



# Synthesizing High-Strength Biodegradable Polymer Film from Ethiopian False Banana Pseudo-Stem Using POSS and Chitosan as a Filler

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## Abstract

Ethiopian false banana, locally known as “enset”, is an indigenous vegetable tree native to southern Ethiopia and mainly utilized as a food source. In this study, we investigated the possibility of using cellulose extracted from Ethiopian false bananas for bioplastic production and its application for food packaging. Ethiopian false bananas contain around 67.63% of cellulose in a dry weight base. Cellulose was extracted by a combination of alkaline treatment by 1 M NaOH and bleaching by H<sub>2</sub>O<sub>2</sub> and the film was produced by solution casting method. To improve the strength of the films, POSS and chitosan are added in different amounts (10, 25, 35, 50, 75%) and glycerol is used as a plasticizer. The effect of the fillers on the mechanical properties, morphological structure, biodegradability, and thermal stability was investigated. The increase of the filler (POSS and chitosan) content led to an increase in the film’s tensile strength and thermal stability. However, when the content of POSS and chitosan was increased to 75%, the tensile strength decreased. The tensile strength of films containing cellulose and POSS was 25.9–36.801 Mpa, and CCHs films containing cellulose and chitosan was 22.7–34.45Mpa. Cellulose films which have POSS as filler show improved tensile strength than the film having chitosan. However, the addition of glycerol slightly lowers the tensile strength of the films (13.911–21.699 Mpa) but flexibility is improved, as indicated by a significant increase in percent elongation (13.127–25.2%).

**Keywords** Cellulose · Extraction · POSS · Chitosan · Glycerol · Bioplastic

## Introduction

Worldwide improvement in the cost of living has greatly contributed to significant population growth. This has had a trickle effect of directly increasing the demand for consumer goods, as more people have buying power. Consumer goods are usually packaged to ensure product safety during transporting, preserve them over a period of time and even to market them through branding the packaging. The packaging

industry has been growing to keep pace with the developing demands and has a market value of over 917 billion USD annually as of 2019 and is expected to exceed a trillion USD by 2024 [1]. Various materials including metallic, paper, textiles, etc., are widely used for packaging. Plastic materials have attracted a lot of attention in the packaging industry due to their low cost and incredibly versatile properties that make them ideal for many applications. Plastic materials used in the packaging industry account for over 35% of all the materials used in the industry, with market value 265 billion USD as of the year 2020 [2].

Polyester, polyethylene (LDPE, HDPE) polyvinyl chloride, polystyrene and polypropylene are the main plastics used for packaging. These plastics find uses in many packaging applications including packaging of food stuff, liquids, medicine, and cosmetics, to name a few [3]. It is almost impossible for one to imagine life without plastic packaging; it is used in almost all areas of packaging and is convenient without necessarily increasing the cost of goods. Also, their low cost has rendered them as the main material for single

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use packaging. Approximately 500 billion plastic bags are made annually and more than 50% these bags are for single use [4]. After using these plastics, they are dumped into the environment and it takes many years for them to fully degrade, posing a serious environmental problem including animal choking, pollution, blockage of channels, rivers and streams, and landscape disfigurement [5–7].

In light of the threat caused by single use plastic package to the environment, several interventions have been explored to remedy the problem. Some of the methods include encouraging recycling of thermoplastics, which has both the advantage of conserving the environment and at the same time saving on the cost of production. However, challenges in collecting the used plastic and the quality of recycled plastic have limited the process to less than 30% recycling [8]. Also extreme climate changes and various calls from countries have resulted in banning single-use plastic packages. Canada aims to ban single-use plastics by 2021; Peru banned single-use plastics in 76 natural and cultural protected areas; and United Nations Member States have pledged to reduce the use of plastics “significantly” by 2030 [4, 9, 10]. This approach seems to be a quick solution, but has the problem of increasing the cost of consumer goods to meet the cost of using expensive packaging, which directly impacts the cost of living. Other approaches include depolymerization of these plastics so that the monomers can be reused as raw materials to make virgin plastics. This approach is still under development and yields still remain low against energy consumption [11].

In the last decade, there has been an increased interest from the packaging industry toward the development and application of biodegradable plastics (BDP) for packaging specifically for food products. Biodegradable plastics are materials that can be broken down in a short period of time by microbes, chewed up and turned into biomass, water and carbon dioxide (or in the absence of oxygen, methane rather than CO<sub>2</sub>) [12, 13]. These BDP are either composed of bioplastics or plastics which are derived from renewable raw materials or petroleum-based plastics which contain additives. Of these bioplastic, plant-based/-derived bioplastics have turned out to be very interesting to researchers due to their availability. Starch from various plants has been used to form plastic-like starch-based films and their properties reported [14–18]. However, the challenges of brittleness, poor mechanical strength and poor water vapour barrier still limit their application. The flexibility of the film can be improved by addition of glycerol plasticizer, but this approach has a negative effect of further lowering the mechanical strength [19].

Introducing nanoparticles in the starch-based film has recently been reported as an excellent way to increase the mechanical and barrier properties of the film while retaining its flexibility. Incorporation of chitosan nanoparticles into

starch-based film resulted in better tensile strength and barrier properties [20]. Nanoclays have also been extensively used to improve the barrier properties of starch-based films. Their effect can be explained by the ‘confinement effect’. Polymer molecules can be ‘confined’ between the dispersed nanoparticles, providing a tortuous path, forcing the water and gas molecules to travel a longer path for diffusion through the film [21]. It is therefore of great interest to further extend the study of incorporation of various nanoparticles into commonly available starch-based films. Polyhedral oligomeric silsesquioxanes (POSS) silica nanoparticle consisting of a silica cage core, as well as other organic functional groups attached to the corners of the cage, has superior properties than most nanoclays and has been extensively used as an additive in production of different polymers to improve their properties [22]. Addition of a combination of POSS and Chitosan to starch films can significantly improve the mechanical properties.

Banana plant is widely grown across the world and it produces high-strength starch suitable for film forming [23]. However, due to its demand as a food crop limits its application in industrial application for film making. False banana is a banana species that has similar features to the ordinary banana, but does not produce banana fruit and thus not used as a food crop. Researchers have been trying to extract and use the starch from false banana plant to make films [24]. However, the films reported were of low strength and poor flexibility. Research studies mostly focused on starch extraction and film making without much attention to the additives to improve the film properties. In this study, we try to extract the starch from false banana plant, using chitosan and POSS as fillers together with glycerine plasticizer to investigate the properties of the film. The choice of false banana plant was based on its ample availability across the southern region of Ethiopia where our university is based. Traditionally the false banana leaves and barks are mostly used for packing different food products to be sold on local markets. A few communities also extract the inner stem for food.

## Methodologies

### Materials

False banana pseudo-stem (enset) was collected from individual farmland, Jimma, Ethiopia. NaOH, H<sub>2</sub>O<sub>2</sub>, citric acid, chitosan and POSS were collected from Jimma University materials and chemistry laboratory.

### Cellulose Extraction

Cellulose was isolated from the outer layer of the banana pseudo-stem by the modification of the mechanism implied

by Pelissari et al. [23] and Lin et al. [25]. The outer part of the banana pseudo-stem was cut using a slicer with a blade size of 10 mm and dried in a cabinet dryer at 40 °C for 2 days. Dried pseudo-stem was then milled using a miller. The pseudo-stem flour (10 g) was soaked in 300 mL of 1MNaOH with continuous stirring for 16 h. After that, the pseudo-stem was washed by centrifugation (5 min) with distilled water to remove THE remaining NaOH. NaOH-treated flour was then bleached for further delignification with 200 mL of 1% H<sub>2</sub>O<sub>2</sub> for 1 h at 70 °C. After 1 h, the mixture was cooled and stirred for another 1 h. The bleached pseudo-stem flour was washed again with distilled water and centrifuged for 5 min to remove any remaining H<sub>2</sub>O<sub>2</sub>. To create cellulose dispersion, the aqueous suspension was homogenized with a mixer and sonicated with a batch sonicator.

### Cellulose (Control) Film Preparation

To make the control sample film, the as-prepared cellulose suspension was mixed with distilled water so that the solid content was 0.7%. The mixture was further homogenized by sonicating for 40 min to form cellulose dispersion. The dispersion of approximately 15 mL was then poured into a standard plastic Petri dish of 9 cm diameter and carefully put in AN air oven to slowly dry out (40 °C, 2 days) to produce a film through the solution casting method.

### POSS-Containing Cellulose Film Preparation

POSS-containing cellulose film was prepared with different amounts of POSS labelled as CP10, CP25, CP50, and CP75 containing 1%, 2.5%, 5%, and 7.5% POSS, respectively. The cellulose and POSS dispersions were first prepared separately before mixing. The cellulose dispersion preparation was as discussed for the control sample, and the POSS solution was prepared with dilute citric acid and oil since POSS is hydrophilic. The two solutions were then combined and stirred for 1 min to ensure a fine dispersion of POSS in cellulose. The dispersion (15 ml) was then poured into a Petri dish and dried for 48 h at 40 °C.

### Chitosan-Containing Cellulose Film Preparation

The chitosan-containing cellulose film was prepared similarly to POSS, using different amounts of chitosan labelled as CCH10, CCH25, CCH50, CCH75 containing 1%, 2.5%, 5%, and 7.5% chitosan, respectively. Cellulose and chitosan were dissolved in a separate solution. The cellulose solution was prepared similarly to control, and the chitosan solution was prepared with dilute citric acid since chitosan is hydrophilic. The two solutions were then combined and stirred for 1 min to ensure fine chitosan dispersion in cellulose.

The dispersion was then poured into a Petri dish and dried for 48 h at 40 °C.

## Characterization Techniques

The morphologies of the cross section of the films were characterized by scanning electron microscopy (EM-30 Mini SEM, COXEM Co., Ltd., Daejeon, South Korea).

The thermal properties of the films were determined using thermogravimetric analysis (TGA) (TGA Q 5000 TA). The analysis was carried out in duplicate.

### Mechanical Test

Tensile testing was used to determine the mechanical properties of the films, such as tensile strength and percent elongation at break, following ASTM Standard D882-12. After that, the films were cut into bone-shaped specimens. A digital caliper was used to measure the width, thickness, and length of each specimen. The load cell 50 N was used for the measurements.

### Biodegradability

Five 400 ml beakers and 4 cm × 4 cm of a pre-weighed piece of bioplastics were taken, the pre-weighed bioplastic material prepared was placed under the beaker containing soil at a depth of 5 cm from the surface. A small amount of water was sprinkled on the soil to enhance bacterial enzymatic activities. These samples were kept in the beaker for about 15 days; we observed the decrease in the weight of the bioplastic material every 3 days and the results were recorded accordingly. Weight loss was measured and used as an indicator of each corresponding sample's biodegradability. The weight loss was calculated using Eq. 1.

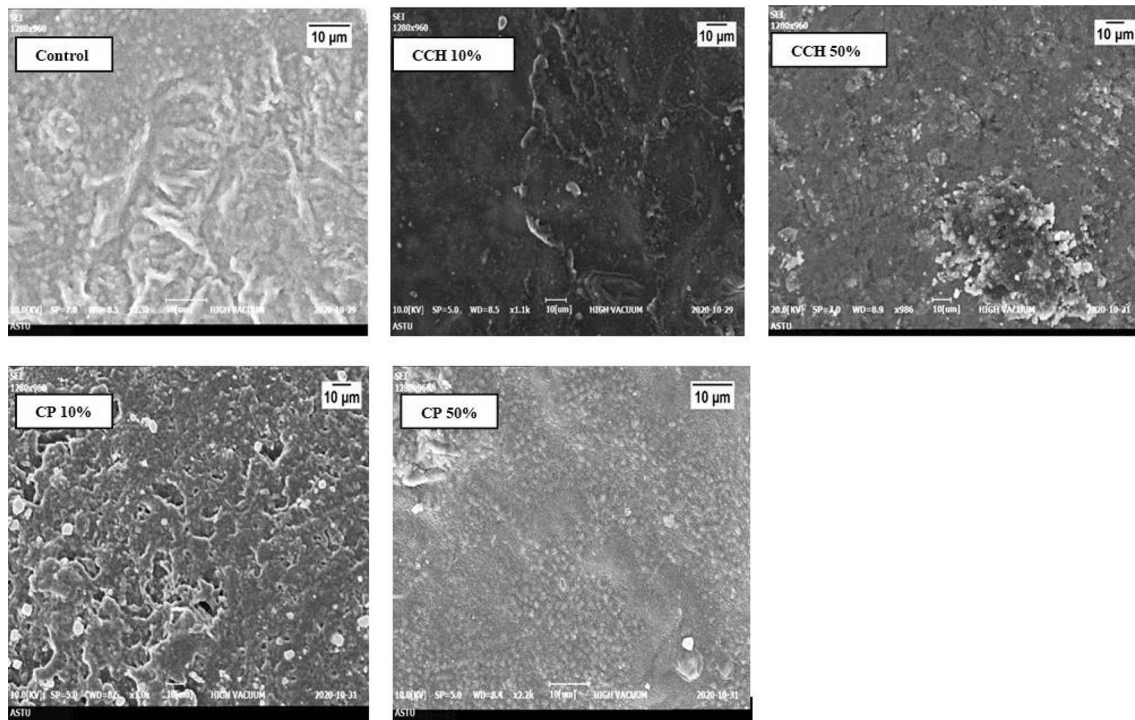
$$\%WL = \left[ \frac{W1 - W2}{W1} \right] \times 100, \quad (1)$$

where %WL is the weight loss percent, W1 is the pre-weight of the sample; W2 is the weight of the sample after burial.

## Result and Discussion

### Morphological Analysis

Figure 1 shows SEM images of the cross section of the control, 10% chitosan-containing cellulose film (CCH10), and 50% chitosan-containing cellulose film (CCH50 films) (a–c). The cross section of the control, which contained no chitosan, exhibits a uniform layer structure. CCH10 has a similar layer structure with a uniform spread out of chitosan in



**Fig. 1** SEM images of **a** control cellulose film, **b** 10% chitosan-containing cellulose film, **c** 50% chitosan-containing cellulose film, **d** 10% POSS-containing cellulose film, **e** 50% POSS-containing cellulose film

the matrix; on increasing the percentage of chitosan to 50%, aggregates of chitosan start emerging within the matrix and makes the surface appear relatively rougher. This is possible because of chitosan agglomeration and phase separation.

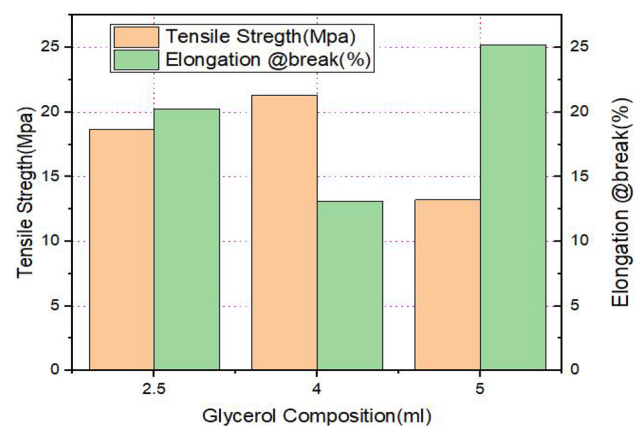
A film's homogeneous matrix is an excellent indicator of structural integrity and, hence, good mechanical and physical properties are plausible [26]. Figure 1d, e shows POSS-containing films. The dispersion of POSS in cellulose for both films is homogenous and uniform, which shows good interaction of POSS and cellulose. The SEM image of 50% POSS is smoother than that of 10% POSS. This is probably an indication of improved mechanical properties of the film as the amount of filler added increases.

### Mechanical Test for Cellulose Films

Percent elongation and tensile strength at break were determined for all of the cellulose films.

The ultimate tensile strength indicates the maximum load that can be gained per cross-sectional area of the film, while percent elongation shows the extent of the film that can be stretched before it breaks [27]. Figure 2 shows the mechanical properties of glycerol-containing films.

Good mechanical strength is the basis for a material, which is widely adopted. Tensile strength is the maximum pull that can be achieved until the film can survive before breaking up. The tensile strength values obtained



**Fig. 2** Mechanical properties of glycerol-containing films

by adding glycerol ranged from 21.325 Mpa, 18.67 Mpa and 13.219 Mpa for 2.5 ml, 4 ml, and 5 ml glycerol-containing film. The amount of plasticizer added has a strong influence on the tensile strength of cellulose films, with the elongation at break increasing significantly as the amount of plasticizers increases. From Fig. 2, it can be seen that as the amount of the glycerol increase in making cellulose film to the composition of 5 ml, the lower tensile strength (13.219 Mpa) of the cellulose film is produced. Figure 2 shows that the elongation at break increases as the amount of glycerol increases to 5 ml. This is due to the increase in

the concentration of the plasticizer, which reduces hydrogen bonds in the film to increase flexibility. This behaviour could be due to structural modifications of the cellulose network when the plasticizer was added. The matrix of the film becomes less dense, facilitating the movement of polymer chains under stress, hence decreasing the film resistance [26]. The tensile behaviour of films with 5 ml of glycerol could be associated with those of ductile polymers, since tensile strength decreased and elongation at break increased significantly compared with less plasticized films. Similar results were obtained by Refs. [28, 29] for acetylated cornstarch and cassava starch films, respectively. Plasticizers interfere with polymeric chain association, facilitating their slipping and thus improving film flexibility. Glycerol decreases the rigidity of the network, producing a less ordered film structure and increasing the ability of polymer chain movement [30]. Glycerol concentrations higher than 4 ml modified the mechanical behaviour of films drastically, showing the typical pattern of very flexible materials. For these films, tensile strength values lowered and elongation at break improved significantly. The nonlinear decrease of tensile strength and the increase of elongation at break with plasticizer content was also reported by several authors for biodegradable lignocellulosic-based films [31].

It was observed that the tensile strength values of cellulose-based films improved gradually with the addition of chitosan. Figure 3 shows the tensile strength and elongation at break of the composite films across the different ratios of cellulose and chitosan.

The chitosan content in the films varied from 10 to 75% (by weight). The tensile strength of the 10%, 25%, 35%, 50%, and 75% additions of chitosan cellulose films was found to be 22.711, 27.031, 31.615, 34.527, and 32.407 Mpa, respectively. The tensile strength increased from CCH10 to CCH50, and further increase of chitosan beyond

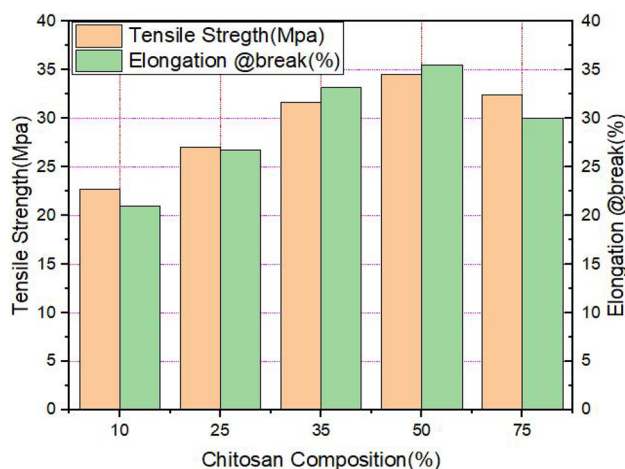


Fig. 3 Mechanical properties of films containing chitosan

50% gave negative results. The EB values of the cellulosic films also increased gradually. The EB % values of 10%, 25%, 35%, 50%, and 75% chitosan-containing films were 21.01%, 26.76%, 33.18%, 35.54%, and 30.02%, respectively. The elongation increased from CCH10 to CCH50, but rapidly decreased at CCH75. The increase in elongation and tensile strength can be attributed to a certain amount of chitosan causing an increase in the intermolecular interaction between the  $-OH$  group of cellulose and the  $-OH$  and  $-NH_2$  groups of chitosan—this works as a reinforcement for the cellulose matrix. However, the addition of more than a certain amount of chitosan caused a decrease in the tensile strength and elongation. This is due to the formation of chitosan intramolecular bonds rather than intermolecular bonds with cellulose. It occurs during phase separation between two components, thus causing nonhomogeneous interaction in the film and weakened mechanical properties [30].

The best proportion of films was 50% chitosan and 50% cellulose, as films with these proportions showed excellent mechanical properties.

The mechanical properties of the cellulose/POSS films, including the tensile strength and elongation at break, are summarized in Fig. 4.

As seen from Fig. 4, the films possessed good tensile strength of 25.9–36.801 MPa and elongation at break of 21.35–31.12 MPa, which were almost in the same range as those of conventional commercial polyolefin films, such as polyethylene (PE) and polypropylene (PP) (the tensile strength = 20–40 MPa). The tensile properties of the cellulose/POSS increased with the content of POSS up to 50%, and then decreased at 75%. Cellulose/POSS film with 50% POSS achieved a maximum tensile strength of 36.8 MPa. This phenomenon is probably correlated to the dispersion–aggregation state of POSS nanoparticles and the

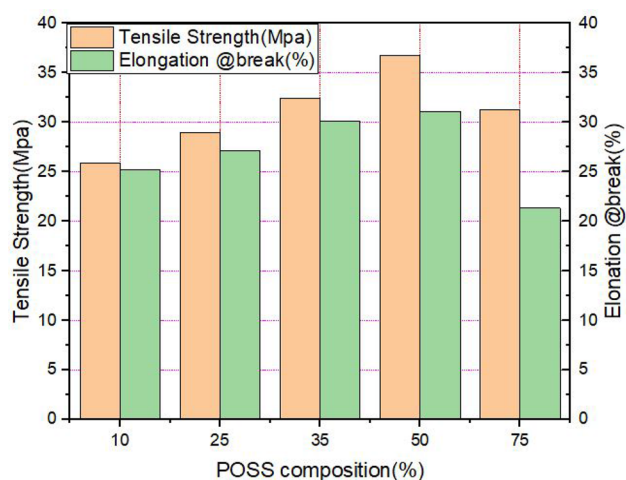
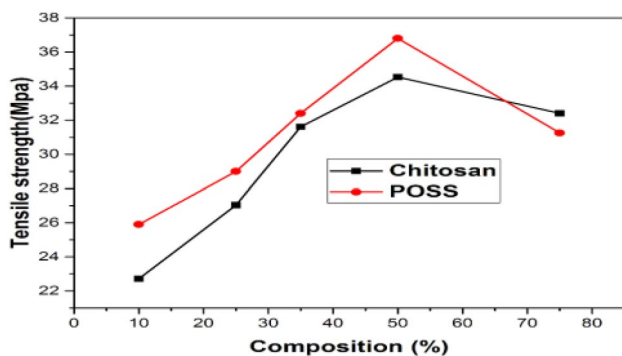


Fig. 4 Mechanical properties of film containing POSS

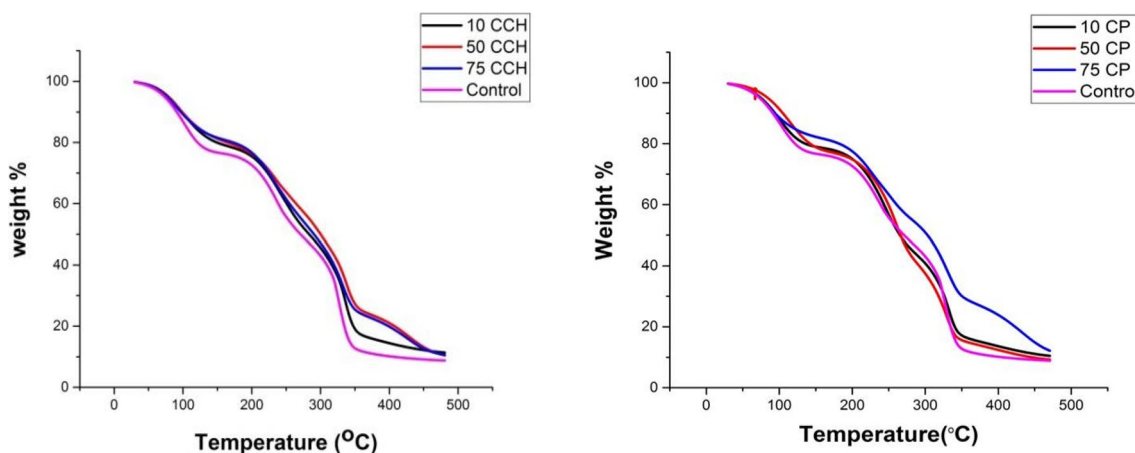
interfacial interaction of organic/inorganic between POSS and cellulose.

The tensile strength comparison of chitosan- and POSS-containing films is shown in Fig. 5.

From Fig. 5, the addition of POSS and chitosan improved the tensile strength of the films: for CPs (films containing cellulose and POSS) it was 25.9–36.801 Mpa and for CCHs (films containing cellulose and chitosan) 22.7–34.45 Mpa. Cellulose films that have POSS as filler showed improved tensile strength than the film which had chitosan. However, the addition of glycerol slightly reduced the tensile strength of the films (13.911–21.699 Mpa), but improved the flexibility, as indicated by a significant increase in percent elongation (13.127–25.2%). A reduction of film strength and improvement in flexibility due to the presence of glycerol have been reported in several studies [32]. This phenomenon could be due to glycerol reducing the internal hydrogen bonding of the polymers, in this case, cellulose, and thus increasing the space between polymers and reducing crystallinity [32]. However, when POSS or chitosan was combined with glycerol in cellulose films, a further increase in



**Fig. 5** Tensile strength comparison of chitosan- and POSS-containing films



**Fig. 6** TGA graph of **a** chitosan-containing samples, **b** POSS-containing samples

percent elongation was observed without compromising the tensile strength. Though the addition of fillers and glycerol improved the percent elongation of the films significantly, the percent elongation of these composite films was still lower than that of the synthetic films. It shows that the cellulose film could bear heavier food products than synthetic films, but could not be stretched as much as synthetic films.

Therefore, more research is needed to improve the flexibility of these cellulose films.

### Thermal Decomposition of the Films

Figure 6a shows that degradation occurred in three steps. The first thermal event around 60–120 °C

denotes the dehydration of the samples. The second step of degradation occurs from around 120–250 °C and the third step from 250 to 350 °C, where the main mass loss steps occurred. The cellulose film in which chitosan was added shows more thermal stability than the control film. Also, as the added amount of chitosan increases, the thermal stability increases. The results of the TGA of the cellulose–POSS film are shown in Fig. 6b. The thermal analysis of the samples was carried out under a stream of nitrogen at a heating rate of 10 °C/min. Temperatures ranging from 10 to 500 °C are used for the TGA results, and the observed weight loss appears in three stages, as follows: the first stage of degradation occurs between 65 and 100 °C, the second between 100 and 250 °C, and the third between 250 and 350 °C. The number of silanols and water molecules (65–100 °C) corresponds to the water molecules that are released in the hybrid composites that are present in the outer spherical surface of the particles, as well as on the inner-pore walls. The surface of the spherical silica consists of a very small portion of free silanols, a large number of hydrogen-bonded silanols, and adsorbed water molecules. The intensive thermal degradation of the cellulose–POSS film is observed approximately

between 100 and 250 °C for the cellulose–POSS film. Also, as the amount of POSS in a cellulose film increases, the thermal stability also increases. This increase in the degradation temperature indicates that the strong organic/inorganic phase interaction greatly influences the thermal resistance. The third step of the thermal decomposition curve indicates correspondence to the cellulose–POSS with the addition of inorganic content. The third degradation shows losses from 250 to 450 °C.

Therefore, as the amount of inorganic moieties present in the cellulose–POSS film increases, so does the thermal stability. Figure 6 shows the TGA graph of chitosan- and POSS-containing samples.

The films with filler show improved thermal stability when compared with control films. Among the fillers, the film prepared with a composition of 50% of POSS shows slightly improved thermal stability when compared with other films. A comparison of TGA for POSS- and chitosan-containing films is shown in Fig. 7.

### Soil Burial Test

The soil burial test is used to determine the degree to which a film degrades after being exposed to decomposition conditions. Cellulose–chitosan film is a biodegradable product that has degradation properties. Thus, a soil burial test was applied to the film to know the degree of degradation of the film. Figure 7 shows the weight change during the degradation of cellulose–chitosan and cellulose film. The slower degradation rate in the cellulose–chitosan film was due to the resistance to water uptake and diffusion through the composite compared to pure cellulose film, which readily takes up water. After day 9, cellulose–chitosan films began to experience significant weight loss over time, with 50% chitosan in cellulose–chitosan film having the lowest weight loss compared to 25% chitosan and control film. This was because the function of the filler, chitosan, mostly filled all the voids in the cellulose film, making the reaction between the film

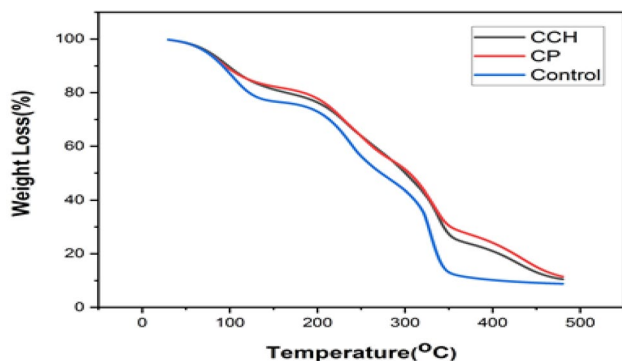


Fig. 7 Comparison of TGA for POSS- and chitosan-containing films

and soil less intense as the amount of filler in the cellulose film increased. Pure cellulose film, on the other hand, lost a lot of weight due to the substitution of the OH group in cellulose with soil, and there were a number of voids inside the cellulose chains compared to others.

From the result, cellulose film containing chitosan as a filler has a lower degree of degradation than pure cellulose film. This is because chitosan has antimicrobial properties which prevented microbial attack. Therefore, cellulose–chitosan film has low weight loss compared to pure cellulose film. A degradation mechanism took place starting from day 3 on the surface of the film. However, from day 10, cellulose–chitosan film showed degradation inside the film and breaking of chains. The cellulose–chitosan film had huge weight loss due to chain breakage and the degradation was faster [33]. After day 15, the cellulose film was almost fully degraded, while cellulose–chitosan film left some residues. Figure 9 shows the cellulose–chitosan film condition before and after 6 days. From Figure 9 it can be seen clearly that some parts of the cellulose–chitosan film started to degrade after 6 days, resulting in significant weight loss in the film. There were microbial attacks by the microbial colonies on the cellulose–chitosan film, causing discoloration on the surface of the film. Microbial colonies contain microorganisms that generate enzymes that cause the breakage of the cellulose and chitosan backbone chain [33]. Hence, the film will degrade completely after a certain period. As a result, in this study, pure cellulose film degraded faster than cellulose–chitosan film after 15 days. Furthermore, the amount of chitosan in the film can affect the biodegradable film's degradation time. Figure 8 shows a comparison of soil burial tests for chitosan- and POSS-containing cellulose films.

After day 12, cellulose–POSS films start to experience significant weight loss. In the cellulose–POSS film, 50% POSS containing had the lowest weight loss compared to 25% POSS and control film. This was due to the filler's function, POSS, which mostly filled all the voids in the cellulose film, making the reaction between the film and soil less intense as the amount of filler in the cellulose film increased. Pure cellulose film, on the other hand, lost a lot of weight due to the substitution of the OH group in cellulose with soil, and there were a number of voids inside the cellulose chains compared to others. From the result, when compared to pure cellulose film, cellulose film with POSS as a filler has a lower degree of degradation. As a result, cellulose–POSS film loses less weight than pure cellulose film. On the surface of the film, a degradation mechanism began on day 3. However, beginning on day 12, the cellulose–POSS film began to degrade within the film with breaking of the the organic/inorganic chains. This is because POSS is an inorganic filler, resulting in an organic/inorganic interaction between cellulose and POSS. Figure 9 shows a comparison of samples before and after the soil burial test

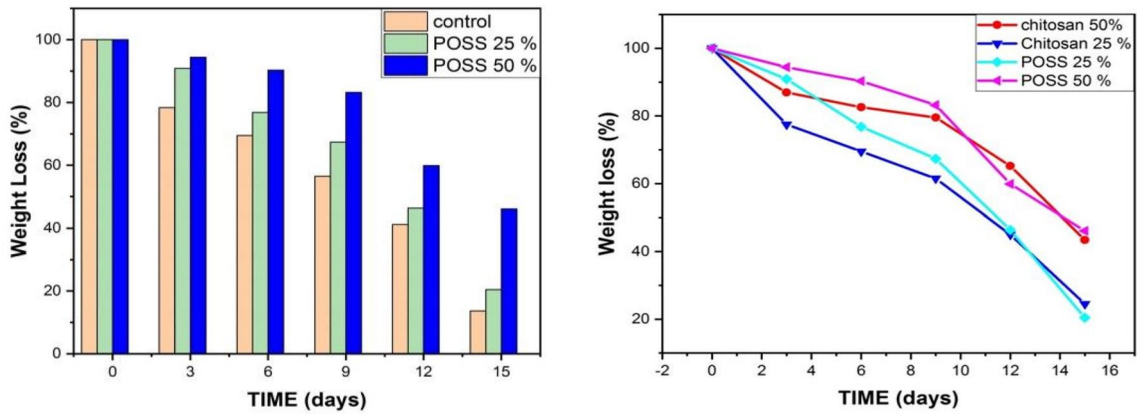


Fig. 8 Comparison of soil burial tests for chitosan- and POSS-containing cellulose films

Sample name	Before burial	After six days
Control		
2.5% Chitosan		
5% Chitosan		
25% POSS		
50% POSS		

Fig. 9 Comparison of samples before and after the soil burial test



## Conclusion

In general, this study on the preparation and characterization of enset cellulose-based bioplastics, as well as the investigation of their physicochemical properties, led to the following conclusions.

- Bio-based packaging materials offer a versatile potential for the packaging industry. The selection of packaging form and materials should be primarily based on considerations of food safety, followed by quality, cost, etc.
- Cellulose is a desirable candidate for making plastic materials due to its abundance, worldwide availability, low cost, and promising film-forming properties. Enset comprises a high quantity of cellulose, approximately 67.76% of the dry weight base.
- A combination of alkaline extraction by NaOH and bleaching by H<sub>2</sub>O<sub>2</sub> is used for the extraction process of cellulose from the enset pseudo-stem.
- To enhance the strength of the films produced from inset pseudo-stem, POSS and chitosan was added in different amounts as filler and glycerol was used as a plasticizer.
- The physicochemical properties of the bioplastic film under optimal conditions consisted of mechanical property and biodegradability.
- The added fillers show improvement in the mechanical properties of the films when compared to the films produced without fillers. Additionally, the film produced from POSS-containing cellulose film showed good tensile strength (25.9–36.801 Mpa) than the film produced from chitosan-containing cellulose film (22.7–36.45 Mpa). The film which has 50% fillers (POSS and chitosan) shows optimum properties than others.
- In this study, the produced plastic was tested for mechanical strength (tensile and elongation at break) and thermal degradation. Soil burial test was used to check biodegradability, and the SEM for morphological structure. The bio-based film produced from enset cellulose showed comparable properties to those of petroleum-based films.
- In general, bioplastics would be an appropriate alternative for food packaging materials in terms of environmental preservation and sustainability, as [34] well as cost-effectiveness.

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## Declarations

**Conflict of interest** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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