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Physical Properties and Surface Morphology of Natural Rubber Latex Films Intended for Seedling Bag Application

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Natural rubber (NR) latex concentrate of the Hevea brasiliensis *species is used to fabricate a seedling bag using a typical latex dipping process. The latex film from the bag demonstrated excellent physical properties such as strength and stiffness, to form the intended product. Incorporating non rubber materials such as calcium carbonate, corn starch or fertilizer into the bag, increased the stiffness of the latex film with reduction in its strength properties. Under natural environmental conditions, the physical properties of the film started to show reduction after two months buried in soil. Substantial reduction in weight of the films was due to NR latex biodegradation expected to occur readily during the soil burial. The degradation of the film surface was observed from FESEM micrographs as cracks and cavities at the degraded area. The added non rubber material as filler, namely corn starch and fertilizer, further amplified the biodegradation rate of the film, while ground calcium carbonate slowed down the biodegradation process of the film. The study confirmed NR latex is a suitable alternate choice to synthetic materials as seedling bag base material. The NR latex seedling bag is in fact an environmentally friendly seedling bag which is able to retain the physical performance while in use and able to self-decompose under soil burial.*

Keywords: natural rubber latex; non rubber filler; environmental exposure, agricultural waste management

Seedling bags or commonly known as polybags are the plastic packaging used in the agriculture industry, typically nurseries to hold young seedlings prior to planting. Depending on the size of plant to be produced, the bags can be of different sizes and dimensions. The application of polybag holding young seedling is to provide a better soil environment during the early stages of planting. It is critical that the bagged young plant root system is well protected in the bag during the growth period. Once the seedling grows to the required size for planting, the seedling bag is removed prior to placing the young plant into the soil with minimum disruption to its root.

Polybags are generally made from plastic materials and do not degrade easily. It is a well known fact that plastic materials are resistant

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to biodegradation and if dumped into soil, plastic materials stay in their original form for a long period of time. Soil microbes are lacking appropriate enzymes to degrade plastic materials, due to the presence of only carbon atoms in its main chain, with no hydrolysable functional group. Therefore, introduction of biodegradable natural rubber latex (NRL) seedling bags as an alternative seedling bag that can be decomposed directly in soil offers a possible solution to solve issues involving polybag wastes.

Latex films made from NRL are durable to a certain extent and can undergo biodegradation[1–3]. Like most common naturally occurring polymers, *e.g.* starches, gelatin, and cellulose, NRL is physically disintegrated through influence of environmental weather conditions (oxygen, sunlight, rain) and is chemically transformed into low molecular weight oxidation products that can be bioassimilated by soil microorganisms upon disposal[1]. Traditional application of NR latex is mainly in the making of single use medical gloves and condoms because of the property of NR latex film which is better compared to a similar film made from synthetic material. This study, proposes the application of NR latex for seedling bags, having the adequate intact properties for agricultural application. In other words, the latex seedling bag is to retain its physical and mechanical properties as a plastic bag while in use and be able to biodegrade or self-decompose upon soil burial.

MATERIAL AND METHODS

Film Preparation

The compounding ingredients used for film preparation in this study are listed in *Table 1*. Vulcanising chemicals and fillers were of industrial grades obtained commercially. A coagulant solution was first prepared by dissolving calcium nitrate in water at 20 weight percent.

The common laboratory NR latex dipping technique[4] for latex products was followed. A cleaned dried former (*Figure 1*) was dipped into the coagulant solution for 15 s at room temperature, dried in an air oven at 80ºC ± 3ºC and then dipped into the compounded NR latex for 20 s at room temperature. The deposited latex film was then dried in an air

TABLE 1. COMPOUNDING FORMULATION

Ingredients	Total solid content (TSC %)	Parts per hundred rubber (p.p.h.r.)
NR latex	60	167
t-butyl hydroperoxide solution	70	0.9
hydroxyacetone	85	0.4
Potassium hydroxide solution	20	0.3
Phenolic Antioxidant[a]	50	1.0
Filler dispersion[b]	50	0, 10, 20, 30

[a] 2,4-dioctylphenyl sulphide-6-methylphenol,
[b] can be either calcium carbonate, corn starch, or a fertilizer (NPK) mixture

oven at 80ºC ± 3ºC for about 5 min for drying followed by rinsing in tap water for 5 minutes. The latex film was then heated at 110ºC ± 3ºC for 20 min to cure. Before stripping, the film was coated with talc to prevent sticking. After stripping, the film was stored under ambient temperature conditions. *Figure 2* shows the flow diagram of film preparation.

Tests

For environmental conditioning, the NRL bags were filled with coarse sandy clay loam soil and left under an open field at the Rubber Research Institute of Malaysia (RRIM) Experimental Station. Tensile properties of films were determined at a one month interval during the study duration. Tensile strength (TS), modulus (M300) and elongation at break (EB) of the films were determined according to *ISO 37*.

For degradation effect on the surface of the film, test samples were cut and placed onto the specimen stub with carbon double sided tape. The specimen was then prepared for examination by evaporative coating with ultra-thin layer of platinum under high vacuum. Field Emission Scanning Electron Microscope (FESEM) was used in this study to visualise surface morphology of the latex film after three months under exposure.

For the biodegradation study, test pieces were placed in nylon mesh bags (38 µm pore size) and then buried in clayey soil type in the open field at RRIM Experimental Station.

Figure 1. Former use for the NR seedling bag.

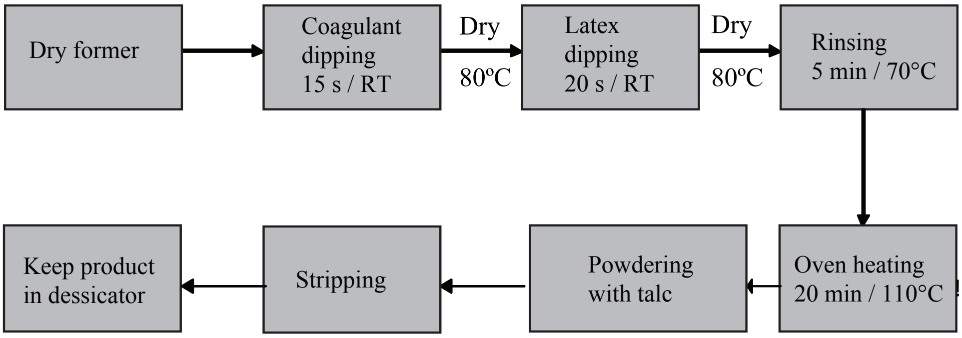

Figure 2. Flow diagram of fabrication process for NR latex seedling bag.

Samples were retrieved from the soil at a 1 month interval during the study duration, washed in running water and dried prior to weighing. The residual weight was determined to evaluate rate of biodegradation of the NR latex seedling bag. FESEM micrograph was used to visualise the degraded surface morphology of the film. A small test piece was also cut from the sample and stained with Schiff's reagent before observation of bacteria and fungus under a light microscope.

RESULTS AND DISCUSSION

The elasticity of NR latex was an advantage enabling easier filling of soil than that of the tough plastics seedling bag. *Figure 3* illustrates the NR latex seedling bag containing a complete plant system. The ability of NR latex film to withstand its shape while holding the soil and plant in nurseries and later to the plantation can be adjusted by understanding physical properties of the NR latex film.

As listed in *Table 2*, NR films can be formulated to have varying physical strength and stiffness. Compatible non elastic material mixed in the NR latex mixture formed NR latex composite of different physical properties. In all of these NR latex films intended for the seedling bag, tensile strength was strong enough to hold the amount of soil expected of the size of the bag without breaking. Comparing stiffness between these films, the highest modulus value was demonstrated by the film with 30 p.p.h.r. corn starch, whilst the highest elongation at break was demonstrated by the unfilled film (control). Meanwhile, addition of calcium carbonate and fertilizer eventually increased stiffness and decreased elongation at break of the film. The non rubber materials in this study are convenient strength properties adjusters, of which the strength of latex films reduced with the higher filled of these non rubber materials. We know from our previous study[5] that non reinforcing fillers tend to agglomerate to form clusters within the latex films. These non elastic clusters contribute to flaws in the latex by inducing stress points. It is thought that shape of the filler material and the manner each material interacted with the rubber matrix within the latex film affected its material properties. In this study, we noted that between the different non rubber materials added as filler into the NR, the milder fertilizer combination of the two materials produced the weakest NR latex film.

Figure 3. The NR latex seedling bag.

TABLE 2. PHYSICAL PROPERTIES OF NR LATEX FILMS BEFORE EXPOSURE

	Parts per hundred rubber									
	Calcium carbonate				Corn starch			Fertilizer		
	0	10	20	30	10	20	30	10	20	30
TS (MPa)	18.2	17.2	16.1	14.7	16.1	13.4	12.8	15.9	12.6	NA
M300 (MPa)	1.06	1.13	1.16	1.24	1.21	1.41	1.87	1.11	1.09	NA
EB (%)	850	800	800	750	750	690	670	750	690	NA

The fertilizer combination contained nitrogen, potassium and calcium. The intention of incorporating fertilizer into the seedling bag was to enrich the soil with nutrients, thus adding extra value to the bag after it decomposed near the plant. The quantity of such combination that can be practically added into NR latex was up to 20 p.p.h.r. Above this amount, the coherent latex film could not be made from the mixture, thus, the formed film was not useful for the intended purpose.

The NRL films were subjected to environmental exposure to determine the extent of degradation of these films. Physical properties of these latex films determined after specific exposure duration are given in *Table 3*.

We observed that the slow ageing process occurring during environmental exposure whereby tensile strength and modulus values of unfilled film increased during the first month. This was attributed to possible formation of crosslinking in rubber that will eventually harden and cause the film to be brittle, due to which tensile properties of latex films dropped significantly after long periods of exposure. The trend of diminishing physical properties was clear in NR latex films with added non rubber materials. For example, after three months of exposure, NRL films filled with 20 p.p.h.r. and 30 p.p.h.r. of corn starch content were found to fail below 300% elongation at break test, indicating loss of rubber elasticity. The degradation rate gauged from the reduction of physical properties was somewhat lesser than those with non rubber fillers. Among the non rubber materials, calcium carbonate sustained better physical properties compared to milder materials such as corn starch or the fertilizer combination.

TABLE 3. PHYSICAL PROPERTIES OF NR LATEX FILMS AFTER EXPOSURE

	Calcium Carbonate				Corn Starch			Fertilizer	
Filler (p.p.h.r.)	0	10	20	30	10	20	30	10	20
1st month									
TS (MPa)	22.3	16.0	16.1	14.1	14.7	13.5	11.5	12.1	12.1
M300 (MPa)	1.28	1.18	1.19	1.34	1.46	1.43	1.85	1.38	1.42
EB %	850	800	800	690	750	690	690	750	750
2nd month									
TS (MPa)	18.0	14.4	12.2	11.3	14.4	9.6	6.1	6.8	4.4
M300 (MPa)	1.33	1.48	1.68	1.79	1.73	1.77	1.89	1.47	1.65
EB %	800	750	600	600	400	400	400	350	350
3rd month									
TS (MPa)	16.0	10.2	9.2	9.8	5.3	1.7	1.6	7.2	5.3
M300 (MPa)	1.38	1.55	1.72	1.84	1.75	-	-	1.50	1.70
EB %	710	690	600	590	330	200	200	330	330

In the other study, we found that the NR latex film was able to degrade under soil burial condition. The biodegradation test of these NR latex films in soil was followed using the method demonstrated by Ikram *et al.*[2,3]. Reduction in weight of each of the NR latex films was determined and graphed as percentage loss against burial period in *Figure 4*. As expected, NRL films started to lose their weight during soil burial. After one month in soil, NR latex films lost between 8 to 15% of their original weight, the percentage loss in weight increased linearly to about 13 to 20% after three months burial. Thus, it is expected that at a rate of about 5% in two months, the NRL films should be almost 70% degraded in about a year. This is an advantage for seedling bag application, as the root system can easily grow out of the degraded bag while the NRL bag degrades naturally.

The occurrence of degradation of NR latex films after the initial increase in crosslinking was visualised by FESEM. Micrographs of the surface of films buried for a three month period, illustrated a typically rubber latex surface with apparent fissure forming throughout the surface (*Figure 5*).

The NR latex films were clearly damaged after three months of soil burial. Although, the micrographs clearly showed evidence of degradation, it is difficult to gauge the severity of degradation influenced by the added non rubber materials. However, from the micrographs, we observed that the films containing calcium carbonate and fertilizer showed larger cracks compared to unfilled and corn starch loaded films. Therefore, the average rate of specific degradation was determined by monitoring the weight loss of the film in milligram per week (mg/wk). The results based on 4, 8 and 12 weeks after soil burial are listed in *Table 4*.

The NR latex films from the latex mix containing 20% fertilizer composition degraded rapidly at a rate of 17.6 mg/wk, indicating 36% more severe than NR latex film without any filler. The interesting trend that can be adapted to product application is that NR latex containing calcium carbonate degraded lesser than NR latex without any filler. Hence, the degrading rate of NR latex films can be controlled to a certain extent by adding different types of filler materials in NR latex. In other words, the rate of degradation of seedling bag films depend on the compounding ingredients and additives used. Milder materials would lead to a rapid degradation of the films, probably due to plasticising effects and rendered the latex films more suitable for any microorganism colonisation such as bacteria and fungus.

The presence of microbial colonies on the degraded film was visualised using a light microscope. The Schiff's reagent staining demonstrated a purplish red color of microbial colonies on the NR film (*Figure 6*). Micrographs A and B illustrated the bacteria growth and fungus growth respectively. Presently, the study of the role of microorganism on biodegradation of NR film is still not clear. Very little is known about the microbial activities and the nutritional and environmental factors that may affect degradation rates in nature. According to Ikram *et al.*[2,3], breakdown of NR chains was influenced by antioxidants and vulcanising agents used in the NR compounding system.

Changes of appearance of the films before and after soil burial were demonstrated in *Figure 7*. The Manila card that was used as control in the study almost disappeared after two months of soil burial and vanished after three months.

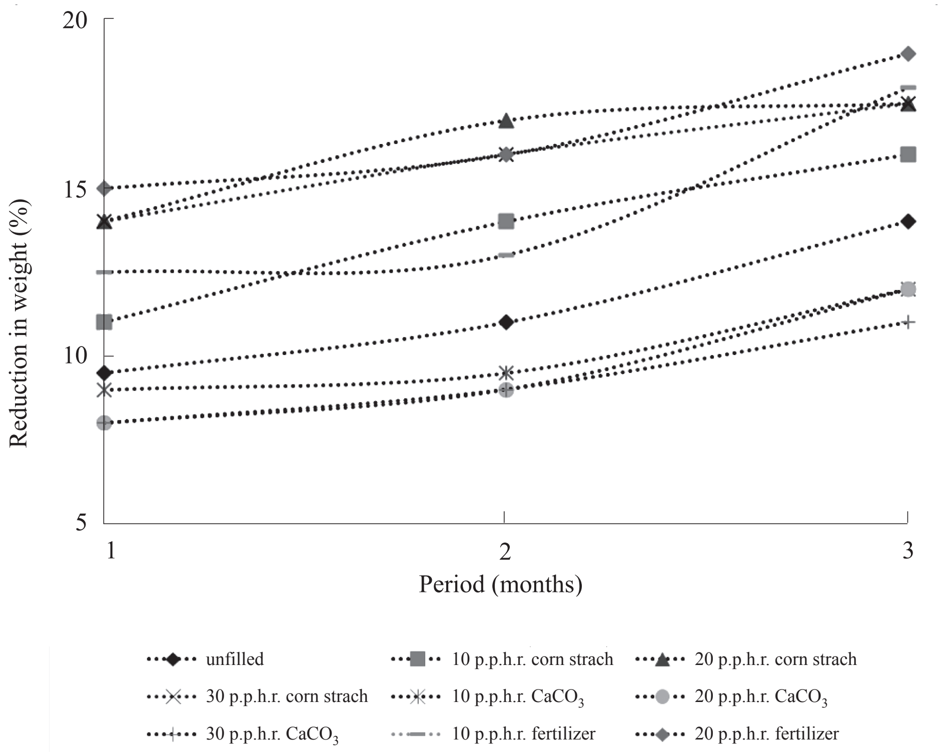

Figure 4. Percentage reduction in weight of NR latex films after soil burial.

TABLE 4. AVERAGE SPECIFIC DEGRADATION RATES OF SEEDLING BAG IN SOIL[a]

Sample name	Average specific degradation rate (mg/wk)	Increment / Decrement (%)
Unfilled	13.0	-
20 p.p.h.r. fertilizer	17.6	36
10 p.p.h.r. fertilizer	16.0	23
30 p.p.h.r. corn starch	16.6	28
20 p.p.h.r. corn starch	17.0	30
10 p.p.h.r. corn starch	15.0	15
30 p.p.h.r. calcium carbonate	11.0	-15
20 p.p.h.r. calcium carbonate	11.3	-12
10 p.p.h.r. calcium carbonate	11.3	-12

[a] Based on 2 replications, sampled at 4, 8, 12 weeks after soil burial

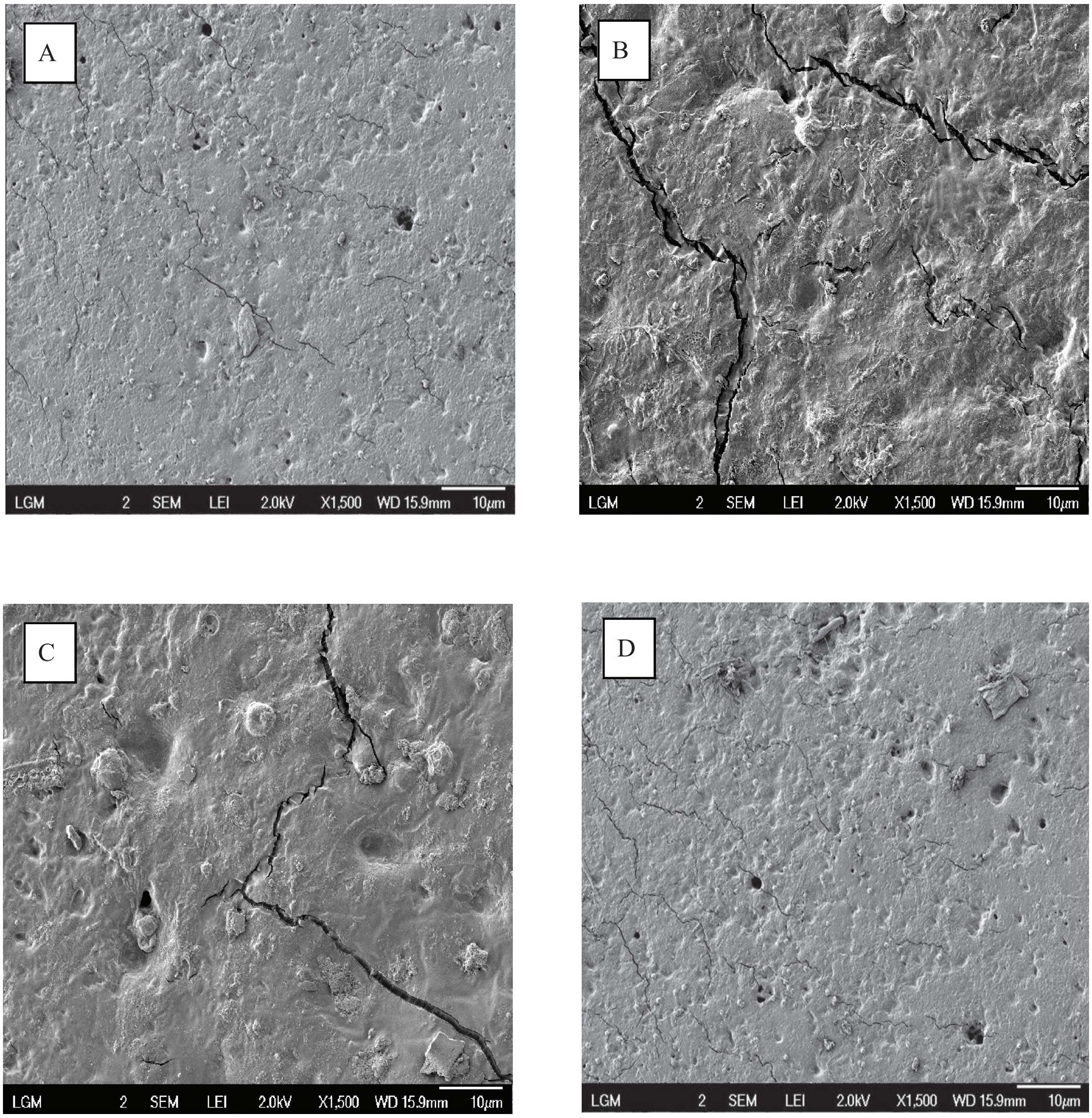

Figure 5. The micrographs of degraded area of unfilled and filled NR latex films; A - Unfilled film, B - Fertilizer loaded film, C - Calcium carbonate loaded film, D - Corn starch loaded film.

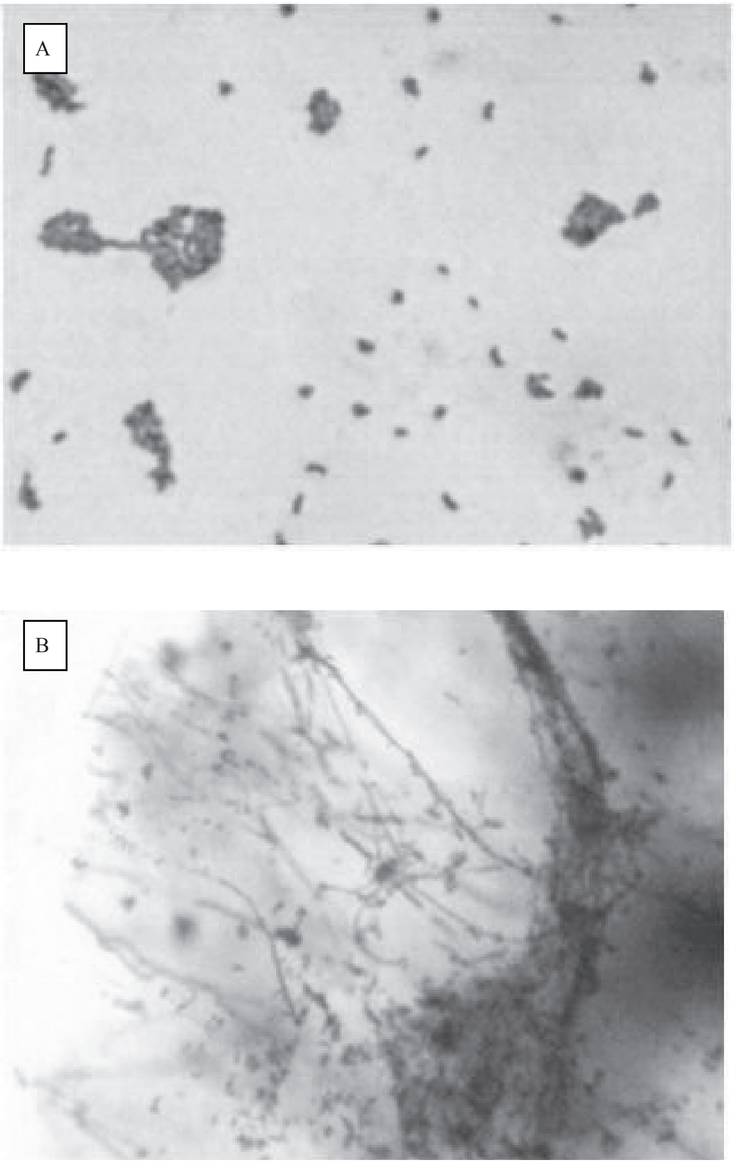

Figure 6. The visualisation microbial colonies on the biodegraded NR film using light microscope.
A - Bacteria; B - Fungus

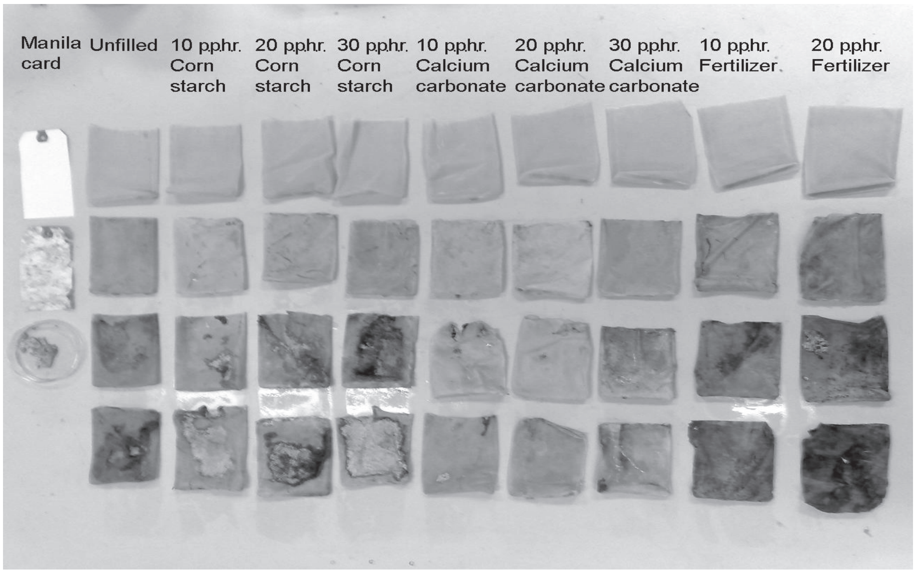

Figure 7. Degradation of the NR latex films of the latex seedling bag.

Note: Samples in the top row are untreated samples, while those in the second row are samples after one month of burial, the third row are samples after two months of burial and the bottom row are samples after three months of burial.

Although rate of biodegradation of NRL latex films was much slower than the Manila paper, the evidence of similar microbial colonies can be seen after the first month of soil burial and was more obvious after two months with areas of colonisation appearing as dark spots on the latex surface.

CONCLUSION

This study demonstrated that NR latex can be an attractive alternative base material to develop biodegradable materials in producing seedling bags for use in nurseries. The bag can be buried together with the young plant, without accumulating waste. The adequate strength property with a somewhat controlled degradation rate is possible with the right compound formulation. Seedling bag made from a natural and renewable material that can easily decompose in soil offers a green alternative to the plastic based seedling bag used currently for agricultural applications.

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