

Characterization of Glycerol and Aloe Vera as Plasticizer in Polyethylene/Starch-Based Film

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ABSTRACT

The combination of starch (S) and polyethylene (PE) increased the mechanical properties of starch and improved the degradation ability of PE. However, the polyethylene-starch (PE-S) combination has inconsistent mechanical properties performance. Therefore, the objective of this paper was to investigate the PE-S-based film's characterization changes and mechanical properties performance upon the addition of different types and formulations of a plasticizer; 30% glycerol, 30% aloe Vera (AV) gel, or a combination of 30% glycerol with 1% AV powder. First, a Banbury mixer was applied to prepare the resin, followed by a hot-pressed technique to obtain a thin film. Glycerol acted as a plasticizer disturbed the functional group appearance of PE-S-based film. Thus, it reduced the tensile strength and elongation at break performance, including increased the water absorption of the film. The results also revealed that an apparent agglomeration of starch appeared in PE-S film upon adding 30% AV gel at once, showing the most deficient mechanical properties with the highest water absorption occurred. Surprisingly, the combination of 30% glycerol with 1% AV powder suggests 1% AV powder acted as a crosslinker between starch and glycerol because the tensile strength increases by 49% compared to PE-S with 30% glycerol only.

Furthermore, the crystallinity percentage of PE-S film reduced upon adding other materials from 54.04% to between 39.90% until 43.93%. In conclusion, the type and percentage of AV played an essential role in PE-S film, either acting as a plasticizer or a crosslinker.

Keywords: Aloe vera, glycerol, plasticizer, polyethylene, starch

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INTRODUCTION

Plastic waste is estimated at 275 million metric tons in 192 coastal countries, and 4.8 to 12.7 million tonnes of plastic waste is directly dumped into the ocean (Sessini et al., 2019). Polyethylene (PE) is a polymer with a chemical formula of $(C_2H_4)_n$, is the primary raw material in a plastic film that has good mechanical properties, good corrosion, and chemical resistance (Ramírez-Hernández et al., 2020). Unfortunately, poor degradation shown by PE was due to PE having antioxidants, stabilizers, and additives. PE needs a very long duration in landfills only to alter the chemical structure of the PE (Ghatge et al., 2020). PE is also water repellent in nature, known as hydrophobic, and resistant to hydro-biodegradation (Al-Salem & Khan, 2015).

The addition of natural polymers into PE improves the degradation ability of PE film with the influence of biological factors (Mierzwa-Hersztek et al., 2019). Ling et al. (2020) added fibers in linear low-density PE found that the tensile strength, elongation at break, and modulus of all the composites decreased after soil burial exposure. Starch is a polysaccharide with the chemical formula $(C_6H_{10}O_5)_n$. Starch also is a sustainable material with high amylose composition content that provides strength to the film (Nizam et al., 2021). It favors chemical modification and a good combination of synthetic polymer (Ramírez-Hernández et al., 2020; Taghizadeh & Abdollahi, 2015). The abundance of starch cause researchers to choose it as the primary source of a biodegradable polymer. Plus, it is a cheap and renewable material (Patnaik et al., 2020). Hence, starch is an excellent sustainable filler material that can better degrade PE film. Potato starch is selected in this paper, was the typical type of starch used in producing thin film and had the most transparent film compared to wheat, corn, and rice starch that contributes to the packaging industry (Domene-López et al., 2019).

However, starch in low-density polyethylene was fragile and brittle after a drying process that led to poor mechanical performance, limiting the starch potential as raw material for various packaging applications. The addition of plasticizer to the starch film lowered the intermolecular forces along the polymer chain. Thus, it increases the blend's flexibility and reduces brittleness (Kormin et al., 2019). Others also mentioned that the compatibility between starch and PE could improve (Kaboarani et al., 2021). The conversion of starch into thermoplastic starch (TPS) occurred by disrupting the crystalline structure of starch. The water molecules (plasticizers) interact with hydroxyl groups, resulting in partial starch granule solubilization (Ribba et al., 2017). Few researchers combined PE and TPS instead of starch alone because TPS has good processing capabilities (Hammache et al., 2020; Kaboarani et al., 2021; Mazerolles et al., 2020). Unfortunately, compatibility remains a concern because of the unsatisfying mechanical properties obtained.

Phthalate is commercially used as a plasticizer harmful to human health and banned for application in the medical, toy, and food industries (Samarth & Mahanwar, 2015). Therefore, non-phthalate plasticizers were introduced, di-esters and phosphate, but not

commercially compound to polymer and caused leaching. Therefore, researchers started to use bio plasticizers, and glycerol was one of them. Much research used glycerol to convert starch to thermoplastic starch. Glycerol can improve the strength and flexibility of starch by performing a solid bond with the water molecules and increasing the starch solubility (Maulida et al., 2016). However, water solubility increased as the plasticizer content increased, leading to film instability and quickly degrading even in an open environment (Diyana et al., 2021).

Aloe Vera (AV) is prominent material rich in polysaccharides and organic acids and has antibacterial, antioxidant, and antifungal properties. Researchers have now employed AV as a crosslinker in a starch-based film to improve its characteristics (Kanatt & Makwana, 2020). On the other hand, PE-S and AV have not been formally explored for AV effects on the PE-S film's characteristics and mechanical properties. Karim et al. (2020) explored the characteristic and mechanical properties changes on PE upon the addition of AV. The results obtained suggested AV could link with PE and increase the tensile strength of PE film. In addition, the presence of organic acids and polyphenolic chemicals in AV contributed to the crosslinking between starch molecules (Gutiérrez & Álvarez, 2016).

Therefore, in this paper, different types and formulations of plasticizers were compared towards their effectiveness in improving the mechanical properties of PE-S film. In addition, another characteristic was also investigated involving the film's physical appearance, thickness, functional group, water absorption, thermal properties, and crystallinity.

METHODOLOGY

Material

Low-density polyethylene with density 0.920 g/cm³, brand Titanlene LD1300YY, (Malaysia) supplied by Vistec Technology Services as the synthetic polymer, potato-soluble starch brand Bendosen, (Malaysia) as biopolymer, glycerol with molecular weight, 92.09 g/mol, from Chemiz, (Malaysia), aloe vera gel and aloe vera powder, both from, Chemmiconnex (Malaysia), were used as the primary raw material involved in the preparation of the film.

Preparation of the Film

Melt blending of polymers for reactive compatibilization has been the most effective method because it allows for particular interactions between the blend components (Akshaya et al., 2020). Melt-mixing, crushing, and hot-press technique was applied to produce the thin film with the different formulation listed in Table 1. The range of plasticizers added into a combination of PE-S in previous papers using glycerol differed among researchers and mostly between 25–40% (Ahmadi et al., 2018; Mazerolles et al., 2019; Sabetzadeh et al., 2017). This paper assumed the amount of 30% glycerol and AV gel as plasticizers based on the review data. No works have been done on AV's use in powder form, and 1% was

considered in this study. The first step was to melt-blend the raw material in the Banbury mixer (Thermo Haake PolyLab Internal Mixer) with an operating condition of 170°C heat and 60 rpm rotation speed of the rotor. The duration of the melt-mixing was fixed at 30 minutes, and the torque condition was monitored as presented in Figure 1. Figure 1 shows the torque value of each mixer for the resin of the film preparation, and it shows that each mixture was homogeneously mixed before the mixing process ended and the resin was produced. The resin was then transferred to a crusher (Rexmac Compact Crusher) to convert the bulk structure of resin into smaller parts to enhance the heat transfer process during the hot-pressed technique. The crushed resin then being pressed by a hot-pressed machine (Cometech Hot Press) to convert it into a thin film sheet. Three steps were involved during the hot-pressing process; 1) pre-heating at 130°C for 10 minutes, 2) pressing at 130°C and 700 psi for 10 minutes and 3) cooled with tap water and waiting until the temperature reduced to 50°C before the film was peeled off from the metal plate.

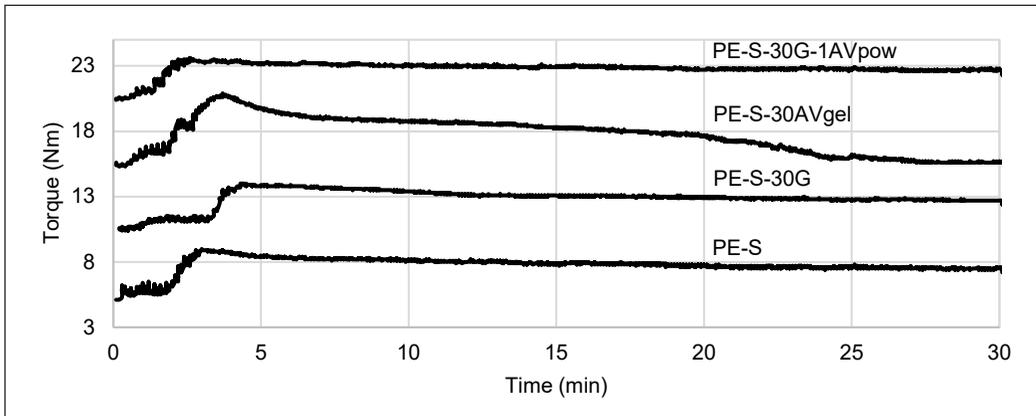


Figure 1. Torque condition of each film during the melt-mixing process in Banbury mixer

Table 1
The film's formulation

Sample name	PE (g)	Starch (g)	Glycerol (g)	AV gel (g)	AV powder (g)
PE-S	18.91	11.58	-	-	-
PE-S-30G	18.91	11.58	4.96	-	-
PE-S-30AVgel	18.91	11.58	-	4.96	-
PE-S-30G-1AVpow	18.91	11.58	4.96	-	0.354

*4.96 g of glycerol or AV gel representing 30% of it in 38% of starch

*0.354 g of AV powder representing 1% of it in total PE, starch, and glycerol

Characterization of the Film

Mechanical Properties. The sample size, a rectangular shape (100 mm x 25 mm), was based on the ASTM D882 sample size required to determine the tensile strength (TS), elongation at the break (EAB), Young's modulus (YM), and break energy (BE) of the

sample. The room temperature was around 28°C, humidity, 58% while conducting the mechanical testing using a Universal testing machine with a load of 2.5 kN and a 25 mm/min crosshead speed.

Thermal Analysis. Thermal material properties are essential for predicting the operating condition and product lifetime performance. The differential scanning calorimetry (DSC), Mettler Toledo, was used to understand the film's thermal properties. The glass transition temperature (T_g), melting temperature (T_m), and crystallization temperature (T_c) was the data obtained. The film was cut into smaller pieces and weighted around 5.2–5.5 mg. Then, the weighted sample is encapsulated in aluminum pans and undergoes a three-cycle process. This paper applied the cycle process to the film. Firstly, the sample was heated up from 25 to 190°C to remove the thermal history of the material. Then cooled from 190 to -10°C before undergoing the second heating process starting at -10°C and ending at 190°C. The setup used nitrogen atmosphere flow rate was 50 ml/min, and the sample was heated at 20°C/min. Two graphs were plotted from the data obtained, data from the cooling curve (representing the crystallization condition of the material) and data from the second heating curve (representing the melting condition of the film).

Crystallinity. The identification of crystallinity was obtained using the X-ray diffraction (XRD) brand Rigaku D/Max 2200V/PC. The film was cut into a circular shape with a diameter size of 25 mm and was in a mold specifically for XRD analysis. The diffraction angles (2θ) range was 5-40, with scan speed, 5°/minutes, 40 kV, and 30 mA. X-ray diffraction analysis (XRD) determined the material's crystallographic structure. The percentage of crystallinity was calculated based on Equation 1.

$$\% \text{ Crystallinity} = \frac{\text{area of crystalline peaks}}{\text{area of all peaks (crystalline + amorphous)}} \times 100 \quad [1]$$

Physical Appearance and Film's Thickness

The Physical Appearance of the sample was observed using the naked eyes, and the image of the sample was taken using a handphone camera (Xiaomi Redmi Note 9 Pro). In addition, three positions (bottom, middle and top) of thickness were measured using a digital micrometer (0–25 mm MITUTOYO 293-230-30 Digital Outside Micrometer) from the sample that had been cut into a rectangular shape (100 mm × 25 mm).

Functional Group. The identification of components presented in the film and formation of interfacial interaction of hydrogen bonding between the materials was figured based on Fourier transform infrared spectroscopy (FTIR), Mettler Toledo FTIR spectrophotometer. The spectrum ranged from 400 to 4000 cm^{-1} , with 4 cm^{-1} and scanning times of 64 seconds.

Water Absorption. The water absorption percentage was measured based on ASTM-D570, as Nguyen et al. (2016) explained. First, all films were conditioned in a desiccator (24% humidity) to prevent any moisture absorbed during storage. Next, the weight of the sample was measured (W_0). The films were then immersed in distilled water at room temperature for 24 hours. Then, all films were removed from the water, drained, and weighed (W_1). Next, the sample was dried in an oven at 50°C for 24 hours, and the final weight (W_2) was measured. Finally, the water absorption percentage was calculated based on Equation 2.

$$\text{Water absorption}(\%) = \frac{W_1 - W_2}{W_0} \times 100 \quad [2]$$

RESULTS AND DISCUSSION

Mechanical Properties

Plasticizer was introduced into a PE-S blend to reduce the stiffness and brittleness at once increase its ductility. In addition, the inclusion of a plasticizer lowers the contact between polymers, lowering chain cohesion (Chaos et al., 2019). Figure 2 depicts the mechanical properties of the film covered the TS (a), EAB (b), YM (c), and BE (d). It shows a similar pattern of results obtained for all four mechanical properties listed. PE-S-30G-1AV has the highest TS, EAB, YM, and BE with 8.9 MPa, 10.92%, 164.25 MPa, and 809750 MJ/m³, followed by PE-S, PE-S-30G, and PE-S-30AV film, as shown in Figure 2. Glycerol and AV gel acted as plasticizers to convert starch into thermoplastic starch, improving the homogeneity during the melt-mixing process and improving adhesion with PE. Kormin et al. (2019) stated that plasticizers improved the incorporation of starch in low-density polyethylene.

Unfortunately, the TS, EAB, YM, and BE of PE-S were reduced with glycerol or AV gel. The TS reduction may be due to glycerol or PE enabling PE chain sliding and lowering secondary connecting forces between polymer chains (Karim et al., 2020). The addition of other components with lubricating properties might lower the TS of PE film (Kamarudin et al., 2019). On the other hand, the plasticizer reduced the strong intra-molecular attraction between the starch chains and reduced the stiffening effect of starch granules, thus reducing the TS and YM. Tarique et al. (2021) found that 30% glycerol reduced the TS and YM of arrowroot starch film from 16.48 MPa to 2.42 MPa and 1258.9 MPa to 52.26 MPa, respectively. The EAB was also reduced due to fewer intermolecular bonds between polymer matrixes and hydrogen bonds between plasticizers and polymer molecules at once, reducing films' flexibility by fewer chain mobility presence. Furthermore, synthetic polymers combined with other polymers with ductile behavior might cause a reduction in EAB because of immiscibility and incompatibility of the secondary phase. Good interfacial interaction between constituent phases is needed to have higher EAB (Radfar et al., 2020).

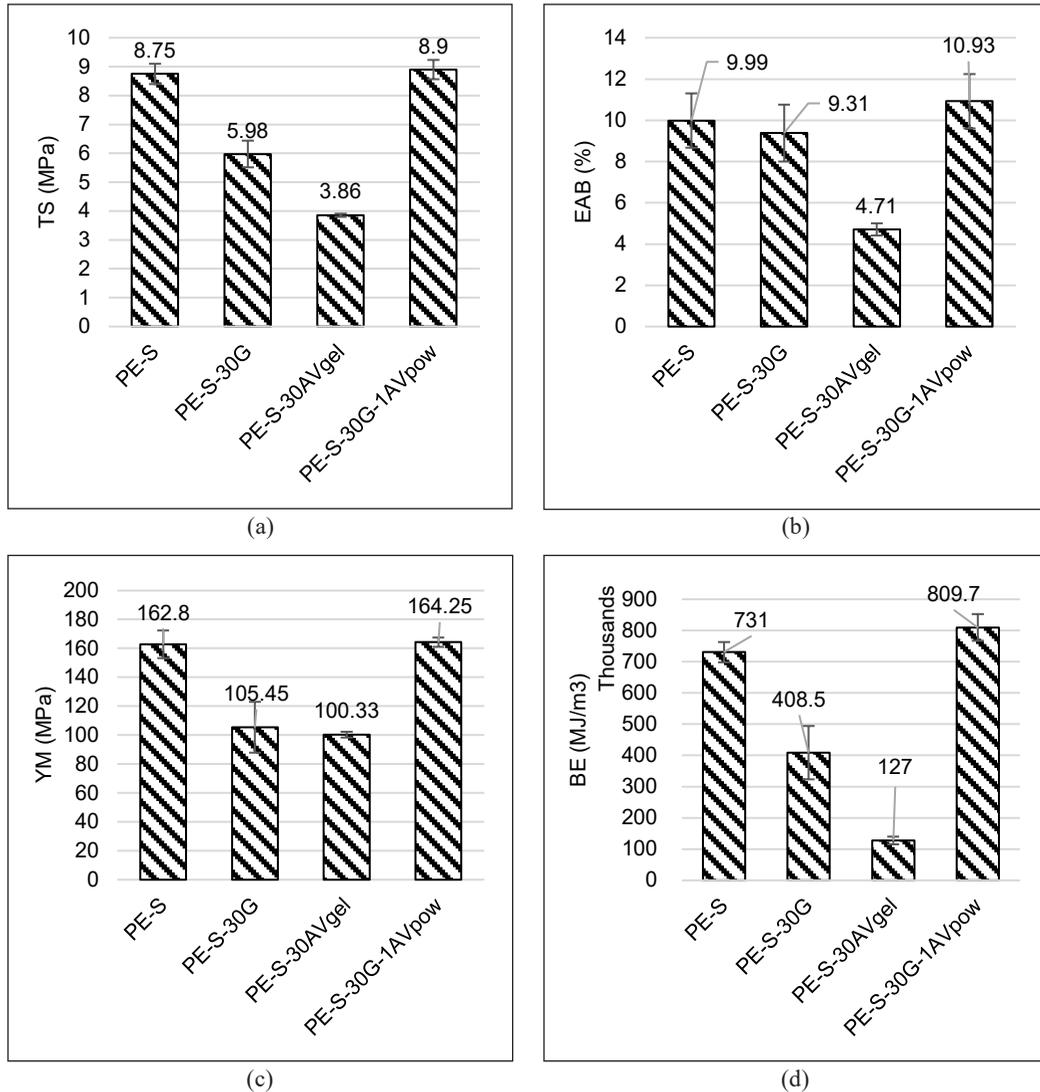


Figure 2. The prepared films' (a) TS, (b) EAB, (c) YM, and (d) BE

PE-S-30G has better TS, EAB, YM, and BE performance than PE-S-30AVgel. Sabetzadeh et al. (2015) found that glycerol favorably stretched the PE-S film. As shown in Figure 5, PE-S with 30% AV gel shows many agglomerations of starch, recommending that poor interfacial adhesion produces between PE and starch due to the presence of AV gel. It led to poor performance of mechanical properties. The TS and EAB of the film were affected by the interfacial adhesion between the polymer material in the film (Ramlee & Tominaga, 2019). By lowering the number of polymer-polymer linkages, plasticization might reduce the rigidity of the three-dimensional structure, allowing deformation (Quispe et al., 2021). Differ plasticizer has different ability to improve flexibility and

stretchability to the film. Others found that 30% sorbitol in palm starch lowers the EAB by 42% compared to 30% glycerol in the sample palm starch film (Sanyang et al., 2015). Sanyang et al. (2015) reported that the anti-plasticization or phase separation might occur in highly plasticized starch films. The anti-plasticization phenomena at higher plasticizer concentrations are associated with more vital interaction between plasticizer and starch molecules that hinder macromolecular mobility and happen when the plasticizer molecules are above the critical value.

However, 1% AV powder in the PE-S-30G did not act as a plasticizer but suggested a crosslinker between glycerol-starch interaction. Crosslinker increased the intermolecular forces between glycerol-starch at once, lowered the free volume, and increased the TS, YM, and BE of the PE-S-30G film. The color has also supported the increment of TS, YM, EAB and changed into yellow as in Figure 5, proving crosslinking happened in the raw material. Low free volume and crosslinking with the PE molecular structure could explain PE-S's increased TS and EAB (Karim et al., 2020). Others found a similar trend, with a lower percentage of AV threshold for obtaining suitable toughness and flexibility (Karim et al., 2021; Khoshgozaran-Abras et al., 2012).

Thermal Properties

Figure 3a represents the film's second heating process to determine T_m , while Figure 3b plotted the film's cooling process for T_c data extraction. The T_g was taken from the first heating process since the T_g was unable to be seen from the second heating data (Figure 3a) because T_g was affected by the thermal history of the material. In addition, the cooling process applied to the film caused crystallization, and the amorphous part of the samples became partial crystalline (Hohne et al., 2003). Thus, T_g becomes smaller for second heating

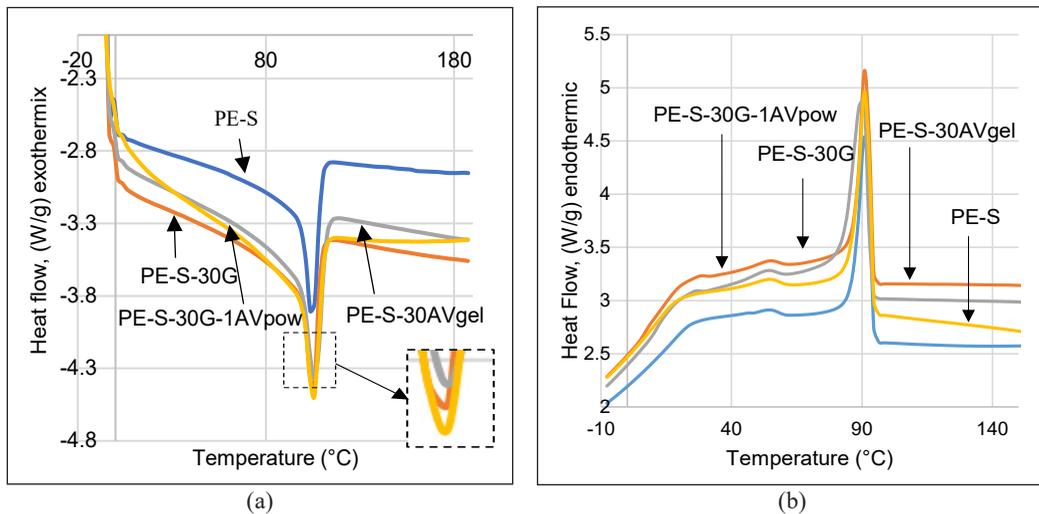


Figure 3. The DSC heating (a) and cooling (b) thermograms of the prepared films

data than first heating data. In addition, if the amorphous fraction is small, T_g will be challenging to observe.

Therefore, data for T_g listed in Table 2 was based on first heating, and the graph was not shown in this paper. The T_m and T_c were almost similar for all films showing

Table 2

The thermal properties of all samples

Sample	T_g (°C)	T_m (°C)	T_c (°C)
PE-S	37.943	105.89	90.85
PE-S-30G	36.239	105.81	90.93
PE-S-30AVgel	36.205	105.77	90.93
PE-S-30G-1AVpow	37.862	105.75	90.95

that the addition of glycerol, AV gel, and a combination of glycerol and AV powder did not significantly change PE-S film thermal properties. Incorporating glycerol and AV slightly decreased the T_g of PE-S because it weakened the intermolecular forces between starch (Tarique et al., 2021). However, contradict the result obtained, which tremendous decrease of EAB value occurred especially for PE-S-AVgel, which 53% EAB reduction compared to PE-S film. The flexibility was decreased due to less formation of H-bond occurred between starch-plasticizer with PE. At the same time, the anti-plasticization phenomenon occurred (Sanyang et al., 2015). Therefore, it is recommended that the starch distribution give more effects towards the EAB while T_g is not so significant. The T_g value was more affected by the primary material, PE-S. Hence, the T_g was considered not to show noticeable changes to be discussed in this case. The T_g did not show changes because the T_g for starch with glycerol was usually at a shallow temperature ($< -80^\circ\text{C}$) (Habitante et al., 2008). Others found that AV did not change the denaturation peak for collagen films, confirming maintaining the collagen structure in the film even with AV addition (Andonegi et al., 2020).

Crystallinity

Since the biodegradable procedure involves amorphous polymer regions, determining the level of PE-S crystallization is critical. Microorganisms that can reach the amorphous parts eat them first. Figure 4 shows the diffractogram intensity of PE film and PE film with starch and plasticizer or crosslinker. The diffraction angle for PE was 19.6° (amorphous) and 21.42° , and 23.66° (crystalline peaks) (Alnaimi et al., 2015; Karim et al., 2020). From Figure 4, the addition of starch, glycerol, AV gel, and AV powder did not show apparent changes since there is no appearance of other peaks observed. However, the sharpness of peak 21.42° seems reduced upon adding those materials. The crystallinity percentage was calculated using Origin8.5 software using Equation 1; baseline correction was conducted on the graph, and subtracting baseline was applied. The crystallinity percentage of the film was 54.04%, 41.80%, 39.90%, 43.93%, and 40.78%, for PE, PE-S, PE-S-30G, PE-S-30AVgel, and PE-S-30G-1AVpow, respectively. Another author also recorded the same crystallinity reduction upon adding thermoplastic starch (starch with plasticizer) (Chandra & Rustgi, 1997; Sabetzadeh et al., 2015). The crystallinity depends on pure PE and the dispersion phase into matrix polymer (Nguyen et al., 2016).

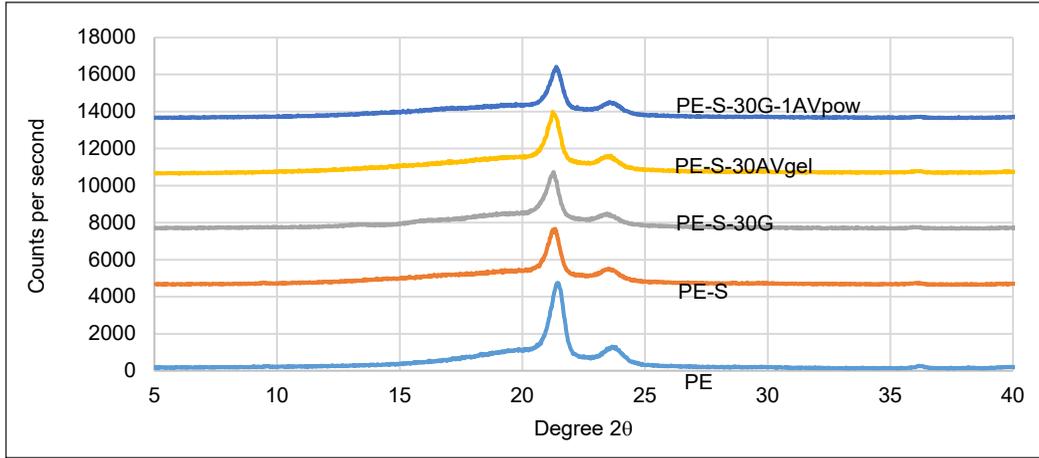


Figure 4. The XRD pattern of the prepared film for degree 2θ between 5 – 40

Physical Appearance and Film's Thickness

Figure 5 pictured the physical appearance before and after hot-pressed resin and thin film, including the film's thickness. The thickness obtained was 0.1759 mm, 0.1763 mm, and 0.169 mm for PE-S, PE-S-30G, and PE-S-30G-1AVpow has almost similar thickness while PE-S-30AV has almost double thickness compared to another film with 0.3038 mm. The agglomeration of starch that appeared on PE-S-30AV as in Figure 5 supports the thicker film obtained. Based on Figure 5, the addition of glycerol did not show any significant changes towards the color of PE-S film. The same color condition occurred for PE-S film with 30% AV gel. However, the agglomeration starch at 30% AV gel suggests the poor interfacial adhesion between starch and PE. This condition is probably due to the high amount of water present in AV gel. Due to rapid crystallization, the high residual solvent content is left in the film. Thus, unsatisfactory particle size distribution in the form of starch agglomeration (Callahan, 2020). The addition of AV powder gives significant changes to

Thickness of the film (mm)	0.1759	0.1763	0.3038	0.1693
Resin (before hot-press)				
Thin-film (after hot-press)				
	(a)	(b)	(c)	(d)

Figure 5. The thickness and physical appearance of the resin (before hot-pressed) and film (after hot-pressed) for (a) PE-S, (b) PE-S-30G, (c) PE-S-30AVgel, and (d) PE-S-30G-1AVpow

the physical color of the film. The yellowness of the film increased with the addition of AV powder. Garavand et al. (2017) mentioned that the degree of crosslinking influenced the film's color because of the material proclivity to oxidize (e.g., tannic acid triggered chitosan). Citric acid crosslinking of proteins results in yellow-brown films formed by citric acid dehydration when subjected to high temperatures (Reddy & Yang, 2010). Surjushe et al. (2008) stated that the AV consists of 20 amino acids. Thus, it suggested that the salicylic acids and amino acids present in 1% AV powder contributed to the yellow-brown PE-S30G film due to exposure to high temperatures during the melt-blending process.

Functional Group

The FTIR spectrum of the film is shown in Figure 6 for a wavelength between 4000 – 500 cm^{-1} . The primary raw material was PE, not recorded in this paper but has peaks 2915 cm^{-1} and 2848 cm^{-1} representing the medium C-H stretching, and having 1472 cm^{-1} and 718 cm^{-1} depicting the CH_2 bending and rocking (Karim et al., 2020; Panrong et al., 2020). The spectrum between 1600–500 cm^{-1} was considered a fingerprint region in polymer blends. The addition of starch did not significantly affect the peak presence since all peaks appearing for PE-S still resemble the PE peak mentioned, but one tiny peak appeared at 1376–1379 cm^{-1} . This peak exhibit C-O-H presence in an anhydrous glucose ring in the starch proving starch and PE combined in a film. Amigo et al. (2019) found this peak in native starch powder. Some new peaks were observed when glycerol was added into PE-S with 3341 cm^{-1} and 1029 cm^{-1} , presenting the O-H stretching region and functional group of C-O-C. Others mentioned that the absorption band for C-O stretching vibrations of starch (polysaccharides) and glycerol was represented by an absorption band higher than 993 cm^{-1} (Hazrol et al., 2021). The absorption band of O-H presence upon the addition of glycerol

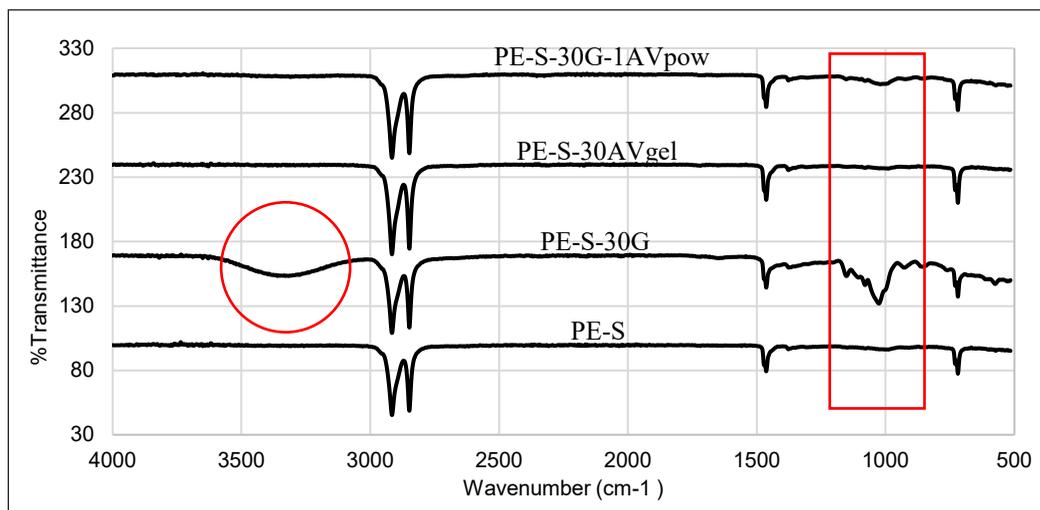


Figure 6. The functional group observation using FTIR for the prepared films

comes from the complicated stretching vibration of a free, inter- and intramolecularly attached hydroxyl group resulting from hydrogen-bonded hydroxyl groups (Panrong et al., 2020). The addition of AV gel seems to contradict results compared to glycerol, proving that the 30% AV gel in PE-S film did not act as a plasticizer for starch to form thermoplastic starch. These FTIR results for PE-S-30AVgel support the agglomeration of starch and poor TS and EAB obtained. Anyhow, the added 1% AV powder into PE-S-30G gives very significant changes towards the peak obtained. The 3341 cm^{-1} peaks disappeared, and peak 1029 cm^{-1} became smaller, suggesting that 1% AV powder became a crosslinker for S-30G and increased the compatibility with PE. Thus, the TS and EAB increased.

Water Absorption

Figure 7 presents the film's water absorption percentage after immersion in distilled water for 24 hours. PE-S-30AVgel displays the highest percentage of water absorption with 54.53%, followed by PE-S-30G (19.0%), PE-S-30G-1AVpow (3.08%), and PE-S (2.69%). PE-S-30AVgel has the highest water absorption because of micro gaps in the polymer matrix that allow water molecules to infiltrate until saturation. The results have also been supported by starch agglomeration (physical appearance), poor mechanical properties performance, and poor interaction between starch and PE (FTIR) shown by PE-S-30AVgel. The water absorption was due to the presence of starch (Khoramnejadian, 2013). The hydrophilic nature of AV gel and the larger interface area between PE and starch could explain the highest water absorption result. In addition, AV's hydrophilic properties and the hydrophilic nature of starch enhance the water absorption percentage. These conditions lead the water to infiltrate into the starch molecules in the film easily. Pereira et al. (2013) also found that alginate films water absorption increased upon adding more AV content. The water absorption capacity of the film increased due to the hydrophilic properties of AV. PE-S-30G has also been considered to have a high percentage of water due to hydrogen bonds between hydroxyl groups in glycerol and starch molecules (Hazrol et al., 2021). The poor water absorption of PE-S-30G-1AVpow must be closely related to the presence of 1% AV powder that acted as a crosslinker. The results show that 1% AV powder considerably increased the moisture resistance of the PE-S-30G by 83.8%.

The interfacial adhesion between PE and S-30G-1AV increased led to stronger bonding and inhibited the starch's ability to absorb water molecules. Similar findings were obtained by a few researchers mentioning that compatibilizer, also known as crosslinker combined with synthetic polymer and bio-based polymers, reduced the water absorption percentage (Kaboarani et al., 2021). Compatibilized composites reduced the number of free hydroxyl groups on the surface and decreased the percentage of water uptake (Zaman & Beg, 2021). Obasi et al. (2020) found that PE grafted maleic anhydride reduced potato starch's water absorption percentage, indicating good stress transfer at the matrix interface. The water

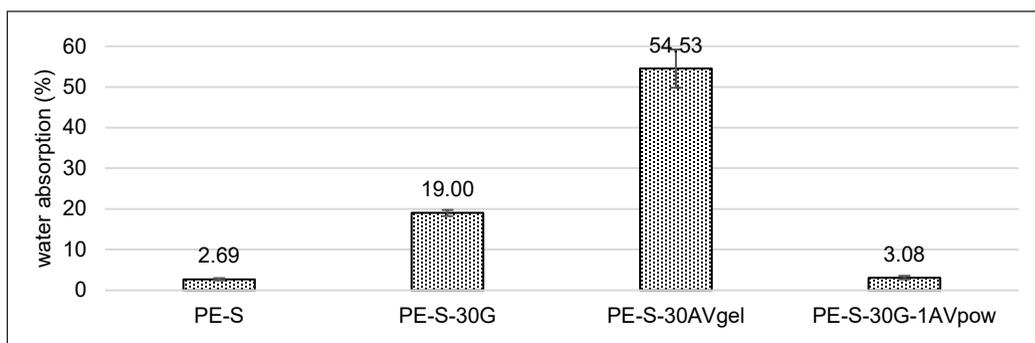


Figure 7. Water absorption performance of the prepared films

being prevented by compatibilizer from entering starch improves adhesion between PE and starch-glycerol interaction, resulting in fewer gaps available in the interfacial region (Yatigala et al., 2018). The same goes for the PE-S combination; the excellent compatibility between starch and PE inhibits water molecules from bonding with starch. PE-S showed the least amount of water absorption, resulting in the least amount of microcracks in the polymer matrix due to PE swelling due to the strong adhesion between fibers and matrix (Gupta, 2018).

CONCLUSIONS

Incorporating 30% glycerol into PE-S as a plasticizer proved but disturbed the film's mechanical performance. Nevertheless, the addition of 30% AV gel shows that AV gel was not essential and could not act as a plasticizer for the starch film when the agglomeration of starch was obvious, proving no improvement in adhesion between starch and PE. Noticeably, a combination of 30% glycerol with 1% AV powder shows promising results, in which AV acts as a crosslinker for starch-glycerol and PE material. Therefore, it suggested that AV type and its percentage play an essential role in improving or disturbing the network structure of the PE-S film matrix. The produced film also can become a polybag for pre-nursery or degradable packaging.

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