Research Article

Biodegradation studies of polypropylene/natural fiber composites

Priyanka Luthra[1,2] · Kakkarakkal Kottiyath Vimal[2] · Vishal Goel[2] · Ram Singh[1] · Gurpreet Singh Kapur[2]

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Abstract
Polypropylene composites were prepared using natural fibers such as pigeon pea stalk fibers and banana peel. Aerobic biodegradation studies in compost have been carried out as per ASTM with composites prepared where cellulose and polypropylene has been taken as positive and negative reference respectively. Various analytical tools like SEM, TGA, XRD, DSC and Color have been used to study the change after biodegradation in composites. Highest fiber loaded composites i.e. 40 wt% depicted highest biodegradation in comparison to 10 and 20 wt% loading of untreated fiber in polypropylene. In comparison to untreated fiber composites, maximum biodegradation was observed in treated fiber composites with same amount of the fiber loading.

Keywords Biodegradation · Polypropylene · Pigeon pea stalk · Composite · Natural fibers

1 Introduction

Many commercially available synthetic polymers and polymer-based composites are catering to human's day to day requirement but at the same time their usage is responsible in contaminating/polluting the environment due to their non-biodegradability [1–3]. There has been shift towards the use of biodegradable polymers like poly(caprolactone), poly(lactic acid), poly(ethylene glycol), polyhydroxyalkanoates etc. in recent times [4–6]. But the market of these kinds of polymers is still facing various kinds of problems like relatively high prices and the lack of infrastructure for effective composting, an extremely critical aspect for biodegradable polymers market success [7].

Another area that has gained attention is the production of natural fiber filled polymer composites due to easy and abundant availability as byproducts in the form of peels, stalks and fibers from the plants sector after harvesting of crops [8–10]. These natural materials/fibers replace the synthetic fillers being added to increase the strength of the commercial synthetic polymers and further making these polymers semi-biodegradable. Lot of work has been done by the researchers which have also provided promising results. Verma et al. [11] worked on biodegradability of coir fiber reinforced epoxy composites under the effect of cow dung by soil burial test (ASTM D 5988). Kiprono [12] worked on degradation behaviors of polypropylene and cellulose blends where biodegradation measurements were also done by soil burial method. Vu et al. [13] in their study used polypropylene as a matrix with rice straw fiber used after alkali and subsequent peroxide treatment. The composites prepared showed soil biodegradability with a weight loss of 3.02 to 23.11 wt% after 50 days of burial. Sahi et al. [14] conducted work on low density polyethylene/alkali treated corn flour composites. The biodegradability of the composites was enhanced with increasing corn flour content in the matrix. Obasi [15] in its work

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✉ Ram Singh, ramsingh@dtu.ac.in; ✉ Gurpreet Singh Kapur, kapurgs@indianoil.in | [1]Department of Applied Chemistry, Delhi Technological University, Delhi 110042, India. [2]Indian Oil Corporation Ltd., Research & Development Centre, Sector 13, Faridabad, Haryana 121007, India.

studied corncob flour obtained from a waste product of corn threshing which was blended with high density polyethylene for preparation of composites. Soil burial method was used to study the biodegradation where loss in weight (nine weeks) was observed in case of prepared composites with time thereby confirming biodegradation.

The present study focuses on the biodegradation studies of composites prepared from banana peel and Pigeon pea stalk fibers using polypropylene (PP) as matrix. The fibers used for the study are untreated and treated (alkali and *laccase* enzyme) with and without addition of maleic anhydride grafted polypropylene as compatibilizer. Composites prepared have been subjected to aerobic biodegradation test in compost as per ASTM D 5338. The composites before and after biodegradation have been characterized from visual appearance (Color), morphology (SEM), thermal stability (TGA) and percent crystallinity (XRD and DSC) to observe the change in the properties due to microbial attack.

2 Experimental section

The composites for the biodegradation study have been prepared according to our reported methods (details given in supplementary information of the manuscript) [16–18]. The composition and sample designation are given in Table 1.

Table 1 Sample composition of the composites

Sample designation	PP (wt%)	Fiber content (wt%)	Compatibilizer (PP-g-MA) (wt%)
PP	100	0	0
PB1	90	BP 10	0
PB2	80	BP 20	0
PB4	60	BP 40	0
PB4C1	59	BP 40	1
PB4C1A	59	BP 40	1
PB4C1E	59	BP 40	1
PS1	90	PS 10	0
PS2	80	PS 20	0
PS4	60	PS 40	0
PS4C2	58	PS 40	2
PS4C2A	58	PS 40	2
PS4C2E	58	PS 40	2

P PP; *B* Banana peel; *S* Pigeon pea stalk fibers, *C* Compatibilizer, *A* alkali treated, *E* enzyme treated fibers

3 Biodegradability test

ASTM D 5338–98 has been followed for the laboratory-scale biodegradability testing apparatus which determines the rate and extent of aerobic biodegradation for plastic materials under controlled-composting conditions [19]. The apparatus comprises of three different components. The first component is the carbon dioxide-free air supply for controlling the amount of CO_2 free air to be supplied. The second component is temperature controlling chamber i.e. incubator in which sample along with compost is present in different bioreactors. The third component is carbon dioxide trapping assembly with three conical flasks in series containing CO_2 scrubbing solution i.e. barium hydroxide for each sample.

The test materials are exposed to compost inoculums obtained from municipal solid waste. Cellulose has been taken as a positive reference and PP has been taken as a negative reference. Close monitoring of temperature, aeration and humidity is carried out. The rate of biodegradation is determined by the conversion of carbon present in the sample to CO_2. The percentage of biodegradability is obtained by determining the percentage of carbon in the test substance that is converted to CO_2 during the duration of the test. A total of 12 composting vessels were taken and labelled accordingly. The sample and mature compost were weighed for each composting vessel. A continuous stream of pressurized CO_2-free air is set for supplying to the composting vessels with a fixed aeration rate. The composting vessels were incubated in dark inside the biodegradability testing apparatus for a period of 45 days. The test temperature was 58 °C for 45 days. The exit stream of air was directly analyzed continuously titrimetrically after sorption in dilute alkali. The CO_2 concentrations in the outgoing air is measured daily after the first week for the remainder of the test by titration of $Ba(OH)_2$ scrubbing solution present in the CO_2-trapping apparatus against hydrochloric acid (HCl). The mean value (from the three replicates) of the net CO_2 produced by controlled composting of the test substances was determined by subtracting the mean CO_2 production from the compost. The percent biodegradation was calculated by using Eq. 1

$$\text{Biodegradation} = \frac{CO_{2(\text{test})} - CO_{2(\text{blank})}}{(CO)_{2(\text{Th})}} \quad (1)$$

where $CO_{2(\text{test})}$ is the cumulative amount of carbon dioxide evolved in each composting reactor containing a tested film sample in grams; $CO_{2(\text{blank})}$ is the cumulative amount of carbon dioxide evolved from the blank reactor in grams; and $CO_{2(\text{Th})}$ = theoretical amount of carbon dioxide of the test sample in grams.

4 Results and discussion

4.1 Biodegradation studies

In the process of biodegradation, the microorganisms start utilizing the polymer surface as its food and grow which is confirmed by the formation of a layer of biofilm (deposition of microorganisms and their polysaccharides) on the polymer surface [20]. The different factors affecting the biodegradation are polymer characteristics such as their tacticity, crystallinity, molecular weight, type of functional groups, type of organism and nature of pre-treatment [21]. The test is considered as unacceptable if 70% of the cellulose is not degraded in 45 days. Total organic carbon content in percentage for cellulose as a reference, pure PP as a negative reference and composites as samples have been summarized in Table 2.

Table 2 Total organic carbon content (%) in positive, negative and test samples

S. no	Sample code	TOC (%)	S. no.	Sample code	TOC (%)
1	Cellulose (positive)	42.62	8	PB4C1E	80.20
2	PP (negative)	94.18	9	PS1	90.39
3	PB1	92.00	10	PS2	88.22
4	PB2	90.00	11	PS4	85.34
5	PB4	86.00	12	PS4C2	80.78
6	PB4C1	84.00	13	PS4C2A	78.15
7	PB4C1A	82.38	14	PS4C2E	75.64

The effect of microorganisms on composites degradation of composites prepared with varied natural filler content, compatibilizer and treatment have been studied. Figure 1 depicts the CO_2 generation for cellulose reference, PP neat, PP/Banana peel and PP/Pigeon pea stalk composites. Cellulose, used as a positive reference showed 80% biodegradation when tested for 45 days which conforms the validity of the test conducted as per ASTM refereed for the test. It was observed that with the increase in natural filler content in PP matrix, the generation of carbon dioxide (CO_2) increased. The composites PB1 and PB4 released 0.021 and 0.032 g/g CO_2 respectively whereas PS1 and PS4 released 0.023 and 0.036 g/g respectively. However, no CO_2 generation was observed for neat PP which further confirms that the natural fillers act as a substrate or feed for the growth of microorganisms. This is in agreement with the literature where high natural filler content leads to fastening of biodegradation due to their susceptibility towards water uptake leading to crack generation of the polymer surface that provide easy attack by microorganism [22].

During biodegradation in compost, some factors such as temperature, water and air, accelerate the biodegradation rate [23]. It is an accelerated/simulated test under defined conditions. During the biodegradation cycle three phases are observed. First is the lag phase during which the microbial population adapts to the available carbon test substrate. After that comes the biodegradation phase during which the adapted microbial population begins to use the carbon substrate for its growth which in turn is confirmed by the conversion of the carbon in the test material to CO_2. The final stage is the plateau phase

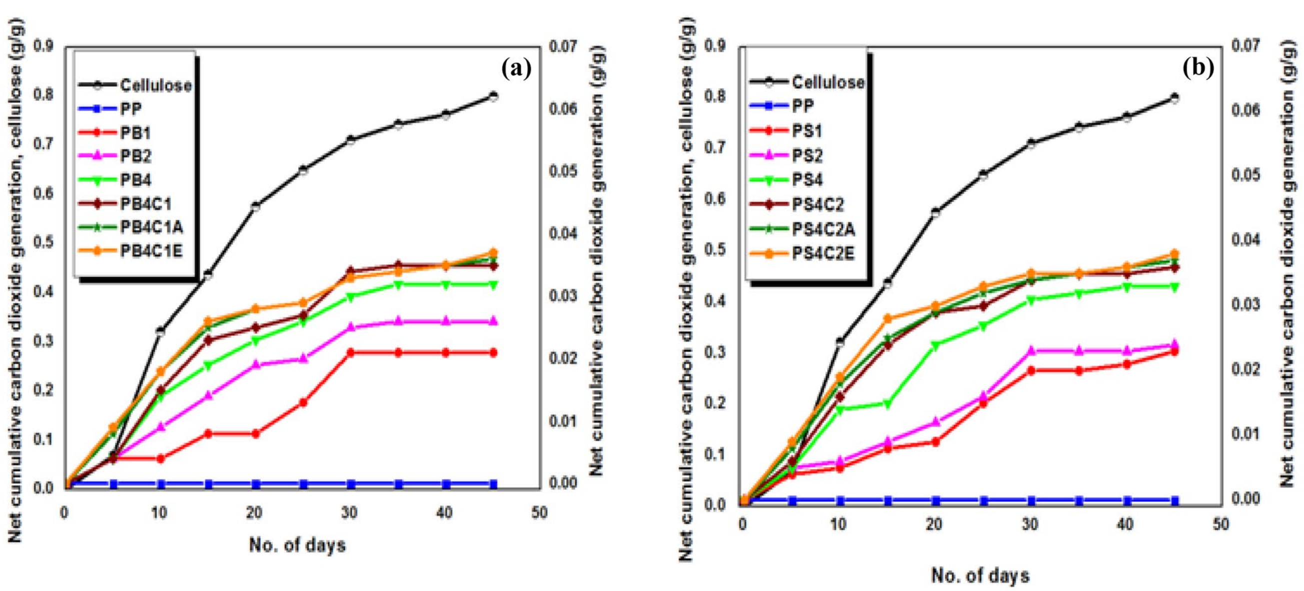


Fig. 1 Net cumulative carbon dioxide per gram of **a** PP/Banana peel and **b** PP/Pigeon pea stalk composites with cellulose

when the carbon test substrate is mostly consumed by microbial population [24]. Biodegradation of PP/Banana peel and PP/Pigeon pea stalk composites in comparison to neat PP ranged from 0 to 3.7 and 0 to 3.8% respectively as can be observed from Fig. 2 against the standard cellulose showing 80 wt% degradation. The observation is in line with the work on biodegradation studies carried out on coffee-based composites [25]. Cellulose have a higher rate of degradation as the hydrophilic hydroxyl group along with polysaccharide chain makes it more susceptible to microbial attack [26]. With the addition of coupling agent and alkali and enzyme treated natural fibers, an increase in biodegradation was observed in composites prepared. This further confirms the reported studies that untreated natural fibers are more resistant to attack of microorganisms due to presence of lignin and hemicelluloses with greater amount than the treated fibers, as lignin act as an adhesion agent in the plant tissue [27].

4.2 Thermal gravimetric analysis (TGA)

TGA of composites has been studied as a function of % weight loss with the increase in temperature. The study has been carried out to analyze the composites thermal stability by TGA under nitrogen atmosphere before and after 45 days of biodegradation. It has been observed that there is no change in the thermal stability of neat PP which confirms that there has been no biodegradation occurred in 45 days, tenure of the test. However, in case of composites, two step degradation has been observed, first step is due to the natural fiber which consist of cellulosic (cellulose and hemicelluloses) and non-cellulosic materials (lignin) and second due to the polymer matrix part in the composite. Degradation in thermal stability of the composites is observed with time (0 day to 45 day) when exposed to the compost environment. Tables 3 and 4 show the thermal degradation of PP/Banana peel and PP/Pigeon pea stalk composites respectively which conforms 5% (T5) and 10% (T10) degradation occur at a lower temperature for the composites that have been exposed to compost for 45 days *vis-a-vis* comparison to 0 day of exposure. This further confirms that some microorganism activity has been initiated which attacks on the fiber part of the composites thus degrading it. TGA scan overlay comparison for PP/Banana peel composites (PB4, PB4C1, PB4C1A and PB4C1E) before and after biodegradation have been depicted in Fig. 3 whereas that of PP/Pigeon pea stalk composites (PS4, PS4C2, PS4C2A and PS4C2E) before and after biodegradation have been depicted in Fig. 4.

Table 3 The 5%, 10% and peak degradation temperature of PP/banana peel composites before and after biodegradation

Sample	T5 (°C)	T10 (°C)	T_{max} (°C)
PP-0	393.0	409.9	443.5
PP-45	392.0	409.0	443.6
PB1-0	336.4	410.3	328.6; 453.1
PB1-45	258.6	303.2	240.2; 450.6
PB2-0	309.6	390.1	298.1; 446.5
PB2-45	259.8	312.0	282.3; 449.1
PB4-0	243.1	283.4	341.5; 450.8
PB4-45	235.1	269.8	286.7; 452.8
PB4C1-0	238.9	293.9	329.2; 439.1
PB4C1-45	248.2	281.4	287.4; 421.6
PB4C1A-0	243.7	288.5	325.9; 451.7
PB4C1A-45	240.0	287.7	329.2; 453.4
PB4C1E-0	257.1	299.2	324.7; 452.4
PB4C1E-45	256.0	291.7	320.0; 440.6

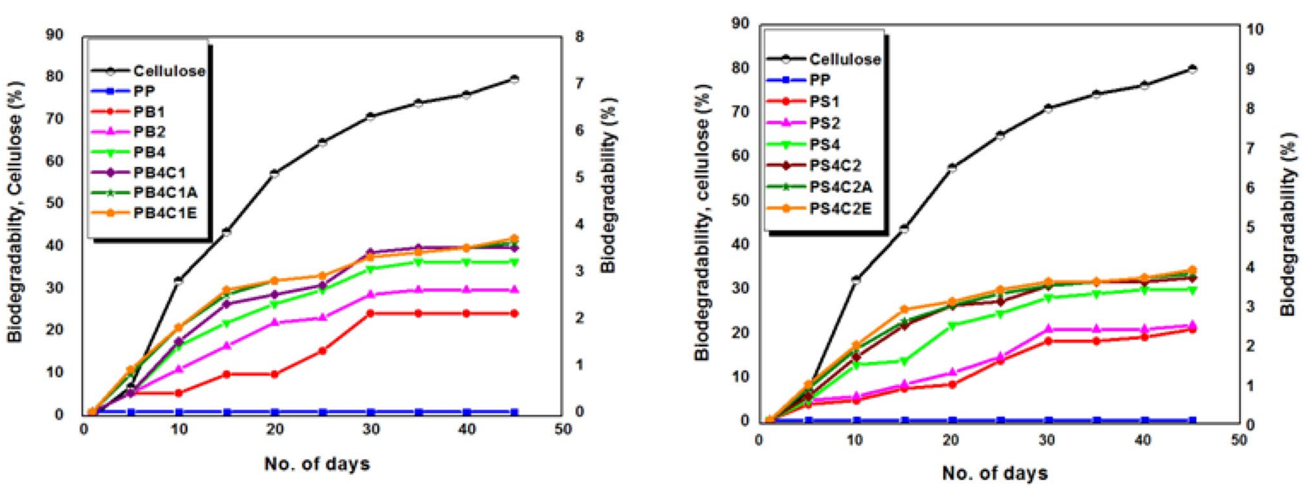


Fig. 2 % Biodegradation of PP/Banana peel and PP/Pigeon pea stalk composites with cellulose

Table 4 The 5%, 10% and peak degradation temperature of PP/Pigeon pea stalk composites before and after biodegradation

Sample detail	T5 (°C)	T10 (°C)	T_{max} (°C)
PS1-0	300.0	352.0	351.7; 449.2
PS1-45	295.2	339.4	328.6; 453.1
PS2-0	272.5	324.7	344.5; 449.9
PS2-45	270.0	314.5	343.0; 407.5
PS4-0	250.4	286.5	334.9; 451.9
PS4-45	234.7	282.9	342.2; 449.7
PS4C2-0	255.3	290.5	347.2; 444.9
PS4C2-45	251.7	301.4	332.7; 446.3
PS4C2A-0	258.4	294.2	354.2; 450.2
PS4C2A-45	257.9	308.6	333.3; 450.5
PS4C2E-0	257.4	288.3	344.4; 427.8
PS4C2E-45	253.6	291.2	348.6; 450.6

4.3 Crystallization studies of polypropylene/natural fiber composites (before and after biodegradation)

4.3.1 Differential scanning calorimetry (DSC)

The change in composite properties with respect to change in crystallization temperature (T_c), melting temperature (T_m) and % crystallinity after biodegradation have been studied with DSC. For T_m and % crystallinity, the second heating curves have been taken for the study. For PP/PS composites, not much change in the T_m is observed after biodegradation. An increase in the % crystallinity and crystallization temperature is observed for the composites prepared and exposed for 45 days due to biodegradation test which thereby confirms that not much change has been initiated by the microbial attack on the matrix part of the composites which being synthetic in nature.

The melting point of composites is in the range of 161.8–163.9 °C before and after biodegradation. Therefore,

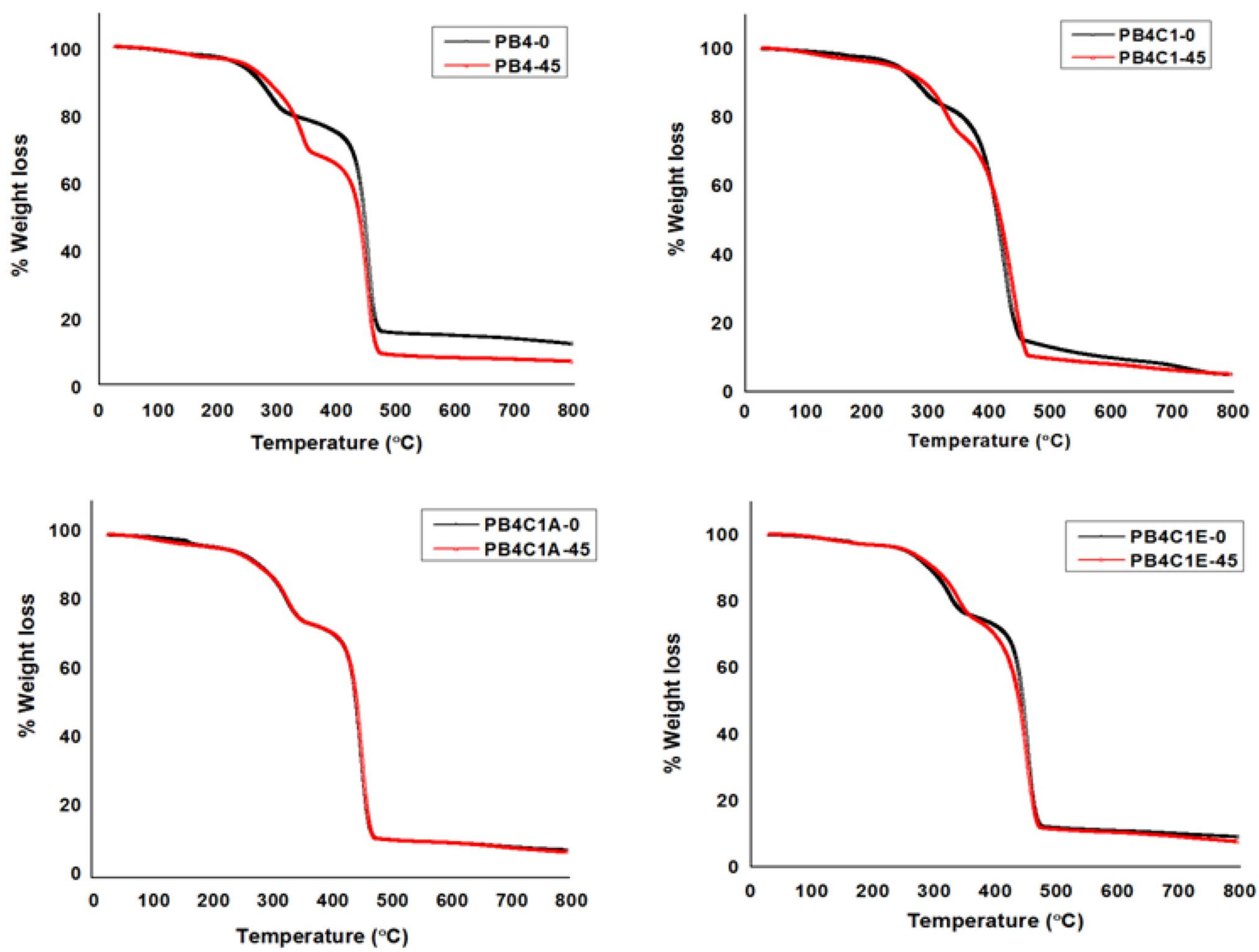


Fig. 3 Overlay comparison of TGA curve of PB4, PB4C1, PB4C1A and PB4C1E before and after biodegradation

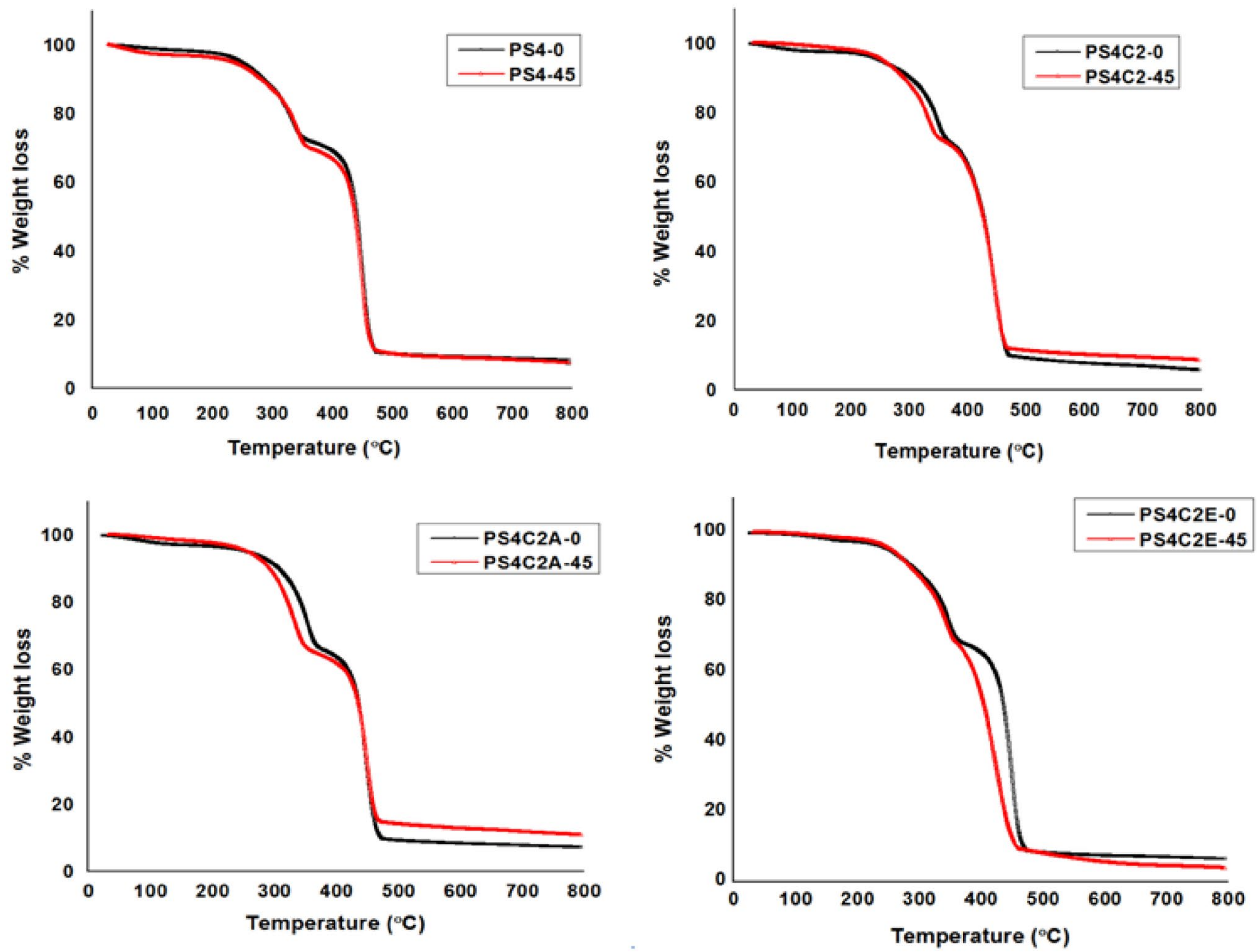


Fig. 4 Overlay comparison of TGA curve of PS4, PS4C2, PS4C2A and PS4C2E before and after biodegradation

it is the natural fiber in the polymer composites, which is the amorphous portion and is easily attacked by the microorganisms, and therefore results in increase in the overall crystallinity of the polymer composites.

The obtained result is in agreement with the literature [28]. The same type of trend is observed for PP/BP composites also. In case of PP/Pigeon pea stalk composites, the percent increase in crystallinity is higher than in case of PP/Banana peel composites as observed from the values tabulated in Table 5. This thereby confirms the slightly higher percent biodegradation of PP/Pigeon pea stalk composites than the PP/Banana peel composites as observed from the biodegradation pattern of the composites studied. In Table 5, after biodegradation of the sample PS4C2, there is an enhancement in % crystallinity by 45%. It could be due to higher fiber length of pigeon pea stalk than the banana peel fiber which leads to increase in biodegradation.

4.3.2 X-ray diffraction (XRD)

The XRD plots of PP/BP and PP/PS composites before and after the biodegradation has been shown in Fig. 5. The plots show the wide-angle X-ray diffraction patterns of untreated and treated composites. Five peaks in the 2θ range of 10–30° at (110), (040), (130), (111) and (041) lattice plane in XRD scan for PP were observed which confirms to the monoclinic α form without any peculiar peak corresponding to beta (β) and gamma (γ) form of PP. A peak that conforms to beta crystalline phase at $2\theta = 16.30$ (degrees) represents the (300) diffraction plane in the composites prepared. Considering the peak areas obtained by integration in relation to crystallinity; the larger the area of the peaks, the more crystalline the material.

The reason for a slight increase in crystallinity after biodegradation could be due to changes in amorphous part (low density area) which is more prone to biodegradation first than the crystalline part of the composite.

Table 5 DSC results of composites before and after biodegradation test for 45 days

Sample code	T_c (°C)		T_m (°C)		% Crystallinity	
	Before	After	Before	After	Before	After
PP	117.63	117.71	161.87	163.90	48	51
PB1	116.02	119.46	162.11	163.18	47	49
PB2	115.63	118.32	162.11	163.13	46	43
PB4	115.05	116.50	161.92	162.10	43	39
PB4C1	118.53	119.39	163.44	163.62	53	54
PB4C1A	121.44	120.35	161.38	163.89	55	49
PB4C1E	120.48	117.67	163.41	163.71	52	53
PS1	119.27	119.46	163.10	163.18	46	49
PS2	118.70	118.32	161.96	163.13	47	43
PS4	116.24	116.50	161.84	162.10	44	51
PS4C2	118.98	119.39	162.99	163.62	44	64
PS4C2A	113.80	120.35	163.15	163.89	44	49
PS4C2E	111.97	117.67	162.44	163.71	47	51

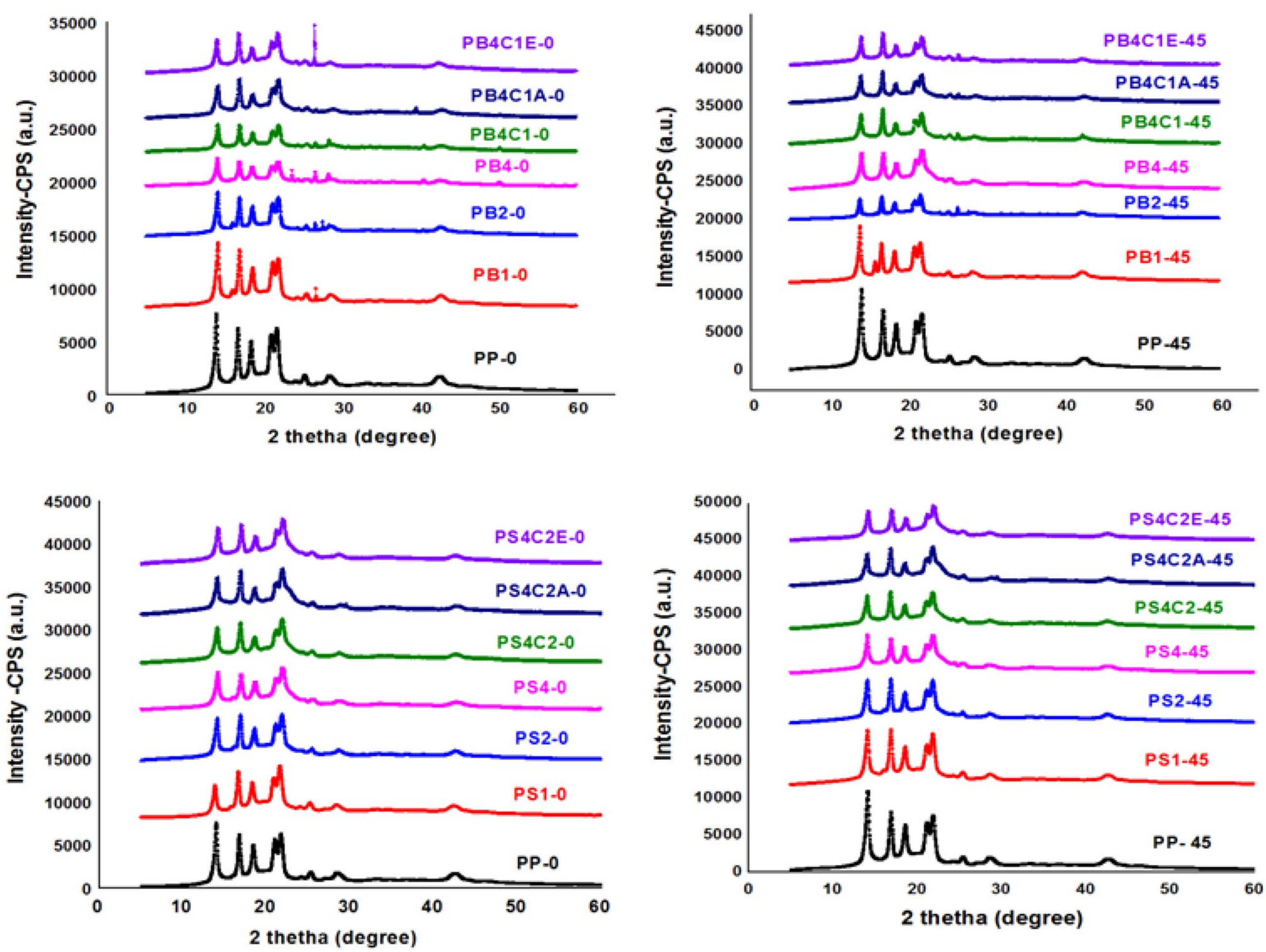


Fig. 5 XRD plots PP/Banana peel and PP/Pigeon pea stalk composites before and after biodegradation

Similar kind of results have been reported by Huanga et al. in their work on study on degradation of composite material polybutylenes succinate/ polycaprolactone [29]. The overlay comparison of XRD scans before and after biodegradation of 45 days for 40 wt% untreated and 40 wt% alkali treated fiber for both PP/Banana peel and PP/Pigeon pea stalk composites have been shown in Fig. 6.

4.4 Scanning Electron Microscope (SEM)

SEM characterization tool is used for the examination of the changes in the morphology before and after biodegradation of the composites. Samples morphology can be observed under high resolution. Cryofracture samples were analyzed microscopically for the changes in the morphology. The figures from SEM (Fig. 7) illustrate the morphology of PP/Banana peel and PP/Pigeon pea stalk composites respectively before and after biodegradation. Formation of cracks, voids have been observed in the samples subjected to biodegradation in compost environment in comparison to the control samples for the composites prepared. These cracks and voids have initiated easy attack of the microbes and thereby leading to degradation in the material.

4.5 Color measurement

Color is an important parameter used in the assessing the quality of polymer by visual appearance. It is the first physical way to assess the deterioration in the visual appearance which could be the first step of indication of the microbial attack. One of the ways of expressing the color of an object is L, a, b color space which is a 3-dimensional color space. It consists of three parameters L* (lightness) axis, a* (red-green) axis, b* (blue-yellow) axis. It has been observed that after the exposure of the samples to the biodegradation the color parameters have increased in comparison to 0-day data. Increase in L* (Fig. 8) value

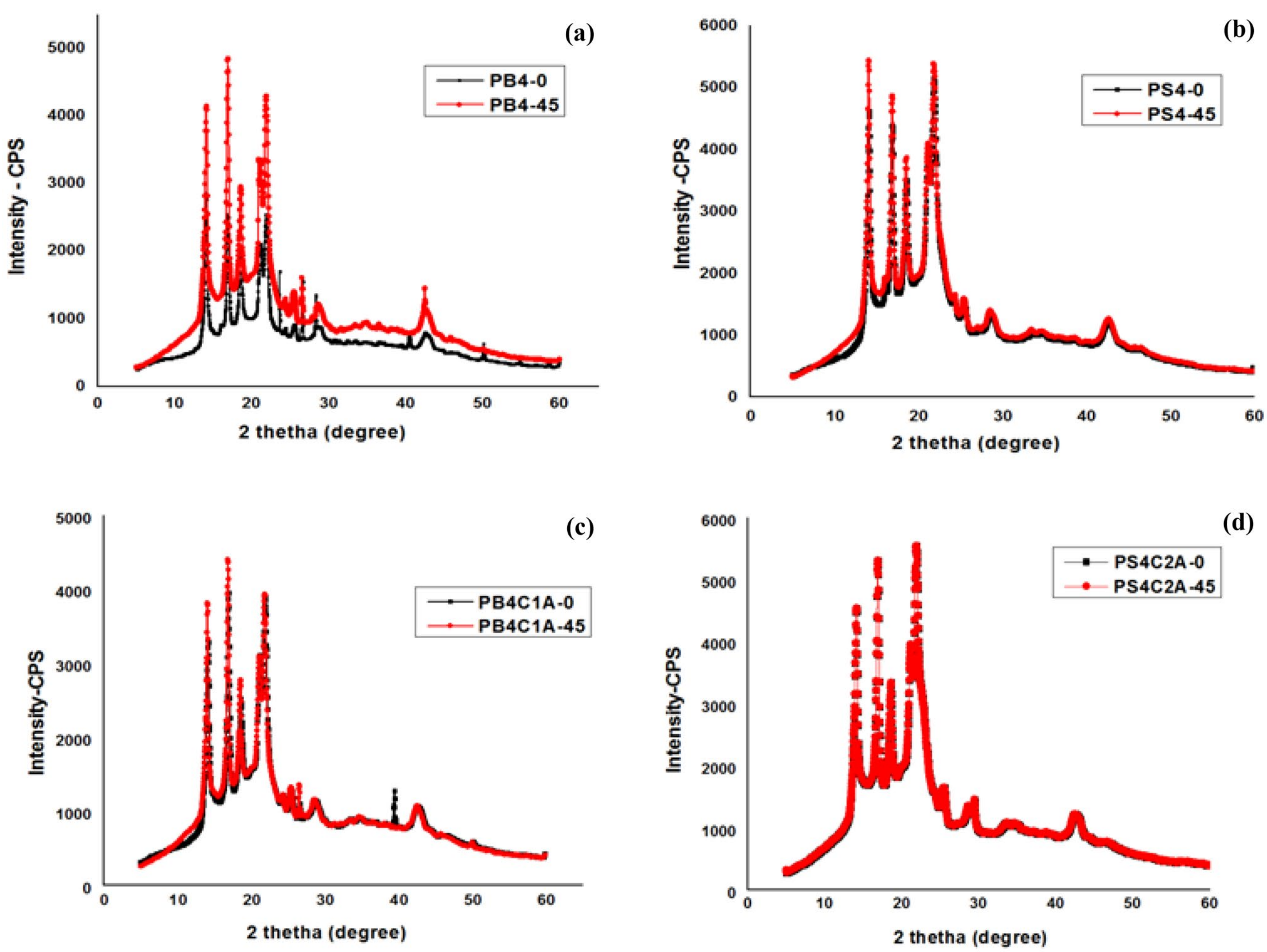


Fig. 6 Comparison of XRD plots of **a** PB4 and **c** PB4C1A (PP/BP composites) and **b** PS4 and **d** PS4C2A (PP/PS composites) before and after biodegradation

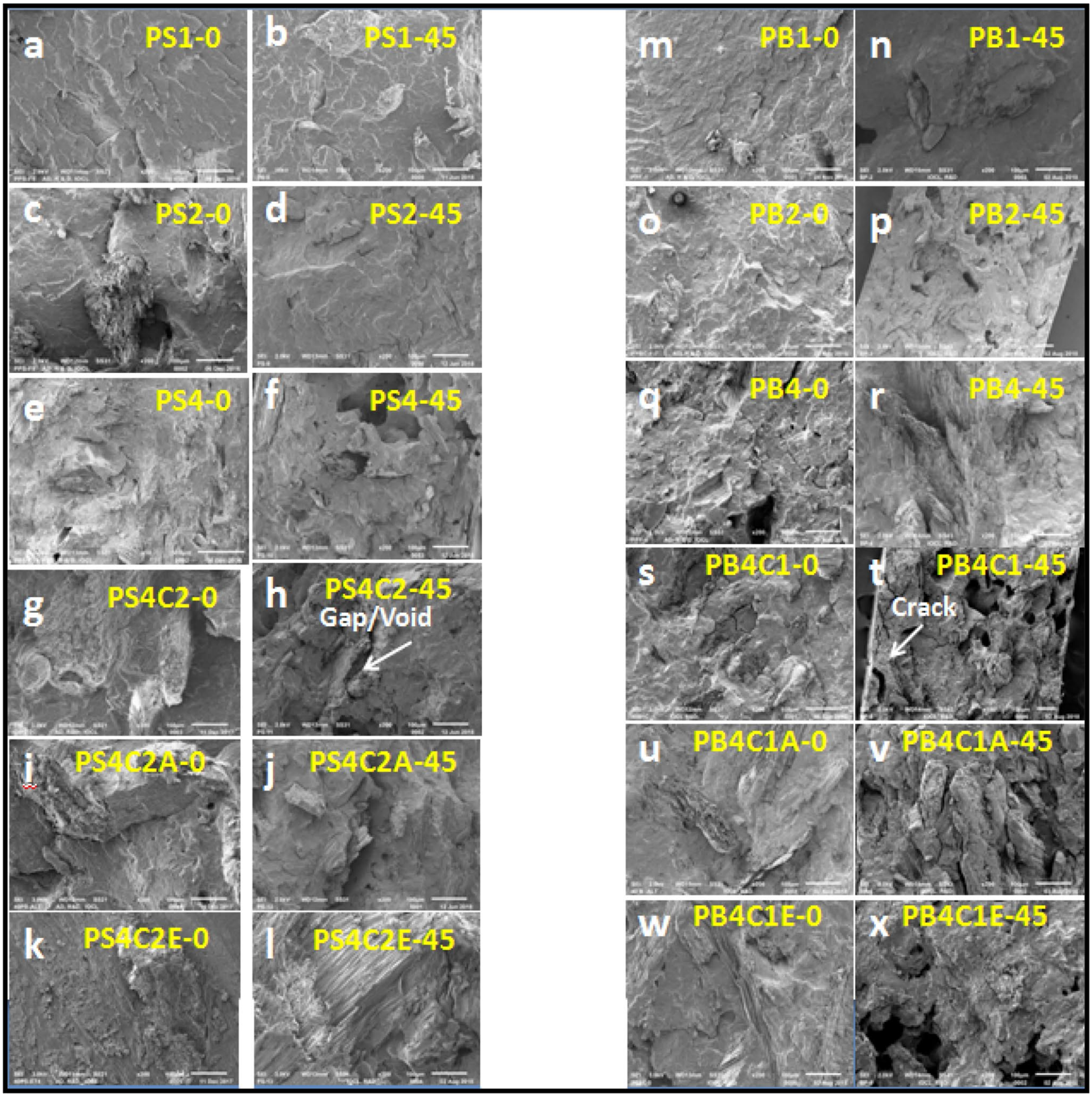
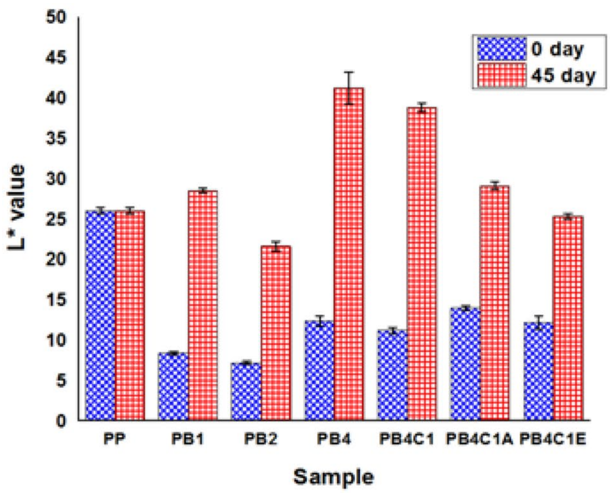


Fig. 7 SEM micrographs PP/Pigeon pea stalk and PP/Banana peel composites before and after biodegradation

after 45 days confirms the sample becoming light in visual appearance. Similar way the a* and b* increased after 45 days thereby confirming the increase in green and yellow tinge in the samples. ΔE which summarizes the change in all the three parameters has also shown an increase after 45 days of exposure of samples to biodegradation. Before biodegradation the samples exhibited dark color, which is expressed on the basis of Lightness /Darkness (L*) of the specimens. Changes in the chemical structure of lignocellulosic complex of the natural fiber of the composites upon biodegradation has led to change in the color of the composites due to the presence of lignocellulosic material. Same kind of behavior of surface color changes has been observed by Butylina et al. [30] during their work with natural fiber filler and biobased biodegradable polymer. It has also been observed from the results that the color change is more in case of untreated fiber composites (PS1, PS2, PS4, PB1, PB2 and PB4) whereas the treated fiber the change in the color is much less which could be due to removal of lignin by the pretreatment procedure of the



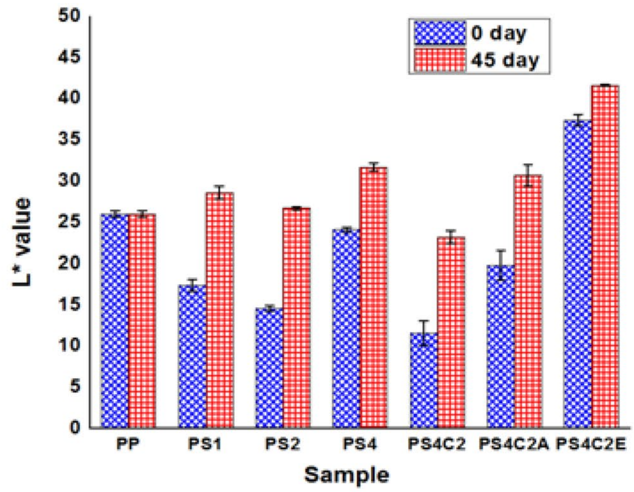


Fig. 8 L* comparison of PP/Banana peel and PP/Pigeon pea stalk composites before and after biodegradation

natural fiber carried out before the preparation of the composites. The values of color parameters of the prepared composites before and after biodegradation have been tabulated as Tables 6 and 7 for PP/Banana peel and PP/Pigeon pea stalk composites respectively. Change in color as observed visually has been complied as Fig. 9 and 10 for PP/BP and PP/PS composites.

5 Conclusion

In the recent work, the biodegradation study of polypropylene/ natural fiber composite has been done where PP is used as a matrix and banana peel and pigeon pea stalk fibers have been used as reinforcing agent. These composites i.e. PP/Banana peel and PP/Pigeon pea stalk have been compatibilized using maleic anhydride PP-g-MA. The samples were subjected to biodegradation test (compost) and were characterized before and after the test for using various techniques.

- Biodegradation of composites have been observed for PP/Banana peel and PP/Pigeon pea stalk composites prepared in comparison to the standard cellulose which was taken as a reference. Maximum degradation was observed with composites prepared with higher loading i.e. 40 wt% of untreated fiber (Banana peel and Pigeon pea stalk). Treated fiber composites (alkali and enzyme) showed more biodegradation vis a vis comparison to untreated fiber composites which thereby

Table 6 Color measurement for PP/banana peel composites before and after biodegradation

Sample detail	L*	a*	b*	ΔE
PP- 0 day	26.0 ± 0.35	-0.79 ± 0.02	-5.3 ± 0.03	0.01 ± 0.001
PP-45 day	25.5 ± 0.44	0.76 ± 0.04	5.4 ± 0.02	0.03 ± 0.01
PB1-0 day	8.4 ± 0.2	3.9 ± 0.1	4.5 ± 0.06	0.02 ± 0.02
PB1-45 day	28.5 ± 0.3	4.7 ± 0.3	10.0 ± 0.16	0.05 ± 0.01
PB2-0 day	7.2 ± 0.2	2.9 ± 0.2	3.5 ± 0.1	0.2 ± 0.03
PB2-45 day	21.6 ± 0.6	5.1 ± 0.1	9.9 ± 0.12	0.5 ± 0.5
PB4-0 day	12.4 ± 0.6	3.7 ± 0.2	6.3 ± 0.2	0.4 ± 0.2
PB4-45 day	41.2 ± 2.0	8.3 ± 0.4	18.3 ± 0.5	2.6 ± 1.3
PB4C1-0 day	11.2 ± 0.4	2.8 ± 0.1	3.6 ± 0.2	0.3 ± 0.2
PB4C1-45 day	38.8 ± 0.5	5.4 ± 0.1	11.8 ± 0.14	0.4 ± 0.2
PB4C1A-0 day	14.0 ± 0.3	4.5 ± 0.3	8.4 ± 0.8	0.6 ± 0.3
PB4C1A -45 day	29.1 ± 0.5	5.8 ± 0.1	11.0 ± 0.2	0.7 ± 0.14
PB4C1E -0 day	12.2 ± 0.8	3.8 ± 0.2	6.9 ± 0.2	0.5 ± 0.12
PB4C1E -45 day	25.3 ± 0.3	5.4 ± 0.04	11.0 ± 0.1	0.2 ± 0.3

Table 7 Color measurement for PP/Pigeon pea stalk composites before and after biodegradation

Sample detail	L*	a*	b*	ΔE
PS1-0 day	17.4 ± 0.7	9.5 ± 0.5	15.0 ± 0.7	0.9 ± 0.3
PS1-45 day	28.6 ± 0.8	7.2 ± 0.3	13.0 ± 0.8	0.03 ± 0.01
PS2-0 day	14.6 ± 0.3	7.4 ± 0.5	11.1 ± 0.8	0.7 ± 0.1
PS2-45 day	26.7 ± 0.2	7.5 ± 0.2	13.7 ± 0.4	2.5 ± 2.9
PS4-0 day	24.1 ± 0.3	7.5 ± 0.05	13.0 ± 0.06	0.3 ± 0.04
PS4-45 day	31.7 ± 0.5	5.8 ± 0.6	11.4 ± 0.7	0.7 ± 0.5
PS4C2-0 day	11.6 ± 1.5	5.9 ± 0.7	7.3 ± 1.4	1.1 ± 0.9
PS4C2-45 day	23.2 ± 0.8	6.1 ± 0.2	10.6 ± 0.8	0.8 ± 1.0
PS4C2A-0 day	19.8 ± 1.8	11.9 ± 0.1	18.4 ± 0.3	1.6 ± 1.3
PS4C2A-45 day	30.7 ± 1.3	8.4 ± 0.3	16.8 ± 0.13	1.8 ± 0.1
PS4C2E-0 day	37.4 ± 0.7	11.4 ± 0.4	21.3 ± 1.0	1.1 ± 0.1
PS4C2E-45 day	41.6 ± 0.1	10.7 ± 0.7	21.7 ± 1.6	1.4 ± 0.3

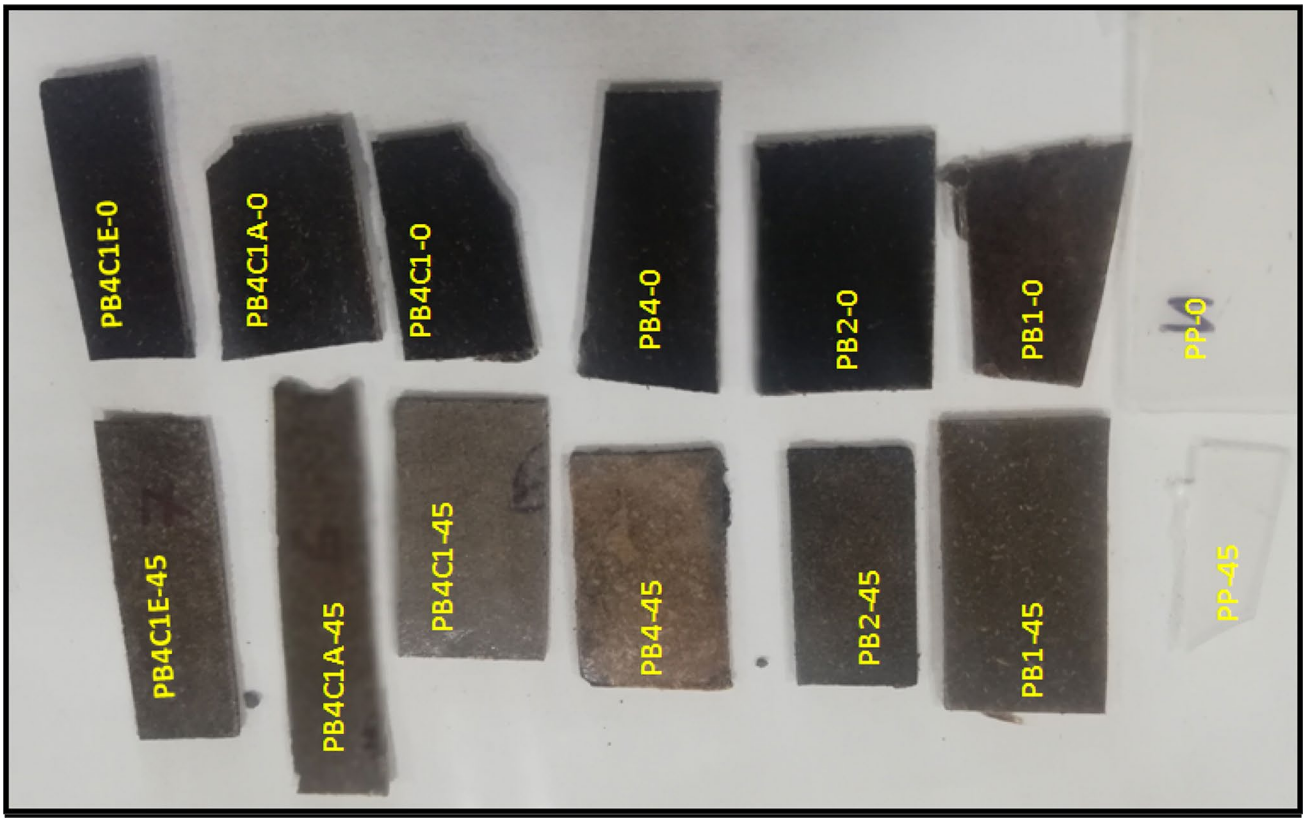


Fig. 9 Color change of PP/Banana peel composites before and after biodegradation

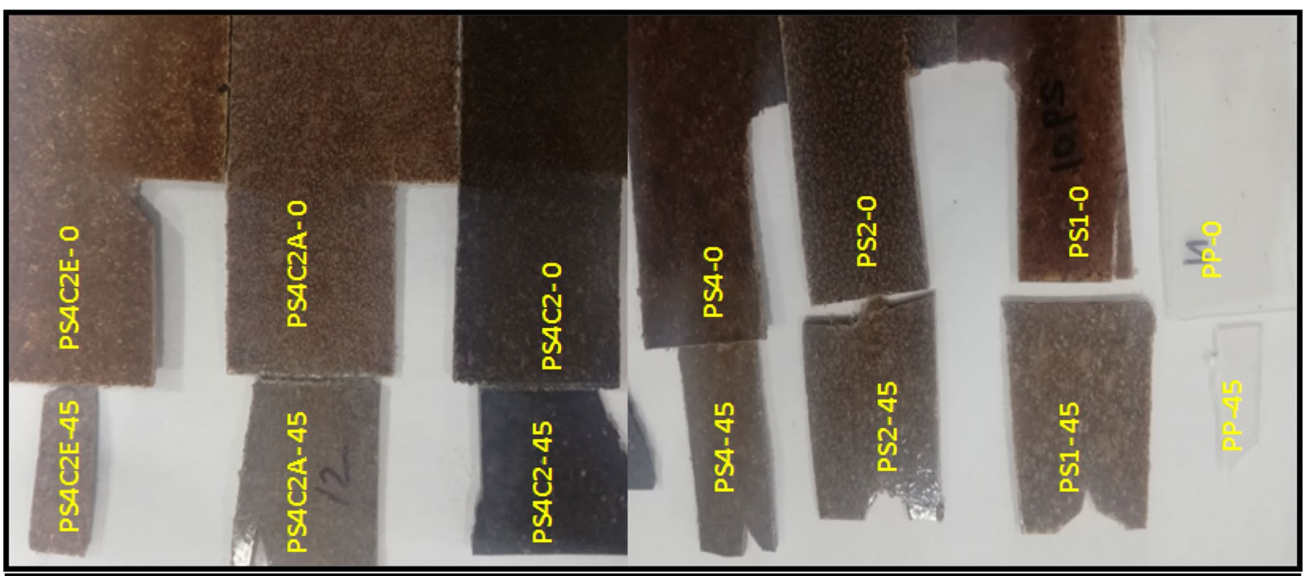


Fig. 10 Color change of PP/Pigeon pea stalk composites before and after biodegradation

confirms that the removal of lignin after treatment which provides a hindrance to the attack of the micro-organisms thereby slowing the rate of biodegradation. Escalation in percent crystallinity and crystallization temperature is observed by DSC and XRD techniques. However, not much change in the melting point is seen by DSC for the composites prepared and exposed to 45 days to biodegradation test.

- TGA data concludes that on exposure to biodegradation test for 45 days, PP/Banana peel and PP/Pigeon pea stalk composites weight loss scan, showed a steep/fast thermal degradation which thereby confirms the microbial activity.
- SEM results showed a change in the morphology of the composites prepared. Cracks and voids observed after biodegradation in the composites.
- Visual appearance of the composites also changed which is characterized by the measurement of color which lightened after the samples were subjected to biodegradation in compost.

This thereby confirms that the natural fibers (Banana peel and Pigeon pea stalk) used in the preparation of the composites are prone to microbial attack and can be used for the preparation of polymer composites thereby replacing the synthetic fiber, which being non-biodegradable in nature. These natural fibers filled polymer composites is a suitable alternate to synthetic fiber filled polymer composites in various sectors i.e. automotive, construction etc.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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