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Degradation behavior of biocomposites based on cassava starch buried under indoor soil conditions

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ABSTRACT

Degradation of cassava (tapioca) starch based composite films during indoor soil burial experiments was analyzed using five factors, three levels Box–Behnken response surface design. From the results, it was observed that, increased water sorption promotes the entry of soil microorganism and it utilizes the starch films as a source of energy for their growth. The reduction in weight and mechanical property was associated with preferential loss of matrix components of the films. The microorganisms associated with the degradation of films were quantified and identified. Scanning electron microscopy (SEM) analysis showed the formation of patterns and cracks on the surface of the materials aged in the soils. From the results, second order polynomial models were developed for the responses. The results of the study demonstrated that, the tapioca starch based composites were showed a limited lifetime in biotic environment which make them suitable for being disposed in landfills after their use.

1. Introduction

Growing consumption of polymeric materials caused the increase in solid waste production. Plastic wastes accumulating in the environment are posing an ever increasing ecological threat. When the solid plastic waste is present in the soil, reduces the soil fertility and prevents the growth of plant life and possess the environmental problems. Hence, development and characterization of environmentally friendly polymeric materials have attracted extensive interest owing to the environmental problem induced by the accumulation of plastic waste (Siracusa, Rocculi, Romani, & Rossa, 2008; Weber, Haugaard, Festersen, & Bertelsen, 2002). In recent years biopolymers have been seen as potential environmentally friendly and sustainable alternatives to petroleum based plastics, particularly in those applications where biodegradability and derivatization of natural resources give added value (Avella et al., 2005).

Development of edible and biodegradable films using natural biopolymers such as starches could also be useful in replacing synthetic non-biodegradable packaging in some applications (Chen, 1995) and have received remarkable attention globally as they are totally eco-friendly and helpful in waste landfill management. The use of starch as a material for preparation of edible or biodegradable films has been widely recognized (Krochta & De Mulder-Johnston, 1997), starch possesses many unique properties and considered as one of the most promising natural renewable resources because of its lower cost, biodegradability, thermoplastic behavior (Mali et al., 2005) and availability in abundance than other natural resources. Starch has been applied in the field of degradable plastics and blend films containing starch are potential packaging materials in the agriculture, medicine, and packaging industries (Funke, Bergthaller, & Lindhauer, 1998; Hulleman, Janssen, & Feil, 1998; Lu, Tighzerta, Dole, & Erre, 2005). Besides, upon disposal, they are completely degraded by micro-organisms in various environments such as soil, sea lakes and sewage (Thiré, Ribeiro, & Andrade, 2006), did not have a negative effect on the environment and also reduced the green house effect (Bastioli, 2001). Surfactants could be incorporated in the film formulation to reduce the surface tension of the solution by improving wettability and adhesion of the films.

Studies on starch based biodegradable films with respect to its biodegradation behavior are important for their application in environment. Biodegradation is a biochemical transformation of compounds by microorganisms and the propensity of a material to get breakdown into its constituent molecules by natural processes. Among various methods of degradation, soil burial method is one of the frequently used methods for the determination of biodegradability of polymer films (Yang, Yoon, & Kim, 2005). Microorganisms (bacteria and fungi) present in the soil could influence the degradation of film by using it as their food source in the natural environment. Hence, the present study is focused

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on the biodegradation of eco-friendly biocomposites based on tapioca starch was exposed to natural mixed micro flora present in soil during indoor burial conditions and it can be considered as a realistic approach to the biodegradation process in the natural environments. Water sorption (WS %) and weight loss (WL %) during soil burial were evaluated gravimetrically. The effect of biodegradation on the mechanical properties of the films was also analyzed. Morphological characterization of the biodegraded specimens was carried out by scanning electron microscopy (SEM). In addition, microorganisms responsible for degradation such as bacteria and fungi were isolated and enumerated. The degradation behavior was quantitatively analyzed in order to develop suitable mathematical models for describing the effects of process variables such as tapioca starch, glycerol, agar, span80 and time on the soil burial degradation properties of tapioca starch based films using five factors three levels Box–Behnken response surface design (BBD). Because, BBD is a spherical, revolving design and also it does not contain combinations for which all factors are simultaneously at their highest or lowest levels. So this design is useful in avoiding experiments performed under extreme conditions, for which unsatisfactory results might occur (Ferreira et al., 2007).

2. Materials and methods

2.1. Raw materials

Tapioca starch was obtained from local market, Erode, Tamil Nadu, India. Amylose, amylopectin, ash, moisture and starch content of tapioca starch were determined and reported elsewhere (Prakash Maran, Sivakumar, Sridhar, & Prince Immanuel, 2013). Glycerol (98% purity) and span 80 (Sorbitan monooleate, 99% purity) were purchased from Merk chemicals, Mumbai, whereas Agar was purchased from Hi-media chemicals, Mumbai. Soil was taken from the campus of Kongu engineering college, Perundurai, Erode, from the surface layer of the ground. All inert materials were carefully removed to obtain a relatively homogeneous mass.

2.2. Preparation of films

The film forming solutions were prepared from various proportions of starch (1–3 g), glycerol (0.5–1.0 ml), agar (0.5–1.0 g) and span-80 (0.1–0.5 ml). Casting method was employed to prepare the films and the details are given in elsewhere (Prakash Maran et al., 2013). The prepared homogenous and transparent films were separated from Petri plates and equilibrated at 25 °C, 58% relative humidity for 72 h prior to the experimental analysis.

2.3. Indoor soil burial degradation

Soil burial degradation tests were performed according to the method described by Di Franco, Cyras, Busalmen, Ruseckaite, and Vazquez (2004) in a series of plastic boxes (80 cm × 15 cm × 10 cm) containing soils and the natural microflora present in the soil was used as the degradation medium for films. The pH of the soil was 6.7. Each film sample were cut into rectangular shape ($2 \times 10\,cm^3$) and dried in an oven until it attains the constant weight. Then the dried film samples were buried at the depth of 8 cm from the surface of the soil. The plastic boxes containing samples were incubated at room temperature ((28–35 °C) and humidity of the soil was maintained at 20–40% by sprinkling of water at regular interval through out the study (30 days). The degradation of the specimen was determined at a regular time interval (5 days) by taking the specimen carefully from the soil and washing it gently with distilled water to remove the soil. Then the sample was dried under vacuum until a constant was obtained. Weight loss (WL) during soil burial was measured according to Rafiemanzelat, Zonouz, and Emtiazi (2012). The mass of each sample was weighed before and after degradation and weight loss of each film sample was obtained using the following formula:

$$WL(\%) = \frac{M_0 - M_1}{M_0} \times 100 \quad (1)$$

where M_0 is the pre-degraded dry weight of the polymer and M_1 is the dry weight of the sample after degradation.

Water sorption (WS) was determined according to method described by Martucci and Ruseckaite (2009). After a specified period of time (t), films were removed from the soil, thoroughly rinsed with tap water, and dried with a tissue paper to remove excess water from their surfaces and weighed (W_h). Water absorption was calculated by the following equation:

$$WS(\%) = \frac{W_h - W_t}{W_0} \times 100 \quad (2)$$

where W_0 is the initial mass, W_t is the remaining mass due to biodegradation at time (t) and W_h is the humid mass.

Materials deterioration and weight loss were accompanied by loss in their mechanical properties. Mechanical properties of the films (tensile strength and elongation) were measured using a material testing machine (Universal tensile strength tester) with 3 kg load cell. The mechanical properties of the films before soil burial test were reported elsewhere (Prakash Maran et al., 2013). The losses in the mechanical properties were calculated using the following equation (Alvarez, Ruseckaite, & Vazquez, 2006)

$$\frac{P_i - P_f}{P_i} \times 100 \quad (3)$$

where P_i is the selected measured mechanical property of the material before burial test and P_f is the selected measured mechanical property of the material after burial test

2.4. Microbial count

Microorganisms (bacteria and fungi) present in the degraded films were analyzed by the procedure suggested by Vijaya and Reddy (2008). The sterile forceps were used to collect the film samples from the soil. The samples are washed gently with sterile distilled water to remove soil debris present in the films. About 1 g of the sample infested with microorganisms was transferred in to a conical flask containing 99 ml of sterile distilled water. The content was shaken vigorously and serially diluted. Pour plate method was adopted to isolate the microorganisms associated with the material. Zobell's agar medium and Martin Rose Bengal agar medium was used to isolate the bacteria and fungi present in the material. For each dilution (10^6 for bacteria and 10^3 for fungi), three replicates were made and the plates were incubated at 30 °C for 2–7 days. The colonies present in the plates were counted (bacterial count (BC) and fungal count (FC)) with the help of a digital colony counter (Toshiba, India) and are referred as colony forming unit (CFU) per gram of sample.

2.5. Identification of microorganisms

Among the bacterial and fungal colonies observed in the plates, the dominant colonies were isolated and sub-cultured repeatedly for getting pure cultures and are preserved in slants for further identification. The bacterial strains which are present in the preserved slant cultures were identified by the method suggested by Oliver (1982). For Gram-negative bacteria, motility, glucose oxidation, penicillin sensitivity and glucose fermentation tests were conducted. Shape, dextrose fermentation, catalase and glucose fermentation tests were conducted for Gram-positive bacteria. The