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Study of the Properties and Destructibility of the Native and Cross-Linked Potato Starch-Filled Polymer Composites for Food Packaging Applications

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Abstract

Plastic is a vital component of modern life, commonly used in daily food packaging for its convenience and durability. Plastic marketing bags are manufactured from low-density polythene (LDPE) which causes ecological inconvenience as most of the plastic components are stored in waste and underground conditions for an elongated time. Plastic is a synthetic or semi-synthetic material that does not decompose naturally, and its primary drawback is its environmental impact, prompting ongoing efforts to accelerate its biodegradation. A material that must be eroded, developed for any cause, such as Pseudomonas aeruginosa, as well as being buried in the ground, is interesting enough to be revealed. In this study, potato starch (PS) was blended with LDPE by using melt compound technique, Destructibility followed by injection molding for PS/LDPE composite formation. The influence of PS concentration and starch cross-linker sodium tripolyphosphate with the additive of composite properties was examined. Mechanical assessment outcomes exhibit that with increasing PS content there is an increase in loss of tensile strength and elongation at break of untreated and treated composites. Exposure to PS/LDPE composites in P. aeruginosa as well as soil environments was implemented to analyze the biodegradability of the composite. P. aeruginosa and the soil environment have lost weight and lost tensile properties due to increased PS and exposure periods, respectively. Modified PS composites also show less corrosion than unmodified PS/LDPE composites.

Keywords: Potato starch, LDPE, mechanical properties, morphology, biodegradability

INTRODUCTION

While plastics and polymeric materials typically make our lives better, they also contribute to global pollution since, up to now; they have not been given any thought to recycling or ultimate disposability. Ordinary plastics often degrade over hundreds of years; however, most synthetic polymers are difficult for the environment to break down. The reasons why plastic wrapper technology has become so dominant are several and include high tensile strength, excellent water resistance, low cost, low weight, and outstanding barrier qualities against aquatic organisms. However, the growing use of plastics has led to a significant increase in solid waste accumulation. Because they do not deteriorate easily, synthetic polymers are persistent in the environment. Numerous problems have arisen because of the environmental buildup of plastic garbage. Plastic garbage overflows landfills, and we need new places to deposit waste every year. These days, a variety of techniques are employed to reduce plastic waste, including source deterioration,

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recyclable plastics, and biodegradable plastics [1]. Since certain plastics cannot be recycled, recycling is not a universal solution for all plastic components. Methane, carbon dioxide, and other natural products can be produced from biodegradable plastics, which are classified as environmentally harmful polymers. Instead of harming the natural world, their surroundings ought to deteriorate. One of the biodegradable polymer classes is plastic with an organic basis. Included in the same experiment with the qualities of plastics and the potential for organic degradation of products are renewable natural polymers including starch, cellulose, lignin, chitin, and chitosan [2–4]. Starch is said to be one of the best natural biopolymers because it is inexpensive, widely accessible, and biodegradable. Starch has reportedly been utilized as filler in polyvinyl alcohol (PVA) combinations, according to several studies. For instance, the solution-casting method was used to study a variety of starches in a mixture of PVA polymers, including corn, potato, tapioca, and cassava starches [5].

Starch has gained attention as a viable component for the creation of biodegradable polymers because of its abundance in nature, renewable nature, affordability, and complete biodegradability [6–8]. Starch serves as the primary polysaccharide standby element and is produced spontaneously by plants, including potatoes, corn, and rice. It accumulates in the form of intricate structures known as granules. It is formed of repeated units of α-D-glucose and is divided into two polysaccharides: amylopectin, a branching polymer, and amylose, a linear polymer [9]. Amylopectin is the primary component of most starches and accounts for over 70% of their polysaccharide content [10]. Currently, biodegradable polymers are improved with the addition of potato starch (PS). In packaging, agricultural mulch, and other low-cost uses, PS is seen to be an excellent option to replace some of the synthetic polymers [11, 12]. PS differs from corn, wheat, and rice starch in that it produces a clear gel when cooled and a high-viscosity paste when heated [13, 14]. The food and non-food sectors use the characteristics of PS to give their goods the necessary density, structure, appearance, and storage stability. PS does, however, have certain drawbacks, including poor solubility and poor resistance to shear and temperature while pasting. These flaws are not being applied enough in industry. Therefore, to improve the physicochemical properties of PS and satisfy buyer requests, a variety of physical (heat-moisture treatment, annealing), chemical (crosslinking, acid hydrolysis, and oxidation), and genetic treatment techniques have been employed [15, 16]. The chemical process of phosphorylation, or phosphate esterification of starch, is often employed to increase the hydrophilicity of starch [17]. Phosphorylated starch yields a pure paste with excellent homogeneity, decent freeze-thaw stability, and emulsifying properties [18]. Products of phosphorylation can be either distarch phosphate or monostarch phosphate. Even at very low concentrations, distarch phosphate, a kind of cross-linked starch, can significantly change the pasting and gel characteristics of a product. Research has been published on the phosphorylation of corn, wheat, sago, pinhao, and rice [19], and low-phosphate treated starch products have been certified for use in the food business [20]. One potential technique for developing the film's biological and physical characteristics is chemical cross-linking. Numerous study reports have documented the use of sodium tripolyphosphate (STP), a safe and nontoxic cross-linking agent that can improve the functional characteristics of polysaccharides [21]. For example, it was employed to crosslink biopolymers like starch [22, 23] and might make the suggested materials less soluble [24]. However, studies utilizing STP to crosslink a composite biopolymer film are rare.

The blending of biodegradable polymers, such PS, with inert polymers, like LDPE, has drawn a lot of attention because of the technology's possible use in the disposal of plastic waste. The idea behind this approach is that the base inert plastic will eventually break and disappear if the ecological element is present in sufficient quantity and is removed by microorganisms in the waste disposal environment [25]. Phase separation and mechanical property loss are usually the result of this mixing since hydrophilic biopolymers and hydrophobic thermoplastic matrix are incompatible in general. Numerous research, including those on starch [7, 26], the treatment of polyethylene [27], and the addition of compatibilizers [7] to the starch and polyethylene mixture, have been conducted in the past to improve compatibility. According to some scientific presentations, mixes of starch and polyethylene do not biodegrade in realistic time periods, but they do biodegrade when they come into touch with the soil environment. Microorganisms, found in large quantities in soil, water, and the atmosphere, are the main invading agents of biodegradation. These include actinomycetes, fungi, bacteria, and others. For their growth and metabolic processes, the essential nutrients are carbon, hydrogen, oxygen, and nitrogen. These microorganisms obtain their nutrition from biodegradable polymers. Despite these mechanisms, no one has attempted to assess how the morphology, tensile properties, and biodegradability of microbial processes relate to one another. To advance the biodegradation of plastics derived from these mixes, the impacts of PS content and the addition of additives to PS-based LDPE composite films have been taken into consideration in the current study.

EXPERIMENTAL

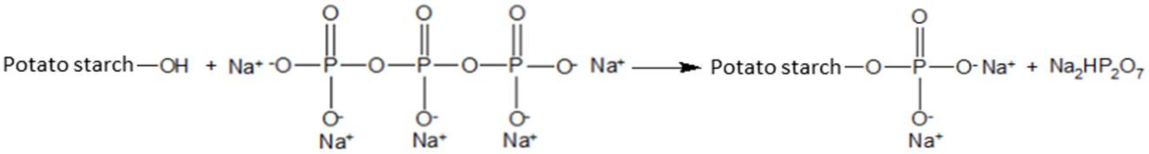
Ingredients

We purchased film-grade low-density polythene (LDPE) from Messrs. The matrix in concern is Reliance Industries, located in Mumbai, India. We bought PS from Aladdin Bio-Chem Technology Co., Ltd. (Shanghai, China), which determined the dry matter content of the sample to be 89.32% starch, 0.27% protein, and 0.42% ash. The combination of urea, PS, and glycerol is the environmental agent. Reagent grade glycerol (glycerin, $C_3H_8O_3$) was acquired from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA), along with urea and epolene wax, for use as a plasticizing agent and STP for use as a starch cross-linker in PS blends. The analytical grade chemicals Na_2SO_4, HCl, and NaOH were obtained from Sigma-Aldrich, located in Singapore.

METHODS

Potato Starch Modification

A reporting approach that was slightly modified was used to carry out the phosphorylation of PS [20]. Using HCl or NaOH solution to get the pH of the solution to 9 (10% -mol/mol), a salt solution containing phosphorylating reagent (5% -w/w STP based on dry starch, 5% Na_2SO_4 based on dry starch, and 13 ml of RO water) was made and mixed at room temperature. After adding 10 g of dry PS to the salt solution, the mixture's pH was once more brought to 9. After an hour of stirring at room temperature, the starch dispersion was dried in a tray drier at 50°C until the water content was between 10% and 15% w/w. The mixture was then cooked for a further two hours at 140°C in the tray dryer. Once room temperature had been reached, the phosphorylated starch products were combined with 30 milliliters of RO water to bring the mixture's pH down to 9. Following a ten-minute centrifugation at 1500 rpm, the mixture was again dispersed in thirty milliliters of RO water with the remnant solid. After repeating the laundry cycle three times, the finished product was finally dried in a tray drier at 50°C until its weight remained consistent. To guarantee data repeatability, each test was performed twice. Scheme 1 is a simple diagram that shows how starch is phosphorylated using STP as the reagent.



Scheme 1. An illustration of the phosphorylation reaction of potato starch.

Sample Setup

To reduce moisture before usage, all ingredients were dehydrated in a vacuum oven set at 80°C for 24 hours. The same number of treated PS was combined with LDPE using additives (glycerol/urea and epolene wax) in a Mini Blender (Most Machine Builder Fairfield, New Jersey, USA) that contains 3% dissolving agent (Epolene wax E-43p). PS was blended with LDPE at varied levels (10%–30 wt%). In Table 1, chemical compositions are listed. A composite sheet for injection molding was created when the overhead mixer was ready by mixing with a co-rotating twin-screw extruder (model: TSE 20, GmbH & Co. KG, Germany). The temperature die (160°C/160°C) was used in the blending process, which ran at a rotor speed of 100 rpm from the feeder (170°C/170°C). A pelletizer was then used to palletize the extruded components. These platelets were put through an injection molding machine (Toyo, model:

Si180iii-E200, Japan) to create dumbbell-shaped samples. Figure 1 shows a schematic representation of the biodegradable composite film's preparation.

Table 1. Compositions of the arranged samples.

Sample Code	**LDPE (wt%)**	**Starch (wt%)**	**^{a}Glycerol:Urea = 2:1 (wt%)**	**^{a}Epolene Wax (wt%)**
Virgin LDPE	100	0	–	–
$L_{90}P_{10}$ (LUP_{10})	90	10	–	–
$L_{80}P_{20}$ (LUP_{20})	80	20	–	–
$L_{70}P_{30}$ (LUP_{30})	70	30	–	–
$L_{90}P_{10}GU_{15}$ (LSP_{10} A)	90	10	15	3
$L_{80}P_{20}GU_{15}$ (LSP_{20} A)	80	20	15	3
$L_{70}P_{30}GU_{15}$ (LSP_{30}A)	70	30	15	3

Note: L: LDPE; U: untreated PS; S: PS treated with STP; The number after the letter P indicates the percentage of potato starch; A; additives; ^{a}glycerol: urea, epolene wax contents on LDPE weight basis.

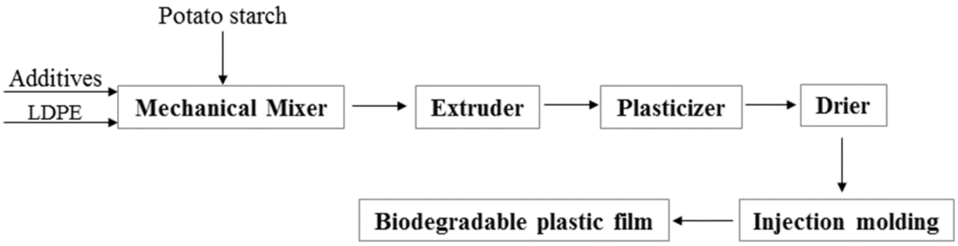


Figure 1. The preparation schematic diagram for biodegradable films.

Mechanical Assessment

Samples shaped like dumbbells (125 × 3 mm^2) were utilized to assess the composites' tensile characteristics. The ASTM-D 638-03 standard was used to evaluate the tensile parameters of the composite, including elongation at break (Eb) and tensile strength (TS), utilizing the Shimadzu UTM (model AG-1, Japan) [28]. A gauge length of 50 mm and a crosshead speed of 10 mm/min were used for the tensile test. Every test was conducted at 25 ± 3°C and 50 ± 5% moisture content. The mean values of the five samples were used to test each outcome.

SETTING UP FOR BACTERIAL

Development

The sample was divided into flat pieces of 5 by 5 cm and put on top of a nutrient-rich agar in a petri dish. In infertility, *Pseudomonas aeruginosa* was isolated using a nutrient-rich agar medium. After being made in saline, the bacterial suspension was applied to the sample. It has a 4 × 4 cm^2 section of parafilm within, and it is protected for 90 days at 35°C and 90% humidity.

Observation of Morphology

Using a Zeiss Evo 50 SEM, the tensile ruptured surfaces of both treated and untreated PS/LDPE composites were examined. To disperse the electric charge during the test, the ruptured edges of the composite specimens were glued in an aluminum spit and encased in a thin layer of gold.

Preparing for Soil Burial

After being dried and weighed, specimens in the shape of dumbbells were buried in perforated plastic boxes so that moisture and microbes might enter. For six months, the box was submerged in a soil complex that included compost, rockery soil, municipal garbage, and *P. aeruginosa* at a depth of 15 to 22 cm below the soil's surface. The specimens were carefully taken out of the soil and silently cleaned with distilled water to blend them with the soil surface at repeated intervals. After that, they were dried until their weight remained consistent. The following was the formula (1) for the weight loss percentage:

$$Weight\ loss\ (\%) = \frac{W_b - W_a}{W_b} \times 100 \qquad (1)$$

W_b stands for mold weight prior to degradation, whereas W_a denotes mold weight after degradation.

RESULTS AND DISCUSSIONS

Mechanical and Morphological Features

Figure 2(a) and (b) illustrates the effects of treated and untreated PS content on the percentages of TS and Eb for PS/LDPE composite. In comparison to virgin LDPE, we saw a progressive increase in the percentage loss of untreated composites (LUP_{10}, LUP_{20}, and LUP_{30}) for TS (Figure 2a). Virgin LDPE had a TS of roughly 8.95 MPa. The increase in PS content has made TS loss more severe. Loss of TS may result from weak interfacial bonds between PS and LDPE. PS has a decreasing effective cross-sectional area of LDPE as its content increases. Because of PS, the surface –OH group has strong intermolecular hydrogen bonds and hydrophilic characteristics. This declaration endorses the results that the researchers were able to achieve [29]. Although it is less than that of untreated PS/LDPE composites (LUP_{10}, LUP_{20}, and LUP_{30}), the percentage loss of TS of treated PS/LDPE composites ($LSP_{10}A$, $LSP_{20}A$, and $LSP_{30}A$) relative to virgin LDPE is steadily rising. Better interfacial bonding that results from the addition of LDPE and additives (glycerol: urea = 15%, ferric stearate 0.1%, and epolene wax 3%), may be the cause of this. The cross-linked PS's –OH group reacts strongly with the phosphate group in STP, and when the amount of STP drops, the cross-linked PS's reaction with the effective -OH group diminishes. Therefore, the desirable PS/LDPE interaction between LDPE or PS molecules rather than intermolecular and intramolecular may be supported by strong hydrogen bonds between PS/LDPE and plasticizer molecules. This would reduce the loss of coherence between LDPE and PS and lessen the amount of TS.

The impact of PS content on the % loss in Eb of treated and untreated PS/LDPE composites is shown in Figure 2(b). It was discovered that the virgin LDPE had an Eb of 132.41%. We found that as the PS content increases, the percentage loss in Eb for the composite increases. This PS has the ability to intervene with its hydrophilic nature and absorption influence by absorbing moisture and reducing the impact of physical bonding at the PS/LDPE interfaces [30]. Agglomeration can happen at a higher point of stress concentration, which initiates cracking in mixtures, as previously said, towards increased PS content. As PS content rises, this results in a percentage loss of Eb in the mixture. Similar trends were seen by Wang et al. [31] with LDPE mixes filled with natural filler.

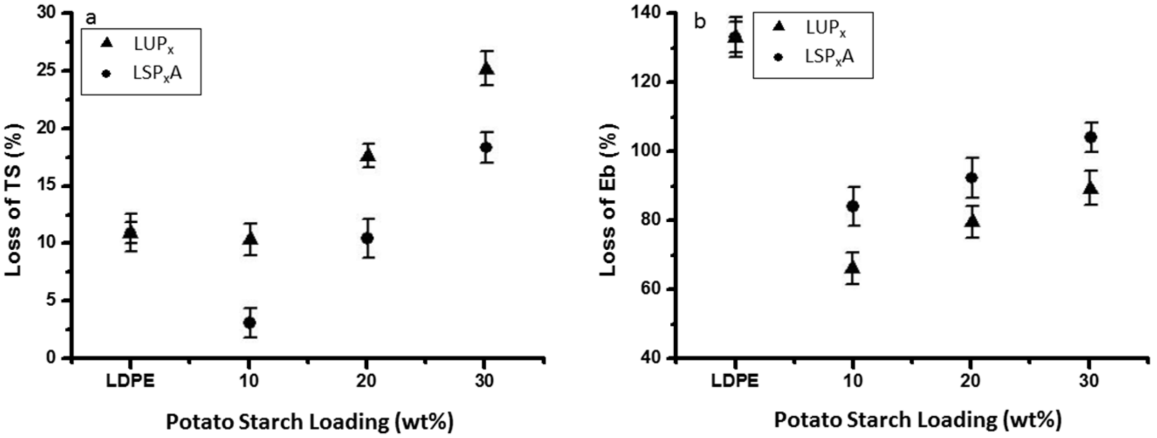


Figure 2. PS content's effect on LUP_x and LSP_xA composites' percentage losses in (a) tensile strength (TS) and (b) elongation at break (Eb). LUP is for LDPE/untreated PS; LSP_xA is for LDPE/treated PS that has additives. After the letter P, a subscript x denotes the percentage of PS.

Figure 3 shows the morphology of PS, virgin LDPE, LUP_{30}, and $LSP_{30}A$. As seen in Figure 3(b), the addition of PS to LDPE caused a weak spread between the two materials. There is proof that the decrease in the mixture's mechanical qualities with the PS concentration is due to this image. In regions with extremely low stress concentrations, interfacial bonds between LDPE and PS can occur. The SEM image of the LSP30A composite with a dispersion agent (Epolene wax) and glycerol/urea plasticizer mixture is displayed in Figure 3(c). The morphology reveals that there was no discernible phase separation between PS and LDPE in the LSP$_{30}$A specimen shown in Figure 3(c). Comparing this to Figure 3(b), it is evident that interfacial morphology is significantly more developed because of improved interfacial adhesion. Because glycerol/urea decreases the intramolecular and intermolecular hydrogen connections between LDPE and PS, mixtures of plasticizers, STPs, and dispersion agents may generate more hydrogen bonds with PS. This explains why the LSP$_{30}$A composite was found to have better mechanical properties than the LUP$_{30}$ composite.

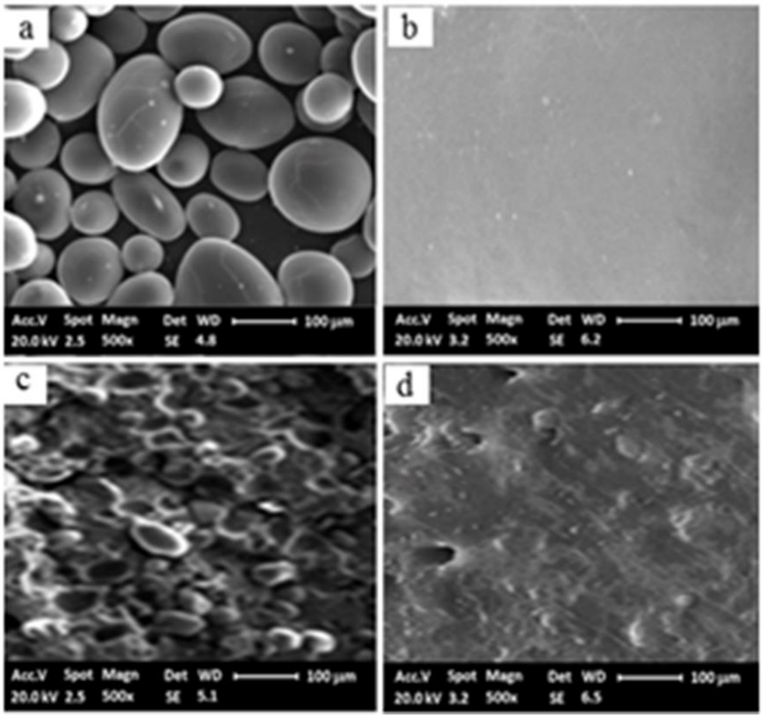


Figure 3. SEM images of (a) potato starch; (b) virgin LDPE; (c) LUP$_{30}$ and (d) LSP$_{30}$A composites.

Pseudomonas Aeruginosa Exposure

When weight loss becomes more efficient over time, it is because biodegradation is being seen [32]. Following a 90-day exposure to *P. aeruginosa*, Table 2 displays the decreased percentage of composite characteristics (weight loss, TS, and Eb) in virgin LDPE, LUP$_{30}$, and LSP$_{30}$A. As a result, the virgin LDPE is a little bit lighter. Because carbon-free media can reduce LDPE, *P. aeruginosa's* biodegradation is the reason for the weight loss [33]. The biodegradation of LSP$_{30}$A and LUP$_{30}$ composites in our study demonstrates a linear rise in weight loss. Black patches on the sample surface in Figure 4(b) and (c) suggests bacterial development, whereas virgin LDPE (Figure 4(a)) did not appear to have improved at all. The notion that the PS of the LDPE composite invites bacteria to attack the composite is further supported by the weight loss of the composite rise within 90 days. The LUP$_{30}$ and LSP$_{30}$A composites showed the highest rates of biodegradation, at 8.23% and 6.12%, respectively. The biodegradation of virgin LDPE was, however, quite low-only 0.35% after 90 days of exposure to *P. aeruginosa*.

Prior to testing, the virgin LDPE, LUP$_{30}$, and LSP$_{30}$A composite's TS and Eb values were 11.25 ± 0.7, 6.78 ± 0.6, and 8.32 ± 0.8 MPa and 132.41 ± 16.4% and 3.8 ± 0.9%, respectively. Ninety days following our *P. aeruginosa* infection, we saw that the effect of Eb was largest and that the percentage loss of TS and Eb grew for all samples. An indicator of the degree of Eb degradation that is more sensitive than TS [34]. As a result, the crystalline nature of LDPE causes its Eb to become less flexible [35]. The degree of opacity increases with material density. The TS loss of LUP_{30} and $LSP_{30}A$ composites rose as exposure time increased. The pattern resembled that of Eb. In the last phase, the percentage loss of Eb was lethal. There was a larger gap between the PS and the LDPE of the LUP_{30} composite than there was for the $LSP_{30}A$ composite because the PS of the LUP30 composite lacked interfacial adhesion to the LDPE. Light and oxygen can enter the interior of the LDPE matrix through this opening. As a result, compared to the LSP30A composite, the TS of the LUP_{30} composite lost more with an increase in exposure duration. The greatest loss of TS and Eb for the $LSP_{30}A$ composite was determined to be 27.8% and 44.7%, respectively, following a 90-day incubation period with *P. aeruginosa*.

Table 2. After 90 days of exposure to *Pseudomonas aeruginosa*, virgin LDPE, LUP_{30}, and $LSP_{30}A$ composites showed weight loss and a decrease in their tensile characteristics (TS and Eb).

Loss in Properties	**Time (Days)**	**Samples**		
		LDPE	***LUP_{30}***	***$LSP_{30}A$***
Weight loss (%)	30	0.10	2.97	2.86
	60	0.25	4.78	3.65
	90	0.31	7.31	5.15
Loss of TS (%)	30	7.3 ± 0.6	19.4 ± 0.6	12.6 ± 0.8
	60	15.4 ± 0.5	29.4 ± 0.8	17.6 ± 0.7
	90	21.6 ± 0.8	38.6 ± 0.7	27.8 ± 0.9
Loss of Eb (%)	30	17.6 ± 0.7	23.7 ± 0.6	19.3 ± 0.7
	60	29.3 ± 0.6	31.2 ± 0.9	30.3 ± 0.8
	90	39.7 ± 0.7	49.3 ± 1.0	44.7 ± 0.7

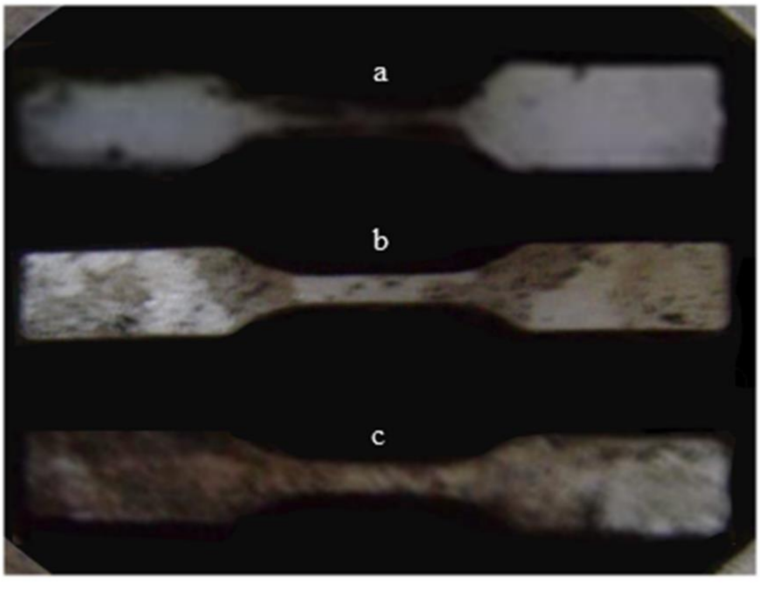


Figure 4. The degradation of the sample was seen when it was exposed to (a) virgin LDPE, (b) $LSP_{30}A$, and (c) LUP_{30} composites.

SEM studies have been carried out to verify bacterial degradation. Figure 5 displays the surface morphology of $LSP_{30}A$ composites both before and after *P. aeruginosa* incubation for 90 days. The $LSP_{30}A$ composite (Figure 5(a)) exhibits a consistent and smooth surface morphology prior to testing. The $LSP_{30}A$ composite has a lot of holes and bores on its surface, as Figure 5(b) illustrates. These holes demonstrate the biodegradation rate and verify the *P. aeruginosa* function's removal of PS. Bore depicts the microorganism-affected area. The primary source of nourishment for *P. aeruginosa* was PS. The polymer is eventually degraded by bacteria that consume PS, which leaves holes in the polymer matrix. Because LDPE chains lose molecular weight during digestion, microbes consume PS to break them down. After that, microbes were drawn to smaller LDPE chains because they were more hydrophilic.

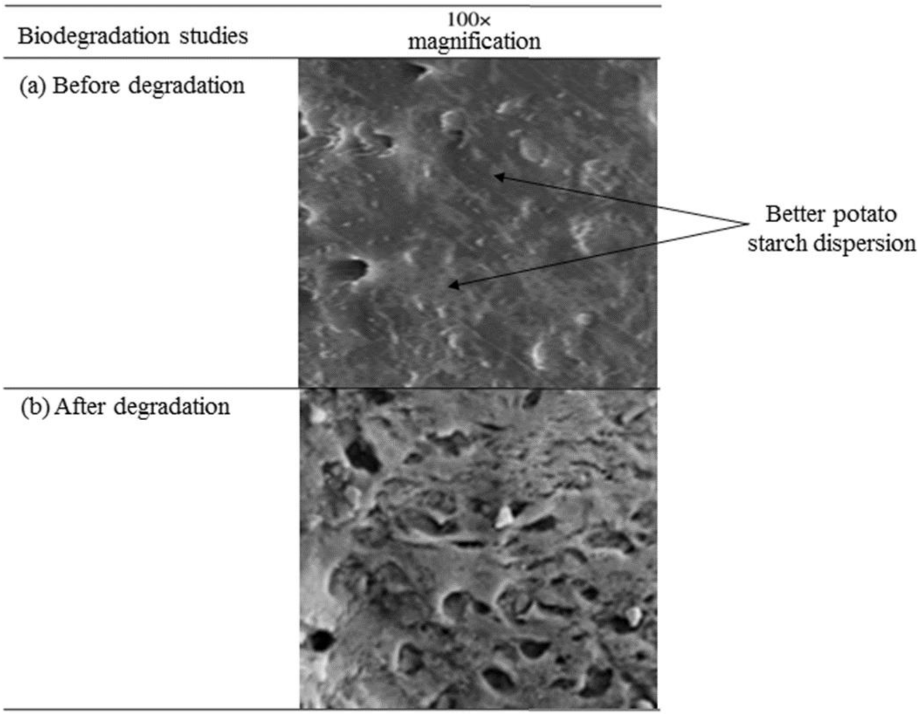


Figure 5. LSP$_{30}$A blend composites under SEM micrographs (magnification 100×) (a) prior to and (b) following a 90-day exposure to *Pseudomonas aeruginosa*.

Assessment of Soil Burial

The environmental use of biocomposite depends on the biodegradable composite performance practice. Soil burial is the most suitable test to determine how biodegradable PS combined with LDPE is. After one, three, and six months of exposure to the soil, weight loss was noted for each sample. Figure 6 shows the weight loss (%) of virgin LDPE, LUP$_{30}$, and LSP$_{30}$A composites over the course of soil burial. Every research period had a noted decrease in weight, with the depletion period lengthening over time. This indicates that the samples decrease with increasing time since the percentage weight loss of the LUP$_{30}$ and LSP$_{30}$A composites rises with the increasing decay duration. The matrix did not exhibit any significant weight loss (around 0.04%) after one month of exposure since its combination with PS showed additional weight loss. After six months in the soil, it shed roughly 5.1% of its weight in the LUP$_{30}$ composite. Over time, virgin LDPE showed the least amount of weight loss, while LUP$_{30}$ composites showed the most weight loss in the soil environment. This result was attributed to the composite's PS content since PS degrades more readily than virgin LDPE. A variety of microbes and macroorganisms make up the soil ecosystem. Polymer shreds that lose weight in the soil can be used as an indicator of their biodegradability in natural settings or landfills. The polymer shreds were destroyed by soil microbes. The PS in the blend initially drew the attention of the microbes. The presence of cavities on the surface of the composites demonstrated that the composites containing 30 weight percent PS were destroyed. The little holes found on the composite’s surface verified that the PS had been eliminated. This is because the composite surface has a greater number of locations on it that microbes can target for attack. O_2 can therefore damage the recently produced surface by forming peroxide and hydroperoxide. The LDPE main chain is broken up into tiny pieces by these radicals, making them more vulnerable to attack from bacteria and fungus. Weight loss metrics guaranteed these outcomes. After six months of exposure, the LSP$_{30}$A composite did, however, achieve a soil environment weight decrease of 3.8%. Figure 6 illustrates the depletion rate of LSP$_{30}$A composites, which was marginally lower than that of the comparable LUP_{30}. The bond between the phosphate group of STP and the -OH group of cross-linked PS, which either represents or prevents the usage of PS by soil microorganisms, could be the cause of this.

The best associated practical standard for determining the biodegradation of films or fibers in maximal applications intended for interaction with soil is the loss of tensile characteristics [36]. Table 3 shows the proportion of tensile characteristics (TS and Eb) lost following soil burial for virgin LDPE, LUP_{30}, and $LSP_{30}A$ composites. As exposure duration rose, so did the percentage loss of TS and Eb in the virgin LDPE, LUP_{30}, and $LSP_{30}A$ composites. The percentage loss of TS and Eb in virgin LDPE films increased by 5.9% and 13.4%, respectively, after six months of exposure to soil burial; in contrast, the addition of 30 weight percent PS to LDPE led to a loss of 33.1% in TS and 45.8% in Eb. The consumption of PS by microbes is the cause of this loss. When PS is used, there is a lack of adhesion between the two stages, and the LDPE matrix develops many voids. The hydrophilic and hydrophobic properties of PS and LDPE, respectively, as well as the incompatibility of the two components can be blamed for this loss. The tensile characteristics of the composites exhibit these variances. Nonetheless, compared to the LUP_{30}, the $LSP_{30}A$ composite showed less loss in tensile characteristics. The percentage loss in Eb increased by almost 45.8% after six months of exposure to soil burial, whereas the $LSP_{30}A$ composite increased by 25.6% in comparison to the untreated ones. Due to the more evenly spaced tiny cavities in the LUP_{30} composite compared to the $LSP_{30}A$ composite, there are more surface surfaces available for bacterial attack. Thus, compared to the $LSP_{30}A$ composite, the LUP_{30} composite had a larger percentage loss in tensile characteristics. The SEM micrograph is displayed in Figure 7 and these findings are in good accord.

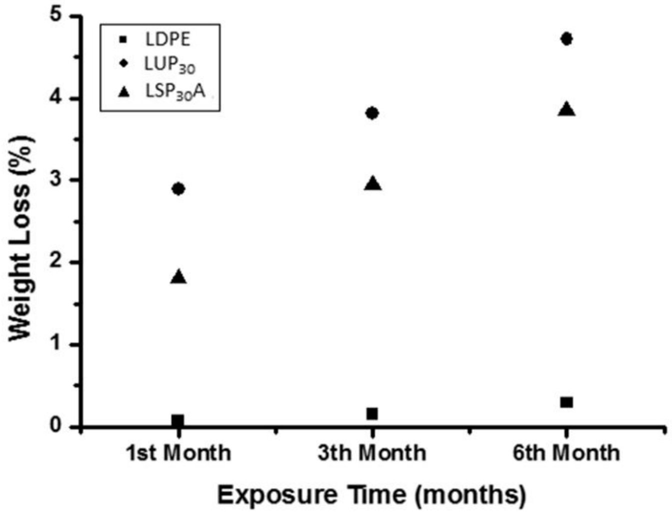


Figure 6. Virgin LDPE, LUP_{30}, and $LSP_{30}A$ blend composites lose weight after six months of being buried in soil.

Table 3. Tensile property (TS and Eb) loss as a percentage following soil burial of virgin LDPE, LUP_{30}, and $LSP_{30}A$ composites.

Loss in Properties	**Time (Months)**	**Samples**		
		LDPE	***LUP_{30}***	***$LSP_{30}A$***
Loss of TS (%)	1	1.5 ± 0.6	16.3 ± 0.7	6.8 ± 0.7
	3	3.8 ± 0.8	25.1 ± 0.9	16.7 ± 0.8
	6	5.9 ± 0.7	33.1 ± 0.8	20.6 ± 0.7
Loss of Eb (%)	1	6.2 ± 0.6	19.8 ± 0.7	11.6 ± 0.8
	3	9.5 ± 0.8	31.2 ± 0.9	19.7 ± 0.7
	6	13.4 ± 0.7	45.8 ± 0.8	25.6 ± 0.8

Figure 7 shows SEM photomicrographs of LUP_{30} and $LSP_{30}A$ composites both before and after soil burial. The mixture's PS particle disintegration was visible in SEM photomicrographs. Regardless of the declining environment, PS particles degrade in all mixes. As the decay time grew, so did the degree of degradation. All specimens showed signs of degeneration because of this occurrence. They either emerge on the surface of their mixture or sequester themselves. The mixture's surface structure varies because of the PS particles' separation. When examined under a microscope, samples buried in moist soil for a period of six months reveal that PS particles totally disintegrate. Figures 7(b) and (d) demonstrate how, following the soil burial test, the surfaces of the LUP_{30} and $LSP_{30}A$ composites developed larger voids and a rougher texture than the control composite prior to the degrading process seen in Figures 7(a) and (c). In addition, persistent gaps and holes caused by PS leakage are seen in 30 weight percent of the PS content. The embedded PS becomes visible when the matrix's surface begins to fracture slightly, presumably because of the matrix collapsing. Some alterations that show up in the mix are total collapse, loss of matrix, and exposure to embedded PS. The outcomes concur with the assessment made by the mechanical evaluation.

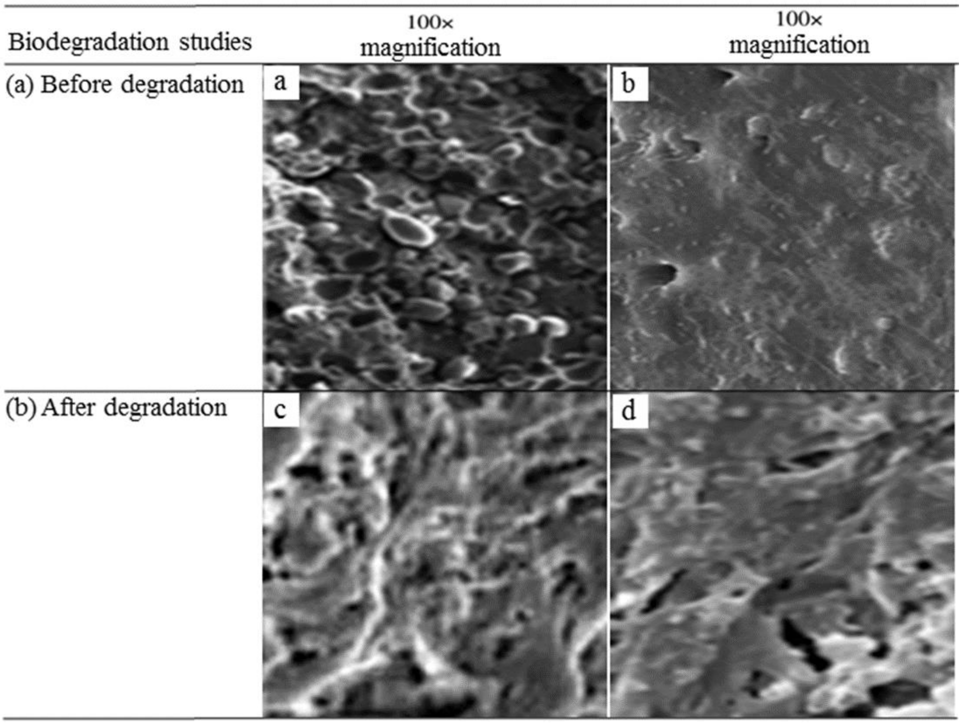


Figure 7. SEM pictures of the PS/LDPE blends (a) LUP_{30} and (c) $LSP_{30}A$ composites before soil burial; (b) LUP_{30} and (d) $LSP_{30}A$ composites following soil burial (magnification 100×)

CONCLUSIONS

It is possible to create a PS/LDPE bio-composite by incorporating varying PS concentrations into an LDPE matrix. The results demonstrate that the hydrophilicity and biodegradability of the polymer are increased when hydrophilic PS is added to hydrophobic LDPE. Compared to original PS, modified PS through STP crosslinking interacted and was more compatible with LDPE. As a result, the improved PS/LDPE composite had a reduced percentage loss in tensile strength but a higher percentage loss in elongation at break. Although the weight loss and loss of tensile qualities have risen with increasing exposure time to *P. aeruginosa* medium, this is because of the good interfacial bond between LDPE and thermoplastic PS. Composites are biodegrading more quickly now than they used to. Additionally, as exposure duration in the soil burial environment rose, so did the loss of tensile qualities, such as elongation at break and tensile strength, for both modified and untreated PS/LDPE composites. Data confirming the applicability of these novel polymer blends to horticulture, packaging, film, flower boxes and bags, and other agricultural plastics applications where quick degradation is desired.

REFERENCES

1. Kyrikou I, Briassoulis D. Biodegradation of agricultural plastic films: A critical review. J Polym Environ. 2007;15(2):125–150. doi: 10.1007/s10924-007-0053-8.
2. Olivera S, Muralidhara HB, Venkatesh K, Guna VK, Gopalakrishna K, and Kumar K Y. Potential applications of cellulose and chitosan nanoparticles/composites in wastewater treatment: A review. Carbohydr Polym. 2016;153:600–618. doi: 10.1016/j.carbpol.2016.08.017.
3. Sajjadi, M. Nasrollahzadeh M, Tahsili MR. Catalytic and antimicrobial activities of magnetic nanoparticles supported N-heterocyclic palladium (II) complex: A magnetically recyclable catalyst for the treatment of environmental contaminants in aqueous media. Separation and Purification Technology. 2019;227:115716. doi: 10.1016/j.seppur.2019.115716.
4. Yusof Y, Kadir MFZ. Electrochemical characterizations and the effect of glycerol in biopolymer electrolytes based on the methylcellulose-potato starch blend. Mol Cryst Liq Cryst. 2016;627(1):220–233. doi: 10.1080/15421406.2015.1137115.
5. Ooi ZX, Ismail H, Bakar AA, Aziz NAA. Properties of the crosslinked plasticized biodegradable poly (vinyl alcohol)/rambutan skin waste flour blends. J Appl Polym Sci. 2012;125(2):1127–1135. doi: 10.1002/app.34860.
6. Zaman H, Beg MDH. Effect of filler starches on mechanical, thermal and degradation properties of low-density polyethylene composites. Prog Appl Sci Tech. 2021;11(2):26–36. doi: 10.14456/past.2021.10.
7. Zaman H, Beg MDH. Study on binary low-density polyethylene (LDPE)/thermoplastic sago starch (TPS) blend composites. Prog Appl Sci Tech. 2021;11(1):53–65. doi: 10.14456/past.2021.5.
8. Babu RP, O’connor K, Seeram R. Current progress on bio-based polymers and their future trends. Prog Biomater. 2013;2(1):1–16. doi: 10.1186/2194-0517-2-8.
9. Zobel H. Molecules to granules: A comprehensive starch review. Starch-Stärke. 1988;40(2):44–50. doi: 10.1002/STAR.19880400203.
10. Janssen LPBM, Karman AP, de Graaf RA. Material properties and glass transition temperatures of different thermoplastic starches after extrusion processing. Starch-Stärke. 2003;55(2):80–86. doi: 10.1002/star.200390020.
11. Khan MA, Khan RA, Haydaruzzaman, Ghoshal S, Siddiky M, Saha M. Study on the physicomechanical properties of starch-treated jute yarn-reinforced polypropylene composites: Effect of gamma radiation. Polymer-Plastics Technology, and Engineering. 2009;48(5):542–548. doi: 10.1080/03602550902824358.
12. Zaman HU, Khan MA, Khan RA. Physico-mechanical and degradation properties of banana fiber/LDPE composites: Effect of acrylic monomer and starch. Compos Interfaces. 2011;18(8):685–700. doi: 10.1163/156855412X626261.
13. Zhang C, Lim ST, Chung HJ. Physical modification of potato starch using mild heating and freezing with the minor addition of gums. Food Hydrocoll. 2019;94(1):294–303. doi: 10.1016/j.foodhyd.2019.03.027.
14. Alvani K, Qi X, Tester RF, Snape CE. Physico-chemical properties of potato starches. Food Chem. 2011;125(3):958–965. doi: 10.1016/j.foodchem.2010.09.088.
15. Wootton M Bamunuarachchi A. Water binding capacity of commercial produced native and modified starches. Starch-Stärke. 1978;30(9):306–309. doi: 10.1002/STAR.19780300905.
16. Wang J, Zhu H, Li S, Wang S, Wang S, Copeland L. Insights into structure and function of high pressure-modified starches with different crystalline polymorphs. Int J Biol Macromol. 2017;102:414–424. doi: 10.1016/j.ijbiomac.2017.04.042.
17. L.Q.a.C.S.W.S.m.a.a.F.C.C. Xie S X. Physical Properties, and Application ed S W Cui (Boca Raton: CRC Press) chapter 8 2005. pp. 357–390. (2005).
18. Lim S, Seib P. Preparation and pasting properties of wheat and corn starch phosphates. Cereal Chem. 1993;70(2):137–137.
19. Passauer L, Bender H, Fischer S. Synthesis and characterization of starch phosphates. Carbohydr Polym. 2010;82(3):809–814. doi: 10.1016/j.carbpol.2010.05.050.

20. Stahl J, Lobato L, Bochi V, Kubota E, Gutkoski L, Emanuelli T. Physicochemical properties of Pinhão (*Araucaria Angustifolia*, Bert, O. Ktze) starch phosphates. LWT-Food Sci Technol. 2007;40(7):1206–1214. doi: 10.1016/j.lwt.2006.07.015.
21. Abed A, Assoul N, Ba M, Derkaoui SM, Portes P, Louedec L, et al. Influence of polysaccharide composition on the biocompatibility of pullulan/dextran-based hydrogels. J Biomed Mater Res A. 2011;96(3):535–542. doi: 10.1002/jbm.a.33007.
22. Carbinatto FM, de Castro AD, Cury BS, Magalhães A, Evangelista RC. Physical properties of pectin–high amylose starch mixtures cross-linked with sodium trimetaphosphate. Int J Pharm. 2012;423(2):281–288. doi: 10.1016/j.ijpharm.2011.11.042.
23. Racksanti A, Janhom S, Punyanitya S, Watanesk R, Watanesk S. An approach for preparing an absorbable porous film of silk fibroin–rice starch modified with trisodium trimetaphosphate. J Appl Polym Sci. 2015;132(8). doi: 10.1002/app.41517.
24. Racksanti A, Janhom S, Punyanitya S, Watanesk R, Watanesk S. editors. Crosslinking density of silk fibroin–rice starch hydrogels modified with trisodium trimetaphosphate. Applied Mechanics and Materials; 2014;446–447:366. doi: 10.4028/www.scientific.net/AMM.446-447.366.
25. Chandra R, Rustgi R. Biodegradable polymers. Prog Polym Sci. 1998;23(7):1273–1335. doi: 10.1016/S0079-6700(97)00039-7.
26. Zaman HU, Beg MDH. Biodegradable composites manufactured from low-density polyethylene and thermoplastic sago starch: Preparation and characterization. Prog Appl Sci Tech. 2021;11(2):42–49. doi: 10.14456/past.2021.16.
27. Chandra R, Rustgi R. Biodegradation of maleated linear low-density polyethylene and starch blends. Polym Degrad Stab. 1997;56(2):185–202. doi: 10.1016/S0141-3910(96)00212-1.
28. Lee WJ, Youn YN, Yun YH, Yoon SD. Physical properties of chemically modified starch (RS4)/PVA blend films-part 1. J Environ Polym Degrad. 2007;15(1):35–42. doi: 10.1007/s10924-006-0040-5.
29. Obasi HC. Studies on biodegradability and mechanical properties of high-density polyethylene/corncob flour-based composites. IJSER. 2012;3(8):259–272.
30. Febrianto F, Setyawati D, Karina M, Bakar ES, Hadi YS. Influence of wood flour and modifier contents on the physical and mechanical properties of wood flour-recycle polypropylene composites. J Biol Sci. 2006;6(2):337–343. doi: 10.3923/jbs.2006.337.343.
31. Wang YJ, Liu W, Sun Z. Effects of glycerol and PE-g-MA on morphology, thermal and tensile properties of LDPE and rice starch blends. J Appl Polym Sci. 2004;92(1):344–350. doi: :10.1002/app.20015.
32. Gattin R, Copinet A, Bertrand C, Couturier Y. Biodegradation study of a coextruded starch and poly (lactic acid) material in various media. J Appl Polym Sci. 2003;88(3):825–831. doi: 10.1016/S0964-8305(02)00039-2.
33. Agamuthu P, Faizura PN. Biodegradability of degradable plastic waste. Waste Manag Res. 2005;23(2):95–100. doi: 10.1177/0734242X05051045.
34. Miltz J, Narkis M. The effect of ultraviolet radiation on chemically crosslinked low-density polyethylene. J Appl Polym Sci. 1976;20(6):1627–1633. doi: 10.1002/app.1976.070200620.
35. Danjaji I, Nawang R, Ishiaku U, Ismail H, Ishak ZM. Degradation studies and moisture uptake of sago-starch-filled linear low-density polyethylene composites. Polym Test. 2002;21(1):75–81. doi: 10.1016/S0142-9418(01)00051-4.
36. Orhan Y, Hrenović J, Büyükgüngör H. Biodegradation of plastic compost bags under controlled soil conditions. Acta Chim Slov. 2004;51:579–588.