Nig J. Biotech. Vol. 20 (2009) 28 – 33
ISSN: 0189 17131
Available online at http://www.ajol.info/index.php/njb/index
and www.biotechsocietynigeria.org

NIGERIAN JOURNAL OF BIOTECHNOLOGY

Evaluation of Starch Biodegradable Plastics Derived from Cassava and Their Rates of Degradation in Soil

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Abstract
Starch derived from two cassava cultivars, one with high amylose (TMS 92/0325) and the other with high amylopectin contents (TMS 91/02324), were screened for their ability to produce biodegradable plastics using different compositions of plasticizers and other materials. The rate of degradation of the bioplastics produced was equally evaluated. It was observed that the degradation values for bioplastics derived from TMS 92/0325 were 70.0%, 85.4%, 90.2% and 98.6%, while those from TMS 91/02324 were 72.4%, 86.6%, 93.5% and 99.2% at the end of 7 weeks for products containing 45%, 60%, 75% and 90% of starch, respectively. This is an implicit indication that the rate of degradability of the bioplastics produced from cassava does not depend on the level of amylose and amylopectin in the starch *per se* but rather on the amount of the starch itself that is used in the formulation. Moreover, our results equally demonstrated that bioplastics produced from the starch derived from cultivar TMS 91/02324 had a higher tensile strength than those gotten from cultivar TMS 92/0325. Taken together, these results are suggestive of the fact that though bioplastics produced from starch having a higher amylopectin level would have a higher tensile strength, however, they do not necessarily have a faster and greater rate of degradation when composted.

Key words: Amylopectin, bioplastics, cassava starch, degradation, environment, sorbitol
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Introduction

Cassava (*Manihot esculenta* Crantz) is a vegetatively propagated shrub grown mainly for its starchy tuberous roots, which constitute about 74 - 85% of the total dry weight (Nweke et al., 1996). Starch from cassava has been exploited as a source of human food, feed for livestock, and raw materials for the chemical, food, and pharmaceutical industries. Lately, it has been found to be a very promising raw material for the production of ethanol which could be used as automotive fuel by blending either with gasoline or diesel depending on the engine. Aside from all of these, usually as cassava starch is a pure, natural biopolymer that is suitable for chemical modification into a thermoplastic product for incorporation during the manufacture of several commercial materials, it has lately been used for the production of biodegradable plastics (Stevens, 2002). Cassava starch is made up of two polymers - amylose, which constitutes about 20 - 30% and amylopectin that contributes about 70 - 80% of the total amount (Nigel et al., 2004). Instructively these two polymers are generally under genetic control. Whereas the granule-bound starch synthase (*GBSS*) gene converts ADP-glucose to amylose, the branching enzymes (BE I and BE II) on the other hand are involved in the formation of amylopectin (Raemarkers et al., 2003).

New regulations, societal concerns and a growing global environmental awareness have triggered a paradigm shift in industry to develop products and processes that are friendly to the environment. Expectedly this has brought up to the fore the issue of designing materials from renewable resources that can be easily utilized, disposed, decomposed, and/or conserved. Ensuring that these materials are biodegradable and end up in an appropriate disposal system is desirable both from the environmental and ecological points of interest. The production of biodegradable plastics from cassava starch, which can easily be decomposed into carbon dioxide, methane and biomass following enzymatic action of microorganisms when disposed, is thus quite significant.

Quite understandably, research on starch-based materials has been widespread in recent years with many university and corporate laboratories assuming leading roles. In many of these cases, the researches have been intended to improve the mechanical properties of such materials for a number of commercial applications. For example, Stevens (2002) reported the production of several biodegradable plastics using formulations with different materials in a bid to increase their strength. During the production of some of the biodegradable plastics that were reported, he added various plasticizers to the materials, which improved their processability, flexibility and stretchability, by reducing intramolecular forces in them.

It has been reported earlier that while a high amylose content in starch signifies lower gel strength as well as gel stickiness (Chaplin, 2005); a high amylopectin level on the other hand confers on a product a better binding power because of its branched chains. Moreover, it has equally been demonstrated that the rate of degradation of bioplastics may vary depending on the season, microbial population in the soil, amount of moisture in the soil, soil pH and soil temperature (Stevens, 2002). This means that the rate and actual duration of biodegradability would obviously vary depending on the application and disposal environment of the products (Stevens, 2002). In fact, Ohtaki and Nakasaki (2000) have put the rate and duration required for complete degradation of the bioplastics they used in their study within the range of a small percentage to approximately 65% over an 8-day period at 50^0C composting. In a related development Wool (1993) has equally reported that the tensile strength of bioplastics decreases as the starch content increases. Invariably, this is an indication that the lower the tensile strength is of the bioplastic, the higher would be its rate of degradation. Due to the sensitive and highly hydrophilic nature of bioplastics, their tensile strengths tend to vary such that an excessively plasticized material could become flexible and pliable following a rapid absorption of water vapour, resulting in a lower tensile strength (Shah, 1984; Stevens, 2002).

Nigeria is currently the world's largest producer of cassava (FAO, 2006) with an estimated annual production capacity of about 39 million metric tons of tubers. Moreover, there is presently a renewed awareness and interest following a government directive in value-added processing of cassava roots into industrial starch and flour for utility in domestic industries as well as for export in order to attract premium price. Encouraged by this development, the present study, therefore, was designed to screen starch derived from two local cassava cultivars, one with high amylose content (TMS 92/02325) and the other with high amylopectin level (TMS 91/0324), for their ability to produce biodegradable plastics on the one hand and to evaluate the tensile strength and ease of degradability of the bioplastics so produced on the other.

Materials and methods

Tubers from the two cassava cultivars (9 months old) used in the study were obtained courtesy of Professor M. Akoroda of the high rainfall sub-station of the International Institute of Tropical Agriculture (IITA), Onne, Rivers State, Nigeria. Sorbitol, glycerol and agar were purchased from Fuza Chemical Ventures, Aba, Nigeria. The tubers were washed, peeled and grated to a fine mash. The grated cassava was mixed with a high volume of clean water (about 10 times the mash volume). Fibres in the mash were removed by sieving the watery mash through a fine muslin cloth while the fine starch particles were allowed to sediment. Immediately thereafter, the water was decanted and the sediments washed again to obtain a white, odourless and tasteless starch. The starch was dried under natural sunlight, thoroughly sieved to remove any unwanted particles, stored in airtight containers and labelled cultivar TMS

91/02324 with an amylase/amylopectin ratio of 19.61% and 80.39% and cultivar TMS 92/0325 with an amylose/amylopectin ratio of 23.78% and76.22%, respectively (Sanni, 2005).

Production of biodegradable plastics: Sorbitol, agar and starch were weighed according to the specific compositions desired using a Mettler balance. The formulations used in the current study contained 45%, 60%, 75% and 90% starch from the two cassava cultivars, respectively, as shown in Table 1. The solid materials were mixed together in distilled water according to the specific compositions used and an appropriate volume of glycerol (see Table 1) from a stock solution was added into the mixture and stirred thoroughly for dissolution. The mixtures produced were loaded into an oven at a regulated temperature of 60^0C - 85^0C for 3 - 8 minutes. At intervals, the contents were stirred to forestall solidification at the bottom. Each of the mixtures was removed from the oven when it began to simmer. Each bioplastic produced was then poured into a non-stick baking pan and allowed to dry for about 3 - 5 days, depending on the humidity, according to Stevens (2002).

Starch composition was determined as the total starch content/total weight of solid materials x 100.

Evaluation of the rate of degradation of the bioplastics (soil burial test): The biodegradable plastics produced were divided into tiny squares of $1mm^2$ each. A rectangular hole of about 1.4cm x 0.5cm was dug on the ground where the bioplastics were placed and covered completely with soil. Data on their rates of degradation were recorded at weekly intervals for a total duration of 7 weeks for the different levels of starch compositions evaluated in the current study.

The percentage of degradation was determined as the number of degraded portion/week/total number of small squares x 100.

Determination of tensile strength of bioplastics: Templates from two different products, polyethylene and styrofoam packaging material, which were designed in a similar form as the bioplastics derived from the cassava starch in the current study, were used as control. The width and thickness of the templates were measured using a meter rule and micrometer screw gauge, respectively, and recorded. Each sample was clamped in place and weights were added slowly and gently to the pan in short time intervals between each addition. The weights provided an increasing stress, which made the sample to become taut, elongating and breaking eventually. The weight at the point of breakage was accurately recorded.

Data analysis: Data collected from the soil burial test (biodegradability rate), tensile strength and thickness were subjected to analysis of variance test and least significance difference (LSD) was used to separate the means for significant results according to Obi (2001).

Results

Rate of degradation of the bioplastics: An analysis of the soil used for the degradation tests indicated that it had a pH value of 7.45, a nitrogen content of 0.14%, carbon content of 2.20%, an hydrogen content that was 1%, moisture (H_20) level that was 22.60% at a temperature of 25^0C.The results demonstrated that there was no significant difference ($P>0.05$) between the starch derived from the two cassava cultivars regarding their rates of degradation. However, as shown in Table 2 the levels of starch used showed a high significant difference ($P<0.05$) on the rate of biodegradability and this was in the order of 45% < 60% < 75% < 90%.

Tensile strength of the bioplastics: Table 3 is a presentation of results depicting the tensile strengths of the bioplastics produced from the two cassava cultivars. The results showed a high significant difference ($P<0.05$) between the two cassava cultivars as well as the levels of starch used. The two control materials used, that is, styrofoam packaging and polyethylene sachet, had $6.19 \pm 0.01kg/cm^2$ and $46.27 \pm 0.61kg/cm^2$, respectively. There was a high significant difference ($P<0.05$) across all the starch compositions tested (Table 3). The results equally showed a significant ($P<0.05$) effect of thickness on the tensile strength of biodegradable plastics (Table 4); an indication that the strength of the bioplastics produced was dependent on the thickness of the products.

Discussion

Many researchers have amassed lots of data using starch from different sources including maize, wheat, rice and potato for the production of biodegradable plastics. Thus far only a few have used cassava starch (Bastioli, 1997). The current results show that the production of biodegradable plastics using cassava starch is feasible as have also been reported by Stevens (2002).

Of even greater interest and significance drawn from the results of our current study are those for the soil burial tests, which are presented in Table 2. These data also confirm the report of Stevens (2002) that an increased starch proportion in the bioplastics increases degradability that is also dependent on the overall composition of the biodegradable plastics produced (Bartha et al., 1997). This is understandable because as the level of starch in the bioplastics is increased, the level of other constituents in it, especially agar, which serves as a gelatinizing agent, is reduced. Consequently, this would weaken the binding power of the bioplastic and easily predispose it to microbial attack and degradation. It is perhaps for this reason that bioplastics derived from 90% starch content degrade faster than the others containing much lower levels of starch. Naturally, starch is hydrophilic and thus any increased absorption of water by bioplastics due to high starch content expectedly would weaken the bonds and make the bioplastics soft, enhancing faster microbial attack. Invariably this would increase the rate of degradability of the bioplastics. The time during which biodegradation occurs could vary depending on the prevalence of some vital factors such as ample soil temperature, acidity of the soil, moisture level and population of micro-organisms (Bartha et al, 1997; Stevens, 2002). It is possible that the high rate of biodegradability observed in the current study could have been influenced by these factors, which may have been adequately available in the soil where the bioplastics were buried. As a matter of fact, Ohtaki and Nakasaki (2000) reported that degradability of biodegradable plastics ranged from a small percentage to approximately 60% over an 8-day period. Stevens (2002) equally reported the degradability of bioplastics in the order of a few days to a few weeks. The present results agree with both of these positions.

It was observed in the current study that though the two cassava cultivars used have different chemical characteristics regarding their percentage amylose and amylopectin contents, however, this did not appear to have made any significant impact on the degradability of the bioplastics produced. A plausible reason might be the fact that the differences in polymer contents between these two cultivars were not large enough to provide any reasonable effect on biodegradation. It would, however, be short-sighted and naïve to conclude based on only the current data that the ratio of amylose to amylopectin in any starch is not important in the degradation of bioplastics unless a screening is conducted with starches containing a much wider margin regarding levels of these two polymers.

The data on the tensile strength of the bioplastics show that those derived from starch of the TMS 91/02324 cultivar have a higher value than those from TMS 92/0325. It could be that the slight variance between the two cultivars regarding their percentage amylose and amylopectin contents may have contributed to the differences in tensile strength. Such reasoning is not out of order since it is known that a higher level of amylose in a particular starch variety usually leads to lower gel strength, which consequently confers upon it a greater level of reduction in product stickiness. Because of the branched chains in the molecules of amylopectin, it is assumed to have a higher adhesive or binding power. It is possible that such differences might have been responsible for the variance in tensile strength of the bioplastics from the two cultivars used in this study. This phenomenon might also be due to the fact that as the starch content increases, the product becomes highly hydrophilic and consequently, becomes softer and breaks easily, lowering the tensile strength. This possibly is the reason the tensile strength of bioplastics produced from TMS 91/02324 is higher than that of TMS 92/0325. Comparing the mean tensile strength of the two controls shows that there are no differences between the styrofoam packaging material and the four levels of starch inclusions, especially for cultivar TMS 91/02324. This however, does not imply that these biodegradable plastics produced can be used in place of styrofoam packaging material. The tensile strength of the polyethylene sachet cannot really be compared with the bioplastics produced because of the material (polyethylene) from which it is produced. Shah (1984) and Stevens (2002) observed that the tensile strength of some bioplastics, especially, those without synthetic polymer could be affected by atmospheric humidity because of their sensitivity to water vapour, resulting in varying tensile strengths. This implies that bioplastics having similar compositions might have this problem. According to Stevens (2002), control over this natural phenomenon is difficult. Wool (1993) equally reported that the tensile strength of biodegradable plastics decreases as the starch content in the formulation increases. Thus from the data presented here on tensile strength, it could be observed that a bioplastic with 90% starch composition had the highest tensile strength. This has not in any way contradicted the observations of Wool (1993), as the deviation could be as a result of the material thickness (Stevens, 2002). It is this discrepancy that might have caused the increase in tensile strength of the 90% bioplastics produced from the two starches. As the thickness of the bioplastics increases, it becomes more difficult to be stretched and the force required for breaking them individually increases (Shah, 1984; Stevens, 2002).

In conclusion, the results reported here are suggestive of the fact that bioplastics produced from cassava starch having a higher amylopectin level will enhance the tensile strength of the products but not necessarily their rates of biodegradation.

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