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Physicochemical and Mechanical Properties of Edible Sodium Alginate Films

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ABSTRACT

This study aims to investigate the physicochemical and mechanical properties of edible films prepared from sodium alginate at concentrations of 0.5% and 1%, with glycerol as a plasticizer at concentrations of 10%, 30%, and 50%. Thickness, tensile strength, percentage elongation, water solubility, water vapor permeability, light permeability, transparency, and antioxidant activity were evaluated. Results showed that the thickness, elongation percentage, water solubility, and water vapor permeability of the films increased with the rise in glycerol concentration from 10% to 30%. In contrast, tensile strength, water solubility, light permeability, and transparency decreased when the sodium alginate concentration was increased to 1% at the same glycerol concentrations. Antioxidant activity increased with higher sodium alginate concentrations at the same levels of glycerol. Hence, sodium alginate can be used as a natural component in food or pharmaceutical industries

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1- Introduction

The widespread plastic waste globally has hazardous toxic effects on the environment, aquatic life, and humans. Due to its non-biodegradable nature and improper disposal, significant research efforts have been devoted to finding eco-friendly alternatives that are self-degradable, edible, and health-safe. These alternatives, known as biopolymers, include proteins, carbohydrates, fats, or their combinations, derived from plant or animal sources, or as by-products of the food industry, reducing industrial waste (Rossi-Márquez et al., 2023).

Edible films have garnered global attention due to their ability to coat food items, biodegrade, and be consumed with food or removed before consumption. They maintain food quality by acting as barriers against moisture and oxygen, preventing undesired chemical, enzymatic, or microbial interactions (Farhana et al., 2022). Polysaccharides have been utilized in preparing edible films due to their affordability, availability, renewable nature, and good mechanical properties that preserve food texture, flavor, and shelf life (Cazon et al., 2017).

Sodium alginate, a biodegradable linear polyuronic acid, consists of α-L-guluronate and β-D-mannuronic acid units. Alginate has excellent gas barrier properties but poor water vapor barrier properties due to its hydrophilic nature. It is a low-toxicity carbohydrate colloid extracted primarily from brown algae, capable of forming gels, making it a vital material in applications such as packaging, tissue engineering, wound dressings, and edible films (Leyva-Jiménez et al., 2023; Li et al., 2022; Foschi and Bonoli, 2019).

The current study aims to prepare edible films using various concentrations of sodium alginate and the plasticizer glycerol and to investigate their qualitative properties.

2.Materials and Methods

Materials:

The materials employed in this study were chosen in a way that would guarantee the reliability of results in light of similar studies conducted in the future. All materials were sourced from Sigma-Aldrich (Germany) unless otherwise specified:

- Sodium alginate: Used as the primary biopolymer for film formation.
- Glycerol (pharmaceutical grade): Served as a plasticizer to enhance film flexibility and mechanical properties.
- 1,1-Diphenyl-2-picrylhydrazyl (DPPH): Used as a standard antioxidant reagent to assess the antioxidant activity of the films.
- Distilled water: Used as the solvent.

Preparation of Edible Films:

These solutions were prepared following the method of Anward et al (2013) with slight modifications This solution consist of sodium alginate 0.5% and 1.% w/v and glycerol 10%, 30% and 50% w/v in 100 ml distilled water The solutions were prepared by mixing on Gellenkamp hotplate magnetic stirrer at 80°C for about twenty minutes. Following gelation of the solution at ambient temperature, the resulting gel was poured into 9.1 cm diameter Petri dishes and allowed to dry at 25-30°C for approximately 20 – 24 hours. The films formed were subjected to relative humidity of 52% and then subsequently analyzed.

Film Thickness, Tensile Strength, and Elongation at Break:

Thickness, tensile strength, and elongation at break of the PCL/Chitosan/HA films were determined using a texture analyzer at Polymer Research Center, University of Basrah based on ASTM standard number D-882-10.

Water Solubility:

According to Jancikova et al., 2020 water solubility was carried out by weighing film squares 2x2 cm, drying them at 105°C until their constant weight was attained, immersing them in distilled water, 50 ml for 24 hours at 25°C, then drying and re-weighing. The solubility was calculated as:

$$\frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \text{x } 100\%.$$

Water Vapor Permeability (WVP):

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Water vapor permeability (WVP) was measured based on the ASTM E96-16 witnessing a modification as well (Mehdizadeh et al., 2020). Unglued plastic cups (3.9 cm outer diameter, 3.75 cm inner diameter, and 6.25 cm depth) were filled to a volume of 10 ml distilled water, covered with the film and rubber band and kept in desiccator containing anhydrous copper sulph. Weight loss was monitored every 6 hours until constant weight. WVP was calculated as:

$$\mathbf{WVP} = \frac{\mathbf{WVT}}{\mathbf{S} * (\mathbf{R1} - \mathbf{R2})}$$

where: G = weight loss (g), t = time (h), A = film area (m²), S = saturated vapor pressure at 25°C, R1 = relative humidity of the surrounding environment (52%), R2 = relative humidity in the desiccator (0%).

Light Permeability and Transparency:

Light permeability was measured using a spectrophotometer (Physics Department, University of Basrah) over a wavelength range of 200–900 nm, as described by Niroomand et al. (2016).

Antioxidant Activity:

Antioxidant activity was measured using DPPH following Al-Hilifi et al. (2023). One milliliter of film solution was mixed with 1 ml of 0.01% DPPH solution, incubated in the dark at 25°C for 30 minutes, and the absorbance measured at 517 nm. Antioxidant activity was calculated as:

$$\text{Antioxidant Activity (\%)} = \frac{\text{Control absorbance} - \text{Sample absorbance}}{\text{Control absorbance}} \text{ x } 100\%$$

3.Results and Discussion

The simple films prepared from sodium alginate at concentrations of 0.5% and 1%, combined with glycerol at concentrations of 10%, 30%, and 50%, exhibited transparency, glossiness, and a smooth texture. They could be easily detached from the plate. Figure 1 illustrates the types of films prepared from sodium alginate.

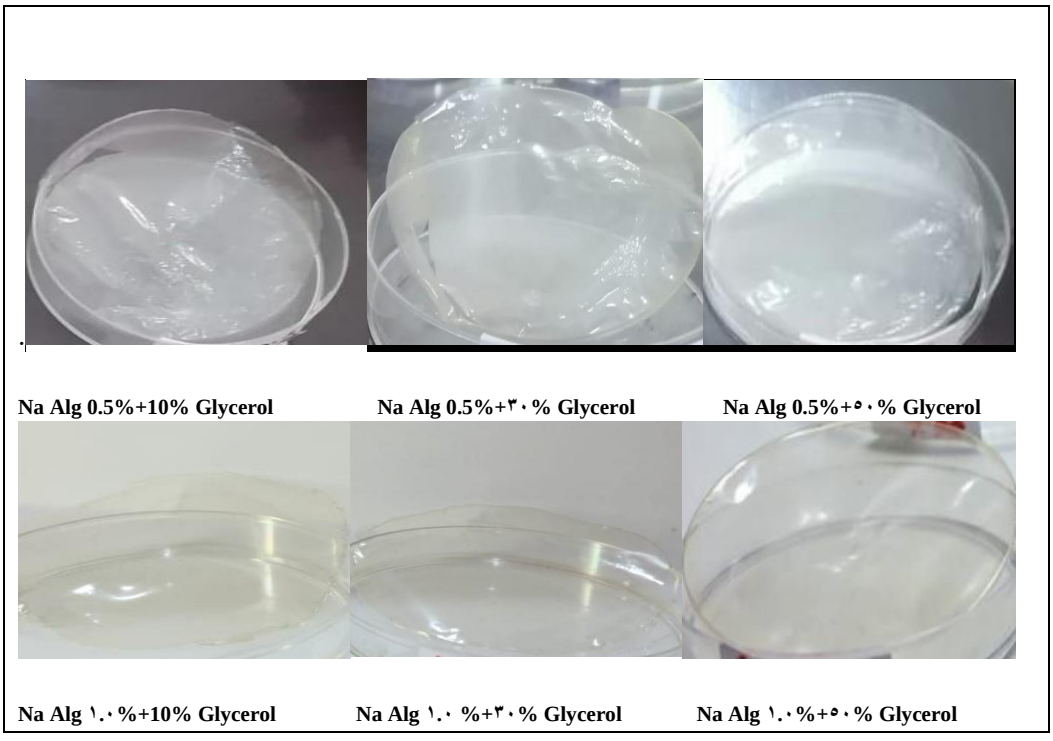

Figure 1: Simple Sodium Alginate Films

Film Thickness:

Thickness is an important factor affecting the application of films for packaging specific products.

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It also influences other mechanical properties such as tensile strength, elongation, water vapor transmission rate, and solubility. Film thickness varies based on film composition; however, for practical application, it must be adjusted according to the product being packaged (Fransiska et al., 2021; Khairunnisa et al., 2018).

Figure ۲ illustrates the thickness of films prepared from sodium alginate at concentrations of 0.5% and 1%, with glycerol concentrations of 10%, 30%, and 50%. An increase in glycerol concentration led to greater film thickness at each alginate level. For films with 0.5% sodium alginate, the thickness values were 0.05, 0.06, and 0.07 mm, while for 1% sodium alginate, the thickness values were 0.06, 0.07, and 0.08 mm. This is attributed to glycerol's solubility in water, which increases solution viscosity and binds water. Higher glycerol concentrations reduced the rate of water evaporation, as some water in the film solution binds to glycerol, influencing the resulting film's thickness. Also, an increase in plasticizer content (glycerol) affects the film components and develops the thickness of the film (Khairunnisa et al., 2018).

Alginate concentration also affected film thickness; the increased sodium alginate concentration caused thicker film formation. This happens because the thickness of the film corresponds to the content of polymers in the solution. It turns out that with the increased concentration of alginate, more polymers are produced, which forms a thicker gel and film (Tavassoli-Kafrani et al., 2016). Additionally, the film thickness of the nanoparticles can also be affected by the manufacturing and drying processes (Racmayani & Husni, 2020).

The film thickness values measured in this study are acceptable based on the JIS for the maximum allowable thickness of edible films, which is 0.25 mm (Suyatno and Ariska 2015). The research data confirmed that even the thickest film used in this research corresponds to the necessary standards when being applied as the primary packaging layer within food production. In addition, with the increase in glycerol content, the thickness of the films was higher due to the interactivity of the said plasticizer with the components of the films (Maria et al., 2018). In the same manner, the thicker films observed at higher sodium alginate concentrations were due to dense polymer content, resulting in increased gel thickness (Tavassoli-Kafrani et al., 2016). It has been found that manufacturing stages affect film thickness and drying processes (Racmayani and Husni, 2020). All films formulated in this study were below the Japanese Industrial Standards (JIS) maximum thickness of 0.25 mm for edible films (Suyatno and Ariska, 2015), meeting the needed food packaging applications.

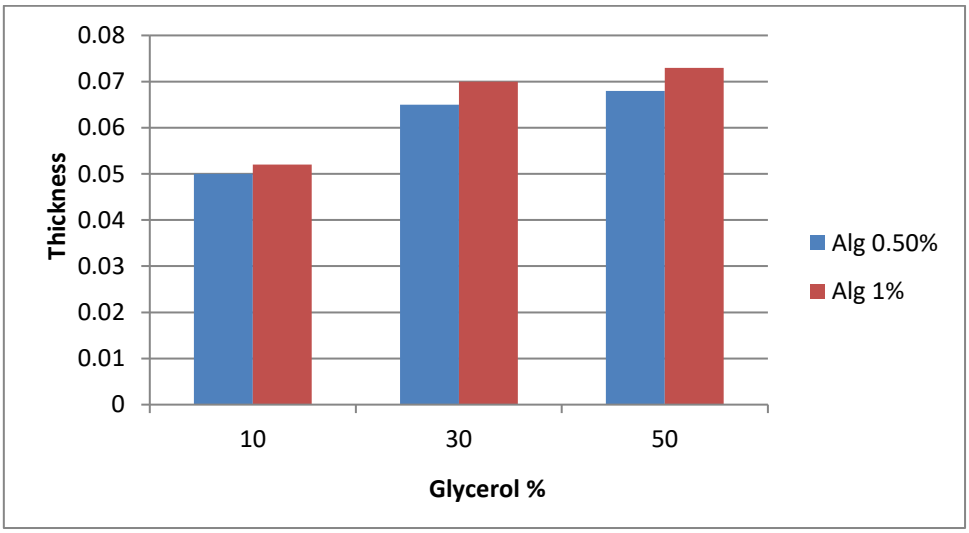

Figure 2: Thickness of Alginate Films

Tensile Strength:

Figure 3 presents the tensile strength of the films made of 0.5% and 1% of sodium alginate with the addition of glycerol at 10%, 30%, and 50%. A clear

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inverse relationship between glycerol concentration and tensile strength is evident (0.5% alginate: 3.89, 3.54, 3.07 MPa; 1% alginate: 5.39, 5.27, 4.85 MPa). This decrease in strength is due to the ability of glycerol to disrupt the interactions between polymer chains within the film matrix (As et al., 2017). However, enhancing alginate concentration leads to a substantial enhancement of tensile strength in accordance with Racmayani and Husni (2020), where the alginate concentration of 2% to 6% provided 0.519MPa to 3.097MPa tensile strength correspondingly. This enhancement results from higher polymer chains and, consequentially, stronger inter-molecular force.

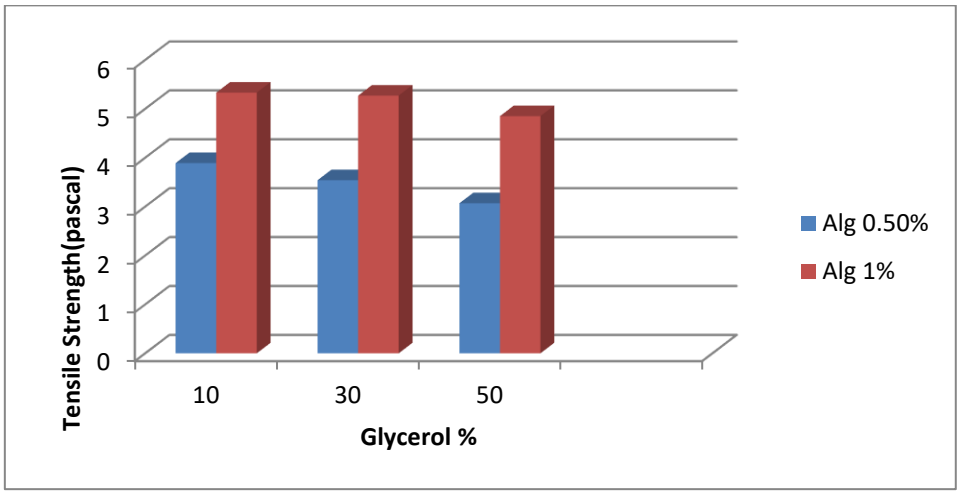

Figure 3: Tensile Strength (MPa) of Alginate Films

Elongation at Break:

High elongation values are critical for films to resist natural stress during application on food. As shown in Figure ٤, the maximum elongation was 1.7% for films prepared with 1% alginate and 50% glycerol, while the minimum elongation was 1.1% for films with 1% alginate and 10% glycerol. For films with 0.5% alginate and 10% glycerol, the elongation was 1.2%, increasing to 1.9% for 0.5% alginate with 50% glycerol. The increase in elongation with glycerol concentration is attributed to molecular interactions between the polymer and plasticizer. Glycerol molecules disrupt hydrogen bonds between polymer chains, increasing molecular flexibility and film elasticity (Sitompul and Zubaidah, 2017).

The alginate concentration also affects elongation, as higher alginate levels increase the solution's viscosity, leading to a more elastic polymer structure (Sitompul and Zubaidah, 2017).

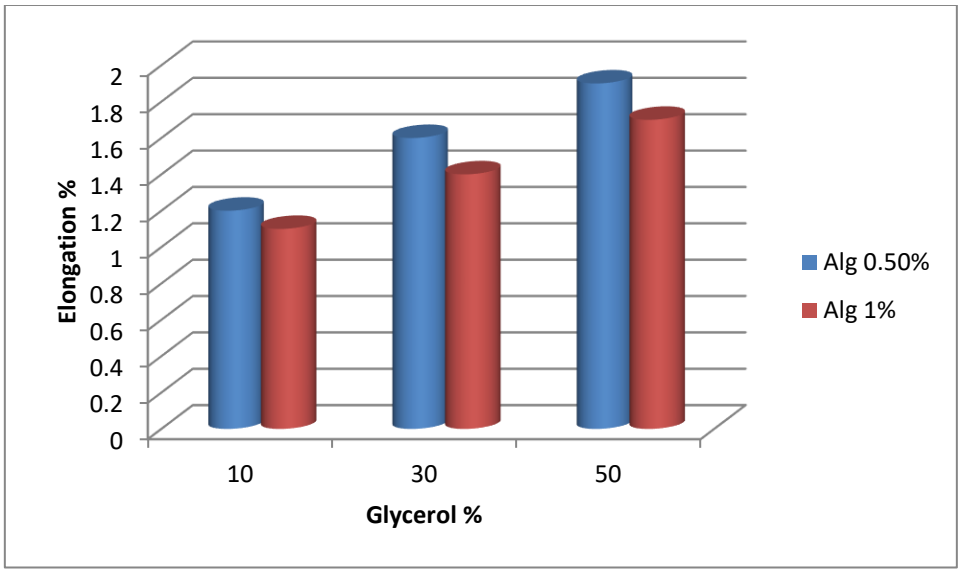

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Figure 4: Elongation Percentage of Alginate Films

Water Vapor Permeability (WVP)

Figure ٥ shows that the maximum WVP was 1.82 g·mm/m²·h·kPa for films with 1% alginate and 50% glycerol, while the minimum WVP was 1.56 g·mm/m²·h·kPa for films with 0.5% alginate and 10% glycerol. WVP increased with higher glycerol concentrations (10%–50%) and alginate concentrations (0.5%–1%). This is because plasticizers disrupt hydrogen bonds within polymer chains, increasing molecular mobility and facilitating water vapor transmission (Senna et al., 2011).

Additionally, a positive correlation was observed between film formulation and permeability values. Increased polymer concentration leads to higher viscosity during mixing, causing air bubbles and larger voids in the film structure, which enhance permeability (Rachtanapun and Rattanapanone, 2011).

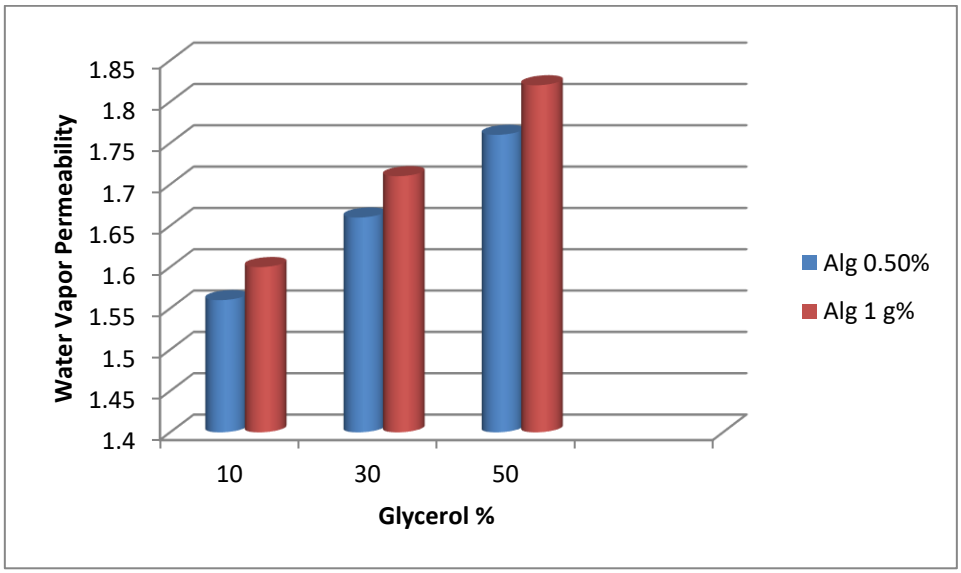

Figure 5: Water Vapor Permeability of Alginate Films

Water Solubility:

The results presented in Figure ٦ indicate the solubility of films prepared with different concentrations of sodium alginate (0.5% and 1%) and glycerol (10%, 30%, and 50%). The maximum solubility was 86.62%, while the minimum solubility was 79.49% for films with 0.5% alginate and varying glycerol levels. For films with 1% alginate, the maximum and minimum solubility values were 84.51% and 78.86%, respectively.

The solubility of the films is influenced by alginate concentration, as alginate is hydrophilic and readily absorbs water. At higher alginate concentrations, the film absorbs more water, and the increased water interaction reduces film density. Since sodium alginate is highly water-loving, it dissolves more easily in water at higher concentrations due to weaker bonds between alginate and glycerol molecules (Racmayani and Husni, 2020).

Edible films with high solubility are ideal for ready-to-eat food products, as they dissolve

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easily upon ingestion. On the other hand, low solubility is a critical requirement for films used to package food products with high water activity (Fransiska et al., 2021; Cazon et al., 2017).

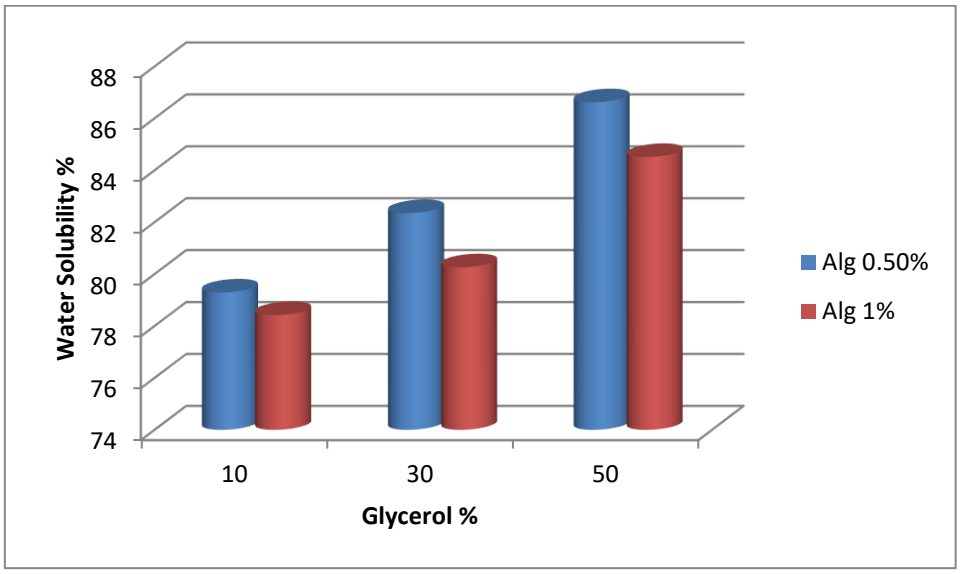

Figure 6: Water Solubility Percentage

Light Permeability and Transparency:

Figure (7) illustrates the percentage of light transmission for sodium alginate films measured at wavelengths ranging from 200 to 900 nm. The transmittance ranged between 55.98% and 82.66% for films prepared with 0.5% sodium alginate and varying glycerol concentrations (10%, 30%, and 50%). However, transmittance decreased when the sodium alginate concentration increased to 1% under the same glycerol concentrations, ranging between 48.784% and 58.566%. Transparency also declined with the increase in both sodium alginate and glycerol concentrations, reaching 3.07 at 0.5% sodium alginate and 50% glycerol and decreasing to 2.07 at 1% sodium alginate and 50% glycerol. This reduction is attributed to increased film density due to the higher solid content and enhanced cross-linking between sodium alginate and glycerol molecules, filling the spaces within the polymer matrix. Consequently, light reflection, scattering, and obstruction take place, which cause the film structure to look less bright and denser (Khairunnisa et al., 2018; Yan et al., 2022; Li et al., 2024).

Such results have similar characteristics with the study of Li et al. (2022) on the evaluation of the optical property of sodium alginate edible films reinforced by tannic acid. This they noted as important since light transmission they postulated plays an important role in the deterioration of food products through effects such as lipid oxidation and nutrient degradation which results to shorter shelf life of foods.

Likewise, the findings harmonized with those of Bhatia et al (2023) regarding the transparency of chitosan/alginate films incorporating fig extract.

Transparency is a term associated with the degree of clarity associated to a film and the capability to pass through light. Transparency can also improve the consumer acceptance of the edible films since it worked as aesthetical value in marketing edible film (Apriliyani et al., 2020).

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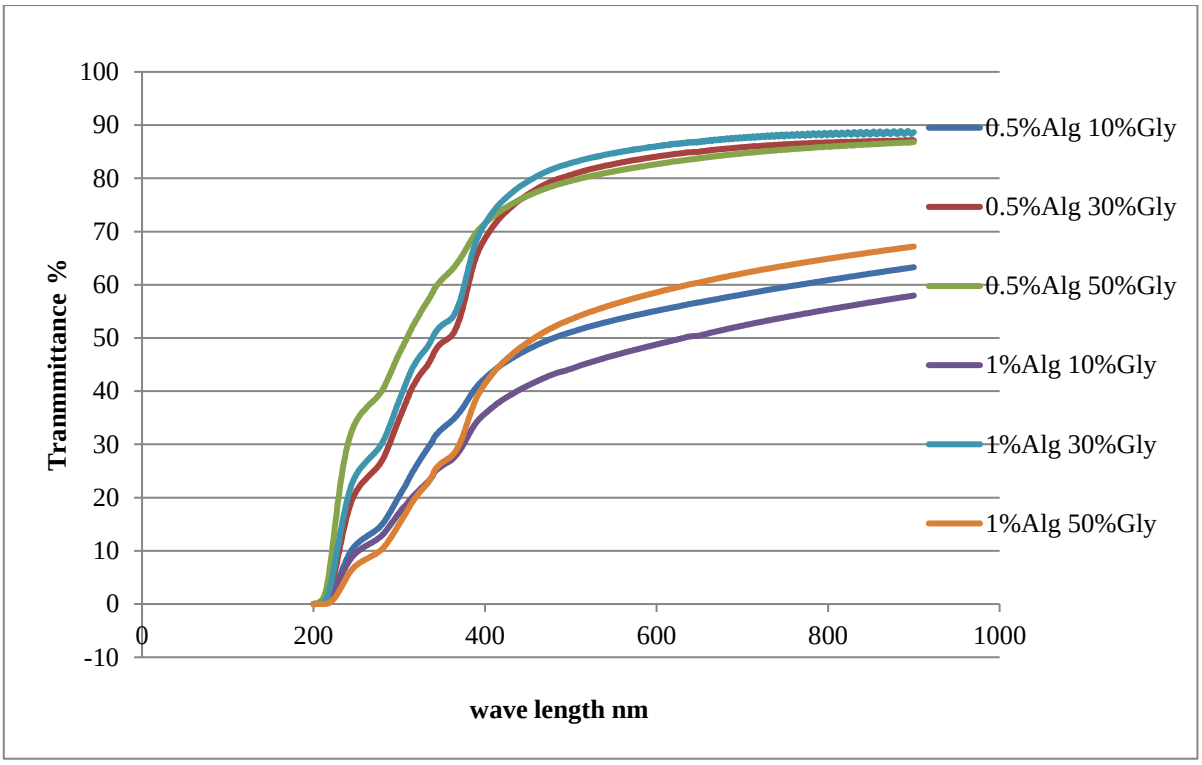

Figure 7: Light Transmission Percentage of Alginate Films

Antioxidant Activity:

The antioxidant activity of the prepared films was evaluated using a simple colorimetric method with DPPH (2,2-diphenyl-1-picrylhydrazyl). In this test, the color of the film solution changed from purple to yellow, and the intensity of the color change was measured to estimate its effectiveness in scavenging free radicals. As shown in Figure (۸), the highest antioxidant activity was 54.31% for the film prepared from 1% sodium alginate and 50% glycerol, while the lowest antioxidant activity was 48.11% for the film prepared from 1% sodium alginate and 10% glycerol. The antioxidant activity was 36.84% for the film prepared from 0.5% sodium alginate and 10% glycerol, and increased to 42.14% for the film prepared from 0.5% sodium alginate and 50% glycerol. These results are in agreement with those found by Sellimi et al. (2015), who studied the antioxidant properties of sodium alginate extract from Tunisian brown seaweed using various antioxidant tests. They observed that sodium alginate exhibited free radical scavenging activity, strong ferrous ion-reducing ability, and high protection against DNA damage. Li et al. (2022) mentioned that sodium alginate is a linear, biodegradable polysaccharide composed of a-L-guluronic acid (G) and ß-D-mannuronic acid (M) in varying ratios, which gives alginate its gelling properties. They also noted that antioxidants work by delaying or preventing food spoilage and quality deterioration caused by oxidation, such as oxidative rancidity and enzymatic browning in certain foods.

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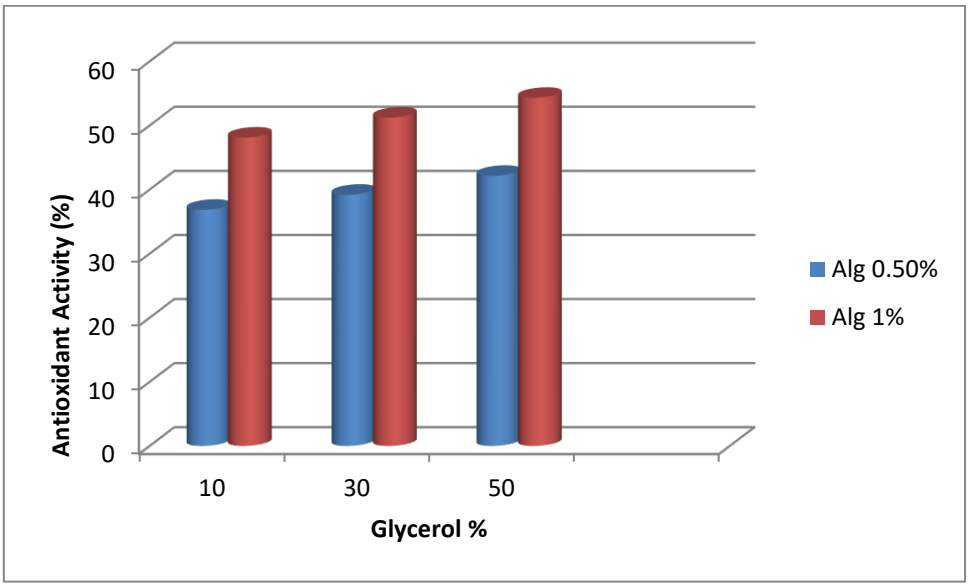

Figure 8: Antioxidant Activity (%)

4.Conclusions

This study successfully prepared edible films using sodium alginate (0.5% and 1%) and glycerol (10%, 30%, and 50%). The results demonstrate that glycerol concentration significantly impacts film properties. Increasing glycerol concentration (from 10% to 30%) led to increased thickness, elongation percentage, water solubility, and water vapor permeability. Conversely, increasing sodium alginate concentration to 1% (at the same glycerol concentrations) decreased tensile strength, water solubility, light permeability, and transparency. However, antioxidant activity increased with higher sodium alginate concentrations at all glycerol levels. All films produced met the Japanese Industrial Standards (JIS) maximum thickness for edible films, making them suitable for food packaging applications. The findings suggest that sodium alginate can be a viable natural component in food and pharmaceutical industries due to its film-forming properties and antioxidant activity. Further research could optimize the concentrations of sodium alginate and glycerol to achieve desired film properties for specific applications.

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