Production of biodegradable film based on sweet potato starch with hydroxypropylation-crosslinking

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Abstract. Plastics that are used as packaging have many advantages including flexible, transparent and not easily torn. The disadvantages of the material used in the manufacture of conventional plastics are non-biodegradable in the environment. One of the ingredients for making biodegradable films is white sweet potato, this is because chemically, sweet potato has amylose content of 35.99\%. Native biodegradable starch films have hydrophilic properties, to overcome these weaknesses, it is necessary to repair or modify starch. Biodegradable hydroxypropylation-crosslinking films have a lower solubility value than unmodified films. High film solubility values indicate a decrease in the quality of the film to be used as food packaging material because the film easily dissolves in water and increases the possibility of damage to packaged products especially for products easily affected by water content. The tensile strength and percent elongation values of the entire modified starch films have a higher value than those of natural sweet potato starch films. Water vapor transmission rate (WVTR) is lower than that of natural sweet potato starch films. Transparency value has decreased to 13.89–14.10 (\%abs/mm) which indicates that the film is in good clarity.

Keywords: Biodegradable film, Dual modification, Starch, Sweet potato

1. Introduction
The use of synthetic plastic as packaging until now can still cause environmental pollution. It is true that synthetic plastics can protect food from contamination and spoilage, but they can also be a source of substances that migrate to food [1]. Biodegradable films are not intended to replace synthetic plastics, but to limit the aroma, moisture and lipid migration between food components where synthetic plastics cannot function. For example, biodegradable films can be used for multipurpose food products to limit oxygen deficiency, improve mechanical properties, reduce moisture loss, and provide physical protection and provide alternatives to synthetic plastics [2]. Starch as a biopolymer can be an attractive solution as a basis for making biodegradable films.

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Starch is one of the raw materials that can be used as a material for making biodegradable films, on the grounds that it is quite cheap, edible, abundant and biodegradable. There are two types of polysaccharides in starch, namely amylose and amylopectin [3]. Linear molecules consisting of several branches are amylose, while amylopectin is a molecule that has many branches. Therefore, amylose content contributes to the strength of film and the branched structure of amylopectin generally leads to films with low mechanical properties [4]. The relationship between amylose content and film forming ability is quite good. This is because starches with high amylose content (around 30% amylose) have excellent film formation properties compared to starches with low amylose content [5]. However, good mechanical properties produce brittle films that do not have the desired properties as packaging, so it is necessary to modify starches [6]. Modified starch is used to improve the properties of the film. Examples include: hydroxypropylated starch; crosslinking starches; mixture of gelatin/hydroxypropyl starch/plasticizer [7] and starch acetate [8]. Films formed from hydroxypropylated starch have low solubility so that it is advantageous to use as a packaging material, especially transparency and flexibility [9]. In addition to hydroxypropylation, the crosslinking method is also used to form stronger chemical bonds so that when the suspension temperature is raised the granules will remain intact. The advantages of crosslinking starch are resistant starch at low pH and stirring [10]. [11] claim that the addition of sodium tripolyphosphate has an effect on reducing gelatinization temperature, increasing viscosity, increasing the stability of pasta. Starches modified through cross-linking can form a strong and rigid film matrix. Based on this, the sweet potato starch which has been modified chemically is assumed to be suitable for use as a base material for making biodegradable films that produce low water vapor transmission and has good mechanical strength.

2. Materials and methods

2.1 Materials and tools
Material for starch modification consists of sodium tripolyphosphate (STPP) as crosslinking reagent (C) and propylene oxide (C₃H₆O) as hydroxypropylation reagent (H), sodium sulfate (Na₂SO₄), hydrochloric acid (HCl), sodium hydroxide (NaOH), sulfuric acid (H₂SO₄). The materials used for making biodegradable films include modified sweet potato starch, sorbitol, distilled water and other analytical chemicals. The tools used in this study include waterbath shaker, strength tester, micrometer screw, spectrophotometer, erlenmeyer and other glass equipment. The material used was white sweet potato starch (*Ipomoea batatas* L.) varieties of AC.

2.2 Methods
The STPP concentration used was determined based on the best treatment value at the highest concentration of the [12] study which was 1.5%. The concentration of propylene oxide used in this study was determined based on preliminary research that is as much as 8% and based on the research of [13] which is 10%. Modification of starch used in the manufacture of biodegradable films made from sweet potato starch, with a modified Crosslinking-Hydroxypropylation (C-H) treatment there were 4 treatment levels and 3 replications with the following details:

- B1 = H8-C1.5 = Propylene Oxide 8% and STPP 1.5%
- B2 = H8-C2 = Propylene Oxide 8% and STPP 2%
- B3 = H10-C1.5 = Propylene Oxide 10% and STPP 1.5%
- B4 = H10-C2 = Propylene Oxide 10% and STPP 2%

The experimental design is a completely randomized design (CRD) with the mathematical model used, namely:

\[ Y_{ij} = \mu + A_i + \varepsilon_{ij} \]  

Information:

\[ Y_{ij} = \text{Parameter observation results} \]
\[ \mu = \text{General midpoint} \]
\[ A_i = \text{Effect of modified H-C treatment factors on the}\ i\ \text{level} \]
\[ \varepsilon_{ij} = \text{Experiment error in treatment to } i \text{ and repeat to } j \]

2.2.1 Modification of hidroxypropylation-crosslinking. Modification is carried out 3 times with 15 g of sodium sulfate (Na\textsubscript{2}SO\textsubscript{4}) (15% based on the dry weight of starch) dissolved into 185 mL of distilled water in a 300 mL erlenmeyer flask at room temperature. Sweet potato starch weighing as much as 100 g (dry weight) is dissolved in sodium sulfate solution until homogeneous. Then the pH is increased to 11.5 by adding 5% sodium hydroxide (NaOH) while stirred for 10 minutes. This stage is called the starch activation step to prepare the starch for the next reaction. Then propylene oxide with concentrations of 8 and 10% (% w/w) is added and dissolved at room temperature for 30 minutes. The suspension is then transferred to the waterbath shaker at a temperature of 40\textdegree C 140 rpm for 24 hours. The starch suspension is transferred to the mixing container at room temperature. After that, STPP (sodium tripolyphosphate) is added with 1.5 and 2% concentration (% w/w). Then the suspension is stirred continuously at 40\textdegree C for 3 hours. The pH of the suspension is reduced to 5.5 by the addition of 1 N hydrochloride (HCl) solution to stop the reaction. Then centrifugation (4000 rpm: 20 minutes) is performed. Then the precipitate is washed with two times distilled water. After that the starch is dried at 50\textdegree C for 24 hours. The resulting starch is dried and the size is reduced by 80 mesh sieve to produce a ready to use starch. Characteristics of natural and modified starches observed are chemical composition (water content, starch, amylose, phosphorus, degree of substitution, levels of hydroxpropyl and molar substitution), amylographic properties (temperature and peak gelatinization), physical properties (granule size) and functional properties (granule size) solubility, swelling power, paste clarity, freeze-thaw stability, and white degree.

2.2.2 Production of biodegradable film. 5 g of modified starch is then dissolved into 100 mL of distilled water at 85\textdegree C for 15 minutes using a waterbath shaker (150 rpm). Then mixed with sorbitol (40% w/starch) and stirred continuously for 15 minutes in a water bath with a temperature of 85\textdegree C. The solution is then lowered to 40\textdegree C and stirred slowly for 20 minutes until the water bubbles disappear. The solution is cast on a plastic petri dish then put in an oven at 50\textdegree C for 20 hours. Then it is dried at room temperature. The resulting film is tested with direct parameters including moisture content and thickness and indirect parameters including SEM (Scanning Electron Microscopy) to determine the dispersion of the solution, film transparency test, water vapor transmission rate (WVTR), solubility in water (solubility), tensile strength, elongation and biodegradability.

3. Results and discussion

3.1 Characteristics of natural and modification starch

The low water content value of all starch has met the 2011 SNI standard for tapioca-like products, where the maximum water content of the product is 14%. The durability of a material can be extended by removing some of the water in the material, therefore a low water content is needed for the manufacture of modified starch. The modified starch levels obtained increased with increasing STPP concentration due to the increasing degree of substitution (DS) in starch molecules. The more DS, the more crosslinking that will strengthen the molecular bonds of starch with the number of phosphate group bonds so that the granule properties are more stable and not easily dispersed in water. In addition, when the phosphate group penetrates into starch granules and forms covalent bonds with starch molecules, it increases the starch molecular weight thereby increasing starch [15].

Sweet potato starch without modification (natural starch) is presented with a value of zero (0) because it is used as a blank for modified starch. MS is the molar level of the substituent monomer group per unit
of D-glucopyranosyl [16]; [17]. Substitution molars are used when substitution groups further react with the chemical itself to form polymeric substituents. In this study different MS values are obtained even though all sweet potato starches are modified with the same amount of propylene oxide (8% and 10%). Hydroxypropylation levels tend to increase with increasing concentration of propylene oxide added. This can result in swelling of the granules thereby increasing the value of swelling power [18]. In addition, the MS value also affects peak viscosity (PV), the higher the MS value of modified starch, the PV is also increasing which indicates a decrease in associative bond strength in the modified starch granules caused by hydrophilic properties. Integrated hydroxypropyl groups facilitate penetration and absorption of water into starch granules from amorphous regions [19]. Low MS values are caused by decreased accessibility of cross-linked starches during hydroxypropylation reactions. The chemical composition and physical properties of natural and modified sweet potato starch are presented in Table 1.

Table 1. Chemical composition and physical properties of natural and modification starch.

| Type of starch | Water content (%) | Starch (%db) | Amylose (%db) | Phosphorus (%) | DS | %HP | MS | Size of granule (µm) |
|----------------|------------------|--------------|---------------|---------------|----|-----|----|---------------------|
| Natural        | 9.02             | 85.23        | 35.99         | -             | -  | -   | -  | 62.74 x 60.03       |
| H8-C1.5 B1     | 8.14             | 87.38        | 39.87         | 0.0187        | 0.0010 | 0.964 | 0.0267 | 68.60 x 60.96 |
| H8-C2 B2       | 8.13             | 87.39        | 40.11         | 0.0242        | 0.0013 | 0.932 | 0.0258 | 72.63 x 66.14 |
| H10-C1.5 B3    | 8.19             | 87.37        | 38.84         | 0.0185        | 0.0010 | 1.109 | 0.0308 | 73.18 x 69.59 |
| H10-C2 B4      | 8.11             | 87.38        | 39.25         | 0.0243        | 0.0013 | 1.020 | 0.0283 | 64.18 x 57.03 |

Phosphorus content measurement is needed to obtain the value of the degree of substitution which proves the formation of phosphate bridges in the amylose chain. Phosphorus content in modified sweet potato starch is in the range of 0.0185–0.0355%. In commercial starch modifications the maximum permissible phosphorus content is 0.4% [20]. According to [21] the value of DS indicates what percentage of the phosphate group forms a crosslink bridge in the amylose chain, in this case it is closely related to the level of phosphorus in the granule. Degree of substitution (DS) is the average number of hydroxyl groups replaced by other compounds in the amylose polymer chain. The degree of substitution (DS) expresses the average number of groups per anhydroglucose unit substituted by another group. Modified starch has a DS value of 0.001, where on average there is 1 group substituted every 1000 units of anhydroglucose.

Table 2. Amylographic and functional properties of natural and modifications starch.

| Type of starch | Amylographic | Functional |
|----------------|--------------|------------|
|                | T (°C) | PV (cP) | Solubility (%) | Swelling power (%) | Whiteness degree (%) | Freeze-thaw stability (%sineresis)** | Clarity (%T) |
| Natural        | 82.80  | 4397   | 6.90          | 16.50           | 77.14            | 95.18                  | 44.97       |
| B1 H8-C1.5     | 86.55  | 5933   | 10.00         | 44.15           | 61.32            | 79.45                  | 40.07       |
| B2             | 86.55  | 5700   | 12.22         | 45.49           | 60.81            | 81.11                  | 40.72       |
|          | H8-C2 | B3       | H10-C1.5 | B4       | H10-C2 |
|----------|-------|----------|----------|----------|--------|
|          |       |          |          |          |        |
| T (°C)   | 85.30 | 6196     | 10.00    | 44.04    | 59.55  |
|          |       |          |          |          |        |
|          | 77.40 | 42.45    |          |          |        |

"): Very significantly different

The starch amylographic properties presented in Table 2. shows an increase in the gelatinization temperature (T) of the modified starch due to recrystallization of the starch granule component so that it is more resistant to heat and requires higher temperatures to gelatinize [22]. In addition, amylose levels also affect the temperature of gelatinization, where the higher the amylose, the higher the temperature of gelatinization. PV values increase with increasing hydroxypropylation reagent concentrations caused by crosslinking reactions that can maintain granules from damage due to high water absorption. This can be seen in Figure 1, where the higher the PV value and swelling power, the larger the size of the granules [23].

![Figure 1. Hydroxypropylated-crosslinking modified starch granules.](image)

Solubility is the weight of dissolved starch divided by the initial weight of starch while swelling power is the maximum weight of starch during development in water divided by the initial weight of starch [24]. Natural starch (without modification) shows a lower value than modified starch for solubility and swelling power, in this case the solubility and swelling power values can be determined by the reagent concentration, the solubility and swelling power of the modified starch for the STPP concentration of 1.5% (B1 and B3) lower than the 2% STPP concentration (B2 and B4). During the heating process the breakdown of starch granules occurs, so that starches with high amylose content, the granules release more amylose and cause increased solubility [25]. In general, a high swelling power value will also increase the solubility value due to increased molecular substitution by the hydroxypropyl group that interferes with inter and intra-molecular hydrogen bonds in the starch chain and weakens the structure of the starch granules, thereby increasing the accessibility of starch grains to water [26].

The degree of white indicates the level of brightness of the white color of starch which is indicated by the wavelength dispersion power. Whiteness or degree of white is a physical characteristic that shows the power to reflect light that hits the surface of the object compared to the standard (BaSO₄). Modified starch shows a decrease in the value of the degree of white, the tendency to decrease the value of the degree of white in the modified starch is because all the modified starch passes through twice the drying process. The first drying process is from fresh white sweet potato to white sweet potato starch which is dried in the oven for 12 hours at a temperature of 50–60°C. Then the second drying process is in the making of modified sweet potato starch using an oven for 24 hours at a temperature of 45–50°C. The value of white degree is decreased due to an oxidation reaction that causes a brown color.

Percent of decreased syneresis shows that modified starch is able to hold more water during the freeze-thaw cycle. So that the modified starch can be used in frozen food preparations that require viscosity. Modified starch emits a lot of fluid during the freeze-thaw cycle due to retrogradation of starch granules during the low temperature cycle where tissue formation and reassociation release water which increases
% syneresis but is still lower than natural starch. In addition, modified starches can develop more numbers of hydroxypropyl groups and fewer numbers of intra- and inter-molecular relationships than natural starches. The syneresis in freeze-thaw stability is related to the increased molecular relationship between the starch chain on the decrease in temperature and removal of water from the gel structure. The use of propylene oxide in hydrophilic modified starches of the hydroxypropyl group increases the ability to retain water from the starch paste by limiting the amount of water that comes out. The modification of the retrogradation of the modified starch which is lower than that of the natural starch can be seen from the %syneresis which also decreases due to the inhibition of reintegration of the starch chain by the hydroxypropyl group. This supports producing clearer and more flexible films compared to natural starch.

Modified starch shows a decrease in the value of pasta clarity compared to natural starch, in this case the concentration of hydroxypropylation reagent (propylene oxide) is quite influential but not in the order of modification. Greater propylene oxide concentrations (10%) also produce greater clarity values than 8% propylene oxide concentrations. This is due to the cross-linked starch linkages in water which form more hydrogen bonds with dissolved starches and this bonding network in its overall form prevents transmittance and reduces the value of paste clarity [27]. Therefore in Table 2 it can be seen that as the concentration of propylene oxide increases, the clarity of the paste also increases. In addition the transmittance value shows a high value along with the swelling power value which also increases.

3.2 Characteristics of biodegradable film

The principle of gelatinization is used in the manufacture of starch-based biodegradable films formed in the presence of an amount of water and heated at high temperatures. Biodegradable film that is formed is yellowish, transparent and soft-textured. The thickness of the film can be adjusted by taking into account the ratio of the print area to the volume of the film solution used. The resulting film was then analyzed by the level of water vapor permeability (WVTR), tensile strength (TS), and elongation (E) previously conditioned at 50% RH and temperature 25±2°C by placing it in a desiccator containing silica gel for ±24 hours after the oven and peeled. For further testing the film sample is transferred to a plastic bag. From the overall characteristics of biodegradable films, the thickness, transparency and WVTR values showed the results of the variance analysis that there were differences in the treatment effects indicated by F count > F table. The functional properties of biodegradable films are presented in Table 3.

Table 3. Characteristics of biodegradable film.

| Treatment  | Thickness (mm)* | Water content (%)* | Solubility (%) | Transparency (%abs/mm)** | Tensile strength (MPa) | Elongation at break (%) | WVTR (g.hours/m²) |
|------------|-----------------|--------------------|----------------|--------------------------|------------------------|------------------------|------------------|
| Natural    | 0.154           | 8.26               | 34.59          | 14.14                    | 5.13                   | 33.72                  | 5.014            |
| H8-C1,5    | 0.144           | 7.18               | 28.96          | 13.93                    | 6.03                   | 37.70                  | 4.216            |
| B2 H8-C2   | 0.146           | 7.27               | 29.79          | 14.10                    | 6.48                   | 34.38                  | 3.954            |
| B3 H10-C1,5| 0.144           | 7.13               | 31.54          | 13.89                    | 9.33                   | 55.46                  | 4.306            |
| B4 H10-C2  | 0.146           | 7.27               | 32.00          | 14.08                    | 9.48                   | 46.28                  | 3.938            |

*) : significantly different ; **: very significantly different
Modified starch films showed lower thickness values compared to natural starch films. The solubility value increases with increasing value of modified starch film thickness along with increasing crosslinking reagents (B2 and B4), these results are obtained due to the presence of crosslinking reagents (STPP) producing phosphate starch so that it interferes with the aggregation of adjacent starch chains resulting from negative charge in the phosphate group which can reduce the relationship between chains and increase the likelihood of hydrated molecules. The order of starch modification also affects the yield on the film, the lower concentration of crosslinking reagents (B1 and B3), the solubility value also increases. In addition, with the same STPP concentrations (1.5 and 2%) but increased propylene oxide concentrations produce lower solubility values than treatments with low propylene oxide concentrations. This is caused by the hydroxypropylation process carried out at the end of the process on the film so that the hydroxypropyl group can improve the hydrophilicity of starch while also decreasing the solubility value of the film and increasing the thickness value. The reduced quality of the film to be used as food packaging material can be seen from the high solubility value of the film because the film is very soluble in water and increases the likelihood of damage to products that are packaged especially for products that are easily affected by water content. In the modified film, the value of water content increased with increasing STPP concentration. High film solubility shows decreased water resistance, but high solubility can be an advantage for some applications. The lower the solubility value of the film, the higher the ability of the film to protect packaged products from the influence of water.

Greater transparency values indicate lower transparency in the film. Films made from starch without modification have higher transparency values (more opaque) than modified starch films. Transparency values tend to decrease along with the increase in propylene oxide in modified starch films, this is due to the large hydroxypropyl and hydrophilic properties making the whole amylose chain difficult to be reconnected and difficult to form a gel network by amylose chains and remnants of granules to produce light transmission which is high. Transparency value increases with increasing crosslinking reagent (STPP) concentration. Transparency value is influenced by film thickness which is also influenced by the order of modification and concentration of STPP reagent, propylene oxide and transparency value. The higher the thickness value, the transparency value will also increase. Moisture content is not affected by the order of modification but is influenced by the concentration of the STPP reagent. The higher the transparency value of the film, the value of water content will also increase where the concentration of STPP is also increasing as in B2 and B4 films. This is presumably because the STPP polar groups are hydrophilic (ions that like water) so that the phosphate fraction is able to bind water causing the binding ability of water by starch to be higher. When starch reacts with a mixture of STPP ionic phosphate groups will be produced [28].

The value of TS and E films from modified starches showed a higher number than films from natural starches. The increase in TS value indicates that the film is stronger than natural films. The increase in TS value is caused by the cross reaction between the hydroxyl group and the crosslinking agent which produces crosslinked starches, crosslinking reagents at low concentrations there is not enough crosslinking between starch molecules to increase TS film and thickness values other than being influenced by the volume of the film solution at the time of in print. Improved mechanical properties of modified starch films other than those mentioned above are due to crosslinking reagents that react with OH groups present in starch thus making the connection of ether and hydroxyl groups that can improve mechanical properties [29]. The same thing happened with the effect of water content on the value of TS film, the higher water content, the TS film value will also increase, due to crosslinking which strengthens the structure of starch granules and limits the absorption of starch water, thereby limiting the mobility of starch chains in amorphous regions [30].
Elongation at break (%E) indicates flexibility and stretch of film. The effect of film thickness on %E is shown by the value of %E which decreases with increasing film thickness. This is due to the increased ability of the film matrix to withstand stretching. Biodegradable films get stiffer and break easily if the value of %E is low. After modification, there was an increase in %E with an increase in propylene oxide concentration. This result is due to the incorporation of hydroxypropylation groups that can disrupt inter and intra-molecular hydrogen bonds in the starch chain, which reduces the formation of the junction zone caused by inhibition of amylose chain interactions, thereby weakening the structure of starch granules [26]. The higher the water content, the higher the elongation value. The use of sorbitol can increase water absorption in the film, this is due to the hydrophilic nature of sorbitol so that it has the ability to bind water. In addition, the presence of hydroxyl (OH) groups in sorbitol causes an increase in water absorption in the film [31]. Because there is no variation in the concentration of sorbitol, the value of the water content of all treatments is relatively the same. In addition, propylene oxide can act like a plasticizer in a film that induces the formation of a starch-plasticizer interaction which results in a higher %E. As a result, the density of intermolecular interactions in the material decreases and the free volume between the polymer chains increases [32].

Modified starch films showed lower WVTR values than natural starch films. This is due to the reduction or replacement of hydroxyl (OH) groups in glucose units with hydroxypropyl ether groups which causes starch to reduce the ability to bind water vapor. The hydroxyl group that has been replaced by a hydroxypropyl ether compound results in a closer composition of the polymer matrix due to an increase in hydroxypropyl ether molecular weight, so that the water vapor crossing becomes slower and results in a lower WVTR value [33]. According to [34], the hydrophilic nature is caused by the chemical structure of starch which contains many hydroxyl (OH) groups that are capable of binding to water. In addition, related to the relationship between the thickness value and WVTR on the film from modified starch, it is found that the more thickness value the WVTR decreases, in contrast to the film from natural starch, where the thickness value is directly proportional to the WVTR value. In the use of hydroxypropylation reagents (propylene oxide) in the modification is strongly influenced by the concentration of STPP, with the same propylene oxide concentration in the modified starch but a low STPP concentration will increase the WVTR value while a high STPP concentration can decrease the WVTR value. The water content value is not affected by the order of modification, but the concentration of the added reagent can affect the moisture content of the film. The higher the concentration of STPP, the higher the value of water content, but the value of WVTR has decreased. This is because crosslinking reagents (reactors) react with the OH groups present in the starch and make an ester linkage with the hydroxyl group. This helps improve the mechanical properties of the film as well as reduce the water absorption behavior [29]. According to [35], that the inter and intra-molecular effects of hydrogen bonds in the starch chain are disturbed by hydroxypropylation, causing starch granules to weaken and freedom of movement of the starch chain in the amorphous region to increase. In addition, the main factor causing the high value of WVTR is that the hydrophobic component is higher than the hydrophilic component [36].

To determine the level of biodegradable resistance of the film to temperature, microbial decomposition and humidity and chemical physicochemical factors contained in the soil, biodegradability test is needed. Biodegradability test uses the soil burial test method [37] using composted soil which is done through visual observation of the film by observing changes that occur every 5 days. The test results show that biodegradable films from biologically degraded on the 15th day. This shows that biodegradable film can be said to be an environmentally friendly plastic. According to [38] degradation by planting faster because the main stage of degradation is the breaking of the main chain to form fragments with low molecular weight (oligomers) that can be assimilated by microbes. Decreased mass of biodegradable film composite specimens along with the time of planting. The biodegradable nature of biodegradable films is caused by
raw materials that easily interact with water and microorganisms and are sensitive to the effects of chemical physics. The biodegradable film degradation process is presented in Figure 2.

![Figure 2](image_url)

**Figure 2.** Biodegradable film degradation process on 15th day.

4. Conclusions and suggestions

4.1 Conclusions

Biodegradable films made from sweet potato starch by dual modification of hydroxypropylation-crosslinking cause a decrease in the solubility value at low propylene oxide concentrations, but cause an increase in high STPP concentrations. Transparency values tend to be the same as natural films, so visually the transparency of the film cannot be seen. Tensile and elongation strength values also increase with increasing concentrations of STPP and propylene oxide. The WVTR value has increased along with the increasing concentration of STPP.

4.2 Suggestions

Characteristics of biodegradable films that are known need to be applied to food products that are in accordance with the characteristics of the biodegradable film produced. The use of biodegradable film as packaging material needs to be analyzed for the effect of its shelf life on the product to be packaged by knowing the storage conditions of both humidity and temperature.

5. References

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