



Development of a Bioplastic Film for Food Packaging

Ijagbemi C. O.¹, Oloruntoba D.T.² and Adeoye A.O.¹

¹ Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria.
² Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure.

A B S T R A C T

Keywords:

Mechanical properties,
 Bio plastic films,
 Biodegradable
 polymer,
 Plasticizer.

*A biodegradable, eco-friendly, non-toxic polymer film was developed from sweet potato (*Ipomea Batatas* (L) Lam) starch. The extracted starch was sun-dried in an aluminium tray for two days before use. Glycerol at pH 6, was used in the plasticization of the starch in an acidic medium of 0.1M HCl. Neutralisation of the medium was done with a basic solution of 0.1M NaOH. The mixture was boiled to a temperature of 200° C, poured into a mould and then dried for 24 hours at 50° C, in an oven, to develop the bio-plastic film. Test specimens were prepared from the film and conditioned at 23° C ± 2o C for 24 hours to investigate its mechanical properties such as tensile strength, tensile modulus, extension, load and energy at break in accordance with the American Society of Testing of Materials (ASTM D882). A mixture of 18.75 g of starch, 75 ml of water, 2.50 ml of glycerol, 22.50 ml of NaOH with 22.50 ml of HCl produced 20 g of bio-film plastics from the compositions. Therefore, a conversion ratio of approximately 1:1 of starch to plastics was obtained in this work. The effects of glycerol on the mechanical properties were also evaluated. Results revealed that polymer plastic film with tensile strength of 9.26 MPa, Modulus of 175.25 MPa, glass transition temperature (T_g) of 970° C and melting point of 1200° C falls within the range of ASTM plastic films used for packaging purposes. It can be concluded that the bio-film developed can stand as a substitute for the production of shopping bags, sweet wraps, food packaging material for bread, chips, and other fast food.*

1. Introduction

As the motivation to “go green” continues across the globe, the environmental impact of persistent plastic wastes is raising general global alarm as disposal methods are limited. Incineration of the plastic wastes do generate toxic air pollution and satisfactory landfill sites are not available. Recycling methods for converting wastes are expensive and energy intensive. Besides, petroleum resources are depletable. It would be imperative to source for durable plastic substitutes, especially in short-term packaging and disposable items. In the United States, bio-polymer products industry has garnered attention as an available solution to this problem. Bio-plastic products are environmental-friendly and consist of a wide variety of products from household cleaners to plastic to fibers (Jody, 2008). This research provides relevant data on how polymer films can be developed from sweet potatoes which are easily grown in Nigeria. The resulting material is completely degradable by composting and it is applicable for food packaging. Food packaging material made from a

blend of potato, wheat and tapioca starch has proven durable enough to be baked in an oven and heated in a microwave.

The use of plastic materials is indispensable in today's world. Plastic is very useful in the building and construction, electronics (laptops wouldn't work well if they were made from glass), packaging and transportation industries. Plastics are used everyday in almost everywhere human being can be found. Plastics made from petroleum product are light, inexpensive, convenient, often disposable and fragile. Plastic containers seem to be the ideal way to refrigerate food and when an air-tight lid is provided, food can be stored, fresh, for days. It is estimated that known global resources of oil will run dry in 80 years, natural gas in 70 years and coal in 700 years but the economic impact of the depletion could hit much sooner; since prices will likely soar as resources are depleted (Grengross and Slater, 2000). It is clearly evident then that researchers need to work towards replacing fossil fuel resources with renewable resources as both fuel and raw materials. A large number of investigations have been carried out recently into the synthesis and manufacture of new thermoplastic materials that are more environmentally acceptable.

These new materials are designed to degrade into safe by-products at the end of the product life under composting conditions.

Annually, 125 millions of plastics are used throughout the world (Aburto et al., 1999). There is a prediction of an increase of 25 million tonnes of synthetic plastics accounted to 230 million tonnes from year 2006 to 2009. (Snell et al., 2009). As the natural environment is continuously polluted by these hazardous plastics, the development and production of environmental-conserved biodegradable plastics are rapidly expanding in order to trim down our reliance on synthetic plastics. The plastic industry has worked on the synthesis and on the formulation of durable material that are more and more adapted to their particular uses (Vert, 1992).

Polymetric materials are solid non-metallic compounds of high molecular weights. They comprise of repeating macromolecules and have varying characteristics depending on their composition. Each macromolecule that comprises a polymeric material is known as a "mer" unit. A single mer is called a monomer, while repeating mer units are called polymers. A variety of materials (renewable and non-renewable) are employed as feedstock sources for modern plastic materials. Plastics that are formed from non-renewable feedstocks are generally petroleum based, and reinforced by glass or carbon fibers (Williams and Pool, 2000). Renewable feedstocks include microbially grown polymers and those extracted from starch. It is possible to reinforce such materials with natural fibers from plants such as flax, jute, hemp and other cellulose sources (Bismarck et al., 2002).

Biodegradable polymers (those derived from plant sources) begin their life cycle as renewable resources, usually in the form of starch or cellulose (Lorcks, 1998). Innovative polymer research and development leads to large scale production of plastic converters. Ideally, the biopolymer will be dissolved in a bio-waste collection and later composted. This process will ultimately leave behind carbon dioxide and water which are environmental friendly by-products. Efforts to produce competitive biodegradable materials are often frustrated by the problem of finding optimal balance between mechanical properties, cost and acceptable level of biodegradability.

Starch, which is a biodegradable natural polymer and produced in abundance at low cost is reported to be one of the most promising candidates for fabrication of bio-plastics (Huangu et al., 2004). Bio-plastics are completely biodegradable and compostable. The innovation of this bio-plastic technology is an excellent example for a sustainable development, which means the responsible use of available natural resources and production processes that take environmental aspects and natural circulations into consideration.

2. Materials and Methods

2.1. Extraction of sweet potato starch

Yellow skinned sweet potato tubers (*Ipomea batatas* L.) were purchased from Mile 12, Market in Ketu, Lagos State, Nigeria. Glycerol (1,2,3-propanetriol) was purchased from Tunnex Laboratories, Demurin road, Ketu, Lagos. The extraction of starch from sweet potato tubers was carried out at the Biotechnology Laboratory of The Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos. Cleaning, peeling, slicing, grating of potatoes tubers were carried out followed by centrifugation using IEC CENTRA CL2

centrifuge. Sieving, using a laboratory strainer was done and followed by decantation. The resulting substrate was sun-dried for 24 hours to obtain the potato starch.

Table 1: Sweet potato starch film formulation 1

Sample A	1	2	3	4	5
Starch(g)	12.5	15.625	18.75	21.875	25.0
Water(ml)	50.0	62.500	75.00	87.500	100.0
HCl(ml)	15.0	18.725	22.50	26.250	30.0
Glycerol (ml)	2.5	2.500	2.50	2.500	2.5
NaOH (ml)	15.0	18.750	22.50	26.250	30.0

2.3 Preparation of film

The plastic solution formed is carefully cast in an aluminum mould which has been prepared to give a uniform thickness of the film, the liquid plastic was placed in a drying cabinet set at a 50 °C heating temperature. This process was continued for about 20 hours and the plastic polymer film was obtained. The processes described above were carried out at a constant volume of glycerol and increasing quantity of starch from the initial amount to 25 %, 50 %, 75 % and 100 %. Polymer films were produced for these. And then the film that gave the highest tensile strength, the quantity of starch that gave birth to it was kept constant and the quantity of glycerol increased by the same percentage given above.

Table 2: Sweet potato starch film formulation 2

Sample B	1	2	3	4	5
Starch(g)	18.75	18.750	18.75	18.750	18.75
Water(ml)	75.00	75.000	75.00	75.000	75.00
HCl(ml)	22.50	22.500	22.50	22.500	22.50
Glycerol (ml)	2.50	3.125	3.75	4.375	5.00
NaOH (ml)	22.50	22.500	22.50	22.500	22.50

2.4. Mechanical Tests

2.4.1. The preparation of the test specimens.

The test specimens were conditioned to conform with standard requirements of thin plastic sheeting in accordance with ASTM D882. From the developed plastic sheet, film strips of uniform width and thickness 1" x 6" (25.4 mm x 152.4 mm) were cut and conditioned at 23 0C ± 2 0C for a day before taken to the machine. Tensile testing of the bio-films was performed according to ASTM D 882 by using Universal Testing Machine (Instron 5567, USA), equipped with a 1 kN load cell at a crosshead rate of 12.5 mm/min. All tested specimens were required in rectangular shape differing from the conventional dumb bell shape of tensile testing.

The test specimens were placed within the grips of the Instron Universal Tester, tightened evenly and firmly to the degree necessary to minimize slipping during the test. The machine is operated until the specimen fails under load. At rupture, the force and deformation were determined.

3. Results and Discussion

3.1. Mechanical Properties

For the bio-plastic film developed to be applied for various engineering purposes, the mechanical properties of the films were evaluated in terms of tensile strength, young modulus, extension, load and energy at break to verify their ability to withstand fatigue for long term durability and heat treatments. The properties are related to the structural characteristics of the films, a food packaging material is usually required to have a reasonable stress with deformation with respect to its intended use. In general, food packaging material must be an undeformable material to provide structural integrity or reinforce food structure, or a deformable film for other applications (Gontard et al., 1992)

3.2. Tensile strength

Tensile strength is the property of a material used in describing the strength of such material. It is one of the fundamental tests in the application of plastic materials for different industrial uses. Since plastic films are susceptible to variability, determining the tensile strength of the developed film will ensure that minimum strength requirements are provided for its application for food packaging purposes. In this study, Instron Universal Tester I3369 was used in determining the tensile strengths of the films according to the standards of ASTM D882. The effects of starch and glycerol additions on the tensile strength of the films were investigated, this is shown in Figure 1a and 1b below.

In Figure 1a, the increase in starch quantity of the plastic films showed that the films obeyed Hooke's law until a starch quantity of 15.31 g (25% increase), after which the tensile strength of the film increases plastically with increase in the quantity of starch to a maximum of 9.26

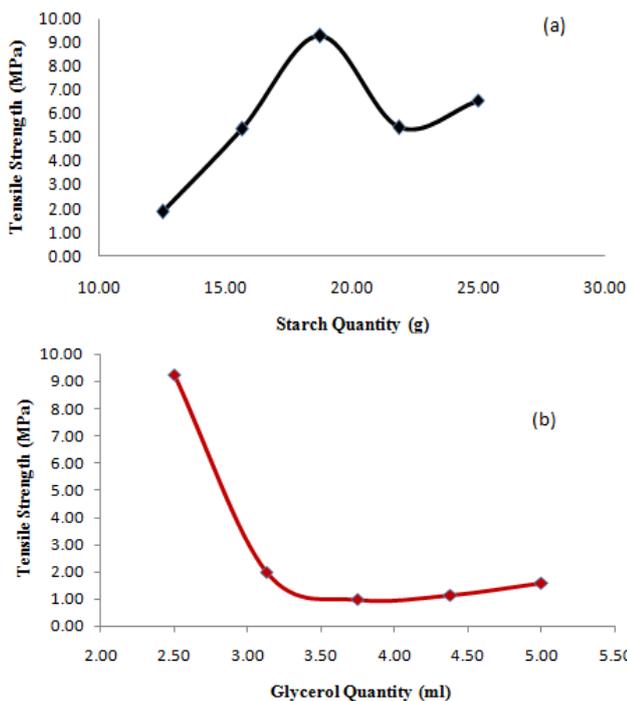


Fig 1: Variations of Tensile Strength with Percentage Quantity Increase of (a) Starch and (b) Glycerol

MPa for a starch quantity of 18.75 g (50% increase), a gradual decrease was observed with additional quantity of starch. While the increase in glycerol quantity shows that the tensile strength of the developed films decrease sharply with increasing glycerol quantity (Fig. 1b). These results from Figures 1 a and b agree with the previous works on cassava starch by Dayangku and Wan, (2011) and Torres et al., (2007). The study showed that the decreasing value in tensile strength which occurred at higher glycerol contents might be associated with the presence of free volume in the sample. These free volumes affected the tensile strength in the composites. Excessive composition of glycerol increased the mobility of mixture however it does not give much effect on the plasticizing process.

3.3 Tensile Modulus

Young modulus is another valuable property of a packaging material. It is used as an index of the stiffness of thin plastic sheeting. It measures the resistance of a material to plastic deformation and an important parameter in designing products which can be allowed to deflect only by a certain amount. It is the ratio of the pressure (stress) on the material to the strain of the material. Figure 2 shows the effects of starch and glycerol additions on the tensile modulus of the plastic bio-fi Fig 2: Variations of Tensile Modulus with Percentage Quantity Increase of (a) Starch and (b) Glycerol. Increase in starch quantity of films shows that the modulus increases plastically (non-linearly) with increasing starch quantity until a maximum value of 175.25 MPa for a starch quantity of 18.75 g (50% increase), additional percentage increase in starch quantity brought about a decrease in the tensile modulus of the films. Whereas, an increase in glycerol quantity revealed a sharp decrease in tensile modulus of bio-films.

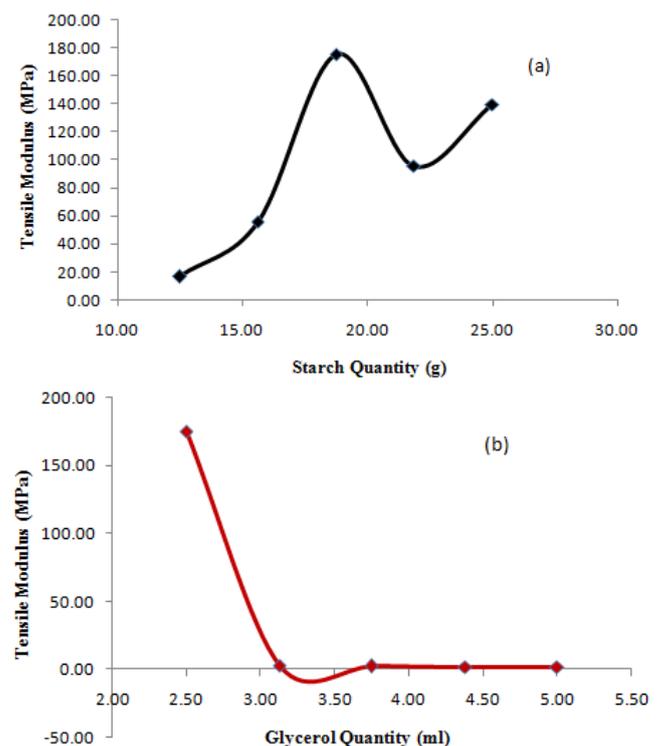


Fig 2: Variations of Tensile Modulus with Percentage Quantity Increase of (a) Starch and (b) Glycerol

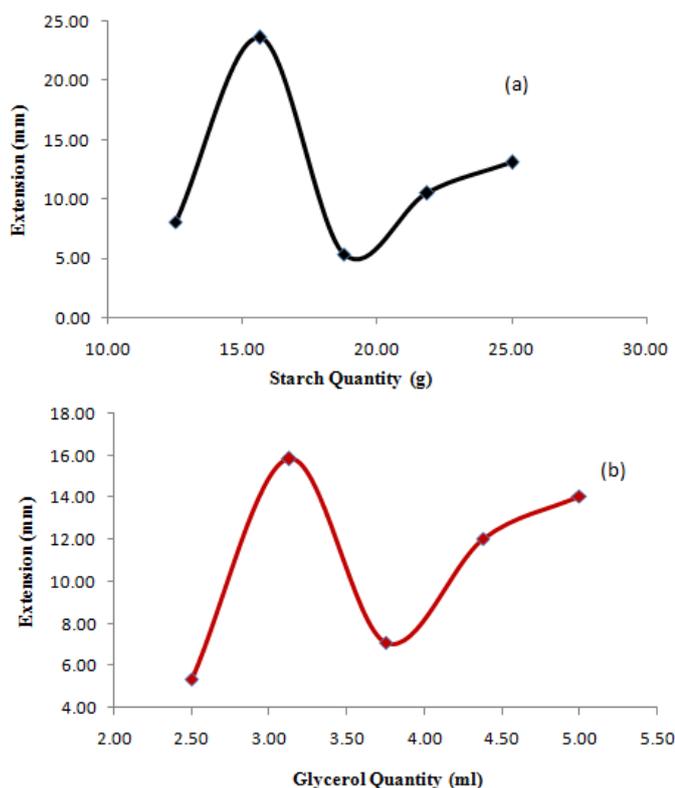


Fig 3: Variations of Extension at Break with Percentage Quantity Increase of (a) Starch and (b) Glycerol

Figure 2 shows the effect of increasing amount of plasticizer content in the mixture which tends to lower the interaction between polymer chains and therefore the resistance to the shear flow decreased (Lin & Ku 2008). The decline in the modulus of the developed bio-films as revealed in the figure may be due to imperfect distribution of the fiber in the film as the glycerol quantity increases. This trend is also supported by similar work on cassava by Dayangku and Wan, (2011).

3.4 Extension at Break

Figure 3 illustrates the effects of the additions of starch and glycerol quantities on the elongation at break of the plastic films. An increase in starch quantity brought about an initial increase in the elongation (extension at break) of the films (Fig. 3a), with percentage starch increase, the elongation increases to a maximum of 25.64 mm for starch quantity of 18.75 g (50% increase), the elongation decreases sinusoidally as the percentage starch quantity is increased. This may be due to the fact that the starch-to-glycerol ratio has not reached saturation. The effects of glycerol additions on the extension at break is very similar to that observed for the increment in starch as supported by similar work on plastic films from cassava starch by Preechawong et al., (2004) showed that the decrease in extension at break value was probably due to more plasticizer content which may lead to lower interaction between polymer chains. Increasing amount of glycerol will increase the composite mobility but it will affect the mechanical properties by lowering the strength of the samples (b). Relatively poor mechanical properties of natural composites have been ameliorated by adding large amounts of plasticizers, such as glycerol or ethylene glycol or by modifying the chemical properties of raw materials itself (Lin and Ku, 2008).

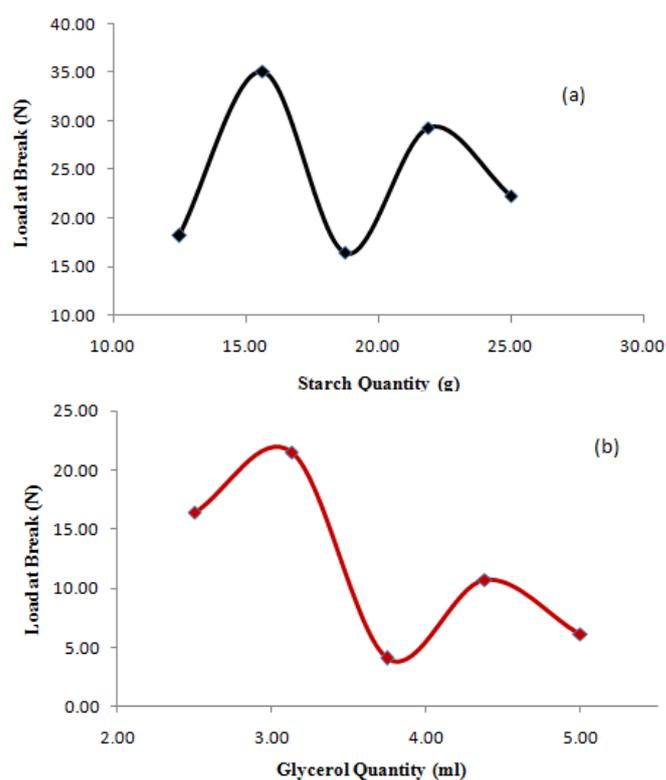


Fig 4: Variations of Load at Break with Percentage Quantity Increase of (a) Starch and (b) Glycerol.

3.5 Load at Break

Figure 4 shows the effects of increase in starch quantity on maximum load that the developed bio-plastic film could withstand during application or use. A gradual increase in load at break was observed as the percentage starch quantity increased (Fig. 4a). A maximum load of 35.19 N was observed for a starch quantity of 15.62 g (25% increase), a further increase in starch quantity resulted in a decline in the load at break of films. A similar behaviour is also observed although at lesser values for the increase in the quantity of glycerol in the films (Fig. 4b). This trend of behavior for load at break correlates with the trends for the tensile strength and young modulus of the films. These findings explain the fact that as the tensile strength and modulus of a material increases and decreases with respect to the starch-glycerol proportions in the films, the load bearing capacity of the material is proportionately affected accordingly.

3.6 Energy at Break

The tensile energy at break (TEB) is the total energy absorbed per unit volume of the specimen up to the point of rupture. In some texts this property has been referred to as toughness. It is used to evaluate materials that are subjected to heavy abuse or that can stall web transport equipment in the event of a machine malfunction in end-use applications. However, the rate of strain, specimen parameters, and especially flaws can cause large variations in the results. In that sense, caution is advised in utilizing TEB test results for end-use design applications. Materials that fail by tearing give anomalous data which cannot be compared with those from normal failure.

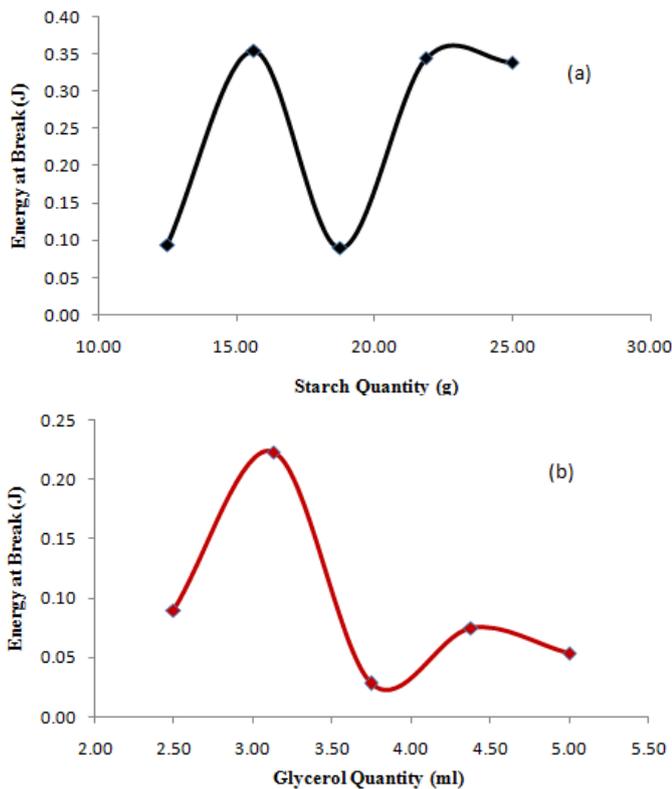


Fig 5: Variations of Energy at Break with Percentage Quantity Increase of (a) Starch and (b) Glycerol.

Figure 5 shows the effects of the increase in starch and glycerol quantities on the energy at break of the bio-films. As the starch quantity

Acknowledgement

The authors would like to appreciate the tremendous assistance of the following people, Mr Imoisili Patrick of the Engineering Materials and Development Institute, Akure. Messrs Alhasan and Okorie, of the Foundry and Bio-technology Laboratory of FIRRO, Lagos

References

- Aburto J, Alric I, Thiebaud S, Borredon E, Bikiaris D, Prinos J, Panayiotou C (1999). Synthesis, characterization, and biodegradability of fatty-acid, esters of amylase and starch. *J. Appl. Polymer. Sci.* 74: 1440-1451.
- ASTM D882-97, Standard Test Methods for Tensile Properties of Thin Plastic Sheeting, ASTM, Philadelphia, PA, USA.
- Bismarck A, Aranberri-Askargorta I, Springer J, Lampke T, Wielage B, Samboulis A, Shenderovic I, Callister WD (1999). *Materials Science and Engineering: An Introduction*, New York, N. Y.: John Wiley and Sons.
- Dayangku IM, Wan AWAR (2011). Tensile and Absorption Properties of Biodegradable Composites Derived from Cassava Skin/ Polyvinyl Alcohol with Glycerol as Plasticizer. *Sains Malaysiana* 40(7): 713-718.
- Gontard N, Guilbert S, Cuq J.L (1992). Edible Wheat Gluten Films: Influence of the main process variables on film properties using response surface methodology. *Journal of food science*. 57(1): 190-195.
- Grengross T and Slater S (2000). "How green are green plastics?" *Scientific American*. 283 (2): 36-41.
- Huangu MF, Yu JG, Ma XF (2004). Studies on the Properties of Montmorillonite Reinforced Thermoplastic Starch Composites, *Polymers* 45, 7017-7073.
- Jody E, Pollok-Newson (2008). Newsletter. Corn Marketing Program of Michigan. Internet Assessed May 09, 2010; <http://www.micorn.org>.
- Lin CA, Ku TH (2008). Shear and Elongation Flow Properties of Thermoplastic Polyvinyl Alcohol Melts with Different Plasticizer Contents and Degrees of Polymerization. *Journal of Materials Processing Technology*, 200: 331-338.
- Lorcks J (1998). Properties and applications of mater-bi starch-based materials. *Polymer Degradation and Stability*, 59(1-3): 245-249.
- Myllarinen P, Buleon A, Lahtinen R, Forssell P (2002). The crystallinity of amylose and amylopectin films.

of the films increases (Fig. 5a), the energy the film could withstand before failure varies sinusoidally as shown in the result.

The effect of the percentage increase in glycerol quantity (Fig. 5b) on the energy at break followed an almost similar trend with that of starch additions but at lower values. These results are similar to the behaviour of plastic films made from cassava starch (Myllarinen et al., 2002), that the interactions between the plasticizer and starch are weak for a plasticizer amount below 10 % wt. The material is then fragile and it is difficult to work with it. When the plasticizer content becomes higher than 20 % wt, flexibility and elongation properties improved.

4. Conclusion

The following general conclusions can be drawn from the results of this work: 1. The addition of plasticizer causes the decrease of tensile strength and tensile modulus of the developed bio-films, this is indicative that the plasticizer penetrates the polymer chains and decreases the intermolecular forces. 2. Depending on the desired strength for a particular application, the varying strength of the different formulation can easily be harnessed for varying applications. 3. The tensile strength and modulus of the developed materials are within the range to make it suitable as a healthy substitute to conventional polymer film products. Up to a maximum of 9.26 MPa tensile strength, 175.25 MPa tensile modulus, a glass transition temperature T_g of 97 °C and melting point of 120 °C was obtained from the sweet potato polymer films.

- Carbohydr. Polym. 48, 41-48.
- Preechawong D, Peesan M, Supaphol P and Rujiravanit R (2004). Characterization of starch poly(ϵ -caprolactone) hybrid foams. *Polymer Testing*, 23: 651-657.
- Snell KD, Peoples OP (2009). PHA Bio-plastic: A Value-added Co-product for Biomass Bio-refineries. *Biofuels, Bioproducts and Biorefining*, 3, 456-467.
- Torres F, Arroyo O. and Gómez C (2007). Processing and mechanical properties of natural fibre reinforced thermoplastic starch biocomposites. *Journal of Thermoplastic Composite Materials*, 20: 207-223.
- Vert M (1992). Preface. *Proceedings of the Second International Scientific Workshop on Biodegradable Polymers and Plastics*, Montpellier, France. 5-8.
- Williams G, Pool R (2000). Composites from natural fibers and soy oil resins. *Applied Composite Materials* 7 (5-6): 421-432