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Producing of Biodegradable Plastic Films from Unmarketable Potato Tubers

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Abstract: This study was conducted to reduce the volume of solid wastes by using unmarketable potato tubers for producing biodegradable plastic films to substitute oil-based plastics “OBP” which is often not biodegradable. Starch-based plastic films “SBP” were produced with different concentrations of glycerol (5, 10,15, 20,25, 30, 99.5%v/v) as a plasticizer. The physical properties of SBP including thickness, density, water absorption, and biodegradability, were studied, as well as mechanical properties including tensile strength, modulus of elasticity, elongation % and the required energy for the firm were also investigated compared with OBP samples. The results showed that the maximum value of extracted starch was 13.5% obtained by blending potato tubers. SBP films with elevated glycerol concentration increased the sample thickness but decreased its density. Glycerol 20% gave the best flexible compact structure SBP films. The average thickness and density of SBP film (20% glycerol) were 0.25 mm and 80.11 Kg/m^3 respectively. Meanwhile, the average thickness and density for OBP films were 0.41 mm and 24.39 Kg/m^3 respectively. The rate of mass loss of SBP films with 20% glycerol concentration was 72% after 96 days while the rate of mass loss for OBP films is neglectable. Consumed energy for the firm was 44.05 and 31.06 N. mm.

1 Introduction

Many countries can not manage solid wastes through proper methods, and these wastes have harmful effects on health and the environment. Egypt produces annually about 90 million tons of solid waste which equals 55.000 tons per day. (Hashem 2020). The mass generation rate of solid waste was estimated as 0.6 to kg/day/capita, with an annual increase of 3.4%, (Kaza et al 2018). One ton of transferring solid wastes costs nearly 100 L.E from collection to disposal. The average cost recovery is about 70 L.E/ton and the total cost recovery is around 200 million L.E./year. The type of waste determines the selling price of sorted waste per ton. The mass of solid waste final destination is 5% landfilled, 9% composted, 83.5% open dumped, 2.5% recycled.

Many researchers mentioned the importance of agricultural waste management and converted it into valuable and useful products (Gupta et al 2019, Maji et al 2020, Duque-Acevedo et al 2020, He et al 2021, Fareed et al 2020, Maraveas 2020). The reduction of wastes defined by Elbasiouny et al (2020) that the reduction of waste means the reduction of weight, and the concept of "Recycling" means the re-use wastes of materials again.

Das et al (2019), and De Clercq et al (2017) observed that our oceans are polluted due to increasing consumption of conventional plastic because most countries do not have suitable management of plastic waste systems. Chua et al (1999) reported that the big difference between conventional plastic and bioplastic is that bioplastic made from renewable sources is biodegradable. Getting rid of oil-based plastic is extremely difficult since when burning it gives off toxic chemicals such as dioxins. Mohee and Unmar (2007) indicated that bioplastics reduce carbon footprint and do not require fossil fuels like oil-based plastics. In addition, bioplastic has the potential to reduce the volume of municipal waste generated. Bioplastics can be composted, thus they can be collected together with food scraps or yard waste and diverted to compost heaps which can be used to feed the soil and grow more plants. Around 6% of the world's oil supply is used in the production of plastics and it is mainly used for plastic packaging and vehicle assembly and in construction. (Bayer et al 2014). Biodegradable plastic produced from spinach stems, parsley, rice hulls and cocoa pod husks have mechanical properties comparable to conventional plastics. Using starch in the manufacturing of bioplastics will reduce the levels of environmental pollution. Conventional plastic takes 3.2 metric tons of carbon dioxide but bioplastic takes only 0.8 metric tons of carbon dioxide. Kim et al (2003) showed that, in order to reduce the rate of environmental pollution, non-biodegradable plastics can be replaced by bioplastics which can be made from potato starch. PotatoPRO (2014) mentioned that Egypt is one of the top 20 producers of potatoes worldwide and the top largest producer in Africa. So, the objective of the present study is to find innovative solutions to reduce the accumulation of municipal waste and ameliorate the quality of life in urban and rural villages via sustainability. To achieve this goal, the following steps were taken:

1. Utilizing some starch-rich agro waste in the production of biodegradable starch-based plastics, unmarketable potato tuber.
2. Analyze the physical and mechanical properties of starch-based plastic compared with traditional plastics.

2 Materials and Methods

The procedures for extracting starch from unmarketable potato tubers, preparing starch-based bioplastic samples and testing their physical and mechanical properties were carried out during the period from April 2020 until February 2021 in the laboratory of the Biochemistry Department and the Laboratory of the Agricultural Engineering Department - Faculty of Agriculture - Ain Shams University.

2.1 Potato tuber

Unmarketable potato tubers (*Solanum tuberosum, cv. Spunta*.) obtained from Osiem's region vegetable local market, Giza governorate. As mentioned by (Ereifej et al 1997). The chemical composition of potato tuber cv. *Spunta* is presented in **Table 1.**

2.2 Chemicals

The chemical materials used for the preparation of Starch-based bio-plastic film were 0.1 M HCL, 0.1 M Na OH and 99.5% glycerol obtained from El-Gomhoria company located in 23 El Sawah st. El-Amiria region, Cairo, Egypt. Glycerol is an additive that softens the material. It functions as a plasticizer used in bio-plastic film production. It is a colorless, odorless, viscous liquid that has a high boiling point and freezes to form a paste.

2.3 Synthetic oil-based plastic

The conventional oil-based plastic film samples were used for comparison with the prepared starch-based bio-plastic samples obtained from Hyma Plastic Company. 22 Al Obor Gardens, Salah Salem St., Nasser City, Cairo. Oil-based plastic film samples with dimensions 28*22 cm with different thicknesses "500:2000 μm" with high-density polyethylene (HDPE) 15% and low-density polyethylene (LDPE) 85%. The oil-based plastic samples are called (OBP).

2.4 Extraction of starch

The starch extraction process from unmarketable potato tubers was carried out according to Salisu et al (2013), and Oladayo et al (2016) which involves after removing damaged parts of potato tubers infected with fungal or bacterial diseases, the unmarketable potato tubers were properly washed with water to remove soil particles before being peeled, it was cut into slices of different thickness, and part of it was also ground in the blender in the presence of water. The homogenates

Table 1. Chemical composition and total solids contents of potato cultivars Spunta (dry weight basis)

Contents	Carbohydrates	Total solids	Fibers	Ash	Protein	Fats
Amount %	76.6	20,7 %	8.2	3.58	11.3	0,35

were mixed with distilled water [homogenate: water (1:5)] and then sieved. The resultant slurry was allowed to settle for 6 hours before the supernatant was decanted. The sediment was washed several times by re-suspending in distilled water and precipitating. The starch mash was dried at 50°C to constant weight. The starch was then sieved (sieve size of 249–212 μm). The sieved material was packed in an air-tight plastic and stored at room temperature for further use. The stages of the potato extraction process from unmarketable potato tubers are presented in **Fig 1**.

2.5 Production steps of bio-plastic films from unmarketable potato tubers

The methodology of producing the bioplastics is carried out according to Soomaree (2016). Add 15 g potato starch to 150 ml distilled water in a 500 ml beaker and a mixture of 18 ml of 0.1 M HCL and the same amount of 0.1 M NaOH for neutralization. Add 12 ml of Glycerol in each treatment as a plasticizer then magnetically stir at 200 r.p.m and 100°C and for about 10 minutes. After 1 hour the mixture turned into opaque gel. This gel was spread on trays. The trays of samples were left to dry at room temperature. After drying, the samples were converted into plastic sheets. Production steps of starch-based plastic films from unmarketable potato tuber were presented in **Fig 2**.

2.6 Test Variables

2.6.1 Starch extraction variables

The starch was extracted from un-marketable potato tubers after cutting into slices of different thicknesses as follows:

(0 mm “blended”, 1.5 mm, 2 mm, 4 mm)

2.6.2 Starch-based plastic production variables

Starch-based plastic film samples were prepared using seven concentrations of glycerol as follows:

(5%, 10%, 15%, 20%, 25%, 30%, 99.5%)

2.7 Samples preparation for tests

To compare the physical and mechanical properties of the produced starch-based plastic “SBP" samples by all tested glycerol concentrations with conventional oil-based plastic “OBP” films. The films from “SBP” and “OBP” were cut into samples with dimensions of 115 mm long and 32 mm wide strips. In order to make reliable comparisons between different samples, it is necessary to standardize the humidity conditions, as well as the temperature, to which specimens of these materials are subjected prior to and during testing. All bioplastic films were conditioned prior to being subjected to physical and mechanical tests according to the standard method. Films used for testing Tensile Strength (TS) were stored at controlled conditions “desiccators” (25˚C and 75% of relative humidity) for 48 hours before measurements.

2.8 Physical properties

2.8.1 Thickness

The thickness of starch-based plastic samples was measured by using a digital vernier caliper. The thickness was calculated during the tensile test and the statistical values of the sample thickness for each treatment were recorded. Determinations of biodegradability and mechanical properties were by using an average thickness equal to 0.25 mm.

2.8.2 Density “ρ”

The density of the starch-based bioplastic “SBP” samples with dimension (A*T) mm^3 was calculated directly by measuring the mass and volume of the sample for each glycerol concentration.

Density “ρ” = $\frac{m}{A*T}$ (kg/m^3) ………………. (1)

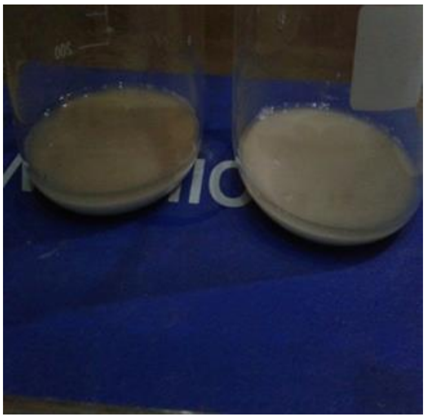
Where, ρ= density, (kg/m^3), m = mass of the sample (kg), A= area = Length*Width (mm^2)
and T= thickness of the film (mm).

(a). Unmarketable potato tuber

(b). Soak the grated or blended potato slices in water for 6 hours

(c). Double-layered cheesecloth for filtration

(d). Filtration of starch for 6 hours



(e). Removing of dark water

(f). Adding amount of water to starch and left 6 hours for starch sedimentation

(g). Sedimentation of starch after water extraction

(h). Dried starch

Fig 1. Stages of Starch extraction process from unmarketable potato tubers

(a). Operating of the magnetic stirrer to prepare bioplastic sample

(b). Turning the mixture to opaque gel

(c). Separate the gel and leave it to dry

Fig 2. Production steps of starch-based plastic film samples from potato tuber

2.8.3 Water Absorption Capacity (W.A.C)

The water absorption capacity was measured according to D570 (ASTM 1998). Two types of plastic samples were starch-based plastic “SBP” and oil-based plastic “OBP” having the same surface area “1 x 2 cm2”. Samples of the two types of plastic were submerged into a beaker containing 60 mL of distilled water “pH 7, room temperature “25°C”. After two hours, the samples were removed from the beaker then water was removed from the surface of these samples with a paper towel. The samples were weighed and re-submerged into the water. Samples were weighed again after each 2 h for 24 h following the same procedure. All measurements were performed in triplicates. The percentage of water absorption of initial weight was determined from the following equation:

$$(W.A.C)=\frac{(\text{Mass of wet film} - \text{Mass of dry film})}{\text{Mass of dry film}} \times 100\ (\%)\ .\ (2)$$

2.8.4 Biodegradability Test

The Biodegradability of the two types of plastic samples SBP and OBP was determined on the basis of mass loss index. Adding 220 g wetted soil in a glass beaker on a high 5 cm laboratory scale. The sample was (2x2 cm^2) constant mass (Mo). The sample was transferred from the beaker and soil particles conjoined this sample were removed and then dried in the sun for 3h. Data was recorded every 72 h to measure the mass M_f. This method was repeated every 72 h and every time, 10 ml water was for the soil before the burial of the sample. The percentage of mass loss (M_L) was calculated from the following equation.

$$M_L\ (\%) = \frac{(M_O - M_F)}{M_O} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ (3)$$

Where, M_L = Mass Loss, (%), M_O = Initial mass of the sample before burial (g), M_f = Final mass of the sample after burial, (g).

2.9 Mechanical properties

Tensile strength, modulus of elasticity "young, s modulus" (E), elongation and firm test for the “SBP” and “OBP” samples were determined at ambient conditions 25°C and RH 48%, according to the method D882-18(ASTM 2018). Using a computer-type bench top materials tensile testing machine (Tinius Olsen - model H5ks - USA). The films were cut into samples of 32 mm wide and 115 mm long. The plastic samples were fixed between two jaws (upper jaw moving, lower jaws fixed) with the rate of speed was 1mm/s. The data were recorded, and the mechanical parameters were calculated as follows:

2.9.1 Tensile strength (MPa)

Tensile strength is obtained from stress-strain curves by using the following equation:

$$\text{Tensile strength (MPa)} = \frac{(\text{Maximum force})}{\text{Initial cross section area}} \ \ldots\ldots\ldots\ldots\ (4)$$

2.9.2 Elongation at break (%)

Elongation at break is an indication of plastic flexibility and is expressed as a percentage, obtained from stress-strain curves by using the following equation:

Elongation at break $(\%) = \frac{(\text{Deformation})}{\text{Initial length}} \times 100$ ………… (5)

2.9.3 Modulus of elasticity (E)

Modulus of elasticity was calculated using the following equation:

$$E\ (MPa) = \frac{stress}{strain} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

2.9.4 Consumed energy for the firm (N.mm)

The consumed energy for the firm was calculated from the area under the curve.

2.10 Statistical Analysis

To select the recommended glycerol concentration for producing bio-plastic films, Glycerol was used in seven levels of 5, 10, 15, 20, 25, 30 and 99.5%, where each level represents three treatments. The collected data were statistically analyzed to get values of (max, min, average, standard deviation (δ) (STDV), and coefficient of variance (C.V) using the Microsoft Office Excel Program.

3 Results and Discussions

3.1 Starch extraction

Fig 3 represents the effect of potato slice thickness on the percentage of extracted starch. The recorded data revealed that the extracted starch % from unmarketable potato tuber increased with decreased slice thickness. The maximum value of extracted starch was 13.5% when blending the unmarketable potato tuber. Meanwhile, the minimum value of extracted starch was 4.2% when the slice thickness was 4 mm.

3.2 Physical properties

3.2.1 Thickness, mm

Table 2 represents the SBP samples' thickness statistical values (Max., Min, Average, STDEV and coefficient of variation) with different glycerol concentrations compared with OBP samples. It is clear that; the thickness of SBP samples was slightly affected by the Glycerol concentration, where the average thickness increased from 0.22 to 0.25 and 0.31 mm with increased glycerol concentration from 5 to 20 and 30 % respectively. Meanwhile, OBP average thickness was 0.41 mm.

3.2.2 Density "*ρ*" Kg/m^3

Table 3 Represents the SBP samples' density statistical values (Max, Min, Average, STDEV and coefficient of variation) with different glycerol concentrations compared with OBP samples. It is clear that, the density of SBP samples was slightly affected by the glycerol concentration, where the average density decreased from 91.06 to 80.11 and 63.85 Kg/m^3 with increased glycerol concentration from 5 to 20 and 30 % respectively. Meanwhile, OBP average density was 24.39 Kg/m^3.

3.2.3 Water Absorption %

Fig 4 represents the water absorption capacity % of starch-based plastic films "SBP" 20 % glycerol, compared with oil-based plastic "OBP" 15% HDPE. It is clear that the water absorption of SBP samples was 49.11% within two hours and 83.33% within 24 hours. While the absorption capacity for OBP samples was 35.11%. It means that SBP films at 20 % glycerol have a higher ability to absorb water because of the hydrophobicity of the glycerol, Whereas the higher ability to absorb water made SBP probably not used in the food industry. Thus, the possibility of a proposal put some additives for SBP samples to increase the resistance of water absorption.

3.2.4 Biodegradability

Fig 5 represents the mass loss % "Biodegradability" of starch-based plastic "SBP" 20% glycerol, compared with oil-based plastic "OBP" 15% HDPE. It is clear that the biodegradability of two types of plastic films buried in moist soil for 96 days was that, within four weeks, the SBP samples lost 30% from their mass "biodegraded" and this value increased to 72% after 96 days. On the other hand, within the investigation time of 96 days, OBP does not show any considerable mass loss value "non-degraded". Thus, the higher ability of SBP films to biodegrade makes it a suitable material for the manufacture of single-use packaging products that are in need locally and globally as eco-friendly products instead of oil-based plastic.

3.3 Mechanical properties

3.3.1 Tensile strength

Fig 6 represents the effect of glycerol concentration on tensile strength of starch-based plastic "SBP" compared with oil-based plastic "OBP" films "15% HDPE". It is clear that tensile strength increased with

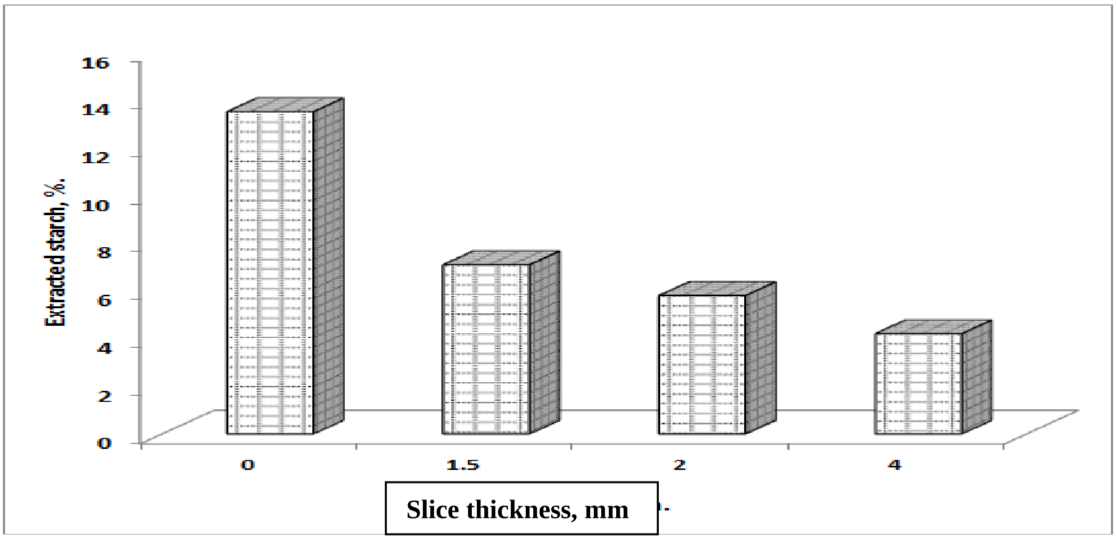


Fig 3. The effect of potato slice thickness on the percentage of extracted starch

Table 2. Effect of glycerol concentration on SBP films thickness statistical values (Max, Min, Average, Stander deviation and coefficient of variation) compared with OBP films

Statistical Values	**Starch-based plastic "SBP"**							**Oil-based plastic. "OBP"**
	Glycerol conc. %							
	5	**10**	**15**	**20**	**25**	**30**	**99.5**	
	Thickness (mm)							
Max.	0.23	0.25	0.26	0.26	0.27	0.29	0.34	0.41
Min.	0.21	0.23	0.23	0.24	0.24	0.25	0.29	0.41
Average	0.22	0.24	0.24	0.25	0.25	0.27	0.31	0.41
SD	0.01	0.01	0.02	0.01	0.02	0.02	0.03	0
C.V.	0.06	0.05	0.08	0.05	0.08	0.1	0.1	0

Table 3. Effect of glycerol concentration on SBP films density statistical values (Max, Min, Average, STDEV and coefficient of variation) compared with OBP films

Statistical values	**Starch-based plastic "SBP"**							**Oil-based plastic. "OBP"**
	Glycerol conc. %							
	5	**10**	**15**	**20**	**25**	**30**	**99.5**	
	Density (Kg/m^3)							
Max.	95.23	86.9	86.9	83.33	83.33	80	68.9	24.39
Min.	86.9	80	76.9	76.9	74.07	68.9	58.8	24.39
Average	91.06	83.45	81.9	80.11	78.7	74.45	63.85	24.39
SD	5.84	4.8	7.07	4.5	6.5	7.8	7.14	0
C.V.	0.06	0.05	0.08	0.05	0.08	0.1	0.1	0

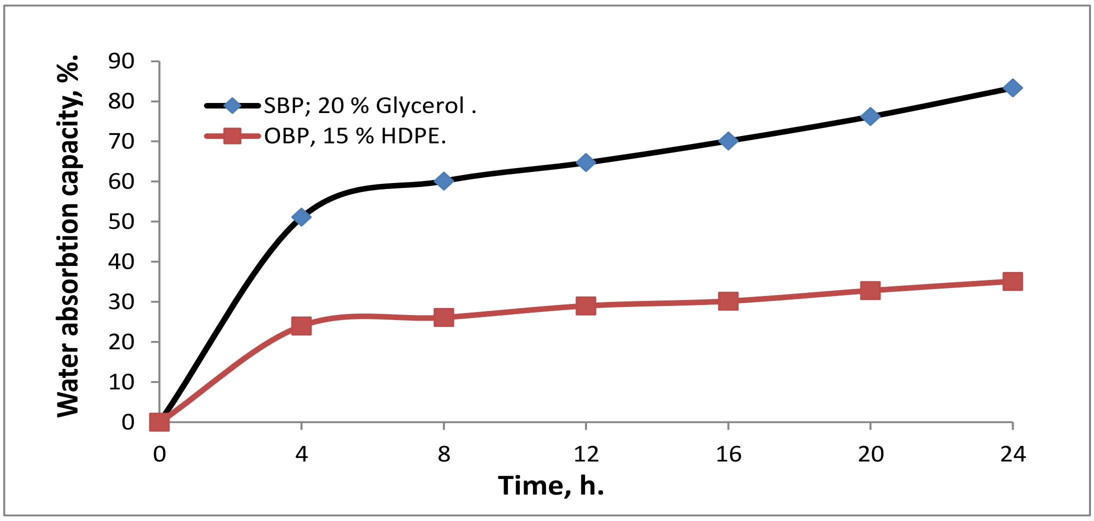


Fig 4. Water absorption capacity % of starch based plastic "SBP" compared with oil based plastic "OBP"

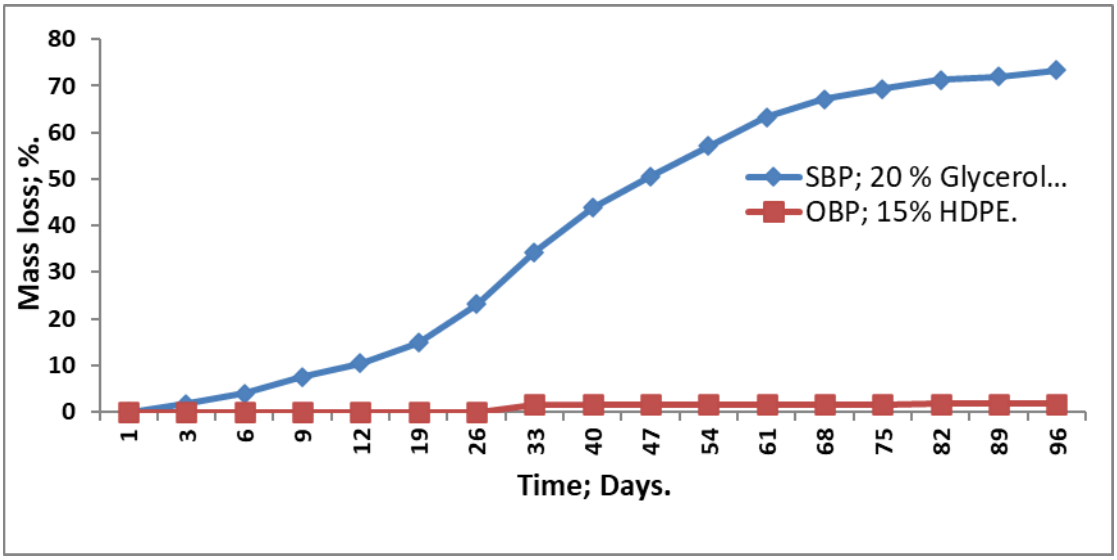


Fig 5. Mass loss % "Biodegradability" of starch-based plastic "SBP 20 % glycerol concentration" compared with oil-based plastic "OBP 15% HDPE".

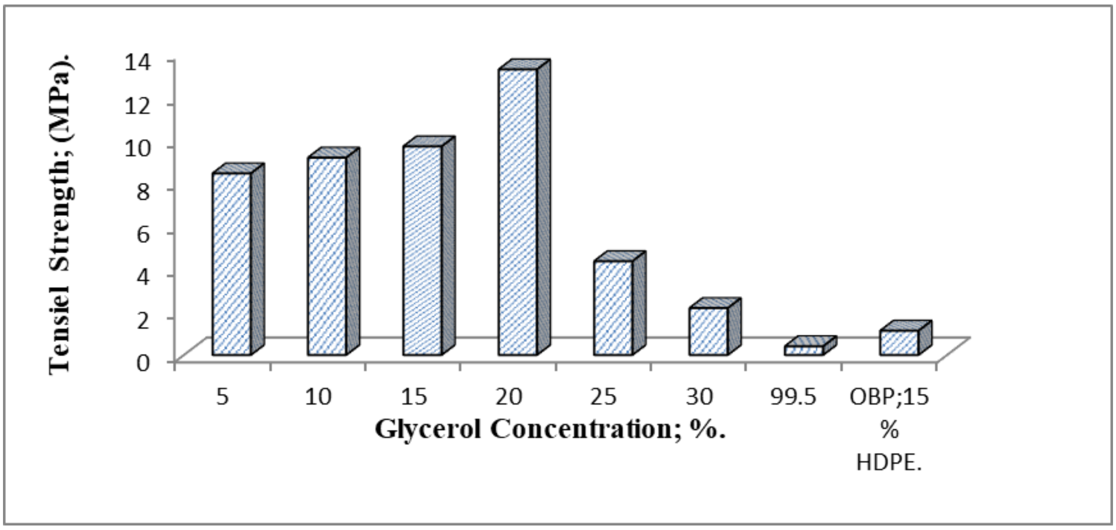


Fig 6. Effect of glycerol concentrations on tensile strength of starch-based plastic "SBP" compared with oil-based plastic "OBP" films "15 % HDPE".

increasing of glycerol concentration from 5 to 20% then reduced to the lowest value with glycerol concentration of 99.5%. The maximum and minimum tensile strengths were (13.23 to 0.4MPa) recorded with glycerol concentration (20 and 99.5%) respectively. Meanwhile, the tensile strength recorded with oil-based plastic "OBP" films was 1.12MPa. The value of tensile strength increased with an increase in glycerol concentration from 5 to 20 % and decreased with increasing glycerol concentration by more than 20%.

3.3.2 Modulus of Elasticity

Fig 7 represents the effect of glycerol concentration on the modulus of elasticity of "SBP" concentration of 99.5%. The maximum compared with "OBP" films. Modulus of elasticity. It is clear that; the modulus of elasticity increased with increasing glycerol concentration from 5 to 20%, then reduced to the lowest value with glycerol and minimum modulus of elasticity were (1556.73 and 7.41 MPa) recorded with glycerol concentration (20 and 99.5%) respectively. Meanwhile, the modulus of elasticity recorded with oil-based plastic "OBP" films was 44.97 MPa. It means that the Starch-based plastic "SBP" sample bearing strength was higher than the value recorded with "OBP" films.

3.3.3 Elongation at break

Fig 8 represents the effect of glycerol concentration on the elongation percentage of starch-based plastic "SBP" compared with oil-based plastic "OBP" films. It is clear that elongation behavior increased with increasing glycerol concentration. The maximum and minimum elongation SBP films were (106.43 and 100.45%) recorded with glycerol concentrations 5 and 99.5% respectively. Meanwhile, the corresponding value of elongation% for oil-based plastic "OBP" films was 107.5%.

3.3.4 Firm force

Fig 9 represents the effect of concentration on the firm force of "SBP" compared with "OBP" films. It is clear that; the firm force for oil-based plastic "OBP" films was 1.08 N, while SBP 20% glycerol firmed by 0.916 N.

3.3.5 Consumed energy during the firm

Fig 10 and 11 represent the consumed energy during the firm of the starch-based plastic "SBP" and oil-based plastic "OBP" films; the area under the curve equals consumed energy during the firm test. The recorded data revealed that; the consumed energy for firm strength with starch-based plastic "SBP" was 44.05 N.mm, Meanwhile, the corresponding value recorded with oil-based plastic "OBP" was 31.06 N.mm.

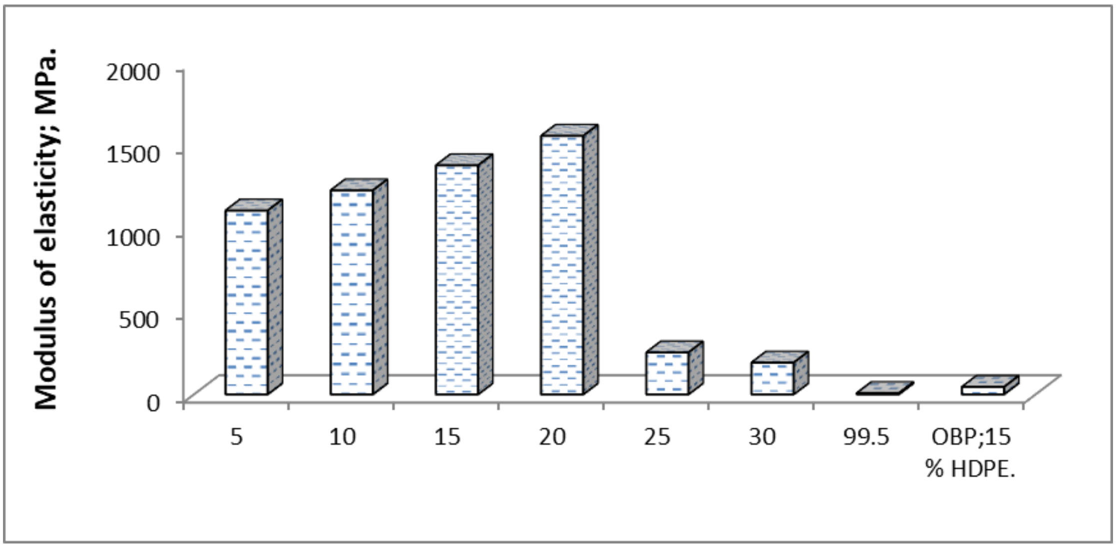


Fig 7. The effect of glycerol concentrations on modulus of elasticity of "SBP" compared with oil based plastic "OBP" films

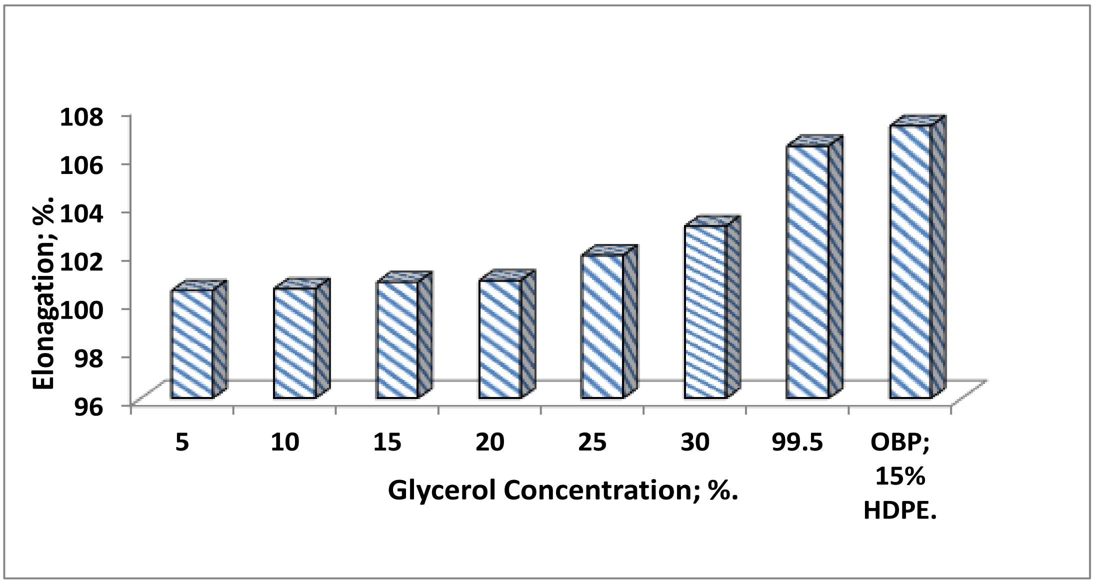


Fig 8. The effect of concentrations glycerol on elongation % of starch based plastic "SBP" compared with oil based plastic "OBP" films

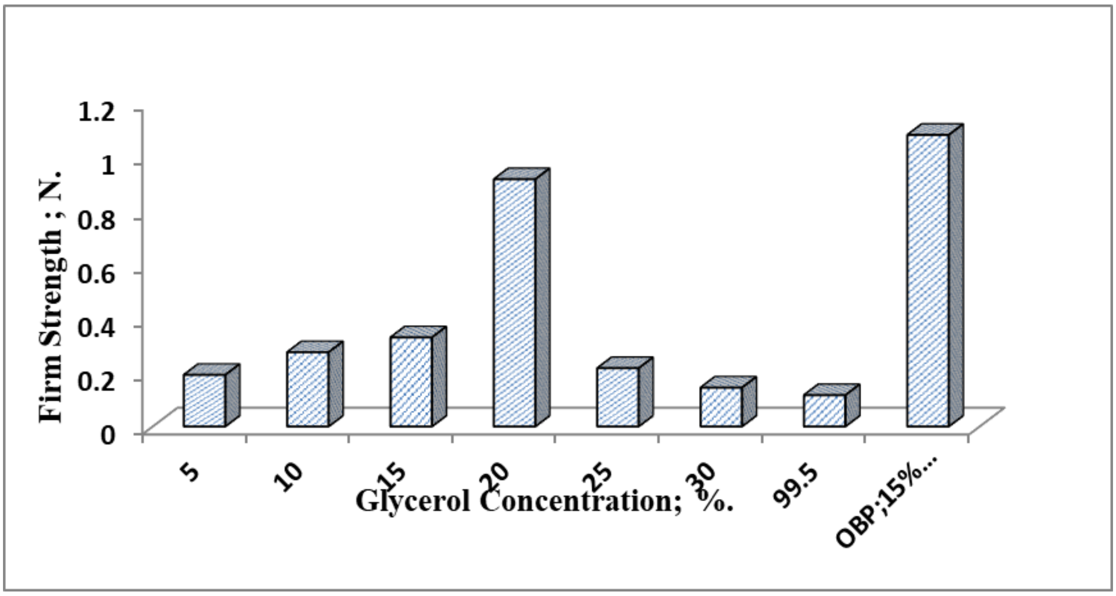
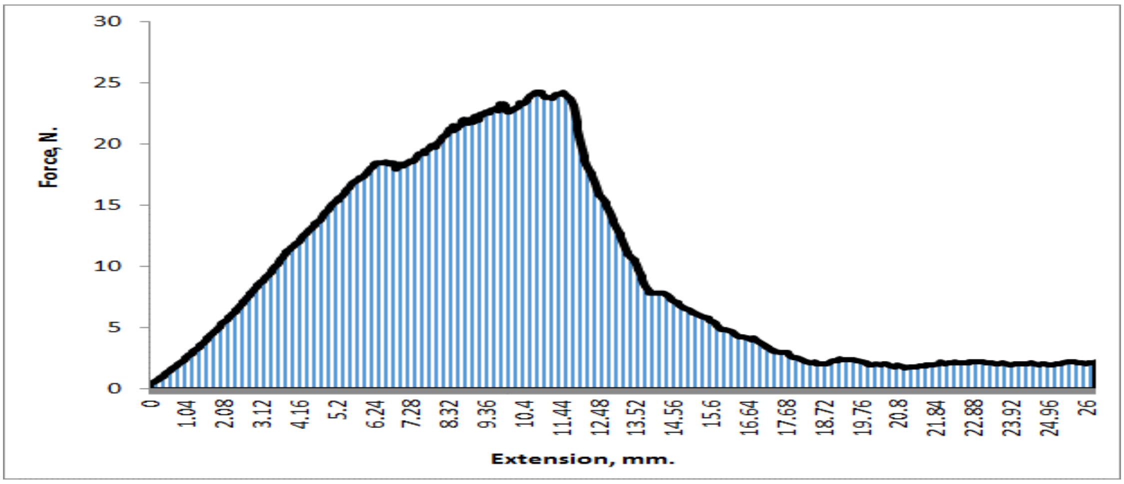


Fig 9. The effect of glycerol concentration on firm force of starch based plastic "SBP" compared with oil based plastic "OBP" films



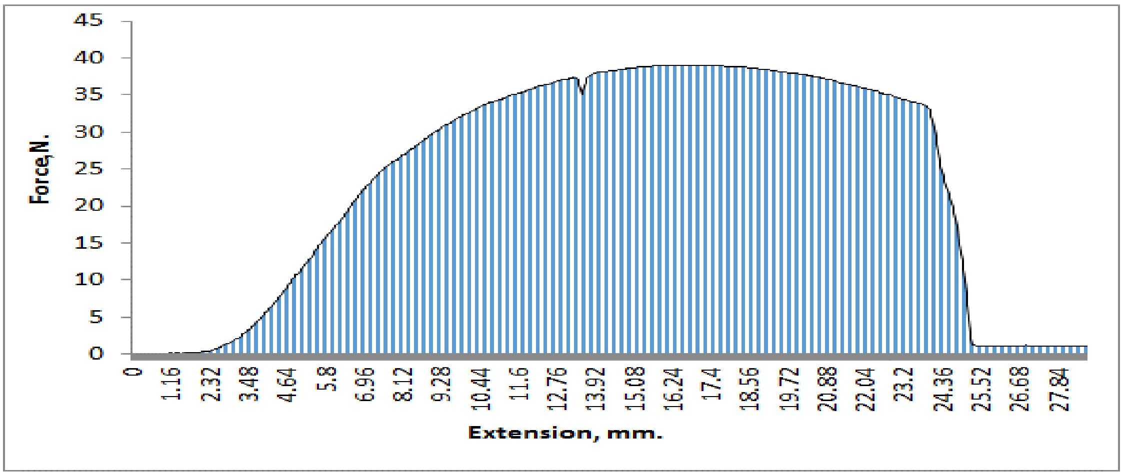


Fig 10, Fig 11. Consumed energy during firm with SBP and OBP films respectively

4 Conclusions

This study succeeded in producing starch-based plastic by using extracted starch from Unmarketable potato tubers plasticized with any polyol such as glycerol. This idea may be considered an innovative method that will reduce the accumulation of MSW and petroleum-based plastic pollution. It was found that blending potato tubers gave a maximum value of extracted starch. As far as SBP physical properties, glycerol concentration affected the thickness and density of the films. Increasing the glycerol concentration leads to increasing the thickness, while the density decreases. SBP film's tensile strength and elongation are two major mechanical properties for the plastic within range to make the product has market potential. However, the higher ability to absorb water made SBP probably not used in the food industry, therefore the possibility of a proposal put some additives to SBP samples to increase resistance of water absorption to be suitable for one-time use packaging materials, since it is characterized by rapid decomposition. Therefore, producing starch-based biodegradable plastic from un-marketable potato tuber will reduce the accumulation of MSW and petroleum-based plastic waste enhancing the rural economy, quality of life and ecosystem in general.

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