac{L - L0}{L0} \times 100\%$$

Description:
L : Film length at break (mm)
L0 : Initial film length (mm)

Microscopic Observation

Microscopic observation of the edible film was conducted following the method described by Chakravartula et al., 2019 with slight modifications. Samples were placed on glass slides and observed using an Olympus CX23 (Japan) microscope under standard illumination at a magnification of 40×.

Data Analysis

The data obtained from the measurements of thickness, water vapor transmission rate (WVTR), tensile strength (TS), and elongation at break (EB) were analyzed using Analysis of Variance (ANOVA) at a 5% significance level. ANOVA were performed to evaluate the effects of different treatments, and when significant differences were observed, further analysis was conducted using Duncan's Multiple Range Test (DMRT). The DMRT was applied to identify specific differences among the treatments.

Results and Discussion

Thickness

As can be seen in Table 2, the thickness of the edible films varied according to the ratio of sodium alginate to gum arabic. The highest thickness value (0.094 mm) was observed in T4 (4:1 of sodium alginate to gum arabic ratio), while the lowest thickness (0.023 mm) was recorded in T1 (1:1 ratio). Increasing sodium alginate concentration corresponded with greater film thickness. This trend can be attributed to the hydrophilic nature of sodium alginate, which forms hydrogen bonds with water molecules, thereby enhancing water retention and contributing to a denser structure after drying (Venkatachalam et al., 2025). As the proportion of gum arabic decreased, the overall water-binding capacity became more dominated by sodium alginate, which retains moisture longer and slows the drying process. This extended drying time facilitates the formation of a stronger polymer network, resulting in thicker films (Parreidt et al., 2018).

Furthermore, the application of calcium lactate spray during casting likely intensified this effect. The ionic interaction between Ca^{2+} ions and the carboxylate groups of alginate chains promotes crosslinking, reinforcing the three-dimensional gel network. This additional crosslinking not only strengthens the film matrix but also reduces structural shrinkage during drying, thereby contributing to the increased film thickness observed in alginate-rich formulations (Parreidt et al., 2018).

Table 2. Thickness of edible films with different ratios of sodium alginate and gum arabic

Sample	Thickness (mm)
T1	0.023 ± 0.001^{a}
T2	0.038 ± 0.002^{b}
T3	0.055 ± 0.001^{c}
T4	0.094 ± 0.012^{d}

*Edible films with sodium alginate and gum arabic ratio of 1:1 (T1), 2:1 (T2), 3:1 (T3), and 4:1 (T4). Values are presented as means of five replicates ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$)

The thickness of the edible films in this study ranged from 0.023 to 0.094 mm, which falls within the common range reported for alginate-based films. These values are slightly lower than those reported by (Rojas-Graü et al., 2007) who obtained film thicknesses of 0.11–0.12 mm in alginate–apple puree edible films, and significantly lower than those reported by Syarifuddin et al. (2025) with 0.14-0.17 mm for sodium alginate/gum arabic/gluten edible films. This difference may be attributed to the lower total solids content and the absence of protein components, which typically increase viscosity and yield thicker films. In addition, the volume of film solution applied per casting area can also significantly influence thickness. Smaller volumes spread over the same surface area naturally produce thinner films, which may partly explain the lower thickness observed in this study.

Table 3. Water Vapor Transmission Rate (WVTR) of edible film with different ratios of sodium alginate and gum arabic

Sample	Water Vapor Transmission Rate (g/m^2/day)
T1	94 ± 4.66^{c}
T2	80 ± 4.07^{bc}
T3	75 ± 4.37^{b}
T4	69 ± 4.07^{a}

*Edible films with sodium alginate and gum arabic ratio of 1:1 (T1), 2:1 (T2), 3:1 (T3), and 4:1 (T4). Values are presented as means of five replicates ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$)

On the other hand, the present thickness range is higher than that reported for pure alginate films (~0.045 mm) (Tupuna-Yerovi et al., 2025), indicating that the addition of gum arabic and the use of calcium lactate spray activation enhanced the polymer network formation. The calcium lactate spray likely promoted localized ionic crosslinking between Ca^{2+} ions and the carboxylate groups of alginates during film casting, reducing matrix shrinkage and resulting in slightly thicker structures compared to non-activated films. Overall, the observed thickness values are consistent with previous findings for polysaccharide-based edible films and demonstrate that the spray activation approach can yield compact yet moderately thick films suitable for food packaging applications.

Water Vapor Transmission Rate

The water vapor transmission rate (WVTR) of the edible films ranged from 69 to 94 g/m²/day (Table 3), with the highest value observed in T1 (sodium alginate 1:1 gum arabic) and the lowest in T4 (4:1). This result is comparable to other edible film study using hydroxypropyl methylcellulose and nanochitosan with WVTR ranging at 50 - 120 g/m²/day (Muna et al., 2023). WVTR decreased with increasing sodium alginate concentration, indicating enhanced barrier properties against water vapor. This trend was consistent with the observed increase in film thickness, as thicker films exhibited a denser polymer network that impeded vapor diffusion (Buchwalder et al., 2023).

The reduction in WVTR with increasing sodium alginate content and decreasing gum arabic concentration can be explained by their relative hydration capacities. Although gum arabic contains hydroxyl groups capable of binding water, its overall hydrophilicity is lower than that of sodium alginate (Setyorini & Nurcahyani, 2016). However, higher alginate content promotes stronger alginate-calcium complex formation as result of spraying treatment. This results in the formation of a more compact polymer matrix, enhancing water retention and reducing vapor permeability. Consequently, alginate-rich films in the current study exhibited superior moisture barrier properties, in agreement with trends reported in the literature for polysaccharide-based edible films (Parreidt et al., 2018).

Tensile Strength

As presented in Table 4, the tensile strength of the edible films increased with higher proportions of sodium alginate. Specifically, T1 (1:1 of sodium alginate to gum Arabic ratio) exhibited a tensile strength of 3.4 MPa, while T4 (4:1 ratio) reached 8.24 MPa, demonstrating a clear enhancement with increasing alginate content. All tensile strength values also complied with the minimum threshold of ≥ 0.39 MPa, indicating that each formulation met the required mechanical performance criteria (Rahmiatiningrum et al., 2019). This improvement is attributed to the greater number of polymer chains formed as sodium alginate concentration increased. Compared to other polymers of similar type, sodium alginate is known to provide both greater strength and flexibility (Erben *et al.*, 2019). With more polymer chains and intermolecular bonds present, the material structure becomes more uniform, effectively filling voids within the edible film matrix and allowing it to withstand higher tensile forces (Yao *et al.*, 2018).

The reduction in gum arabic content also influenced the tensile strength values obtained. Lower concentrations of gum arabic tended to decrease the tensile strength. This is because gum arabic possesses an amorphous and highly branched structure, which results in a less organized film with weaker molecular cohesion (Syarifuddin et al., 2025). The numerous branches in gum arabic's chemical structure hinder the formation of a compact and uniform film network (Mohamed et al., 2025). Consequently, physical interactions such as hydrogen bonding between polymer chains become less efficient. The uneven molecular distribution leads to a less integrated film structure, thereby reducing its ability to withstand high tensile stress.

Table 4. Tensile strength of edible films with different ratios of sodium alginate and gum arabic

Sample	Tensile Strength (MPa)
T1	3.40 ± 0.74^{a}
T2	5.32 ± 0.69^{b}
T3	4.81 ± 1.16^{b}
T4	8.24 ± 1.10^{c}

*Edible films with sodium alginate and gum arabic ratio of 1:1 (T1), 2:1 (T2), 3:1 (T3), and 4:1 (T4). Values are presented as means of five replicates ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$)

The tensile strength values observed in the present study fall within the expected range for alginate-based edible films and represent the higher end of performance under favourable formulation conditions. For comparison, alginate films reinforced with tragacanth gum have been reported to achieve tensile strengths exceeding 67 MPa at optimal reinforcement levels, though these results were obtained under a significantly different film matrix and formulation context (Hadi et al., 2022). Whereas sodium alginate–gum arabic–gluten films with high plasticiser content exhibited very low tensile strengths (0.01–0.13 MPa), highlighting the sensitivity of mechanical properties to plasticiser level and film composition (Syarifuddin et al., 2025).

Table 5. Elongation at break of edible films with different ratios of sodium alginate and gum arabic

Sample	Elongation at Break (%)
T1	13.50 ± 1.74^{b}
T2	30.94 ± 3.71^{c}
T3	14.05 ± 0.95^{b}
T4	7.50 ± 0.23^{a}

*Edible films with sodium alginate and gum arabic ratio of 1:1 (T1), 2:1 (T2), 3:1 (T3), and 4:1 (T4). Values are presented as means of five replicates ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$)

Elongation at Break

Table 5 presents the elongation at break of sodium alginate-gum arabic edible films. The elongation values obtained in this study fall within the range of 10 – 50%, which is classified as indicating good extensibility (Rahmiatiningrum et al., 2019). Based on the analysis, it can be observed that an increase in the proportion of sodium alginate leads to a decrease in the elongation value of the resulting edible film (T2-T4, 2:1 to 4:1 ratio). This phenomenon is primarily attributed to structural factors and polymer-polymer interactions occurring during film formation. Sodium alginate, which possesses a rigid and linear molecular structure, forms a dense and highly ordered polymer network. However, as its concentration increases, the flexibility of the film decreases. Higher sodium alginate concentrations enhance intermolecular bonding, which strengthens the film matrix but restricts the mobility of polymer chains, consequently reducing the elongation value while increasing tensile strength (Luan et al., 2025). These interactions improve the cohesive strength of the film but simultaneously limit its extensibility.

The initial elongation increase observed in 1:1 to 2:1 ratio likely reflects a transitional phase in which ionic cross-link formation has not yet become predominant, as in higher-alginate formulations, but is sufficiently developed to reduce elasticity relative to the lowest sodium alginate treatment. At this intermediate stage, a portion of the polymer chains is already ionically cross-linked, whereas the remaining segments retain substantial mobility. This partial network development produces a film structure that is not yet fully stabilized, leading to detectable variability in elongation values across replicates (Malektaj et al., 2023). The increase observed at treatment T2 (2:1 of sodium alginate to gum arabic ratio) suggests that this ratio represents an optimal formulation. At this optimum level, hydrogen bonding and electrostatic interactions between sodium alginate, gum arabic, and water molecules are well balanced, resulting in improved flexibility and integrity (Parreidt et al., 2018). However, the subsequent decline in elongation observed in T3 and T4 treatments is attributed to the excessive increase in sodium alginate concentration, which promotes denser cross-linking and over-aggregation of polymer chains. This reduces the available free volume within the network, making the film structure more rigid and less extensible, thereby decreasing its elongation capacity (Malektaj et al., 2023).

Microscopic Observation

The microscopic observations revealed distinct morphological differences across treatments. In label A (1:1 of sodium alginate to gum Arabic ratio), large and irregular phase separations were visible on the film surface. In contrast, label B (2:1 of sodium alginate to gum arabic ratio) displayed a more uniform and smoother surface morphology. Pores appeared more evenly distributed, with smaller and dispersed air bubbles, and no major phase separation was detected. The entrapped air observed was attributed to incomplete degassing during mixing, which left voids after water evaporation in the drying stage (Lan et al., 2018).

The morphology of label C (3:1 of sodium alginate to gum arabic ratio) showed less homogeneity, with uneven sodium alginate distribution and noticeable voids (Figure 1). This condition was caused by the higher alginate proportion, which reduced flexibility and homogenization due to the limited contribution of gum arab. Such an imbalance resulted in weaker molecular interactions and microcracks in the film structure (Sun et al., 2023). Meanwhile, label D (sodium alginate 4:1 gum arabic) presented the most stable structure among all treatments. The surface appeared coarse with evenly distributed pores, consistent with the increased cross-linking potential of alginate carboxyl groups as alginate concentration increased (Giz et al., 2020). The formation of large aggregates in several areas can also be attributed to the coagulation of sodium alginate with calcium lactate droplets during the spraying process (Soazo et al., 2015). Therefore, ideal spray gel activation can be achieved when small droplets of calcium lactate are spread evenly on the surface of the alginate film solution.

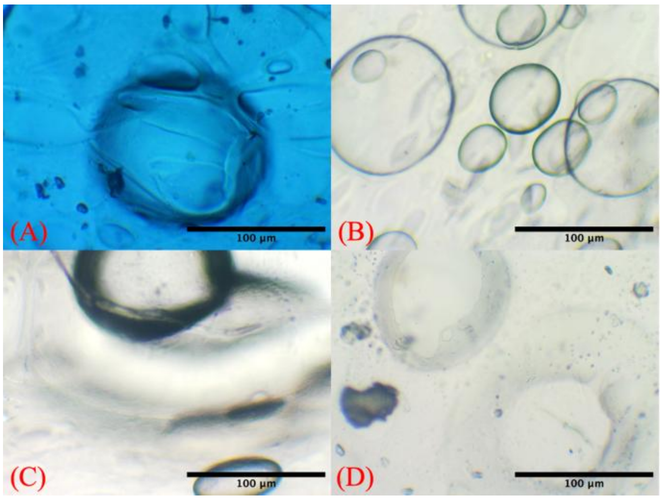

Figure 1. Microscopic observation of edible films with sodium alginate and gum arabic ratio of (A) 1:1, (B) 2:1, (C) 3:1, and (D) 4:1

Conclusion

This study demonstrated that variations in the sodium alginate–gum arabic ratio significantly influenced the physical and mechanical properties of the resulting edible films. Increasing the proportion of sodium alginate consistently enhanced film thickness and tensile strength while reducing water vapor transmission rate (WVTR), indicating improved structural integrity and barrier performance. Conversely, higher gum arabic content promoted flexibility but reduced mechanical strength due to its highly branched and amorphous structure. A key innovation of this work was the use of calcium lactate spray during the casting process, which represents a departure from the conventional immersion-based activation typically applied in edible coatings. Compared with values reported in previous studies, the films developed here exhibited competitive tensile strength (up to 8.24 MPa) and a moderate WVTR range (69 – 94 g/m²/day), suitable for practical food-packaging applications. The findings confirm that the calcium lactate spray activation technique offers an efficient and controllable approach for improving the physicomechanical quality of alginate-based edible films, potentially expanding their applicability as biodegradable packaging alternatives.

References

Buchwalder, S., Nicolier, C., Hersberger, M., Bourgeois, F., Hogg, A., Burger, J. 2023. Development of a Water Transmission Rate (WTR) Measurement System for Implantable Barrier Coatings. Polymers 15(11): 2557. DOI:10.3390/polym15112557.

Cao, L., Lu, W., Mata, A., Nishinari, K., Fang, Y. 2020. Egg-box model-based gelation of alginate and pectin: A review. Carbohydrate Polymers 242 116389. DOI:10.1016/j.carbpol.2020.116389.

Chakravartula, S.S.N., Soccio, M., Lotti, N., Balestra, F., Dalla Rosa, M., Siracusa, V. 2019. Characterization of Composite Edible Films Based on Pectin/Alginate/Whey Protein Concentrate. Materials 12(15): 2454. DOI:10.3390/ma12152454.

Erben, M., Pérez, A.A., Osella, C.A., Alvarez, V.A., Santiago, L.G. 2019. Impact of gum arabic and sodium alginate and their interactions with whey protein aggregates on bio-based films characteristics. International Journal of Biological Macromolecules 125 999–1007. DOI:10.1016/j.ijbiomac.2018.12.131.

Eslami, Z., Elkoun, S., Robert, M., Adjallé, K. 2023. A Review of the Effect of Plasticizers on the Physical and Mechanical Properties of Alginate-Based Films. Molecules 28(18): 6637. DOI:10.3390/molecules28186637.

Giz, A.S., Berberoglu, M., Bener, S., Aydelik-Ayazoglu, S., Bayraktar, H., Alaca, B.E., Catalgil-Giz, H. 2020. A detailed investigation of the effect of calcium crosslinking and glycerol plasticizing on the physical properties of alginate films. International Journal of Biological Macromolecules 148 49–55. DOI:10.1016/j.ijbiomac.2020.01.103.

Hadi, A., Nawab, A., Alam, F., Zehra, K. 2022. Alginate/aloe vera films reinforced with tragacanth gum. Food Chemistry: Molecular Sciences 4 100105. Elsevier. DOI:10.1016/J.FOCHMS.2022.100105.

Jeong, C., Kim, S., Lee, C., Cho, S., Kim, S.-B. 2020. Changes in the Physical Properties of Calcium Alginate Gel Beads under a Wide Range of Gelation Temperature Conditions. Foods 9(2): 180. DOI:10.3390/foods9020180.

Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E., Hortyńska, P. 2021. Polysaccharides as Edible Films and Coatings: Characteristics and Influence on Fruit and Vegetable Quality—A Review. Agronomy 11(5): 813. DOI:10.3390/agronomy11050813.

Lan, W., He, L., Liu, Y. 2018. Preparation and Properties of Sodium Carboxymethyl Cellulose/Sodium Alginate/Chitosan Composite Film. Coatings 8(8): 291. DOI:10.3390/coatings8080291.

Li, X., Qiao, Y., Liu, H. 2025. Biological activities and health benefits of sodium alginate: A review. Journal of Functional Foods 129 106856. DOI:10.1016/j.jff.2025.106856.

Liah, J.L., Lahming, Rauf, R.F. 2023. The Effect of Additional Lemongrass Extract (Cymbopogon nardus L.) on the Characteristics of Edible Film Sodium Alginate and Arabic Gum. Formosa Journal of Science and Technology 2(8): 2055–2068. PT Formosa Cendekia Global. DOI:10.55927/fjst.v2i8.5722.

Liu, Z., Zhao, M., Zhang, Z., Li, C., Xia, G., Shi, H., Liu, Z. 2023. Chitosan-based edible film incorporated with wampee (Clausena lansium) seed essential oil: Preparation, characterization and biological activities. International Journal of Biological Macromolecules 253 127683. DOI:10.1016/j.ijbiomac.2023.127683.

Luan, Q., Wang, Y., Chen, Y., Chen, H. 2025. Review on improvement of physicochemical properties of sodium alginate-based edible films. Journal of Food Science 90(2):. DOI:10.1111/1750-3841.70016.

Malaka, R., Maruddin, F., Arief, F.A., Hakim, W., Irwansyah, Kasmiati, Putranto, W.S., et al. 2024. Evaluation Dangke Cheese Processing by Edible Film Coating Made from Whey Combined with Konjac Flour. Journal of Food Processing and Preservation 2024 1–11. DOI:10.1155/2024/4676923.

Malektaj, H., Drozdov, A.D., deClaville Christiansen, J. 2023. Mechanical Properties of Alginate Hydrogels Cross-Linked with Multivalent Cations. Polymers 15(14): 3012. DOI:10.3390/polym15143012.

Mohamed, S.A., Elsherbini, A.M., Alrefaey, H.R., Adelrahman, K., Moustafa, A., Egodawaththa, N.M., Crawford, K.E., et al. 2025. Gum Arabic: A Commodity with Versatile Formulations and Applications. Nanomaterials 15(4): 290. DOI:10.3390/nano15040290.

Muna, A., Wicaksono, R., Wibowo, C. 2023. Characterization of Layer-by-Layer Biodegradable Films Based on Hydroxypropyl Methylcellulose-Nanochitosan. Journal of Applied Food Technology 10(2): 37–47. Dept. Food Technology, Faculty of Animal and Agricultural Sciences, Diponegoro University. DOI:10.17728/JAFT.20868.

Olivas, G.I., Barbosa-Cánovas, G. V. 2008. Alginate–calcium films: Water vapor permeability and mechanical properties as affected by plasticizer and relative humidity. LWT - Food Science and Technology 41(2): 359–366. DOI:10.1016/j.lwt.2007.02.015.

Oliveira, I., Pinto, T., Afonso, S., Karaś, M., Szymanowska, U., Gonçalves, B., Vilela, A. 2025. Sustainability in Bio-Based Edible Films, Coatings, and Packaging for Small Fruits. Applied Sciences 15(3): 1462. DOI:10.3390/app15031462.

Pratama, Y., Abduh, S.B.M., Legowo, A.M., Hintono, A. 2019. Effect of chitosan-palm olein emulsion incorporation on tapioca starch-based edible film properties. International Food Research Journal 26(1): 203–208.

Rahmawati, P.A., Dewi, D.M.A., Hanif, M.L.F. 2024. Utilization of Edible Film and Edible Coating as Eco Friendly Packaging instead of synthetic packaging. Journal Agrifoodtech 3(1): 9–21. Retrieved from https://jurnal2.untagsmg.ac.id/index.php/agrifoodtech

Rahmiatiningrum, N., Sukardi, S., Warkoyo, W. 2019. Study of Physical Characteristic, Water Vapor Transmission Rate and Inhibition Zones of Edible Films from Aloe vera (Aloe barbadensis) Incorporated with Yellow Sweet Potato Starch and

Glycerol. Food Technology and Halal Science Journal 2(2): 195. DOI:10.22219/fths.v2i2.12985.

Rojas-Graü, M.A., Avena-Bustillos, R.J., Olsen, C., Friedman, M., Henika, P.R., Martín-Belloso, O., Pan, Z., et al. 2007. Effects of plant essential oils and oil compounds on mechanical, barrier and antimicrobial properties of alginate–apple puree edible films. Journal of Food Engineering 81(3): 634–641. Elsevier. DOI:10.1016/J.JFOODENG.2007.01.007.

Senturk Parreidt, T., Müller, K., Schmid, M. 2018. Alginate-Based Edible Films and Coatings for Food Packaging Applications. Foods 7(10): 170. DOI:10.3390/foods7100170.

Setyorini, D., Nurcahyani, P.R. 2016. Effect of addition of semi refined carrageenan on mechanical characteristics of gum arabic edible film. IOP Conference Series: Materials Science and Engineering. p. 1–7. DOI:10.1088/1757-899X/128/1/012011.

Soazo, M., Báez, G., Barboza, A., Busti, P.A., Rubiolo, A., Verdini, R., Delorenzi, N.J. 2015. Heat treatment of calcium alginate films obtained by ultrasonic atomizing: Physicochemical characterization. Food Hydrocolloids 51 193–199. DOI:10.1016/j.foodhyd.2015.04.037.

Suhasini, M.R., Rajeshwari, K.M., Bindya, S., Hemavathi, A.B., Vishwanath, P.M., Syed, A., Eswaramoorthy, R., et al. 2023. Pectin/PVA and pectin-MgO/PVA films: Preparation, characterization and biodegradation studies. Heliyon 9(5): e15792. DOI:10.1016/j.heliyon.2023.e15792.

Sun, J., Wang, L., Chen, H., Yin, G. 2023. Preparation and Application of Edible Film Based on Sodium Carboxymethylcellulose-Sodium Alginate Composite Soybean Oil Body. Coatings 13(10): 1716. DOI:10.3390/coatings13101716.

Syarifuddin, A., Haliza, N., Izzah, N., Tahir, M.M., Dirpan, A. 2025. Physical, Mechanical, Barrier, and Optical Properties of Sodium Alginate/Gum Arabic/Gluten Edible Films Plasticized with Glycerol and Sorbitol. Foods 2025, Vol. 14, Page 1219 14(7): 1219. Multidisciplinary Digital Publishing Institute. DOI:10.3390/FOODS14071219.

Tordi, P., Ridi, F., Samorì, P., Bonini, M. 2025. Cation-Alginate Complexes and Their Hydrogels: A Powerful Toolkit for the Development of Next-Generation Sustainable Functional Materials. Advanced Functional Materials 35(9):. DOI:10.1002/adfm.202416390.

Tupuna-Yerovi, D.S., Schmidt, H., Rios, A. de O. 2025. Biodegradable sodium alginate films incorporated with lycopene and β-carotene for food packaging purposes. Food Science and Technology International 31(1): 23–35. SAGE PublicationsSage UK: London, England. DOI:10.1177/10820132231172362.

Venkatachalam, K., Charoenphun, N., Nitikornwarakul, C., Lekjing, S. 2025. Effect of Sodium Alginate Concentration on the Physicochemical, Structural, Functional Attributes, and Consumer Acceptability of Gel Beads Encapsulating Tangerine Peel (Citrus reticulata Blanco 'Cho Khun') Extract. Gels 11(10): 808. DOI:10.3390/gels11100808.

Yao, J., Zhou, Y., Chen, X., Ma, F., Li, P., Chen, C. 2018. Effect of sodium alginate with three molecular weight forms on the water holding capacity of chicken breast myosin gel. Food Chemistry 239 1134–1142. DOI:10.1016/j.foodchem.2017.07.027.

Ravindran, R., & Jaiswal, A. K. (2019). Wholesomeness and safety aspects of irradiated foods. In *Food Chemistry* (Vol. 285, pp. 363–368). Elsevier Ltd. https://doi.org/10.1016/j.foodchem.2019.02.002

Siegrist, M. (2008). Factors influencing public acceptance of innovative food technologies and products. *Trends in Food Science and Technology*, *19*(11), 603–608. https://doi.org/10.1016/j.tifs.2008.01.017

Siegrist, M., & Hartmann, C. (2020). Consumer acceptance of novel food technologies. In *Nature Food* (Vol. 1, Issue 6, pp. 343–350). Springer Nature. https://doi.org/10.1038/s43016-020-0094-x

Silindir, M., & Özer, A. Y. (2009). Sterilization Methods and the Comparison of E-Beam Sterilization with Gamma Radiation Sterilization. In *J. Pharm. Sci* (Vol. 34).

Singh, R., & Singh, A. (2019). Food irradiation: An established food processing technology for food safety and security. *Defence Life Science Journal*, *4*(4), 206–213. https://doi.org/10.14429/dlsj.4.14397

The Economist Intelligence Unit. (2016). *Fixing Food – Towards a More Sustainable Food System*. https://impact.economist.com/perspectives/health/fixing-food-2016-towards-more-sustainable-food-system

Wang, K., Pang, X., Zeng, Z., Xiong, H., Du, J., Li, G., & Baidoo, I. K. (2023). Research on irradiated food status and consumer acceptance: A Chinese perspective. In *Food Science and Nutrition* (Vol. 11, Issue 9, pp. 4964–4974). John Wiley and Sons Inc. https://doi.org/10.1002/fsn3.3511

World Health Organization. (2015). *WHO estimates of the global burden of foodborne diseases : foodborne disease burden epiemiology reference group 2007-2015*. World Health Organization. https://iris.who.int/handle/10665/199350