# Ecoblend: Enhancing Compatibility And Performance In Low-Density Polyethylene-Starch Composites With EMA-Zn

**Zeena P. Hamza[1,2*], Thomas Kurian[1]**

[1]Department of Polymer Science and Rubber Technology, Cochin University of Science and Technology, Kochi, Kerala, India, 682022,
[2]Post Graduate and Research Department of Chemistry, Maharaja's College, Ernakulam, Kerala, India, 682011

[*]**Corresponding author:** Dr. Zeena P. Hamza
[*]Department of Chemistry, Maharaja's College, Ernakulam, Kerala, India, 682011
[*]Emails: zeenaphamza@maharajas.ac.in, zeenaphamza@gmail.com

**Abstract:**
Maleic anhydride (MA) and the zinc salt of polyethylene-co-methacrylic acid (EMA-Zn) were used to create blends of low density polyethylene and starch. Mechanical characteristics, melt flow measurements, spectroscopy, and scanning electron microscopy were all used to examine the compatibility behaviour of blends. Blends devoid of compatibilizer exhibit subpar characteristics typical of polymer blends that are incompatible. Spectroscopic and morphological characteristics demonstrated that the ionomer functions as a highly effective compatibilizer for low density blends of polyethylene and starch. The results of the biodegradability tests of blends show that they are only partially biodegradable.

**Keywords:** Compatibilizer, Low density polyethylene, Starch, Ionomer, Biodegradability

## INTRODUCTION

Since low density polyethylene (LDPE) is inexpensive, flexible, and insensitive to moisture, it is widely used as a packing material. But in nature, LDPE is not biodegradable (Hiraga **et al.**, 2019). Biopolymers, like starch, are renewable and biodegradable, and they are also reasonably priced ( Averous et al., 2001; Ghatge and Yang, 2020). Low density polyethylene blends can have their biodegradable qualities improved by adding a small quantity of starch. Thus, combining biopolymers with low density polyethylene presents an intriguing way to create novel materials with specific characteristics(Ali **et al.**, 2018; Taghizadeh **et al.,** 2013).

It is discovered that the majority of polymer mixes are incompatible and immiscible. A proper interfacial tension results in a phase size small enough for the material to be regarded as macroscopically homogenous, and an interphase adhesion strong enough to assimilate stresses and strains without disrupting the established morphology are the two structural parameters that determine the overall physico-mechanical properties of miscible blends(Paul and Newman, 1978).

Immiscible blends of low density polyethylene and starch result in big particles in the dispersed phase due to strong interfacial tension and weak adhesion(Hernández **et al.**, 2020). Stress applied to these immiscible blends results in poor stress concentration at the polymer-polymer interface, which prevents the stress from being transferred between the dispersed and continuous phases. Blends with inadequate mechanical characteristics are the outcome of this incompatibility (Costagliola **et al.**, 1979; Hallden **et al.**, 2000). Compatibilization has been used in many studies to improve the blend qualities. It can involve changing one of the blend components(Imre and Pukánszky, 2013; Seier, M. **et al.**, 2020)) or adding a minor-component compatibilizer (Feng **et al.,** 1996; Ndlovu **et al.,** 2013; Zheng **et al.,** 2003). The mechanical properties of the blend are enhanced by the addition of a compatibilizer, which increases stress transmission between the continuous and dispersed phases(Borah and Chaki , 2011).

Numerous studies on the use of compatibilizers to enhance the morphological and mechanical characteristics of LDPE blends have been reported. It has been observed that maleic anhydride grafted polyethylene functions as a compatibilizer in LDPE blends (Mantia **et al.,** 2017). Additionally, grafted LDPE with glycoside methacrylate has been utilised as a compatibilizer in LDPE blends (Sailaja **et al.,** 2001; Li **et al.,** 2018).

Ionomers are hydrocarbon-based ionic polymers with pendant acid groups that are at least partially neutralised to generate salt groups(Overbeek, 1976; Ma **et al.,** 1995). There is increasing industrial and scholarly interest in the special qualities of ionomers. One of the busiest areas of current polymer science research is the study of ionic interaction in macromolecular systems. Ionomers possess a special property that allows them to make some blends that are incompatible work together, such PP/EVOH (Abad **et al.**, 2004) LDPE/Nylon-6 (Lahor **et al.**, 2004; Leewajanakul **et al.**, 2003), HDPE/Nylon–66 (Chatreenuwat **et al.**, 2007), and so on. Various ionomers have been effectively employed in the literature to compatibilize incompatible blends. These include poly(ethylene-co-sodium methacrylate) (Lahor **et al.**, 2004), poly(styrene-co-sodium methacrylate)(Watanabe **et al.**, 2001), and metal salts of sulfonated PET(Ju **et al.**, 2018). Ionic cross-links are created at the binary blend's interface when ionomers are introduced and thus homogeneity is improved.

The findings of research on ionomer (the zinc salt of polyethylene-co-methacrylic acid, or EMA-Zn) and maleic anhydride (MA) as compatibilizers for low density polyethylene and starch blends are presented in this article. Maleic anhydride is a reference in this study and has been utilised extensively as a compatibilizing agent for these kinds of systems. Table 1 lists the samples that were used along with their descriptions.

**Table 1:** Description of sample designations

| Sample designation | Description |
|---|---|
| C5M | LDPE-20% starch-5% MA |
| C5Z | LDPE-20% starch-5% (EMA-Zn) |
| LDS(x)-MA(y) | LDPE- x% starch-y% MA |
| LDS(x)-Zn(y) | LDPE- x% starch-y% (EMA-Zn) |

## MATERIALS AND METHODS

### Materials

### Low density polyethylene (LDPE)

The film grade low density polyethylene (LDPE 24FS040) from Reliance Industries Limited, Mumbai, India, with melt flow index (190 °C/2.16 kg) of 4 g/10 min and density (23 °C) of 0.922 g/cm$^3$ was supplied by Periyar Polyfilms, Edayar, Kerala, India.

### Starch

The tapioca starch (100 and 300 mesh) was obtained from Jemsons Starch & Derivatives, Aroor, Alappuzha, Kerala. As these fillers were hygroscopic in nature they were oven dried at 120°C for 1h prior to mixing.

### Ionomers

Ionomer used in this study was Zinc salt of poly(ethylene-co-methacrylic acid) (HIMILAN 1702 EMAAZn) with melt flow index (190°C/2.16 kg) of 16 g/10 min. Ionomer was supplied by Mitsubishi Plastics, Inc., Japan.

### Methods

### Preparation of blends

A Thermo Haake Polylab system (Rheocord 600p) equipped with roller-type rotors was used for melt mixing. The mixing chamber has a volumetric capacity of 69 cm$^3$. A mixing time of 8 minutes was given for all the compounds at a rotor speed of 30 rpm at 150 °C. LDPE together with ionomer was first melted for 2 minutes followed by the addition of filler. Mixing was continued for another 6 minutes.

### Preparation of test specimens

The test specimens were prepared from neat LDPE and the compounds by moulding in an electrically heated hydraulic press for 5 minutes at 150°C under a pressure of 20 MPa. After moulding, the samples were cooled down to room temperature under pressure.

### Characterization

### Mechanical properties

The mechanical properties were evaluated using Shimadzu Autograph AG-I series universal testing machine at a crosshead speed of 50 mm/min. Tensile strength, elongation at break and elastic modulus were measured according to ASTM D-882 (2002). Averages of at least five sample measurements were taken to represent each data point.

### Melt Flow Index (MFI)

The melt flow index (MFI) of each blend of LDPE with filler was measured using a CEAST Modular Line Melt Flow Indexer in accordance with ASTM method D-1238 using a 2.16 kg load at a melt temperature of 190°C.

### Biodegradation studies

The biodegradation studies on the blends were carried out according to ASTM D-6691. Bacterial cultures were obtained from culture collections of Microbial Genetic Lab, Department of Biotechnology, Cochin University of Science and Technology. These cultures were isolated from sediment samples collected from different locations in Cochin backwaters and Mangalavanam mangroves. These cultures were previously identified as the genus Vibrionacea based on their morphological and biochemical characteristics outlined in Bergey's Manual of Systematic Bacteriology(Sailaja **et al.**, 2001). They were preserved in 10mL glass bottles employing the paraffin oil overlay method.

To prepare the inoculum the individual isolates of the consortium were grown overnight at 37 °C at 120 rpm on an Orbitek shaker (Scigenics Pvt. Ltd, Chennai, India) in nutrient broth (Himedia, Mumbai) pH 7.0 ± 0.3 with 1% NaCl. The cells were harvested by centrifugation at 5000 rpm (2292 g) for 20 minutes, washed with physiological saline and then pooled. 5mL of this pooled culture ($OD_{660}$ = 1) was used to inoculate 50mL amylase minimal medium (Ma **et al.**, 1995) lacking starch. The samples prepared from the blends previously wiped with 70% alcohol were added to this medium and these strips acted as the sole source of carbon. Incubation was in the Orbitek environmental shaker at 37 °C and 120 rpm for a total period of 3 months with regular sampling. The medium without the inoculum with corresponding starch-plastic blends and subjected to the same treatment as above were used as controls.

### Water absorption characteristics

Water absorption was measured using 3 x 1 inch film strips of <1mm thickness according to ASTM D-570-81 method. Water absorption measurements were performed by soaking the samples in distilled water. The water absorption was calculated as the weight difference and is reported as a percentage increase of the initial weight. The results reported are average of three measurements.

### Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of the samples were recorded in the transmittance mode using a Thermo Nicolet, Avatar 370 FTIR spectrophotometer in the spectral range of 4000–400 cm$^{-1}$.

### Morphological studies

In the present study the tensile fractured surfaces were mounted on a metallic stub with the help of a silver tape and conducting paint in the upright position and were sputter coated with platinum within 24 hours of fractures in a JFC 1600 Autofine coater and then examined under JEOL model JSM-6390LV scanning electron microscope (SEM).

## RESULTS

### Mechanical properties

The mechanical properties of the compatibilized as well as uncompatibilized LDPE-starch blends are shown in the Figs 1-3.

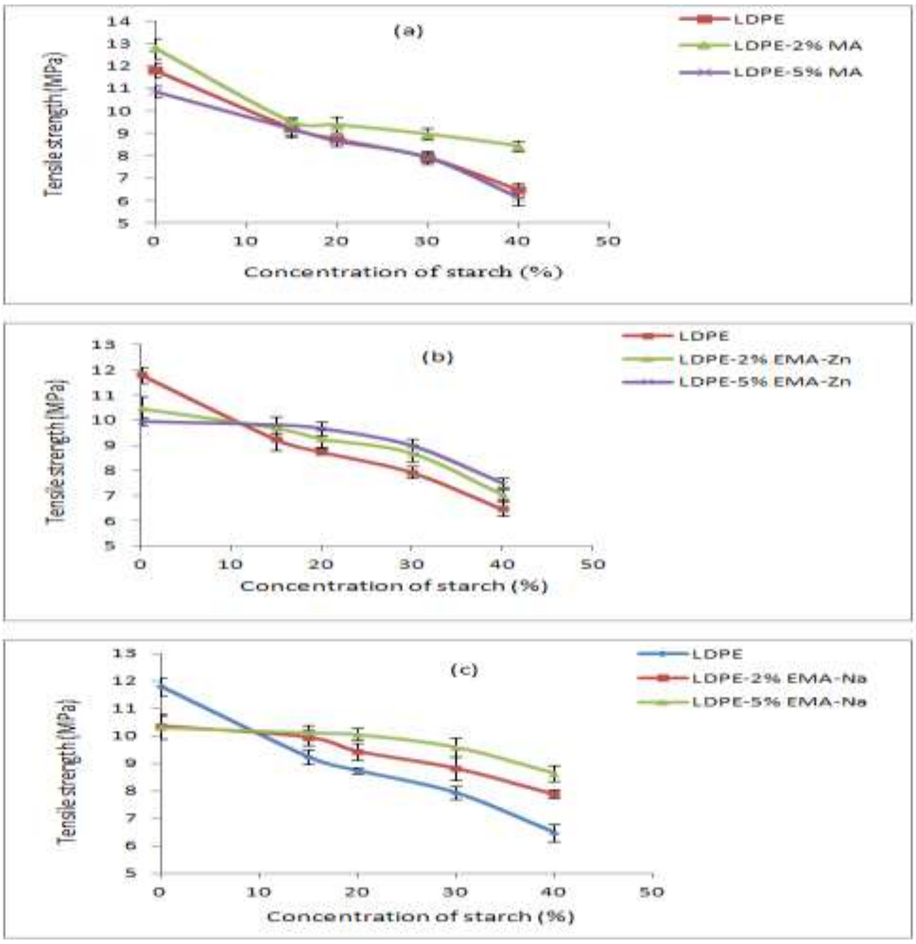


**Fig 1:** Variation of tensile strength with the concentration of starch for: (A) LDPE-starch -MA blends and (B) LDPE-starch-(EMA-Zn) blends

The ductility, as measured by the elongation at break of the blends, is shown in Fig 2.

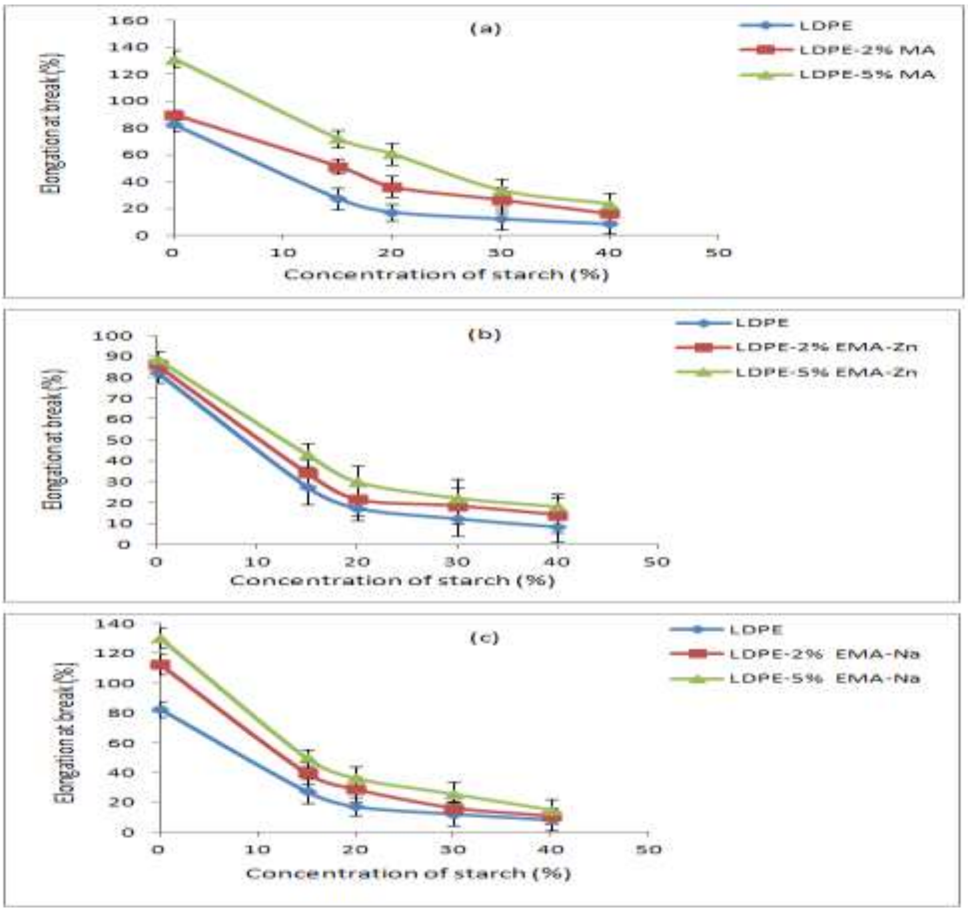


**Fig 2:** Variation of elongation at break with the concentration of starch for: (a) LDPE-starch -MA blends and (b) LDPE-starch-(EMA-Zn) blends

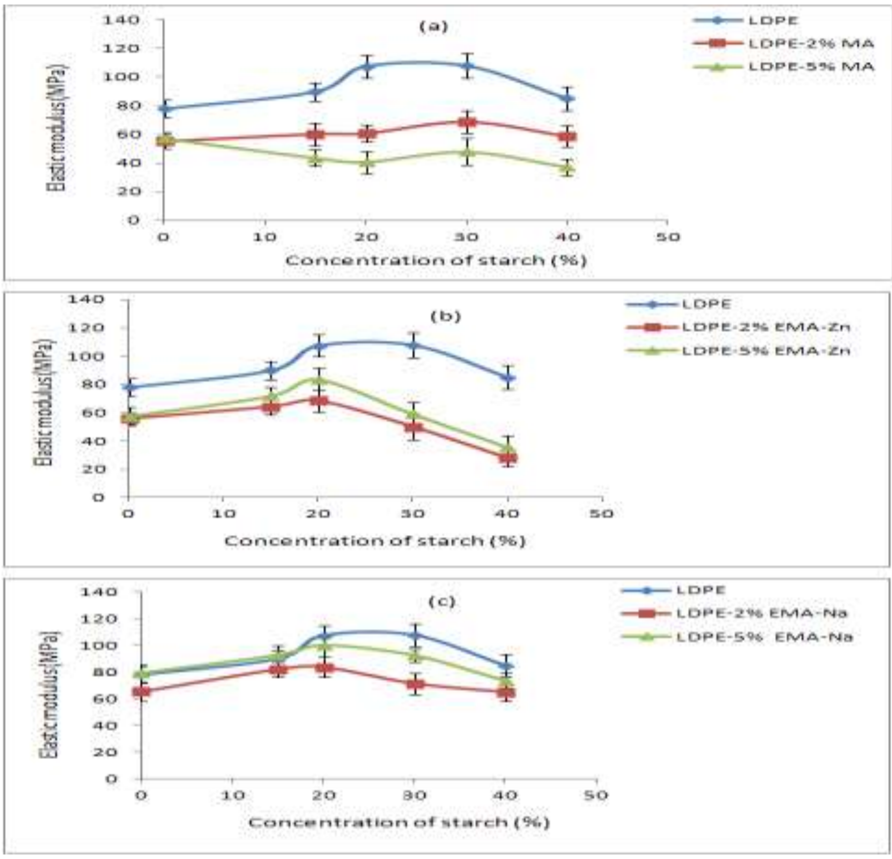


**Fig 3:** Variation of elastic modulus with the concentration of starch for: (a) LDPE-starch -MA blends, (b) LDPE-starch-(EMA-Zn) blends

The effect of the addition of the ionomer as compatibilizer on the tensile strength of LDPE- starch blends is shown in Fig 4.

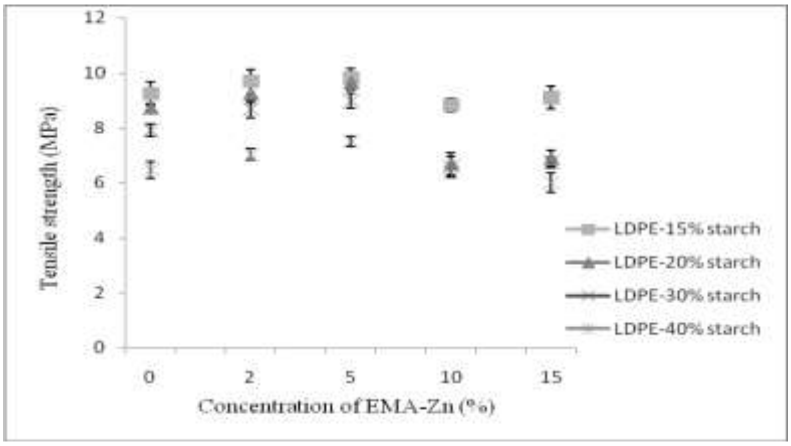


**Fig 4:** Effect of concentration of EMA-Zn as compatibilizer on the tensile strength of LDPE- starch blends

**Melt flow measurements**

Fig 5 shows the variations of melt flow indices with varying concentration of starch in the case of LDPE-starch-(EMA-Zn) blends.

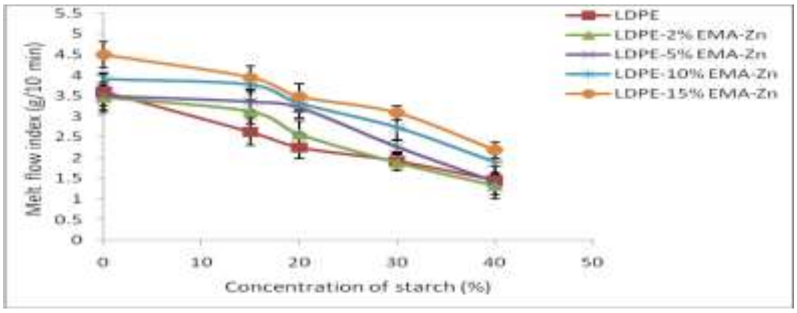


**Fig 5:** Variation of melt flow index with the concentration of starch in LDPE-starch-(EMA-Zn) blends

**Biodegradation studies**

Table 2: Percentage decrease in weight of LDPE-starch-MA blends after biodegradation in culture medium for four months

| Sample | Initial weight (g) | Weight after four months (g) | % weight loss |
|---|---|---|---|
| LDS(0)-MA(2) | 0.3042 | 0.3041 | 0.03 |
| LDS(0)-MA(5) | 0.2254 | 0.2253 | 0.04 |
| LDS(15)-MA(2) | 0.2411 | 0.2320 | 3.77 |
| LDS(15)-MA(5) | 0.2769 | 0.2659 | 3.97 |
| LDS(20)-MA(2) | 0.2155 | 0.2056 | 4.59 |
| LDS(20)-MA(5) | 0.2858 | 0.2669 | 6.61 |
| LDS(30)-MA(2) | 0.1888 | 0.1718 | 9.00 |
| LDS(30)-MA(5) | 0.1583 | 0.1409 | 10.99 |
| LDS(40)-MA(2) | 0.3141 | 0.2445 | 22.16 |
| LDS(40)-MA(5) | 0.1552 | 0.1095 | 29.45 |

Tables 2 and 3 illustrate the weight loss of compatibilized LDPE-starch blends after biodegradation in culture medium for four months.

Table 3: Percentage decrease in weight of LDPE-starch-(EMA-Zn) blends after biodegradation in culture medium for four months

| Sample | Initial weight (g) | Weight after four months (g) | % weight loss |
|---|---|---|---|
| LDS(0)-Zn(2) | 0.2269 | 0.2268 | 0.04 |
| LDS(0)-Zn(5) | 0.2765 | 0.2764 | 0.04 |
| LDS(15)-Zn(2) | 0.1625 | 0.1580 | 2.77 |
| LDS(15)-Zn(5) | 0.1863 | 0.1831 | 1.72 |
| LDS(20)-Zn(2) | 0.1133 | 0.1083 | 4.41 |
| LDS(20)-Zn(5) | 0.1453 | 0.1405 | 3.30 |
| LDS(30)-Zn(2) | 0.2687 | 0.2486 | 7.48 |
| LDS(30)-Zn(5) | 0.1862 | 0.1755 | 5.75 |
| LDS(40)-Zn(2) | 0.1054 | 0.0895 | 15.09 |
| LDS(40)-Zn(5) | 0.2093 | 0.1860 | 11.13 |

Fig 6 exhibits the tensile properties of LDPE-20% starch-compatibilizer blends after biodegradation in culture medium.

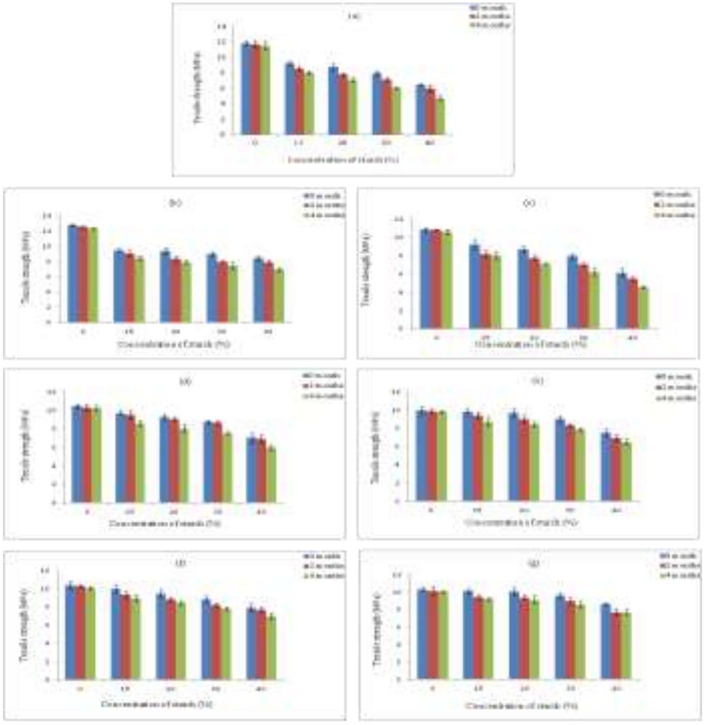


**Fig 6:** Biodegradation of: (a) LDPE-starch blends, (b) LDPE-starch-2% MA blends, (c) LDPE-starch-5 % MA blends, (d) LDPE-starch-2% (EMA-Zn) blends and (e) LDPE-starch-5% (EMA-Zn) blends

## Water absorption studies

**Table 4:** Water absorption of LDPE-starch-(EMA-Zn) blends

| **Sample** | **Initial weight (g)** | **Weight after 24 hours (g)** | **% water absorption** |
|---|---|---|---|
| LDS(0)-Zn(2) | 0.2999 | 0.3001 | 0.07 |
| LDS(0)-Zn(5) | 0.2537 | 0.2538 | 0.04 |
| LDS(15)-Zn(2) | 0.2432 | 0.2453 | 0.86 |
| LDS(15)-Zn(5) | 0.2996 | 0.3016 | 0.67 |
| LDS(20)-Zn(2) | 0.3722 | 0.3771 | 1.32 |
| LDS(20)-Zn(5) | 0.4332 | 0.4387 | 1.27 |
| LDS(30)-Zn(2) | 0.3080 | 0.3156 | 2.47 |
| LDS(30)-Zn(5) | 0.4317 | 0.4373 | 1.30 |
| LDS(40)-Zn(2) | 0.3721 | 0.3870 | 4.00 |
| LDS(40)-Zn(5) | 0.4072 | 0.4201 | 3.17 |

Table 4 shows the water uptake of LDPE-starch-ionomer blends after 24 hours of immersion.

### Fourier transform infrared spectroscopic analysis

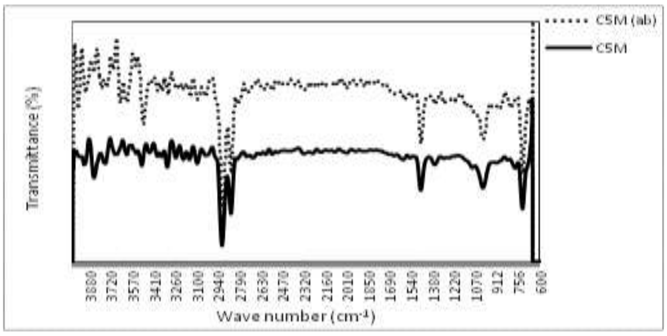


**Fig 7a:** FTIR spectra of LDPE-starch-MA blends before and after (ab) biodegradation

The FTIR spectra of LDPE-starch-compatibilizer blends before and after biodegradation for four months are shown in figures 7a and 7b.

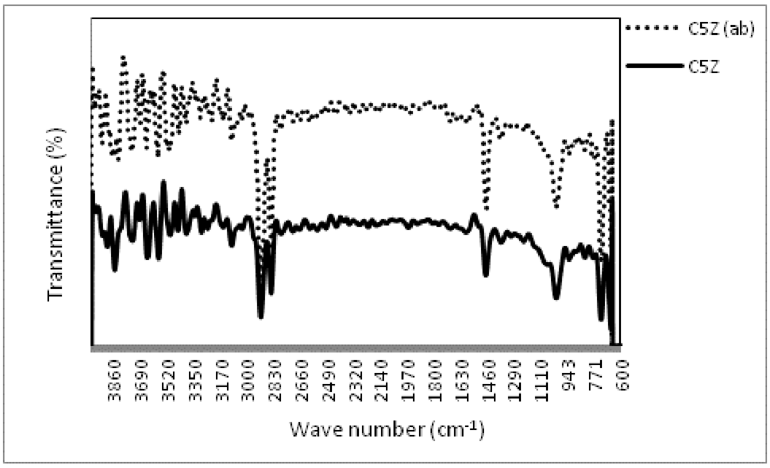


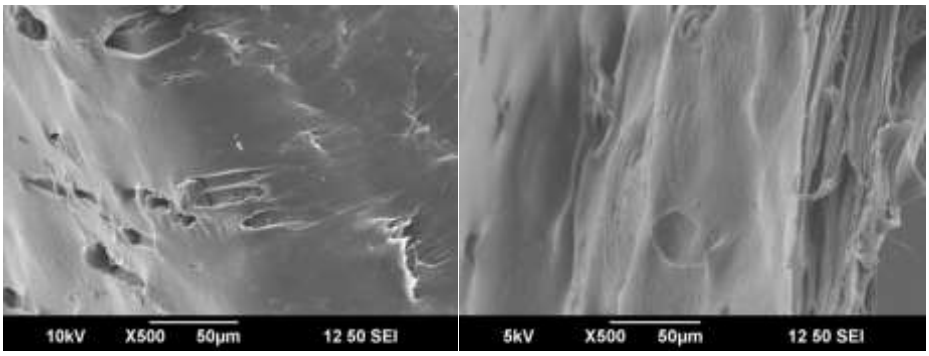
**Fig 7b:** FTIR spectra of LDPE-starch-(EMA-Zn) blends before and after (ab) biodegradation

**Table 5:** Characteristic FTIR spectral peaks in C5M, C5Z and C5S

| Sample | Peak position (cm$^{-1}$) | Characteristic group |
|---|---|---|
| C5M | 2913, 2847 | C-H stretching |
| | 1790 | C=O stretching |
| | 1591 | C=O stretching |
| | 1463 | $CH_2$ scissor and asymmetric bending |
| | 1361 | C-H bending |
| | 1011 | O-C stretching |
| | 916 | O-H deformation |
| | 722 | $CH_2$ rocking |
| C5Z | 2913, 2846 | C-H stretching |
| | 1790 | C=O stretching |
| | 1700, 1591 | C=O stretching |
| | 1463 | $CH_2$ scissor and asymmetric bending |
| | 1366 | C-H bending |
| | 1011 | O-C stretching |
| | 928 | O-H deformation |
| | 722 | $CH_2$ rocking |

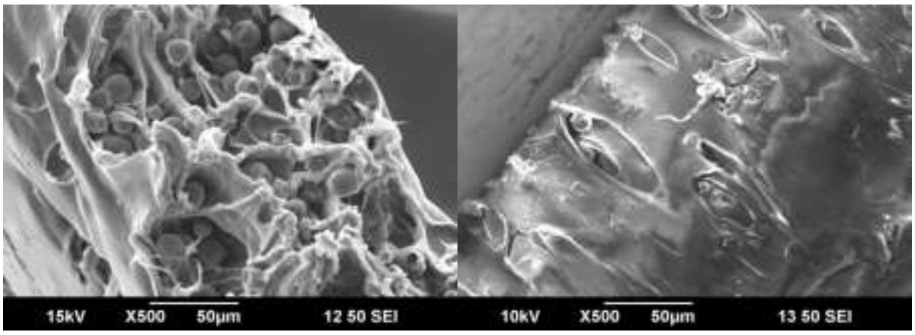
### Morphological studies

Figures 8a and 8b show the SEM microphotographs of the fractured surfaces of the compatibilized LDPE-starch blends (75/20/5).



**(i)** **(ii)**

**Fig 8a:** Scanning electron micrographs of LDPE-starch-MA (75/20/5) blend: (i) before biodegradation and (ii) after biodegradation for four months



**(i)** **(ii)**

**Fig 8b:** Scanning electron micrographs of LDPE-starch-(EMA-Zn) (75/20/5) blend: (i) before biodegradation and (ii) after biodegradation for four months

## DISCUSSIONS

### Mechanical properties

Because of the weak interfacial adhesion between hydrophilic starch and hydrophobic LDPE, the tensile strength dropped as the concentration of starch increased (Ahmed, 1996, Hamza **et al.**, 2009). Tensile strength is higher in samples containing maleic anhydride and EMA-Zn compatibilizing agents than in blends that are not compatible. The highest tensile strength for blends that are compatible with MA is obtained by adding 2% of MA, whereas the highest tensile strength for blends that are compatible with ionomers is obtained by adding 5% of ionomer in the case of EMA-Zn. It appears that variations in phase behaviour are what cause the tensile strength variations. Compatibility between LDPE and starch rises when compatibilizer is added because it increases interfacial adhesion, which promotes effective stress transmission from one phase to another.

In comparison to the uncompatibilized blend, all compatibilized blends showed an increase in elongation at break(Fig 2). The stronger interfacial adhesion and the decrease in particle size are responsible for the rise in ductility, which also indicates compatibilization.

On the other hand, when the starch loading is increased, the elastic modulus rises (Fig 3). It appears that following processing, the starch integrated into LDPE kept its granular form. Due to their stiffness, these grains serve as stiff fillers. In general, a material's hard domain and modulus are tightly correlated. Both the hard domain content and the blend's tensile modulus rise with an increase in starch content. Due to the blends' flexibilization, the compatibilized blends' elastic moduli are, nevertheless, lower than those of the uncompatibilized blends.

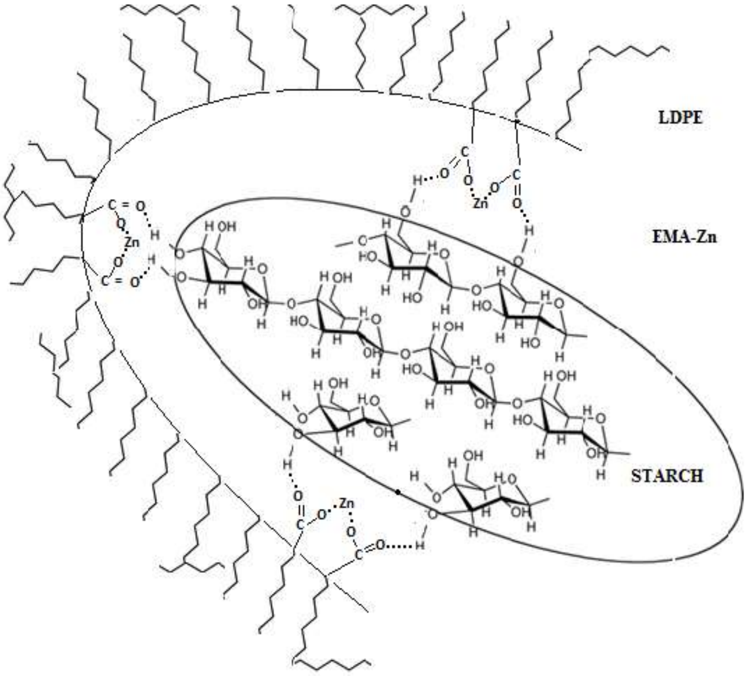


**Fig 9:** Proposed schematic representation of the interaction between starch, EMA-Zn and LDPE

It appears that ionic cross-links form at the blend interface when ionomers are introduced to the binary mix, improving homogeneity. The ionomers employed in this work consist of two unique regions: a region rich in polyethylene and another region that is primarily made up of a pair of metal cations and carboxylate anion. As suggested in Fig 9, the carboxyl groups of the ionomers might be interacting through polar-polar interactions with the hydroxyl groups of starch. The LDPE and the ionomers' nonpolar polyethylene domain are compatible. It is thought that co-crystallization, amorphous chain entanglement, or a combination of the two ways that the ionomers' polyethylene domain and the LDPE associate( Magaraphan **et al.**, 2007, Kaseem **et al.**, 2015). Though the contacts between the nonpolar LDPE molecular chains and the nonpolar region of the ionomers are of the weak van der Waals type, the same might be of a much stronger type as suggested in the figure due to the carboxyl groups of the ionomer and the hydroxyl groups of starch.

Up to a five weight percent increase in ionomer content, the tensile strength increases. Tensile strength does not increase any more when more than 5% of ionomer is added. This shows that the strength of the matrix, which is greatly influenced by the amount of compatibilizer in the blend, determines the tensile strength of a compatibilized blend in addition to interfacial adhesion (Penava **et al.**, 2013). The limited solubility of the ionomer in the blend or the limit on ionomer migration to the interface during processing may be the cause of the lack of improvement in characteristics with greater ionomer concentration in the blend(Lee **et al.**, 2018).

### Melt flow measurements

The inverse of melt viscosity, the melt flow index is a measure of average molecular mass. When compared to samples without starch, the MFI values of all the samples with starch are lower. As the starch concentration rose, the MFI values dropped. This might be the result of an increase in viscosity brought on by a concentration of spherical starch particles in the LDPE matrix. It was shown that when the ionomer content rose from 2 weight percent to 15 weight percent, the melt flow increased in all cases of LDPE-starch-ionomer blends. For the ionomers utilised in this investigation, the increase in melt flow may be attributable to their low molecular weight backbone, even though ionomers typically exhibit greater melt viscosities relative to their base polymers(Molnar and Eisenberg, 1992)). This demonstrates unequivocally the benefits of ionomer as a compatibilizer.

### Biodegradation studies

Following biodegradation, the tensile strength of each blend significantly decreases. Microorganisms' consumption of starch is the cause of this decrease. The blends containing a larger starch content appear to have more exposed starch, which leads to a higher proportion being devoured by microorganisms. This is demonstrated by the blends' steeper decline in stress-strain characteristics following biodegradation. In mixes with lower starch contents, the starch may be nearly entirely encased in LDPE, rendering it inaccessible to microorganisms(Ratanakamnuan and Aht-Ong, 2006).

The uncompatibilized blend films' tensile properties were inferior to those of the compatibilized blend films over a four-month biodegradation period in culture medium. It appears that the LDPE matrix contains the starch granules without any bonding for the uncompatibilized mixes. As a result, the LDPE matrix becomes more porous, which facilitates microbial invasion. The interfacial adhesion between the two components of the LDPE-starch film with compatibilizer can make it more challenging to remove the starch granules from the films.

Because the bacteria are consuming the starch, the weight of all the components has decreased. While its blends with starch showed better weight reduction, LDPE in culture media did not demonstrate any discernible weight loss. It was noted that with the blend containing 40% starch, the biodegradation rate rose quickly.

According to the table, the ionomer compatibilized films degraded more slowly than the MA compatibilized films. It is possible to infer that the compatibilizer prevents the film from biodegrading. The polar-polar interactions between the ionomer's carboxyl groups and the starch's hydroxyl groups, which prevent microbes from consuming starch, could be the cause of this ionomer effect.

### Water absorption studies

Because starch has a far higher water absorption rate than LDPE, blends' water uptake rises as the starch proportion climbs(Acierno and Puyvelde, 2005). Ionomer, however, reduces water absorption; decreased water absorption is shown with larger ionomer amounts. This might be because ionomer compatibilized blends have lower void volumes, which promotes better blend component adhesion and limits water storage and penetration at the interface.

### Fourier transform infrared spectroscopic analysis

The disintegration of the polyethylene chain in degradable settings, which led to a rise in the terminal group numbers, may be the cause of the increase in the intensity of peaks at 2921-2848 $cm^{-1}$, 1473-1463 $cm^{-1}$, 1156-1028 $cm^{-1}$, and 730-720 $cm^{-1}$ following degradation. The elimination of starch from the plastic film is indicated by the significant variations in the C-O stretching absorbance at 1260-1000 $cm^{-1}$ region between the spectra of the C5M mix before and after biodegradation.

However, in C5Z mixes, these variations are not as noticeable, which might be because starch and ionomer have higher phase adherence. The loss of absorbed water as starch is eliminated by microorganisms was confirmed by a minor drop in the intensities of the broad O-H stretching peak at 3700-3000 $cm^{-1}$ region and the O-H bending peak at 1640 $cm^{-1}$ detected in the spectra of the C5M and C5Z blends after biodegradation.

### Morphological studies

Figures denoted by (i) show the morphology of the LDPE-starch-compatibilizer (75/20/5) blends. Despite having a shape that is very similar to the uncompatibilized blend, the two phases show evidence of increased interactions between them in the form of plastic deformation at the interfaces and some broken starch particles following the cryogenic fracture. Figures demonstrate how the inclusion of compatibilizer clearly affects the morphology by enhancing the dispersion of the dispersed phase into the LDPE matrix and decreasing its dimensions. This shrinkage implies that the starch agglomerates are getting smaller. Thus, the inclusion of ionomers results in the formation of evenly distributed starch particles. Compatibilite transition and a reduction in interfacial tension are shown by the more uniform particle size distribution and smaller total size.

The SEM micrographs of blends of LDPE, starch, and compatibilizer following biodegradation are provided in the figures indicated by (ii). The micrographs' black pores demonstrate how LDPE-starch mixes biodegrade. During the biodegradability tests, starch is not entirely eliminated. Compared to the compatibilized film, the uncompatibilized film contains more randomly distributed microscopic holes because it has a larger surface area that can be targeted by microorganisms. The removal of starch granules from the films is more challenging because of the compatibilizer's increased interfacial adherence of starch into the LDPE matrix.

## CONCLUSION

The polyethylene-co-methacrylic acid ionomer can be used to compatibilize blends of low density polyethylene and starch that have been melted together. The ionomer was added as a compatibilizer, which enhanced the blends' stress-strain characteristics. The study employed several dosages of ionomers as compatibilizers. For EMA-Zn, the highest increase in mechanical characteristics was observed with a weight percentage of 5%. The inclusion of the ionomer also resulted in an increase in the melt flow of the blends. According to biodegradation experiments, the degradation rate of ionomer-compatibilized films was slightly slower than that of MA-compatibilized films. Studies using spectroscopy show that starch and ionomer interact. Morphological analyses reveal that the use of ionomers as compatibilizers improves the blend's starch particle dispersion.

**CRediT authorship contribution statement.** Author 1: Methodology, Investigation, Formal Analysis Author 2: Supervision.

**Declaration of competing interest.** The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## REFERENCES:

1. Abad, M. J. et al. (2004) “Use of a sodium ionomer as a compatibilizer in polypropylene/high-barrier ethylene–vinyl alcohol copolymer blends: The processability of the blends and their physical properties,” Journal of applied polymer science, 94(4), pp. 1763–1770. doi: 10.1002/app.21107.

2. Acierno, S. and Van Puyvelde, P. (2005) “Rheological behavior of polyamide 11 with varying initial moisture content,” Journal of applied polymer science, 97(2), pp. 666–670. doi: 10.1002/app.21810.
3. Ahamed, N. (1996) “Studies on Chenopodium quinoa and Amaranthus paniculatas starch as biodegradable fillers in LDPE films,” Carbohydrate polymers, 31(3), pp. 157–160. doi: 10.1016/s0144-8617(96)00019-7.
4. Ali, A. et al. (2018) “Preparation and characterization of starch-based composite films reinfoced by polysaccharide-based crystals,” Composites. Part B, Engineering, 133, pp. 122–128. doi: 10.1016/j.compositesb.2017.09.017.
5. Averous, L., Fringant, C. and Moro, L. (2001) “Starch-based biodegradable materials suitable for thermoforming packaging,” Die Starke, 53(8), p. 368. doi: 10.1002/1521-379x(200108)53:8<368::aid-star368>3.0.co;2-w.
6. Borah, J. S. and Chaki, T. K. (2011) “Dynamic rheological, morphology and mechanical properties of compatibilized LLDPE/EMA blends,” Journal of polymer research, 18(5), pp. 907–916. doi: 10.1007/s10965-010-9488-z.
7. Chatreenuwat, B., Nithitanakul, M. and Grady, B. P. (2007) “The Effect of Zinc Oxide Addition on the Compatibilization Efficiency of Maleic Anhydride Grafted High-Density Polyethylene Compatibilizer for High-Density Polyethylene/Polyamide 6 Blends”,” Journal of Applied Polymer Science.
8. Costagliola, M. et al. (1979) “Mechanical and swelling properties of polystyrene-polyolefin blends,” Journal of materials science, 14(5), pp. 1152–1158. doi: 10.1007/bf00561299.
9. Feng, H., Tian, J. and Ye, C. (1996) “Compatibilization effect of graft copolymer on immiscible polymer blends. II. LLDPE/PS/LLDPE-g-PS systems,” Journal of applied polymer science, 61(13), pp. 2265–2271. doi: 10.1002/(sici)1097-4628(19960926)61:13<2265::aid-app4>3.0.co;2-a.
10. Ghatge, S. et al. (2020) “Biodegradation of polyethylene: a brief review,” Applied biological chemistry, 63(1). doi: 10.1186/s13765-020-00511-3.
11. Hallden, A., Bertil and Wesslen, B. (2000) “Bengt,” Journal of Applied Polymer Science, 78(13), pp. 2416-2424C.
12. Hamza, Z. P. et al. (2009) “Studies on the biodegradability of linear low-density polyethylene–dextrin blends using vibrios from the benthic environment,” Progress in rubber, plastics and recycling technology, 25(3), pp. 129–139. doi: 10.1177/147776060902500301.
13. Hiraga, K. et al. (2019) “Biodegradation of waste PET: A sustainable solution for dealing with plastic pollution,” EMBO reports, 20(11). doi: 10.15252/embr.201949365.
14. Imre, B. and Pukánszky, B. (2013) “Compatibilization in bio-based and biodegradable polymer blends,” European polymer journal, 49(6), pp. 1215–1233. doi: 10.1016/j.eurpolymj.2013.01.019.
15. Ju, L. et al. (2018) “Synthesis and characterization of phosphonated Poly(ethylene terephthalate) ionomers,” Polymer, 151, pp. 154–163. doi: 10.1016/j.polymer.2018.07.065.
16. Kaseem, M. et al. (2015) “Melt rheology of poly(vinylidene fluoride) (PVDF)/low density polyethylene (LDPE) blends,” Polymer Science Series A, 57(2), pp. 233–238. doi: 10.1134/s0965545x15020054.
17. Lahor, A., Nithitanakul, M. and Grady, B. P. (2004) “Blends of Low-Density Polyethylene with Nylon Compatibilized with a Sodium Neutralized Carboxylate Ionomer,” European Polymer Journal.

18. Lee, J. H. et al. (2018) “Dispersion-solvent control of ionomer aggregation in a polymer electrolyte membrane fuel cell,” Scientific reports, 8(1). doi: 10.1038/s41598-018-28779-y.
19. Leewajanakul, P. et al. (2003) “The Use of Zinc-Neutralized Ethylene-Methacrylic Acid Copolymer Ionomers as Blend Compatibilizers for Nylon 6 and Low Density Polyethylene,” Journal of Applied Polymer Science.
20. Li, X. et al. (2018) “Improved compatibility in Recycled-PE / LDPE using glycidyl methacrylate, acrylic acid grafted mPE,” Polymer testing, 69, pp. 508–513. doi: 10.1016/j.polymertesting.2018.06.008.
21. Ma, X., Sauer, J. A. and Hara, M. (1995) “Poly(methyl methacrylate) based ionomers. 1. Dynamic mechanical properties and morphology,” Macromolecules, 28(11), pp. 3953–3962. doi: 10.1021/ma00115a031.
22. Magaraphan, R., Skularriya, R. and Kohjiya, S. (2007) “Morphological study of LLDPE-NR reactive blending with maleic anhydride,” Journal of applied polymer science, 105(4), pp. 1914–1921. doi: 10.1002/app.26243.
23. Mantia, F. P. L. et al. (2017) “Effect of a compatibilizer on the morphology and properties of polypropylene/polyethylentherephthalate spun fibers,” Polymers, 9(2), p. 47. doi: 10.3390/polym9020047.
24. Molnar, A. and Eisenberg, A. (1992) “Miscibility of polyamide-6 with lithium or sodium sulfonated polystyrene ionomers,” Macromolecules, 25(21), pp. 5774–5782. doi: 10.1021/ma00047a032.
25. Ndlovu, S. S., van Reenen, A. J. and Luyt, A. S. (2013) “LDPE–wood composites utilizing degraded LDPE as compatibilizer,” Composites. Part A, Applied science and manufacturing, 51, pp. 80–88. doi: 10.1016/j.compositesa.2013.04.005.
26. Overbeek, J. T. G. (1976) “Ionic polymers, L. Holliday, Ed., Halsted Press, a division of John Wiley & Sons, Inc., New York, 1975, 416 pp. $43.50,” Journal of Polymer Science Polymer Letters Edition, 14(2), pp. 114–115. doi: 10.1002/pol.1976.130140211.
27. Penava, N. V., Rek, V. and Houra, I. F. (2013) “Effect of EPDM as a compatibilizer on mechanical properties and morphology of PP/LDPE blends,” Journal of elastomers and plastics, 45(4), pp. 391–403. doi: 10.1177/0095244312457162.
28. “Polymer Blends” (1978). Elsevier. doi: 10.1016/c2012-0-01621-3.
29. Ramírez-Hernández, A. et al. (2020) “Thermal, morphological and structural characterization of a copolymer of starch and polyethylene,” Carbohydrate research, 488(107907), p. 107907. doi: 10.1016/j.carres.2020.107907.

30. Ratanakamnuan, U. and Aht-Ong, D. (2006) “Photobiodegradation of low-density polyethylene/banana starch films,” Journal of applied polymer science, 100(4), pp. 2725–2736. doi: 10.1002/app.23048.
31. Sailaja, R. R. N. and Chanda, M. (2001) “Use of maleic anhydride-grafted polyethylene as compatibilizer for HDPE-tapioca starch blends: Effects on mechanical properties,” Journal of applied polymer science, 80(6), pp. 863–872. doi: 10.1002/1097-4628(20010509)80:6<863::aid-app1164>3.0.co;2-r.
32. Seier, M. et al. (2020) “Effect of different compatibilization systems on the rheological, mechanical and morphological properties of polypropylene/polystyrene blends,” Polymers, 12(10), p. 2335. doi: 10.3390/polym12102335.
33. Taghizadeh, A., Sarazin, P. and Favis, B. D. (2013) “High molecular weight plasticizers in thermoplastic starch/polyethylene blends,” Journal of materials science, 48(4), pp. 1799–1811. doi: 10.1007/s10853-012-6943-8.
34. Watanabe, N., Akiba, I. and Akiyama, S. (2001) “Compatibilizing effects of poly(styrene-co-methacrylic acid) on immiscible blends of polystyrene and poly(ethylene glycol),” European polymer journal, 37(9), pp. 1837–1842. doi: 10.1016/s0014-3057(01)00059-3.
35. Zheng, X., Zhang, J. and He, J. (2003) “Compatibilization of nylon 6/liquid crystalline polymer blends with three types of compatibilizers,” Journal of applied polymer science, 87(9), pp. 1452–1461. doi: 10.1002/app.11581.