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Thermal Properties and Moisture Absorption of LDPE/Banana Starch Biocomposite Films

Duangdao AHT-ONG* and Kanjana CHAROENKONGTHUM

Department of Materials Science, Faculty of Science, Chulalongkorn University

Abstract

The aim of this research is to investigate the effects of starch and compatibilizer contents on the thermal properties and moisture absorption of new polymeric-based biocomposite films from low-density polyethylene (LDPE) and banana starch. The compatibilizer used in this work was ethylene vinyl acetate copolymer (EVA). Banana starch was extracted from green banana using 0.05N sodium hydroxide solution. Banana starch content was varied from 5 to 20% by weight of LDPE, whereas EVA content was 0, 5, 10, and 20wt% based upon banana starch content. The average size of extracted starch granules was 21-24 μm, whereas the density of the starch was 1.74 g/cm^3. Addition of banana starch had no effect on the melting temperature of LDPE/banana starch films. Similarly, EVA had no influence on the melting temperature, but did affect the degree of crystallinity of the biocomposite films. For thermal stability, it was found that the LDPE/banana starch with 20% EVA had the highest thermal stability. As expected, moisture absorption of the films increased as the amount of banana starch was increased. The films containing 20% banana starch absorbed moisture up to 4.5%. However, the absorption decreased with increasing EVA content.

Keywords: LDPE, Starch, EVA, Biocomposite

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*To whom correspondence should be addressed
E-mail: duangdao.a@chula.ac.th Tel: (662) 218 5544-6, 218 5559 Fax: (662) 218 5561

Introduction

During recent decades, there has been a continuous increase in the use of plastics and it has become the major new material replacing some traditional ones such as paper, steel and aluminum in many applications. The main advantages of plastics are their low cost and lightweight. In addition, they are easy to formulate and require low energy for their transportation and production. The ever-growing production and use of plastics have led to a waste disposal problem because, generally, they are inherently inert to the microorganisms or the chemicals in an environment (Prinos, *et al.* 1998). As a result, they can not degrade when exposed to the environment.

Conventional garbage disposal methods such as incineration, landfill and recycling are not so attractive due to their respective limitations. Incineration needs high temperatures of more than 800°C, which makes it rarely used nowadays. Landfill has some problems of odor and the scattering of lightweight waste materials by the wind. Recycling has not yet gained widespread acceptance because of its difficulty in classifying and separating the types of used plastics. For these reasons, there has been an increased interest in the production and use of fully biodegradable polymers replacing nonbiodegradable plastics, especially those used in packaging applications. This is because the municipal solid waste of packaging accounts for approximately one third of the waste stream by weight (Selke, 1997). Such biodegradable plastics are polycaprolactone, poly(hydroxy alkanoates), poly(vinyl alcohol), poly(ethylene glycol), etc. However, they are not widely used because these polymers are much more expensive as compared with polyethylene (PE) or polypropylene (PP), which are commonly used for packaging applications (Prinos, *et al.* 1998).

Starch has drawn a lot of attention in the preparation of biodegradable plastics. It is abundantly produced by photosynthetic plants and, therefore, is renewable and cheap. The addition of starch to synthetic plastics is known to enhance the biodegradability. Banana is one of the most important fruits in Thailand. It is inexpensive and rich in starch content (14-23 % on a fresh weight basis or 62% on a dry weight basis) (Lii, 1982; and Renata, *et al.* 2000). In Thailand, banana is abundant because it can grow all year long. Therefore, this research focuses on the addition of low cost, biodegradable banana starch to LDPE as a route to improve the value-added of raw material in the country. However, the incompatibility and poor interfacial adhesion due to the differences in the polarity and hydrophilicity of these two phases, synthetic polymers and starch, lead to poor mechanical properties. These problems, however, can be improved by using a compatibilizer that can react with the hydroxyl group of starch and form hydrogen bonds or covalent bonds with synthetic polymers.

The most frequently used compatibilizer for starch/polyolefin blends is ethylene-co-acrylic acid copolymer (EAA). Although EAA has some disadvantage that its cost is 4 times more expensive than starch and it retards the biodegradation, the use of EAA to promote the compatibility in starch-based plastics has been studied extensively. (Otey, *et al.* 1979; and Willet, 1994) Recently, Prinos, *et al.* (1998) studied a series of LDPE blends with plasticized starch and granular starch and used ethylene vinyl acetate copolymer (EVA) as a compatibilizer. They found that EVA has a small exhibiting effect on the biodegradation rate. Thus, EVA was used as a compatibilizer in this research. Our previous study (Aht-Ong and Charoenkongthum, 2002) has shown that banana starch significantly affected the biodegradability and tensile properties of the LDPE/banana starch films. However, in every day life plastic films may encounter other factors such as heat and moisture as well. It has been found that the resistance of conventional plastics against microorganisms is primarily owing to their relative impermeability of water or moisture. In other words, moisture absorption of the plastic films is also a key factor to promote or facilitate the biodegradation rate in the films. Thus, this work aims to fully characterize the effects of banana starch and EVA contents on the thermal properties and moisture absorption of LDPE/starch biocomposite films.

Experimental

Materials

Low-density polyethylene (LDPE) extrusion film grade LD1902F obtained from

Cementhai Co., Ltd. (Thailand) was used as a polymer matrix. Its melt flow index (MFI) and density as reported by the manufacturer were 2.0 g/10 min and 0.919 g/cm^3, respectively. Ethylene vinyl acetate copolymer (EVA) grade N8038, supplied by the Thai Petrochemical Industry Co., Ltd. (Thailand) was used as a compatibilizer. Its vinyl acetate content was 18%. The melt flow index and the density as also reported by the manufacturer were 2.3 g/10 min and 0.941 g/cm^3, respectively. Banana starch was used as a biodegradable additive. Preparation of banana starch will be described in the next section.

Banana Starch Preparation

Banana starch was extracted according to Lii (1982). First, green banana was peeled and sliced into small pieces. It was then suspended in 0.05 N NaOH. The mixture was ground in a kitchen-aid mixer (moulinex) for 2 minutes until it was homogenized. The slurry was filtered through a sieve of 120 µm pore size with distilled water. Prime starch was sedimented from the filtrate. The starch was washed several times with distilled water until the supernatant layer was substantially free of color. Finally, starch was dried in an air oven at 80^{o}C and kept in a dessicator until being used.

Plastic Film Preparation

Banana starch was dried in an air oven at 80^{o}C for 24 hrs prior to being mixed with the LDPE in a twin screw extruder. The temperature profiles used on the extruder from zone 1 to 6 were 60, 130, 135, 140, 145, and 150^{o}C, respectively. Banana content was varied from 5 to 20% by weight of LDPE, whereas three different amounts of EVA, 5,10 and 20 wt% based upon starch content, were added. The extrudate was cooled in water, pelletized, and dried. Finally, the starch – based LDPE films were prepared using a chill-roll cast-film extruder using a screw speed of 25 rpm.

Characterization of Banana Starch

Granular morphology of banana starch was examined by a scanning electron microscope (SEM). Prior to the examination, starch was dried overnight in an air oven at 80^{o}C and mounted on a stub with double sticky tape. The stub was then coated with a thin layer of gold in order to improve conductivity and prevent electron charging on the surface. The SEM was operated at 15 kV to image the samples.

The chemical composition of the banana starch was analyzed according to the AOAC (Association of Official Analytical Chemists) method. Starch, protein, lipid, ash and amylose were determined quantitatively. Additionally, the density of banana starch was measured using the picnometric technique.

The thermal properties of the banana starch were evaluated by using differential scanning calorimetry (Perkin Elmer DSC7) and a thermogravimetric analyzer (Perkin Elmer TGA7) under nitrogen atmosphere using a heating rate of 10°C/min from 40 to 100°C and 20°C/min from 50 to 600°C, respectively. The gelatinized temperature (T_G) of banana starch was obtained from the peak maxima of the DSC thermogram and the degradation temperature (T_d) of banana starch was estimated from the onset of the degradation.

In order to measure moisture absorption the banana starch was dried in a hot-air oven for 24 hours at 80^{o}C and cooled in a dessiccator. The dried starch was placed in an enclosure containing distilled water. The starch was removed and then weighed to determine the weight change or moisture uptake periodically. The starch was immediately placed back after each measurement. At first, the weight change of the starch was measured at every 1 hour for 6 hours, and then at every 2 hours until there was no further change, i.e., its moisture absorption reached an equilibrium. Finally, the moisture absorption was calculated from the difference in the weight at an arbitrary time and the initial, dry weight of the sample, according to the following equation:

$$M(\%) = \frac{W_i - W_0}{W_0} x\,100 \qquad \text{..... (1)}$$

Where:

M = moisture absorption (%).
W_i = weight of specimen at time t (g).
W_0 = initial weight of oven-dry specimen (g).

Characterization of LDPE/Starch Film

Thermal Properties

Similar to the banana starch, a differential scanning calorimetes (Perkin Elmer DSC7) and a thermogravimetric analyzer (Perkin Elmer TGA7) were employed to characterize the thermal properties of the LDPE/banana starch films.

A sample size with an average weight of 8.50 mg encapsulated in a hermatically sealed aluminum pan was prepared for each film sample. Initially, the sample was heated from 40 to 200°C, followed by cooling the sample to 40°C, and finally reheated to 200°C at a scanning rate of 10°C/min for each trial. The melting temperature (T_m) and heat of fusion (ΔH_f*) of the film samples were determined from the peak maximum and the area under the peak, respectively. The degree of crystallinity of the biocomposite LDPE/banana films and the LDPE phase was calculated using the following equation:

$$\%\ \text{Crystallinity} = \frac{\Delta H_f^*}{\Delta H_f^0}\, x\, 100 \qquad \ldots..\ (2)$$

Where:

ΔH_f^* is the heat of fusion of the semi-crystalline LDPE blends.

ΔH_f^o is the heat of fusion for 100% crystalline LDPE.

Besides the thermal transition and the degree of crystallinity, thermal degradation temperature and percentage of weight loss as a function of banana starch, EVA contents were also investigated. Approximately 7 mg of each film sample was heated at a heating rate of 20°C from 200 to 600°C under a nitrogen atmosphere. Prior to the experiment, the samples were dried in a vacuum oven at 60°C for 24 hours. The onset of degradation temperature for each sample was recorded.

Moisture Absorption of Films

Moisture absorption of the pure LDPE and the LDPE blend films were measured using a sample size of 1.5 cm wide by 20 cm long. Similar to other experiments, the films were dried in a hot-air oven at 60°C for 24 hours before starting the experiment. The dried film samples were then placed in an enclosure containing distilled water. The measurement was performed following the same procedure of the banana starch, as previously explained. The moisture absorption was calculated using equation (1). Five specimens were measured for each sample and the results were averaged to obtain a mean value.

Scanning Electron Microscopy (SEM)

SEM was used to observe the surface and fractured surface of the LDPE/banana starch films. For the fractured surface investigation, the blend films were fractured immediately after freezing in liquid nitrogen and were sputter – coated with gold to avoid charging under the electron beam. For surface morphology analysis, the blend films were also coated with a thin layer of gold prior to the examination.

Results and Discussion

Characterization of Banana Starch

Morphological Study

The morphological characteristic of the extracted starch was determined by SEM. Clearly, **Figure 1** reveals that the surface of the banana starch granules is very smooth. In fact, it is quite similar to other kinds of starch. Its shape is ranging from oval to irregular with the size being varied from 5 to 45 μm. However, the average size is in the range of 21-24 μm.

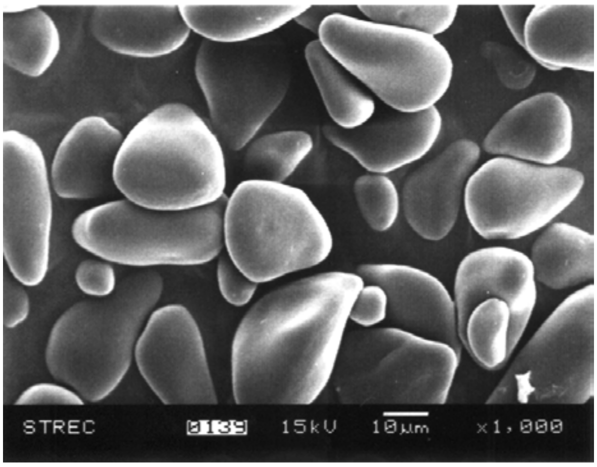

Figure 1 SEM micrograph of banana starch granules

Compositional Analysis

Table 1 shows the compositional analysis of banana starch after extraction. Obviously, banana starch contains only 0.11% of protein in its molecule. This value is a key composition that differentiates between flour and starch. The existence of protein in the flour molecule can be reduced after extraction. Like any other starches, other compositions including amylose content were analyzed and the proximate analysis is also presented in **Table 1**. The amount of amylose in banana starch granules implies that banana starch consists of both linear and branch molecules in approximately the same quantity.

Table 1 Composition of banana starch

Component	Amount (%)
Starch	92.87 ± 1.09
Protein	0.11 ± 0.01
Lipid	0.03
Ash	0.044 ± 0.017
Amylose	55.42 ± 0.98

These results are quite similar to the values published by Lii (1982). The only difference, however, is the lipid content in which their result was much higher (0.11-0.37%) than that obtained in our present study. The protein and lipid contents of the extracted starch were also different from those reported by Kayisu, *et al*. (1981). In their work, the protein and lipid contents are 2 times and 7 times higher than those presented in **Table 1**. The relative composition of these two constituents is very much dependent on the stage of maturity and on the variety of banana species. Therefore, this different finding is in fact the result of the variety in source and stage of maturity of the bananas used in each study.

Starch Density Measurement

The density of the banana starch was measured by a picnometric technique. Diethyl ether was used as a non-solvent in this test. It was found that the density of banana starch was 1.74 g/cm^3.

Thermal Properties

Differential Scanning Calorimetry (DSC)

The gelatinization temperature range obtained from the DSC thermogram of banana starch is presented in **Figure 2**. As can be seen, the gelatinization temperature ranges from 72 to 78°C. From the literature, Lii (1982) investigated some properties of banana starch and observed a gelatinization temperature range of 74-81°C for green banana and 79-83°C for ripening banana. The difference between our data and those published in the literature may be due to the difference in varieties and the degrees of ripening of the bananas.

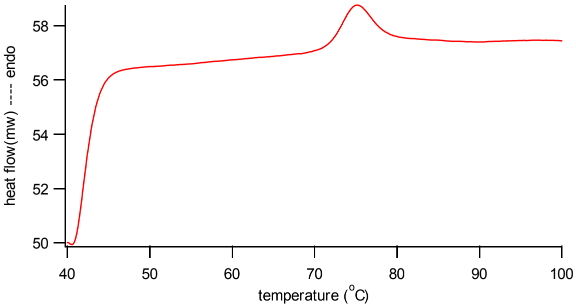

Figure 2 DSC thermogram of banana starch.

Thermogravimetric Analysis (TGA)

The thermogravimetric analysis (TGA) of banana starch is shown in **Figure 3**. As can be seen, the initial weight loss began at approximately 50°C and reached a constant weight plateau after losing 6% of its initial weight. This weight loss corresponds to the loss of the moisture content from the banana starch. The weight loss clearly occurred at approximately 315°C. At this temperature, the banana starch began to degrade, this was defined as the degradation temperature of banana starch (T_d). Less than 2% residue was left at 600°C.

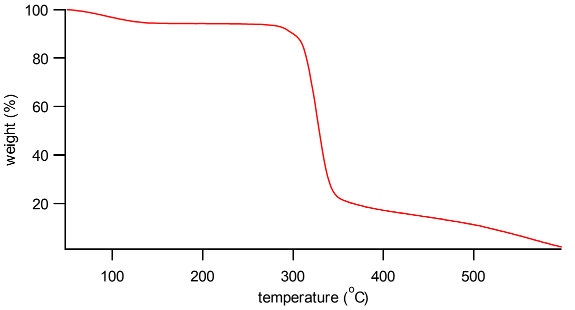

Figure 3 TGA thermogram of banana starch

Moisture Absorption

The plot of moisture absorption as a function of time for banana starch is exhibited in **Figure 4**. As expected, moisture absorption increased with increasing exposure time. Because of its hydrophilic nature, banana starch absorbs moisture from the atmosphere. The absorption rate was relatively fast at first and then slowed down a little until it reached an equilibrium within a day. Its moisture absorption at equilibrium is almost 20%.

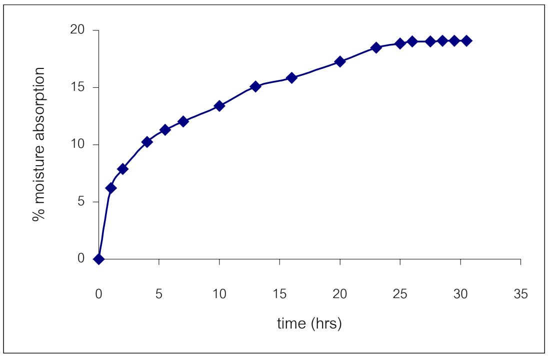

Figure 4 Moisture absorption of banana starch

Characterization of LDPE/Banana Starch Film

Thermal Properties

Differential Scanning Calorimetry (DSC)

The second heating cycles of DSC thermograms for pure LDPE and LDPE/starch/EVA blends are shown in **Figure 5**. Compared with the DSC thermogram of the pure LDPE film, there was no change in the melting temperature of the LDPE phase at about 103°C.

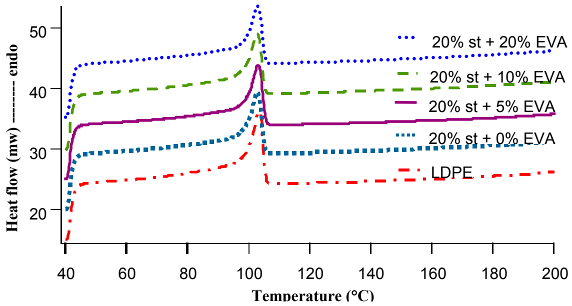

Figure 5 Second heating of the DSC thermograms for LDPE and compatibilized LDPE/20%banana starch films

Although there is only one endothermic transition for the starch/LDPE or starch/LDPE/EVA blend films, this does not mean that the blends are compatible. In fact, like any other starch, banana starch has no melting temperature, but gelatinization and degradation temperatures; therefore, the endothermic transition that occurred was solely attributed to the LDPE phase.

The percent of crystallinity of the LDPE phase in the blends determined from the DSC thermograms are given in **Table 2**. A value of ΔH_f^o (276 J/g) (Shogren, *et al.* 1992) for purely crystalline polyethylene (PE) and the heat of fusion (ΔH_f^*) obtained from the total area of the melting peak including the initial broad region were used to calculate percent of crystallinity. Comparing the difference between pure LDPE and LDPE/20% banana starch films, there is an apparent decrease in the heat of fusion as the amount of starch increases. However, when the heat of fusion is corrected by taking into account only the LDPE content in the blends, it is evident that there is no change in the degree of crystallinity of the LDPE phase. This result suggests that the LDPE phase is hardly miscible with the banana starch. For compatibilized blends with EVA, the degree of crystallinity of the LDPE phase in the blends slightly decreased as EVA content increased. This decrease may be due to the presence of an interaction between LDPE and starch, which hinders the close packing of LDPE chains.

Table 2 Percent of crystallinity of LDPE in various blends

Film Samples	**ΔH_f^* (J/g)**	**% Crystallinity (total)**	**% Crystallinity (LDPE phase)**
LDPE	54.13	19.61	19.61
20% starch	40.90	14.82	19.60
20% starch + 5% EVA	39.83	14.43	18.22
20% starch + 10% EVA	38.64	14.00	17.86
20% starch + 20% EVA	36.54	13.24	17.21

Thermogravimetric Analysis (TGA)

Effect of Starch Content

The effect of banana starch content on the thermal degradation behavior of the LDPE/starch blends is presented in **Figure 6**. Obviously, the LDPE/starch blends degraded in two stages. The first one around 310-340°C is due to starch decomposition as similarly shown in **Figure 3** for pure starch. With a further rise in temperature to 600°C, all the films exhibited no substantial weight changes up to *ca*. 450°C. The second stage of thermal decomposition began near 454°C, with the weight decreasing rapidly at 500°C. This higher thermal decomposition is owing to the EVA. **Table 3** summarizes the onset of degradation temperature (T_d (onset)) for both stages and also percentage of weight loss and residue at the specific temperatures for all the blends. As listed, less than 2.5% residue was left at 510°C. Clearly, the first T_d (onset) shifted towards low temperature as the amount of banana starch increased. The LDPE film with 5% starch started to degrade at 313.2°C, whereas the film containing 20% starch began to degrade at 308.5°C. Certainly, the banana starch content affected the amount of weight loss of the blend films at this stage. For example, at 330°C, weight loss of the films increased as a function of banana starch content. These results confirm that the first weight loss must be due to the decomposition of banana starch.

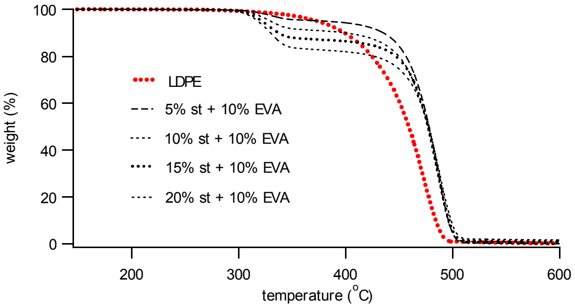

Figure 6 Effect of banana starch content on the TGA thermograms of LDPE films containing 10% EVA

Table 3 Effect of banana starch content on the onset of the degradation temperature and percentage of weight Loss for LDPE blend films

Sample	T_d (°C) (onset)		Percent Weight Loss		Residue at 510°C (%)
	First	Second	At 330°C	At 450°C	
LDPE	-	418.9	-	39.17	0.87
5%st + 10% EVA	313.2	454.6	2.58	15.70	0.52
10%st + 10% EVA	311.7	454.2	5.10	20.10	1.11
15%st + 10% EVA	310.0	455.6	7.78	21.25	1.41
20%st + 10% EVA	308.5	454.0	10.13	25.35	2.30

However, there was no effect from banana starch content at the second stage of thermal decomposition. The second T_d (onset) was not dependent upon the banana starch content, but the existence of EVA. This is because as shown in **Figure 3** banana starch has already been degraded. In addition, the degradation temperature of LDPE and EVA is 419°C and 450-500°C (Brandrup, *et al.* 1999), respectively. Therefore, the shift of thermograms toward higher temperature around 454°C is due to the effect of EVA. However, the influence of EVA content on the thermal stability behavior of the LDPE blend films will be explained in the next section. These results imply that no matter how much banana starch was added, the LDPE blend films will absolutely decompose approximately at the same temperature, i.e., 500°C.

Effect of EVA Content

On the other hand, the influence of EVA content is shown in **Figure 7**. Although the blend films show two stages of thermal decomposition as previously described, obviously, the difference exists between these two plots (**Figure 6 and Figure 7**). From **Figure 7**, as the amount of starch was kept constant, the first period of thermograms for all the blends were completely superimposed up to about 330°C. In fact, the second stage of thermal degradation started after

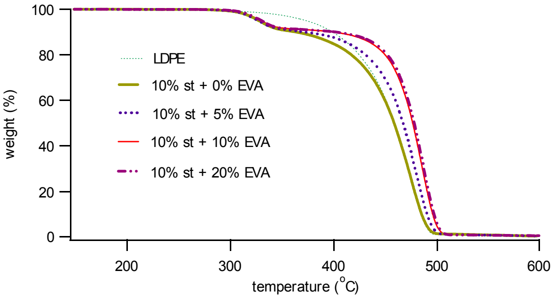

Figure 7 Effect of EVA content on the TGA thermograms of LDPE/10% banana starch films

the first stage, in particular the uncompatibilized blend film (0% EVA). This result confirms the effect of EVA on the thermal stability of the LDPE/banana starch blend films. As shown, thermal stability of the films increased with respect to the amount of EVA. Among them, the LDPE/banana starch compatibilized with 20% EVA had the highest thermal stability. Similar to **Figure 6**, all the blends further degraded up to about 500°C, where the blends almost completely decomposed.

From these two Figures it then can be concluded that the blends of LDPE with starch showed two decomposition stages. As the amount of banana starch was increased, the first T_d (onset) shifted towards a low temperature indicating that the first stage of degradation at 310°C is due to starch decomposition. However, there was no effect from banana starch at the second stage of thermal degradation. As the content of banana starch was kept constant, the first stage of thermograms for all the blends are identical; however, the second T_d (onset) increased as a function of EVA content. Also, as presented in **Table 4**, weight loss at 450°C decreased as the amount of EVA increased. This result confirms that the second stage started to degrade at about 419°C and is due to the LDPE decomposition. And the thermal stability of the blend films increased upon increasing EVA content as indicated by the shift of the second stage of thermal decomposition of the compatibilized LDPE blend films towards a higher temperature. In other words, the LDPE/banana starch films compatibilized with EVA have higher thermal stability than pure LDPE film.

Table 4 Effect of EVA content on the onset of the degradation temperature and percentage of weight Loss for LDPE blend films

Sample	**T_d (°C) (onset)**		**Percent Weight Loss**		**Residue at 510°C (%)**
	First	**Second**	**At 330°C**	**At 450°C**	
LDPE	-	418.9	-	39.17	0.87
10%st + 0% EVA	308.2	431.4	4.93	40.39	1.32
10%st + 5% EVA	309.0	438.8	5.08	30.72	1.12
10%st + 10% EVA	311.7	454.2	5.10	20.10	1.11
10%st + 20% EVA	313.1	459.9	5.09	18.98	1.05

Moisture Absorption of Films

Effect of Starch Content

Figure 8 illustrates moisture absorption as a function of time for pure LDPE and LDPE/banana starch films at various banana starch contents. All the blend films were uncompatibilized. As can be seen, the moisture absorption in the uncompatibilized blends depends on the exposure time and the starch content of the blends. Unlike the pure LDPE film with almost 0% of moisture absorption, the LDPE blend films absorbed more moisture as the amount of banana starch increased. The LDPE film with 20% starch had the highest moisture absorption compared to the others. The rate of moisture absorption also depended on the starch content. At 5% starch, the blend film absorbed moisture gradually until it reached an equilibrium. However, at high volume fractions of starch, the moisture absorption isotherm is slightly different. The absorption rate was very fast, although every blend films reached their own equilibrium within the same period of time, i.e., at 26 hours. These results ensure that banana starch is more hydrophilic than LDPE, leading to an enhancement of hydrogen bond formation between hydroxyl groups in the starch and moisture; as a result, the moisture uptake of the LDPE films increased as a function of banana starch content.

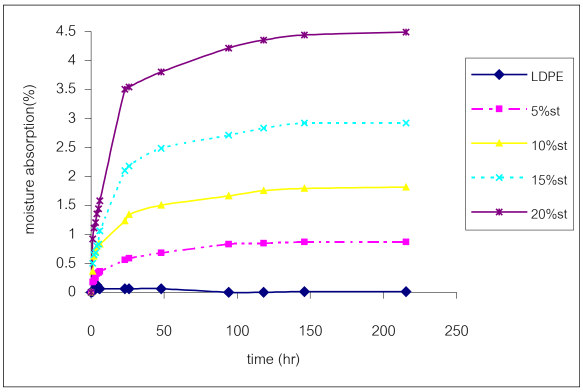

Figure 8 Effect of banana starch content on moisture absorption of uncompatibilized LDPE films.

Effect of EVA Content

The plot of moisture absorption as a function of time for compatibilized blends with EVA is shown in **Figure 9**. Although the uncompatibilized blends (0% EVA) absorbed more moisture than the compatibilized blends, their absorption decreased with increasing compatibilizer or EVA content. For uncompatibilized blends, starch granules are merely encapsulated within the LDPE matrix without any bonding. As seen in **Figure 10**, there is a gap between the starch particle and the LDPE matrix. As opposed to the compatibilized blend film there is a co-continuous phase between the two phases as shown in **Figure 11**. This is because EVA helps to promote the interfacial adhesion between the LDPE phase and the banana starch phase. In other words, uncompatibilized blends have more surface area between starch and moisture than compatibilized blends; as a result, they can absorb more moisture. Whereas, the EVA in the compatibilized blends can react to form hydrogen bonds with the hydroxyl groups of the banana starch, or to form a physical interaction between ethylene segments in EVA and in LDPE. Hence, the amount of hydroxyl groups in the banana starch to absorb or form hydrogen bonds with moisture was reduced.

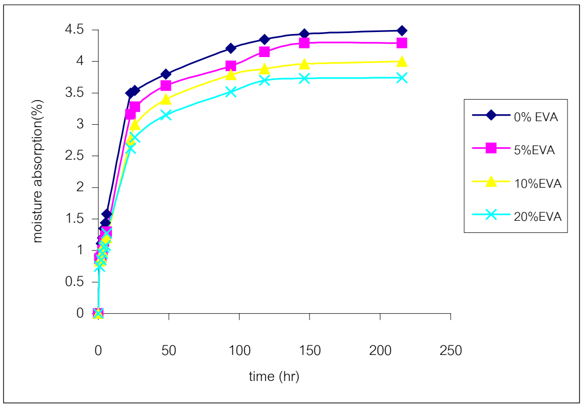

Figure 9 Effect of EVA content on moisture absorption of LDPE/20% banana starch films.

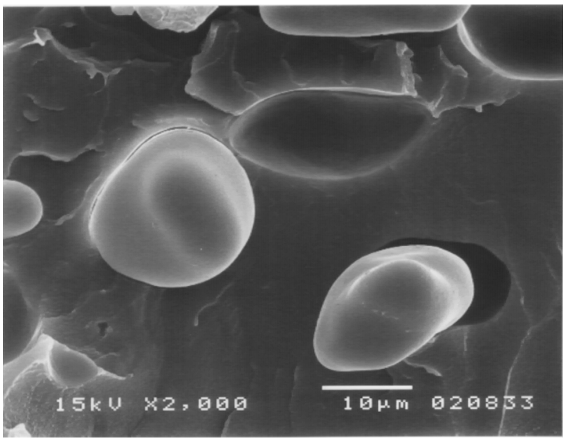

Figure 10 SEM micrograph of uncompatibilized LDPE/banana starch film.

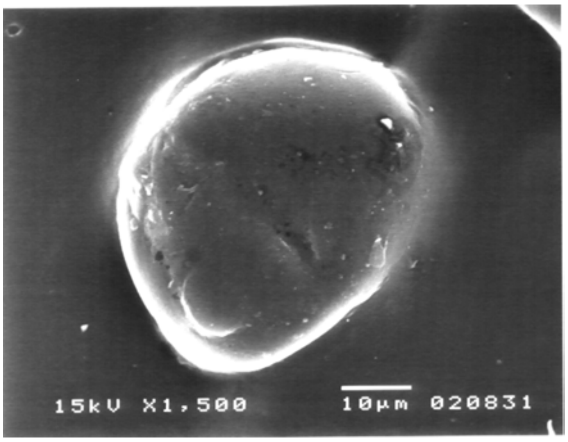

Figure 11 SEM micrograph of the LDPE/banana starch film containing 20% EVA

Conclusions

Banana starch is a new material that can be used to make biodegradable plastics. After being extracted in 0.05N NaOH, it was found that the shape of the banana starch granules ranged from oval to irregular. Its size varied from 5-45 μm in diameter with an average size of about 21-24 μm. The gelatinization temperature and degradation temperature were found to be in the range of 72-78°C and 310-345°C, respectively. The density measured by picnometric techniques was 1.74 g/cm^3.

From the DSC thermograms, no change was observed in the melting temperature of LDPE in any of the blends. The degree of crystallinity of the LDPE phase in the blends slightly decreased as EVA content increased. For TGA measurement, the LDPE/banana starch films showed two stages of decomposition behavior. The first stage around 310-340°C is due to the starch decomposition. The second stage near 454°C is due to the EVA decomposition. The degradation temperature of starch shifted towards a low temperature as the amount of banana starch increased. On the other hand, thermal stability of the films increased with respect to the amount of EVA.

Moisture absorption of the pure LDPE film was almost 0%, whereas for the LDPE/banana starch films, their moisture absorption increased as the amount of banana starch increased. These results ensure that banana starch is more hydrophilic than LDPE, leading to an enhancement of hydrogen bond formation between hydroxyl groups in the starch and moisture. In addition, it was found that the LDPE/banana starch films compatibilized with EVA absorbed less moisture than the uncompatibilized films.

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