Synthesis of sodium alginate composite bioplastic films

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SUMMARY

In recent years, plastic pollution has reached high levels; eight million metric tons of plastic waste leaked into the oceans in 2010, with estimates predicting 53 million metric tons of emissions annually by 2030. The increasing use of single-use plastics accounts for much of this mismanaged plastic. Aside from harming marine ecosystems, burning plastic waste in landfills may release toxic chemicals that cause illnesses. Bioplastic, a plastic derived from biological sources, has emerged as a sustainable alternative to mitigate this issue. However, their lack of biodegradability and high costs restrict widespread adoption. We investigated the development of alginate-based bioplastic films as a sustainable plastic alternative. We hypothesized a sodium alginate-based bioplastic film synthesized in ambient conditions would demonstrate higher biodegradability, higher tensile strength, higher solubility in water, lower oxygen permeability, and lower water vapor permeability compared to PET plastic packaging films. We synthesized the films in ambient conditions with glycerol and calcium chloride as an added plasticizer. The material displayed transparency and flexibility. Additionally, the film was able to dissolve in water after 180 minutes and biodegrade in microbial conditions (i.e., environments that can sustain microbes and other decomposers) within seven days. Ultimately, our research supports sodium alginate composite films as a biodegradable bioplastic film that exhibits higher solubility in water, and greater biodegradability compared to PET plastic films. However, contrary to our hypothesis, sodium alginate composite films also demonstrated lower tensile strength and higher water vapor permeability. This suggests sodium alginate composite films are not ready to replace PET packaging films in the industry.

INTRODUCTION

Since its first synthesis in the 20th century, plastics have been a crucial centerpiece of society (1). Plastics are synthesized from petroleum (2). Their durability, flexibility, and transparency are central to the packaging industry (1). In 2015, 359 million tons of plastic were produced (1). However, with the advent of consumerism and throwaway culture, plastics are increasingly wasted every year. Globally, eight million metric tons of plastic waste leaked into the oceans in 2010, projected to increase to 53 million metric tons by 2030 (1).

Single-use plastic packaging accounts for 36% of all plastic production, and packaging production has readily increased throughout the years (3). Over time, macroplastics degrade into microplastics: plastic with a diameter of less than 5 mm; these plastics can enter the human food chain as fish consume the material (1). In landfills, incinerating plastic releases toxic chemicals and other gases into the atmosphere, causing cancers and other respiratory health problems once inhaled (1). There are three main types of plastic packaging: primary packaging, which maintains direct contact with the product in packages; secondary packaging, which groups individual units for transportation; and tertiary packaging, which is used for storage and handling (4). Primary packaging is typically difficult to recycle, as it is composed of many layers (4). As a result, despite recent advances in recycling technology, only 5% of all plastic generated is recycled (4). Recent sustainable initiatives have emerged to mitigate this single-use plastic pollution. One such effort is the development of bioplastics.

Bioplastics are plastics derived from biological sources (e.g., chitin, cellulose), synthesized similarly to petroleum-based plastics, with the only difference being the bioplastic's source (e.g., agricultural waste, bacteria, fermentation) (2). Not all bioplastics are completely biodegradable. Biodegradability is the tendency of a material to break down into basic compounds when in contact with natural microbes and decomposers. For instance, bio-polyethylene terephthalate is not biodegradable, despite the "bio" prefix (2). Thus, due to its lack of biodegradability, bioplastic residue pollutes the environment in the same manner as conventional plastics; there is no substantial difference between their effects (2). Along the same lines, even if a bioplastic is deemed biodegradable, it does not mean the material can be disposed of anywhere (2). Most bioplastics require specific facilities with proper conditions to degrade safely. As a result, while the bioplastic market grows, petroleum-based plastics are still predominately used (2). Thus, it is essential that the bioplastic industry research novel, sustainable alternatives – ones that are compostable at home.

This study aimed to synthesize a sodium alginate composite film. Sodium alginate is a compound extracted from sargassum brown seaweed or algae (5). Sodium alginate films are intrinsically hydrophilic because sodium alginate is a hydrophilic biopolymer (5). Hydrophilicity allows the compound to be processed in ambient conditions with water, deviating from the extreme heat and pressures in conventional bioplastics manufacturing (6). As such, sodium alginate films are synthesized in water-based reactions, as seen in a study by Amariei et al. In this study, sodium alginate films were synthesized by blending sodium alginate, agar, glycerol, and calcium chloride in distilled water (6).

With the addition of modification and additives, however, other properties, like tensile strength, can be improved (6). In the same study, glycerol and calcium chloride were used as additives to improve the properties of sodium alginate bioplastics (6). Glycerol was used as a plasticizer, changing the molecular configuration of the polymer chains to enhance flexibility (6). On the other hand, calcium chloride was used to improve material elongation and tensile strength (6). Another study found that reducing glycerol introduced brittleness, which limits its ability as a packaging film (7). The same study also found that the amount of calcium chloride added to the sodium alginate film was proportional to the tensile strength (7). In other words, decreasing the calcium chloride concentration decreased tensile strength. Sodium alginate films are intrinsically brittle with poor tensile strength. Thus, it is necessary to add glycerol and calcium chloride to improve the flexibility and tensile strength of the sodium alginate film (7). While calcium chloride has been used in other studies to measure its effect on tensile strength, this study focuses on evaluating its effectiveness as a hydrophobic agent and increasing the hydrophobicity of the film. Our procedure and study differ from the one facilitated by Amariei *et al.,* because instead of focusing on both agar and alginate, this study looks specifically at the synthesis of a sodium alginate bioplastic film. Additionally, instead of drying the films at room temperature after blending the calcium chloride into the solution, this study explores using industrial ovens to accelerate the process and spray calcium chloride on the film afterward.

In this study, we added glycerol and calcium chloride to improve the film's mechanical properties (6). These non-toxic plasticizers and additives were used to leave no traces of pollutants in the soil during the biodegradation of the film. When calcium chloride degrades in soil, it increases the moisture content by attracting moisture (8). The same phenomenon is observed for sodium alginate (9). Similarly, glycerol increases bacterial biomass, diverging from conventional bioplastics that perpetuate soil damage (10). Hence, the film is able to biodegrade safely without causing damage to the soil. Ultimately, the film's synthesis in ambient conditions and with such non-toxic plasticizers was important because it allowed the material to demonstrate biodegradability in microbial conditions within seven days.

We hypothesized that a sodium alginate composite film with glycerol and calcium chloride additives would demonstrate higher biodegradability, higher tensile strength, higher water solubility, lower oxygen permeability, and lower water vapor permeability compared to conventional PET plastic packaging films. Tensile strength measures how strong the material is, while water solubility measures the material's ability to dissolve in water. Oxygen and water vapor permeability refers to the material's ability to prevent oxygen or water molecules from penetrating its surface. Biodegradability is the breakdown of organic materials by microorganisms. Our findings show that sodium alginate bioplastic films exhibit higher solubility in water, and greater biodegradability compared to traditional PET plastic films. However, contrary to our hypothesis, sodium alginate composite films also demonstrated lower tensile strength and higher water vapor permeability. The higher solubility in water and higher water vapor permeability are consistent with previous literature, due to the hydrophilic nature of sodium alginate (6, 7). This suggests that sodium alginate films are

not ready to replace conventional PET packaging films in food packaging applications. More research is necessary to improve the tensile strength and water vapor permeability of sodium alginate composite films before they enter the market.

RESULTS

We synthesized alginate composite films at ambient conditions (i.e., 25°C and 1 atm) by preparing an aqueous solution of water, sodium alginate, and plasticizers. We then cast this solution on a molding tray to form a flexible film. We evaluated the extent to which alginate composite films could act as a suitable alternative to conventional plastic packaging by assessing the physical qualities of the film against PET plastic packaging films. The physical properties tested included: water vapor permeability, water solubility, tensile strength, biodegradability, and oxygen permeability.

100 mL of 0.046 M sodium alginate aqueous solution produced a 0.35 ft^2 film with a thickness of 87 μm. After visual inspection, we determined the transparency of the alginate composite was comparable to conventional PET plastic films. There was no evidence of air bubbles in the matrix of the film and the transparency was uniform across the entire material. The 0.5% (w/v) sodium alginate solution displayed the lowest viscosity, 26 Pa·s, while the 2.0% (w/v) sodium alginate solution displayed the highest, at 1300 Pa·s. High viscosity was not favorable because it restricted the movement of the solution to the molding tray and limited the extent of uniform stirring. For reference, the viscosity of distilled water is 0.001 Pa·s. We added glycerol to enhance flexibility. After visual inspection, we determined that 1.0% (v/v) glycerol was the optimal amount in conjunction with 1.0% (w/v) sodium alginate to maximize flexibility. Visual inspections further showed glycerol facilitated uniform texture, higher flexibility, and transparency. We added calcium chloride to improve hydrophobicity. To prevent clumping of the solution when calcium chloride was blended, we sprayed calcium chloride onto a dried film (**Figure 1**). We determined the solubility of the film in water by observing the structure of the material over time following complete submersion in water. By coating a dried film with a 0.01% (w/v) calcium chloride solution, the rate at which the film disassociated in water increased from 10 minutes to 180 minutes (**Figure 2**).
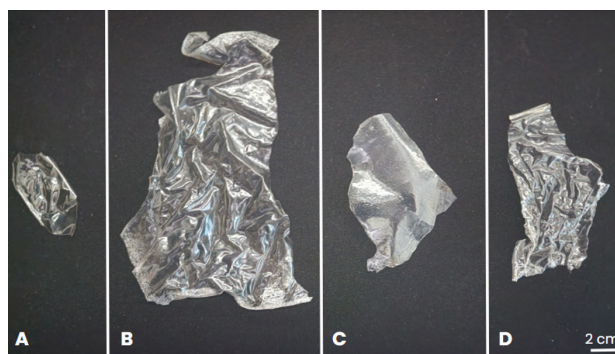

Figure 1. Hydrophilic and hydrophobically modified bioplastic packaging films. Four films with different hydrophobic modifications. Film A has no hydrophobic modification; film B has calcium chloride blended into the solution; film C had a calcium chloride solution spray before and after solvent casting; film D had the calcium chloride solution spray after drying. The different sizes of the samples are not significant as hydrophobicity was being measured.

Figure 2. Volume reduction from water submersion. Representation of one sample degrading over 90 minutes as a result of water submersion. The sample was submerged in 100 mL of distilled water, with periodic check-ins every 90 minutes. Complete hydrolysis was achieved in 180 minutes.

To test the oxygen permeability of the film, we wrapped two uncut apples. One was wrapped with a PET plastic film and another with a sodium alginate composite film. After two weeks, neither apple showed evidence of mold or any other physical change, suggesting low oxygen permeability (**Figure 3**). Additionally, we analyzed the tensile strength of sodium alginate films against PET plastic ones. The film with 0.5% (w/v) sodium alginate and 1.0% (v/v) glycerol displayed the lowest tensile strength of 5.7 MPa. The sodium alginate film with 1.0% (w/v) sodium alginate and 1.0% (v/v) glycerol displayed a tensile strength of 7.4 MPa. The sodium alginate film with 2.0% (w/v) of sodium alginate and 1.0% (v/v) of glycerol displayed a tensile strength of 9.5 MPa while PET plastic films displayed a tensile strength of 13 MPa. We determined water vapor permeability by measuring the amount of water that escaped from a beaker of boiling water covered with PET plastic or alginate film. 98% of the water remained in the beaker covered in PET plastic film. 86% of the water remained in the beaker covered with sodium alginate film, suggesting the sodium alginate film displays higher water vapor permeability compared to PET plastic films. For the vapor permeability tests, the thickness of the PET film was 85 μm while the sodium alginate film was 87 μm thick.

We evaluated biodegradability by burying the alginate films in microbial conditions (i.e., environments that can sustain microbes and other decomposers). For our study specifically, we buried our film in soil. After complete burial in these conditions, the alginate composite film completely degraded after seven days (**Figure 4**). In contrast, the PET plastic film showed no evidence of degradation after the same time interval.

DISCUSSION

The sodium alginate film was biodegradable, flexible, transparent, and tensile; it displayed low oxygen permeability and high water vapor permeability. Compared to PET packaging films, the sodium alginate composite film displayed higher water permeability, higher solubility in water, and lower tensile strength. Unlike PET plastic films, the sodium alginate film dissolved in water after three hours of complete submersion and degraded in microbial conditions within seven days. The oxygen permeability of the bioplastic film compared to conventional PET plastics was inconclusive. While the film exhibits low oxygen permeability, biodegradability, and flexibility, due to its high vapor permeability, water solubility, and low tensile strength, there are major limitations when considering their applications
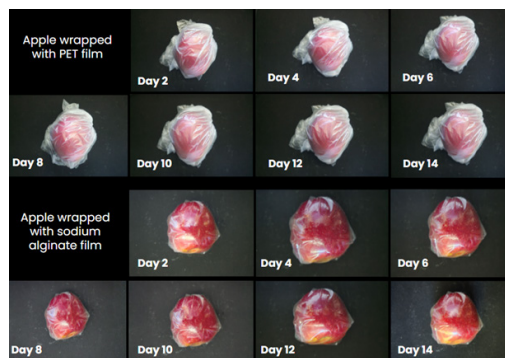

Figure 3. Oxygen permeability of sodium alginate composite films and PET packaging films. A two-week oxygen permeability test was conducted to compare the oxygen permeability of PET films against sodium alginate composite films. One apple weighing 87 grams was wrapped with a PET film, while another identical apple (87 grams) was wrapped with the sodium alginate film. After 2 weeks, there was no visible physical change on the apples, thus the test was inconclusive in determining whether one film displayed better oxygen permeability than the other.

Sodium alginate is comprised of repeating units of β-D-mannuronic acid and α-L-guluronic acid linked by 1 to 4 glycosidic bonds, and it contains many hydroxyl groups (6). As a result, it is soluble in water, making it an optimal solute for ambient reactions (6). The use of glycerol was important because it is also soluble in water: glycerol disrupts the interactions between the molecular chains in the aqueous solution, rearranging them to maximize flexibility (6). However, increasing the weight percentage of glycerol increased film adhesion, making the material challenging to handle.

The use of calcium chloride crosslinked calcium ions with the carboxyl groups on the sodium alginate (6). Calcium chloride attracts moisture which allows it to dissolve in water (6, 8). Despite this, the addition of these ions and functional groups reinforced the molecular chains of the solution to exhibit increased hydrophobicity (7). The sodium alginate film's water vapor permeability was higher than conventional PET plastic films. Further studies to lower the water vapor permeability must be explored. In a study by Marangoni *et al.,* nano-SiO_2 was added to sodium alginate solutions to lower water vapor permeability by forming hydrogen bonds between the polymer matrix and oxygen atoms of the nanoparticles (11). Adding nan-SiO_2 could thus be a viable way to reduce water vapor permeability (11).

The sodium alginate film degraded in microbial conditions within seven days. Contrary to conventional bioplastic films, the sodium alginate film is expected to degrade without negatively impacting the makeup of natural soils due to the utilization of non-toxic plasticizers. For instance, calcium chloride attracts moisture in soils (8). The same phenomenon holds for sodium alginate (9). Additionally, glycerol increases soil microbial biomass (10). Glycerol molecules contain carbon atoms (10). Thus, once glycerol is added to microbial conditions, it increases the supply of organic carbon, stimulating the growth of new biomass in the soil (10). As a result, the incorporation of glycerol and calcium chloride compounds into the chemical structure of the sodium alginate film promotes the safe degradation of the material in microbial soils. However, the effects of biodegradation of the film in soil were not explicitly measured in this study.

Figure 4. Biodegradability of sodium alginate composite films. Volume reduction after six days in microbial conditions. A composite film was submerged in a plot of soil and observed daily. After seven days in microbial conditions, the film completely degraded.

Figure 5. Sodium alginate film with blended calcium chloride. Sodium alginate film with 2 mL of 0.1% (w/v) calcium chloride blended into it. The calcium chloride solution was mixed at 1500 rpm for 30 minutes to produce this film. The resulting film displayed inconsistencies in its transparency in the form of white spots.

Previous work by Amariei *et al.* looked at a similar synthesis of agar-alginate films with the addition of glycerol and calcium chloride as plasticizers (6). The procedure blended calcium chloride into the aqueous solution instead of spraying it, as was the case in our experimental method (6). We tried replicating this study and blended 2 mL of a 0.1% (w/v) calcium chloride solution into the sodium alginate solution with continuous stirring. When casting the solution, we found irregularities in its texture; some of the calcium chloride did not fully dissolve in the distilled water and was visible upon visual inspection as white spots in the overall transparent film. However, we did not perform any mechanical testing on this film, so we can't compare the mechanical properties (tensile strength, water vapor permeability, etc.) between a film with blended calcium chloride and sprayed calcium chloride. The comparison of mechanical properties between spraying and blending calcium chloride into the sodium alginate film may be explored in future studies. However, from our findings, we believe blending the calcium chloride compromises the transparency of the film by introducing white spots and texture irregularities (**Figure 5**).

Thus, in our study, instead of mixing this compound into our solution, we sprayed 1 mL of the compound onto each side of the final film. We hypothesized a separate solution of 0.1% (w/v) calcium chloride to spray on the film allows for the calcium chloride to blend into the film while not compromising the texture and transparency of the material. The final film exhibited no transparency irregularities, validating our hypothesis. One significant limitation of the experiment was the excessive drying time. The mixture took 90 minutes to form into a film in a 200°C oven. While this is better than conventional plastic drying, which is dried at roughly 190°C for 6-24 hours, it is not favorable for sustainability metrics as too much energy and time are used (12). If the mixture was initially heated to higher temperatures, then there would be a proportionate decrease in the drying time as the mixture cools faster. However, due to the physical qualities of the solution, this was not possible as exceeding 90°C blackened the solution.

Further study into the incorporation of calcium chloride would benefit from additional research. A pressure chamber to disperse the aqueous solution more evenly would have been optimal to achieve a uniform spread. We hypothesize this would also aid in allowing the calcium chloride to react with inner sodium alginate molecules rather than just the

surface, reinforcing the hydrophobicity of the film. It must be noted that while the film could dissolve in water, after visual inspection, the material was still hydrophobic enough to withstand dissolution in the presence of water vapor in humid conditions. In other words, in the presence of water vapor during the water vapor permeability test, the film remained intact. While we didn't measure the mass of the film before and after the water vapor permeability test, after visual inspection, we concluded the material was still intact with no damage inflicted. It was only after complete submersion and constant agitation that the film underwent dissolution. The high hydrophobicity of conventional PET plastic films restricts its hydrolysis (12). In contrast, the lower hydrophobicity of the sodium alginate film allowed for complete solubility in three hours. Sodium alginate is inherently hydrophilic, leading to high water vapor permeability. The use of calcium chloride as an additive deterred this physical behavior, reinforcing the surface of the film by crosslinking the calcium ions with the carboxyl groups to decrease water solubility (7). Despite this, the water vapor permeability of the film was still substantially higher than that of conventional PET films.

The low oxygen permeability of the film is favorable for food packaging applications, as it acts as a barrier to create an oxygen-free environment (13). It must be noted that the results of the oxygen permeability test were inconclusive to determine whether sodium alginate-based bioplastic films displayed superior oxygen permeability compared to conventional PET plastic films. Both experimental groups showed no case of mold on the apple; this suggests both materials have good oxygen barrier properties. However, because we did not perform additional experiments on wrapping apples using sodium alginate composite films with and without calcium chloride, we do not know if calcium chloride specifically contributed to the oxygen permeability of the bioplastic film. Further testing is required with an oxygen permeability tester to measure the oxygen transmission rate through both the bioplastic and plastic films at a molecular level to ascertain whether one film exhibits lower oxygen permeability compared to the other.

There are various considerations for future experiments based on the results of this study. We did not explore the film's ability to undergo heat sealing in this study. Sealing films with heat is critical to forming packaging bags and other products (12). Due to the low melting point of sodium alginate, roughly

90°C from the results of this study, the use of heat to meld two films together has merit. However, one must be cautious to prevent the blackening and burning of the film due to its water-soluble properties, which occur when the solution exceeds 90°C. Additionally, the utilization of water sealing experiments can be explored in the future. By applying water to a sample of a film and attaching another similar sample of the film to the area where water was applied, the two films could potentially wield together after the water evaporates (14). This was seen in a previous study, where a similar water-based bioplastic – aquaplastics – underwent "aquawielding" (14). This is a process where water is used to seal films together instead of heat (14). While aquaplastics are produced from bacteria, because it is also synthesized in water-based reactions, we hypothesize a similar phenomenon may occur for sodium alginate composite films.

Additionally, different mass-volume ratios between sodium alginate and glycerol can be further explored. While adding excessive volumes of glycerol induces film adhesion to make the material difficult to handle, increasing the mass of the sodium alginate in relation to the volume of the glycerol may increase the tensile strength of the film, as seen in this study. Supplementary sodium alginate increases the strength of the overall molecular structure of the film, as evidenced by the increase in the tensile strength of the film as the weight percentages of sodium alginate increased. The film with a 0.5% (w/v) of sodium alginate displayed a tensile strength of 5.7 MPa while the film with a 2.0% (w/v) of sodium alginate displayed a tensile strength of 9.5 MPa. However, when exploring this variable, it is crucial to be aware of the viscosity of the sodium alginate aqueous solution, as excessive viscosity makes the solution difficult to cast.

The material may also be subjected to different environments in future studies. While the bioplastic film was exposed to water vapor during the water vapor permeability tests, environments with extreme temperatures were not considered. Doing so adds further discussion to potential future applications in the packaging industry. When studying the behavior of this film in differing temperatures, it is critical to observe the change in the material's flexibility, as sodium alginate is unstable during heat treatment (15). However, there are various limitations in the mechanical properties of the film that must be addressed when considering the film's applications and future studies. Firstly, the film exhibited higher water vapor permeability than PET packaging films. This could be attributed to the fact that the film was made in water-based reactions. Sodium alginate is hydrophilic, which could have contributed to the higher water vapor permeability (5). This is not favorable for applications, especially when packaging food. This limitation can be circumvented by manipulating the composition of sodium alginate. According to a study by Cazón *et al.,* sodium alginate films with a higher amount of α-L-guluronic acid displayed lower water vapor permeability (16). The lower tensile strength of the film is also another major limitation when considering the film's applications. Compared to a tensile strength of 13 MPa, the sodium alginate film that displayed the highest tensile strength in this study across the samples was a 2.0% (w/v) solution of sodium alginate in 100 mL of distilled water, with a tensile strength of 9.6 MPa. To improve the tensile strength, the weight percentage of sodium alginate can be increased, as our findings suggest a proportional relationship between the weight percentage of sodium alginate and tensile strength.

The sodium alginate composite film synthesized in this study exhibited low tensile strength comparable to conventional PET plastic wrappings. Unlike PET plastic films, the sodium alginate film could biodegrade within seven days under microbial conditions without compromising the health of the soil. The sodium alginate film achieved water dissolution under complete submersion within three hours and exhibited low oxygen and high water vapor permeability. Furthermore, the material was flexible and transparent, matching the physical qualities of conventional wrappings. Compared to conventional PET plastic packaging films, the sodium alginate film was superior in its solubility in water, and biodegradability. However, the sodium alginate film failed to compete with the high tensile strength and low water permeability of conventional PET plastic packaging films. Thus, additional research is needed to improve various mechanical properties like tensile strength and vapor permeability before sodium alginate films are considered for applications.

MATERIALS AND METHODS

Our research aim was to evaluate the extent to which sodium alginate bioplastic packaging films could replace PET packaging films based on biodegradability, tensile strength, solubility, and permeability. Our data collection reflects this aim, focusing specifically on modifying the concentrations of additives. 0.5%, 1.0%, and 2.0% (w/v) sodium alginate solutions were made by mixing sodium alginate powder (ChemCenter, Cat# 9005-38-3) with distilled water (BISupply, Cat#2795) at 60°C under continuous stirring until dissolved. Then, glycerol (HiMedia, Cat# GRM081-1L) was introduced into the sodium alginate aqueous solution to prepare 0.5%, 1.0%, and 2.0% (v/v) glycerol solutions. The glycerol solutions were stirred at 80°C for 2 minutes. This solution was then cast onto a molding tray and dried in the oven at 200°C for 90 minutes (**Figure 6).**

Additionally, a 0.1% (w/v) calcium chloride aqueous solution (Innovating Science, CAT#12035) was prepared. This solution was placed in a water sprayer. Once the film was removed from the oven, it was cooled for 15 minutes at room temperature. Afterward, it was held and sprayed with 1 mL of the calcium chloride solution on each side of the film and set to dry for 15 minutes.
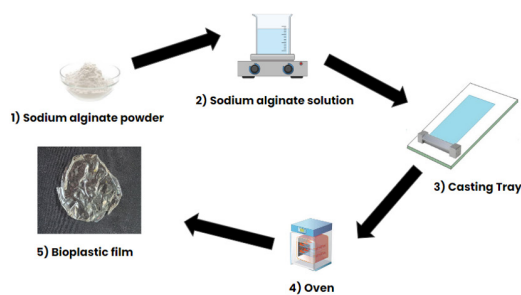

Figure 6. Solvent-solute casting method of sodium alginate. Production cycle of the film, incorporating the dissolution, solution casting, and drying processes. To produce the film, 0.5% (w/v), 1.0% (w/v), and 2.0% (w/v) sodium alginate solutions were made by mixing sodium alginate powder with distilled water.

Mechanical Properties

The oxygen permeability of the film was determined by wrapping an intact apple with a sodium alginate composite film and another apple with a PET plastic film. We visually monitored the apples wrapped in film for mold every other day for two weeks. The material's water solubility was determined by submerging it in water and measuring the time it took for the film to dissolve completely. The biodegradability of the alginate composite or PET plastic film was determined by burying 0.35 ft^2 of film in soil. Every 24 hours for seven days, the film was unearthed to measure the rate of degradation. The water vapor permeability was measured by boiling water and placing a sodium alginate film or a PET plastic film on top of a beaker, covering any openings. The initial volume of the beaker was measured at a time reading of 0 seconds and measured every 90 minutes for 180 minutes. The volume difference indicated the water vapor permeability of the material. A tensile strength tester (Digikey, Cat#2779-ES20-ND) was used to determine the tensile strength of the sodium alginate and PET film.

The viscosity of the sodium alginate solutions (0.5% (w/v), 1.0% (w/v), and 2.0% (w/v)) was measured. Each solution was poured into a graduated cylinder. The solution weighed 7.88 g, 8.81 g, and 9.15 g respectively. Afterward, a circular marble was dropped into the solution. The time interval of the marble's displacement from the surface of the solution to the bottom of the cylinder was measured, along with the density of the solution and marble sphere. The viscosity equation was used to calculate the viscosity with the experimental data.

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