

1 ENVIRONMENTAL ASSESSMENT OF CORN STARCH BASED BIODEGRADABLE  
2 PLASTIC WITH GLYCEROL AND FRUCTOSE

3  
4 Lakshmiganthan S M<sup>1\*</sup>, Vaddi Seshagiri Rao<sup>1</sup>, Sathish R<sup>1</sup>, Srividhya S<sup>2</sup>

5 <sup>1</sup>Department of Mechanical Engineering, St. Josephs College of Engineering,  
6 Chennai – 600, 119, India, sml.automobile@gmail.com

7 <sup>2</sup>Department of Civil Engineering, Builders Engineering College, Tirupur, 638108.

8 \*Corresponding author: Lakshmiganthan S M

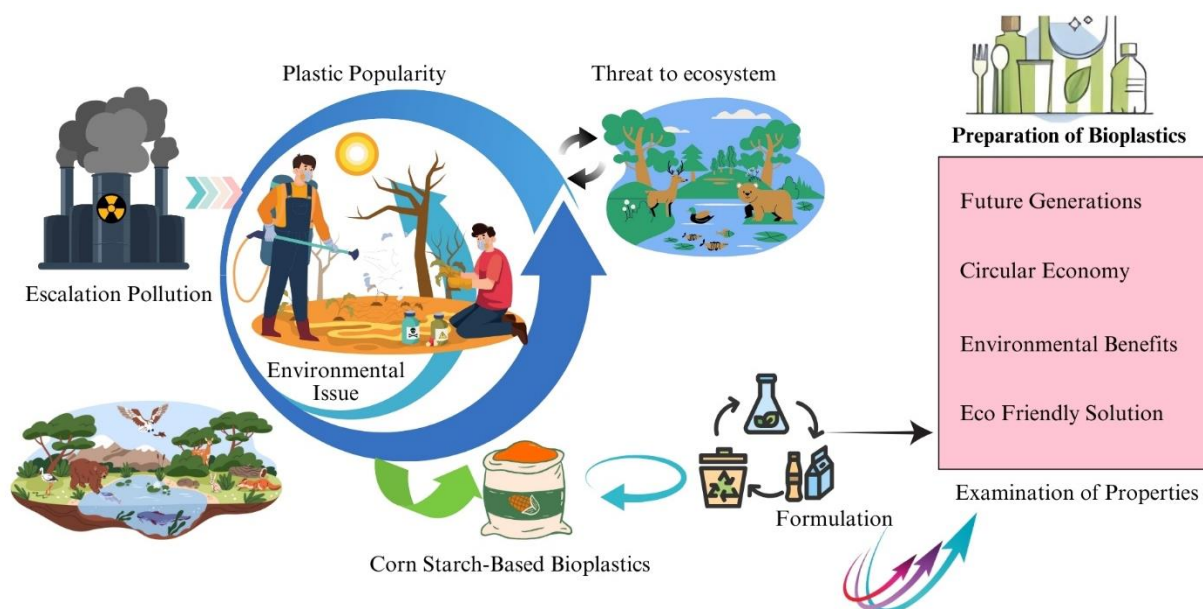
9 E-mail: sml.automobile@gmail.com

10

11

ACCEPTED MANUSCRIPT

## 12 Graphical Abstract



13

## 14 Abstract

15 Plastic has gained significant popularity due to its lightweight, durability, and cost-effectiveness  
16 compared to traditional materials like metals and clay. However, its non-biodegradable nature  
17 has led to an alarming escalation in environmental pollution, posing a severe threat to  
18 ecosystems. To address this issue, the current study evaluates the potential of corn starch-based  
19 biodegradable plastics as a sustainable alternative to conventional plastics. This research focuses  
20 on the formulation of bioplastics by combining 10% corn starch with plasticizers like glycerol  
21 and fructose at varying concentrations (15%, 30%, 45%, and 60% by weight). The bioplastics  
22 were prepared using traditional solutions to create eco-friendly materials that reduce reliance on  
23 petroleum-based plastics, thereby promoting a greener and more sustainable environment. Key  
24 physical and mechanical properties, including water solubility, tensile strength, water absorption,  
25 and biodegradability, were thoroughly examined. The findings highlight that bioplastics made  
26 from corn starch demonstrate remarkable biodegradability, breaking down naturally without  
27 harming the environment. Moreover, these bioplastics exhibit superior mechanical properties,  
28 such as enhanced tensile strength and durability, compared to traditional polymers. The  
29 environmental benefits of corn starch-based plastics are profound. They significantly reduce  
30 industrial waste and lower the risks associated with conventional plastics, such as pollution and  
31 resource depletion. Additionally, they offer an economically viable solution for industries  
32 seeking sustainable alternatives. By adopting bioplastics derived from renewable resources like  
33 corn starch, we can move closer to a circular economy. This shift not only minimizes the  
34 environmental footprint but also safeguards ecosystems for future generations.

35 Keywords: Bioplastic, Biodegradability, Corn starch, Fructose, Mechanical properties

## 36 1. Introduction

37 Plastics derived from petroleum are currently widely employed for various applications because  
38 they have a wide range of mechanical properties and are relatively inexpensive [1]. In 2014,  
39 global plastic production was projected to be 311 million tons, which increased to 381 million  
40 tons by 2015. By 2050, this production is expected to quadruple. Although plastics made from  
41 petroleum have contributed significantly to the global economy, their inability to decompose  
42 poses serious ecological threats. This has been a root cause of numerous environmental hazards  
43 [2-5]. In 2015, it was reported that over 300 million tons of waste were generated, with  
44 approximately 79% comprising plastics. Of this, only 9% was recyclable, and 12% could be  
45 incinerated. Plastics derived from petroleum are among the most pressing ecological issues due  
46 to their resistance to recycling and biodegradation. Consequently, finding environmentally  
47 friendly substitutes has become a priority. In the current scenario, bio-based plastics with a low  
48 environmental impact present a promising alternative to reduce reliance on conventional plastics  
49 and their hazardous waste. Biodegradable plastics are produced using natural biopolymers or  
50 synthetic bio-based polymers [6-7]. Materials derived from plants and animals, such as cellulose,  
51 glycolipids, and natural fibers, can reduce the impact of petroleum-based plastics on the  
52 environment and mitigate the depletion of oil resources. These biopolymers also help in reducing  
53 greenhouse gas emissions, making them suitable for environmental applications [8-11].

54 Starch is one of the most commonly used biopolymers for producing biodegradable biofilms due  
55 to its excellent performance, accessibility, and cost-effectiveness. Globally, maize is the primary  
56 source of starch, contributing over 85% of the starch production, with other plants like wheat,  
57 rice, and potato playing a smaller role [2-14]. Around 70% of a corn granule comprises semi-  
58 crystalline starch, with the rest being glucose, protein, oil, and ash. In recent years, starch-based  
59 materials have gained attention in packaging applications, driven by concerns over global  
60 warming. While the biopolymer market has achieved success, particularly in reducing  
61 environmental impact, challenges remain in replacing petroleum-derived plastics due to the poor  
62 mechanical properties and moisture sensitivity of biopolymer-based films. Since the early 1800s,  
63 plasticizers have been used to enhance the malleability and toughness of polymers [15-19].  
64 Plasticizers improve the mobility of polymer macromolecular chains, decreasing the glass  
65 transition temperature and enhancing the flexibility and stiffness of plasticized starch films.

66 The primary role of plasticizers is to reduce the hydrogen bonding affinity within the starch  
67 network of amylose and amylopectin, improving the mobility of polymer chains and enhancing  
68 the physical characteristics of biopolymers [20-21]. This results in better processing capabilities,  
69 such as reduced second-order transition temperatures and increased cold flexibility. Plasticizers  
70 also lower processing temperatures, improving flow properties. Various plasticizers, including  
71 fructose, glucose, and sucrose, have been studied for producing biopolymers. Research has  
72 shown that films with 25% fructose exhibit excellent mechanical strength. The effect of glycerol  
73 concentrations (0%, 20%, and 40%) on corn starch revealed that increasing glycerol reduced  
74 tensile strength but improved elongation at break. Polyols like glycerol and sorbitol also

75 increased water vapor permeability [21-25]. The combined effect of multiple plasticizers can  
76 enhance the characteristics of cellulose acetate films. The current study utilizes corn starch as the  
77 primary component, along with glycerol and fructose as plasticizers in varying proportions, to  
78 produce an environmentally friendly and sustainable bioplastic film. The outcomes of this  
79 investigation into the mechanical characteristics of starch-based bioplastics provide a foundation  
80 for further comprehensive research.

## 81 2. Problem Statement

82 Traditional plastics contribute to long-term pollution and damage ecosystems because they  
83 cannot be decomposed. Traditional plastics take hundreds of years to decompose, during which  
84 the materials release many toxic chemicals and microplastics into the environment. Bioplastics  
85 are sustainable alternatives that are derived from renewable resources and have improved  
86 biodegradability, although this is relative since the environmental benefits associated with  
87 bioplastics need much more definition if the product is to be considered better than traditional  
88 plastics. Therefore, the main aim in this research is to comparatively analyze and evaluate the  
89 impact of both traditional plastics and proposed bioplastics on the environment in terms of  
90 decomposition rates, carbon footprint, and overall ecological impact.

## 91 3. Experimental methodology

### 92 3.1 Materials

93 The primary resources utilized in this study are easily accessible within the local area. The  
94 plasticizer utilized in the study comprised of glycerol and fructose, which were procured from  
95 Sakthi vendors located in India. Table 1 displays the composition of the corn starch used in the  
96 current study. In the present investigation, glycerol and fructose were employed as plasticizers in  
97 the synthesis of bioplastic with the aim of reducing film brittleness. This was achieved by  
98 reducing intermolecular tensions among polymer chains, so enhancing their mobility and  
99 ultimately yielding a film with increased elasticity and flexibility.

100 Table 1. Composition of corn starch

Properties	Moisture Content (%)	Ash Content (%)	Protein (%)	Fat (%)	Fiber (%)	Amylose (%)	Amylopectin (%)	Density (g/ml)	pH
Corn starch	5.82	0.32	0.38	0.32	0.10	20.4	72.66	1.356	6.72

101

102

### 103 3.2 Preparation of bioplastic film

104 In this investigation, corn starch (CS) based films were molded using the solution of plasticizer  
105 was prepared. Figure 1 depicts the experimental setup schematically. Initially, both plasticizers  
106 were added to 180 ml of distilled water in a beaker. The mixture was then heated in water bath  
107 for 20 minutes at 85°C to form a homogenous solution. Then, 10 g of corn powder was added to  
108 the solution at varying plasticizer concentrations (0,15,30,45, and 60%w/v ). The solution was  
109 brought back to the water bath for 20 minutes at the same temperature, and the mixture was  
110 allowed to cool down before being cast on a thermal platform. The mold containers were  
111 weighed to ensure uniformity of film thickness. The mixture was desiccated in the oven at 65°C  
112 for 15 hours. The dehydrated films were removed from the mold plates and stored in plastic  
113 containers at room temperature for over one week prior to undergoing characterization. Films  
114 plasticized with various concentrations of glycerol, fructose, and glycerol/fructose mixtures were  
115 given the following designations: G15%, G30%, G45%, and G60%; F15%, F30%, F45%, and  
116 F60%; GF15%, GF30%, GF45%, and GF60%; and CCS for the control made from corn starch  
117 film. The ratios of material used are listed in Table 2.

### 118 3.3 Role of plasticizers in Biodegradability

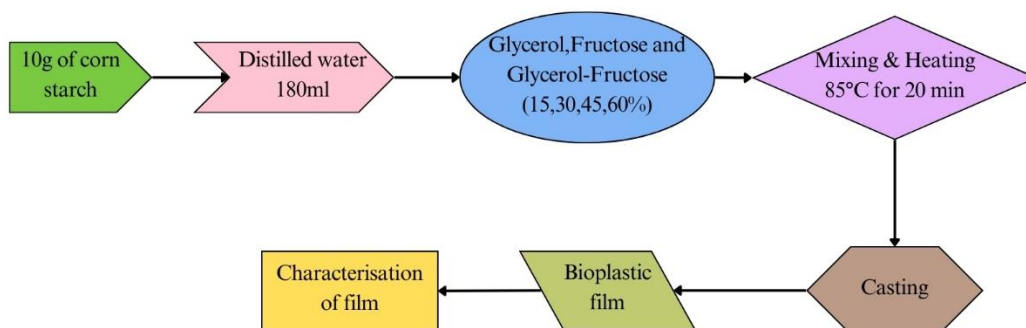
119 Plasticizers, like glycerol and fructose, act in a twofold manner by enhancing the flexibility and  
120 processability of bioplastic and, in turn, its degradation. Higher concentrations of plasticizers  
121 increase hydrophilicity; thus, water absorption into the material facilitates microbial accessibility,  
122 leading to faster biodegradation. The existence of plasticizers increases the amorphous regions  
123 within the bioplastic and thus becomes easier for enzymes and microorganisms to attack the  
124 chains. The hydrophilic nature of glycerol and fructose attracts moisture, further promoting  
125 microbial colonization and degradation. The paper has suggested that the range of plasticizer  
126 concentration could be 10%–20% in order to reach a good balance in the mechanical properties  
127 and in the biodegradability of the system.

128 Table 2. Ratios of Glycerol, Fructose and corn starch

Sample	Corn starch (%)	Glycerol (%)	Fructose (%)
CCS	10	-	-
G15	10	15	-
G30	10	30	-
G45	10	45	-

G60	10	60	-
F15	10	-	15
F30	10	-	30
F45	10	-	45
F60	10	-	60
GF15	10	7.5	7.5
GF30	10	15	15
GF45	10	22.5	22.5
GF60	10	30	30

129



130

131

Figure 1. Fabrication process of bioplastics

132

## 4. Characterization

133

### 4.1 Physical characteristics

134

#### 4.1.1 Thickness measurement

135

A digital micrometer with 0.001 mm accuracy was used to measure the thickness of each film sample. The average film thickness was calculated from measurements taken at three points inside each film sample.

136

137

138

#### 4.1.2 Water solubility test

139 Three samples (30mmx10mm) were selected from each film to test solubility and were  
140 dehydrated for 24 hours in an oven at 105°C. The initial dry weight of the samples is taken  
141 ( $W_{si}$ ). Following that, each specimen was incubated for 24 hours at a temperature of 25°C in a  
142 glass beaker with 100 ml of distilled water, with periodic stirring. After that, a portion of the film  
143 samples that did not dissolve were taken out of the solution and dried at 110°C for 24 hours. The  
144 weight of insoluble residue is noted ( $W_{sf}$ ). Equation (1) has been used to compute the proportion  
145 of total soluble matter.

$$146 \quad \text{Water solubility (\%)} = [(W_{si} - W_{sf})/W_{si}] \times 100 \text{ --- (1)}$$

147  $W_{si}$  and  $W_{sf}$  – Initial and final weight of the film (g)

### 148 4.1.3 Moisture content

149 Films moisture content was determined by monitoring their weight changes over time. For each  
150 sample three trials were considered and the initial weight of the samples was noted ( $W_i$ ). Then  
151 the samples were dried for 24 hours at 110°C and the dry weight was noted ( $W_f$ ). Equation (2)  
152 has been applied to determine the moisture level.

$$153 \quad \text{Moisture Content (\%)} = [(W_i - W_f)/W_i] \times 100 \text{ --- (2)}$$

154  $W_i$  and  $W_f$  – Initial and final weight of the film (g)

### 155 4.1.4 Water absorption

156 The water absorption test was conducted on the bioplastic samples in accordance with the  
157 standard D570-98 recommended by the American Society for Testing and Materials. The  
158 specimens were carefully measured, and the initial weights were accurately recorded ( $W_{wi}$ ).  
159 Then the samples were placed in the beakers filled with water. The samples were taken out of the  
160 water every 10 minutes and the excess water was wiped off. After the samples were dry, the final  
161 weights of the samples were measured ( $W_{wf}$ ). The absorption test was conducted over duration  
162 of four hours, during which the weight of water absorbed was recorded. The amount of water  
163 absorbed was calculated using (3).

$$164 \quad \text{Water absorption (\%)} = [(W_{wi} - W_{wf})/W_{wi}] \times 100 \text{ --- (3)}$$

165  $W_{wi}$  and  $W_{wf}$  are Initial and final weight of the film (g)

### 166 4.2 Tensile test

167 Tensile strength, elongation at break, and Young's modulus were evaluated using Tinius Olsen  
168 H10KL universal Tester according to ASTM D882. A moving cross-head was used to  
169 pull the dumbbell shaped specimens apart with a load cell of 250 N and a test speed of 10

170 mm/min. The samples were prepared in accordance with the specified dimensions outlined in  
171 the ASTM standard. Film samples have been cut into dumbbell shapes for each specimen.

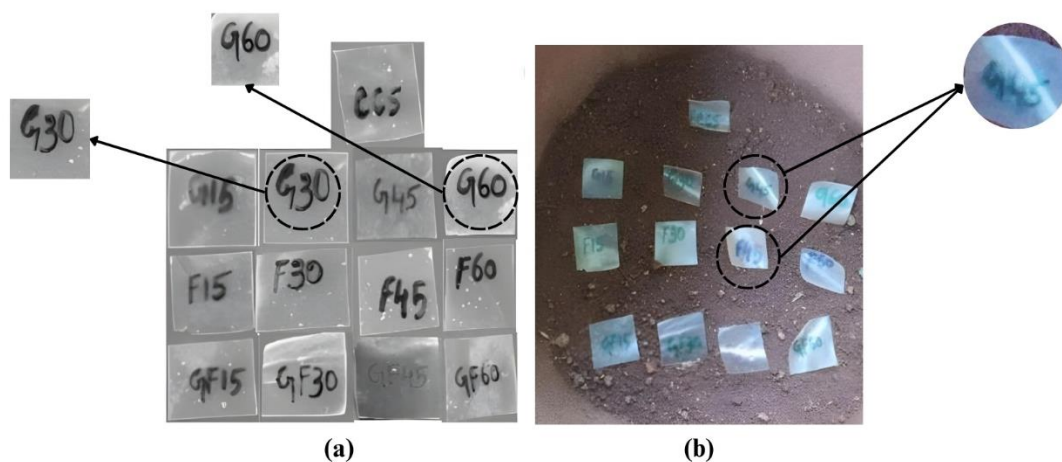
### 172 4.3 Environmental characteristics

#### 173 4.3.1 Biodegradability test

174 For the soil burial test the sample was cut into pieces of size 4 cm<sup>2</sup>. The initial weight of the  
175 sample was measured (W<sub>i</sub>). Soil sample was collected in a container and the film sample was  
176 kept inside the soil at a depth of 3 cm for period of 9 weeks under the room condition. The  
177 degradation of sample is measured at 2 weeks, 4 weeks, 6 weeks and 9 weeks respectively. The  
178 degradation weight was measured (W<sub>f</sub>). The amount of biodegradability of the sample specimen  
179 was measured using Equation (4). The test setup of soil burial test was shown in Figure 2 for all  
180 film samples.

$$181 \text{ Weight Loss (\%)} = [(W_i - W_f)/W_i] \times 100$$

182  
183 W<sub>i</sub> and W<sub>f</sub> are the weights of samples before and after the degradation in the soil.  
184



185  
186 Figure 2. Soil degradation (a) Sample specimens (b) Samples placed inside the soil

#### 187 4.3.2 Photodegradation test

188 Many plastic films are susceptible to photo degradation and oxidation under normal conditions.  
189 Photodegradation is the breakdown of a photodegradable molecule resulting from the absorption  
190 of photons, especially those wavelengths found in sunlight, including infrared radiation, visible  
191 light, and ultraviolet light. Figure 3 depicts the process of photo degradation of bioplastic film.  
192





193

194 Figure 3. Film before and after exposure of sunlight




195 **5. Results and discussion**


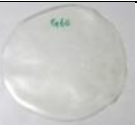


196 **5.1 Physical characteristics**

197 **5.1.1 General appearance of bioplastic films**

198 The visual appearance of non-plasticized and plasticized films with different plasticizers was  
 199 shown in Table 3. The specimen CCS films denote control films without plasticizers. The CCS  
 200 films were brittle, rigid, and fragile. More number of cracks were observed on the film surface. It  
 201 is difficult to peel and handle, possibly because of solid hydrogen bonds between the corn starch  
 202 molecules. It results in brittle and stiff films with surface cracks that give the macromolecular  
 203 chains less movement.

204 Table 3. General appearance of non-plasticized and plasticized CS films

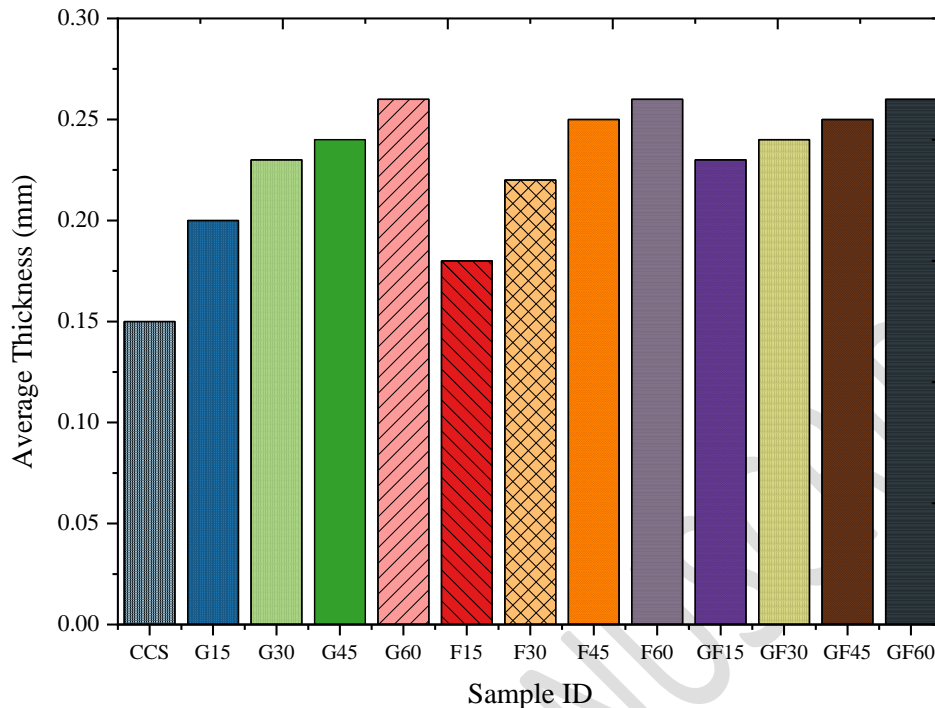
Sample	Plasticizer	% of plasticizer	Film appearance	
CCS	-	-		Transparent, surface cracks, brittle and fragile, difficult to peel
G15	Glycerol	15		More transparent, sticky, not brittle and not fragile, flexible, easy to peel
G30	Glycerol	30		More transparent, more sticky than G15, not brittle and not fragile, flexible, easy to peel

G45	Glycerol	45		More transparent, more sticky than G30, not brittle and not fragile, flexible, easy to peel
G60	Glycerol	60		More transparent, more sticky than G45, not brittle and not fragile, flexible, easy to peel
F15	Fructose	15		Crystal clear, rigid, non-sticky, not brittle and not fragile, flexible, peelable
F30	Fructose	30		Crystal clear, rigid, non-sticky, not brittle and not fragile, Flexible than F15, peelable

205

### 206 5.1.2 Thickness of films

207 Figure 4 shows the variation in film thickness due to different plasticizer concentrations. The  
 208 results show that the thickness of plasticized films increased when the plasticizer content  
 209 increased from 15% to 60%, irrespective of the type of plasticizer was employed, and a similar  
 210 observation was reported [22]. Similar findings were observed and suggested that plasticizers  
 211 affected the deformation of the intermolecular polymer chain matrix [18]. The deformation of the  
 212 polymer chain matrix resulted in more free volume being provided, which led to an increase in  
 213 film thickness. Also, the thickness results from different plasticizer types showed that the  
 214 thicknesses of different plasticized films were very close, even though the molar mass of fructose  
 215 is almost twice that of glycerol. It is revealed that the plasticizer's molar mass did not  
 216 significantly affect the film's thickness. This result contradicted the findings reported in earlier  
 217 investigations, which concluded that the thickness of the plasticized film was highly connected to  
 218 the molar mass of the plasticizer utilized [18, 21].

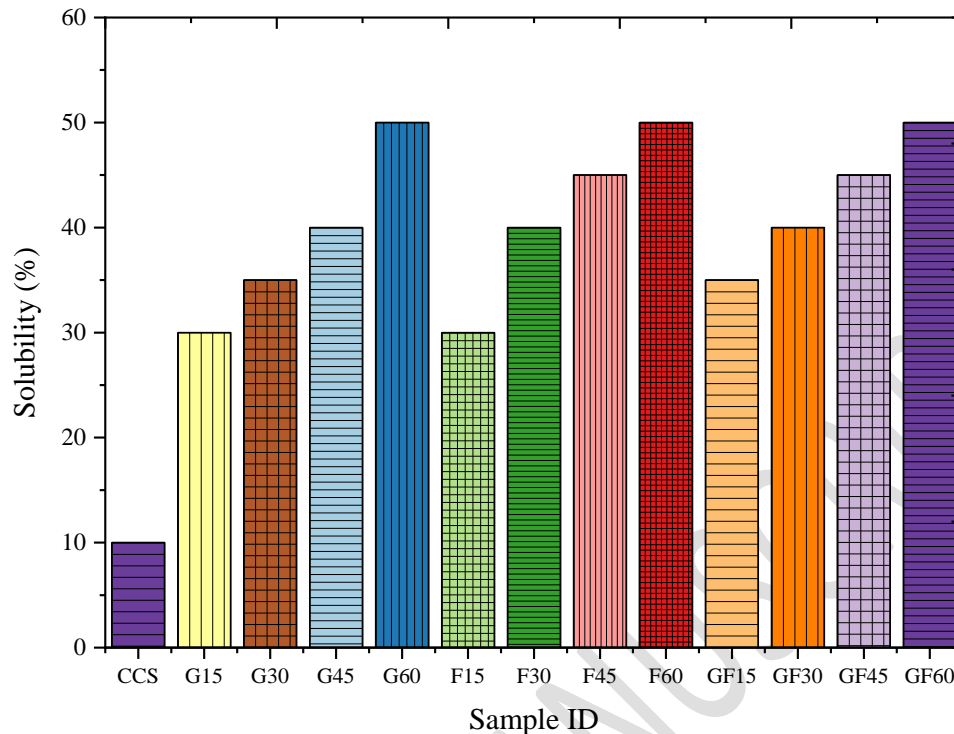


219

220 Figure 4. Thickness of bioplastic films

### 221 5.1.3 Water solubility

222 During the characterization of the water solubility test, the thickness of the film is a significant  
 223 characteristic that should be considered. The thickness of the film is significant for food  
 224 packaging applications, which occasionally need water insolubility and resistance [27]. In the  
 225 same way that the results of the thickness test were observed, similar results were observed for  
 226 the plasticized films' solubility test. The results of the study indicate that there was a considerable  
 227 increase in solubility when the concentration of plasticizer was increased from 15% to 60% for  
 228 all types of plasticizers, as depicted in Figure 5. The selected sample exhibits moisture affinity  
 229 because of polyols which contribute to the weakening bond between polymer molecules and the  
 230 expansion of the free space volume in the chains. The expansion made the films more soluble  
 231 because water could more easily penetrate the polymer matrix [18]. Figure 5 also shows that the  
 232 solubility varied from 32.75 to 48.98% for G-films, 37.4 to 51.2% for F-films, and 33.19 to  
 233 52.78% for FG-films, indicating that the results were very consistent throughout plasticizer  
 234 types. Similar results may be due to the fact that both glycerol and fructose have a strong  
 235 attraction to water. It was identified that the control specimen film with glycerol and fructose  
 236 exhibited high water solubility percentage compared to the control specimen.

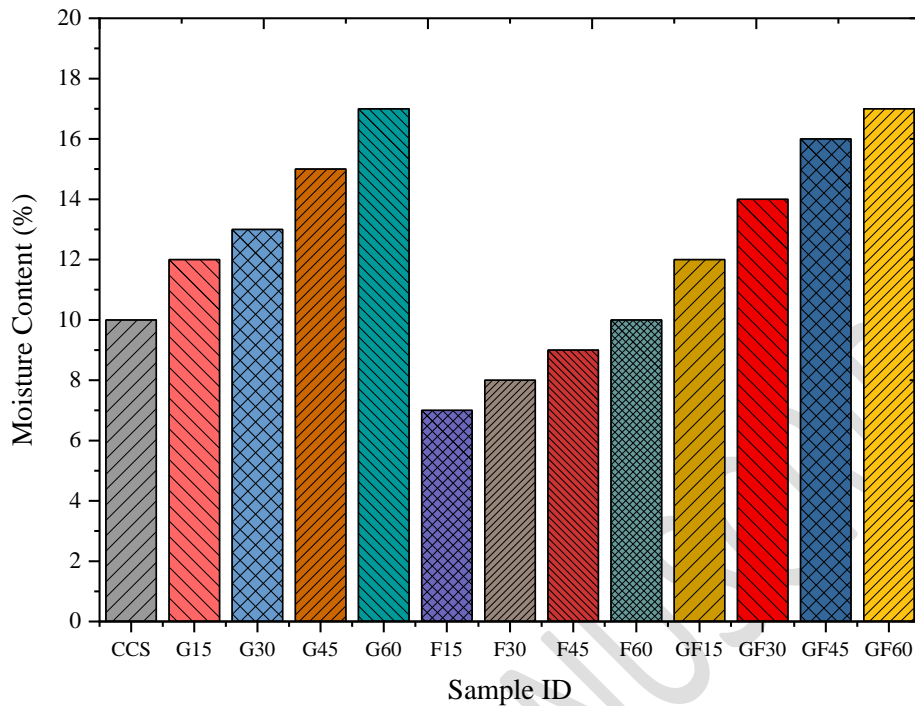


237

238 Figure 5. Water solubility of bioplastic films

### 239 5.1.4 Moisture content

240 Figure 6 depicts the moisture content of bioplastic films at various combinations. According to  
 241 the figure, the G-film was found to have the maximum percentage of moisture content, while the  
 242 F- film was found to have the lowest moisture content. In addition, the moisture content  
 243 decreased as the concentration of the F-plasticizer increased from 15 to 60%. In contrast, the  
 244 moisture content increased considerably from 12.3 to 18.6% as the amount of glycerol  
 245 plasticizer increased from 15 to 60% in the F-plasticized film. Similar to the Gplasticizer, the  
 246 increase in the concentration of the combined GF-plasticizer substantially increased the moisture  
 247 content, with 11.08 and 15.26% observed for GF-plasticizer concentrations of 15% and 60%,  
 248 respectively. However, the observed rise in the moisture content that occurred due to the addition  
 249 of GF-plasticizer was significantly lower than the increase that occurred due to the addition of G-  
 250 plasticizer to the film. When compared to glycerol-containing films, F-plasticized films have less  
 251 moisture content. Low moisture content could be because the fructose and glucose units of the  
 252 polymer have a similar molecular structure, which makes it easier for fructose molecules to  
 253 connect to the intermolecular chains in the film [17,21]. As a result, there was less chance that  
 254 the fructose molecules would come into contact with the water molecules. On the other hand,  
 255 glycerol molecules with hydroxyl groups had a high affinity for water, which made it easier to  
 256 form hydrogen bonds and keep water in the matrix of G-plasticized films [28]. Thus, fructose  
 257 and glycerol were water-resistant and water-holding agents, respectively [21].



258

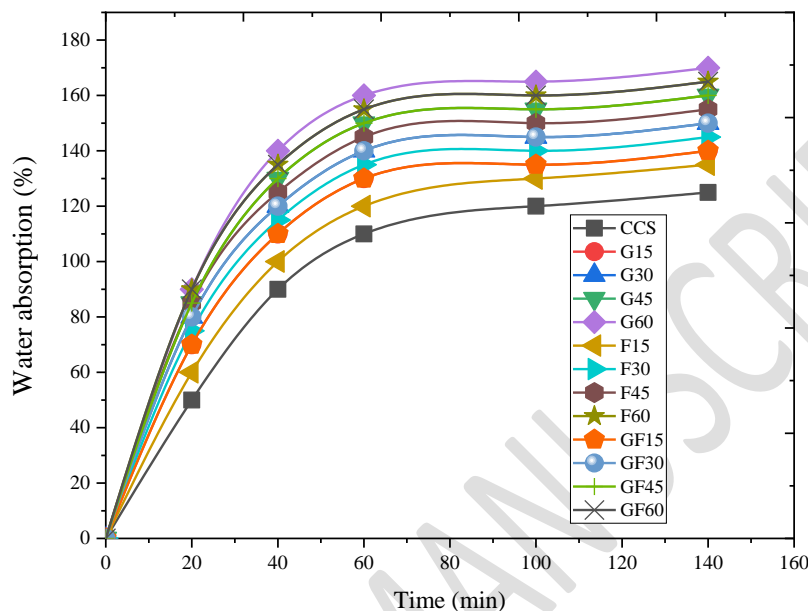
259 Figure 6. Moisture content of bioplastic films

260

### 261 5.1.5 Water absorption

262 Starch films require a high capacity for water absorption since water plays such an essential role  
 263 as a plasticizer. The plasticity of plasticized films increases as the percentage of water in the film  
 264 increases [18,22]. Since it has been reported that plasticized samples began dissolving in water  
 265 after 140 minutes [29], the period of biofilm soaked in water was fixed at 120 minutes in this  
 266 work. The findings of an investigation into the water absorption of plasticized films at various  
 267 plasticizer concentrations are shown in Figure 7. The results indicate that around 30 minutes after  
 268 immersion, all of the films, including the control film, had attained saturation, at which time  
 269 further water absorption was minimal. The control sample absorbed about 185.6% more water  
 270 than the other samples. At 15% plasticizer content, F-film absorbed the most water (173.45%),  
 271 followed by GF- film at 155.56% and Gplasticized film at 148.45%. Water absorption was also  
 272 found to decrease as plasticizer concentration was increased across all three categories of  
 273 plasticized films. The water absorption of F-plasticizer decreased from 173.45 to 126.69% when  
 274 the plasticizer concentration was raised from 15 to 60%; the water absorption of GF-plasticized  
 275 film decreased from 148.45 to 113.46%, and the water absorption of G-plasticized film  
 276 decreased from 155.56 to 72.90%. As a result, compared to G-plasticized and GF-plasticized  
 277 films, Gplasticized films had greater resistance to water. Because of glycerol's strong

278 hydrophobicity, soluble plasticizers may block the micro-voids in the matrix of the film,  
279 resulting in a decrease in water absorption. Hydrophobic plasticizers, on the other hand, might  
280 lead to the development of discontinuous regions or various phases in the film's matrix, both of  
281 which reduce its flexibility[30].



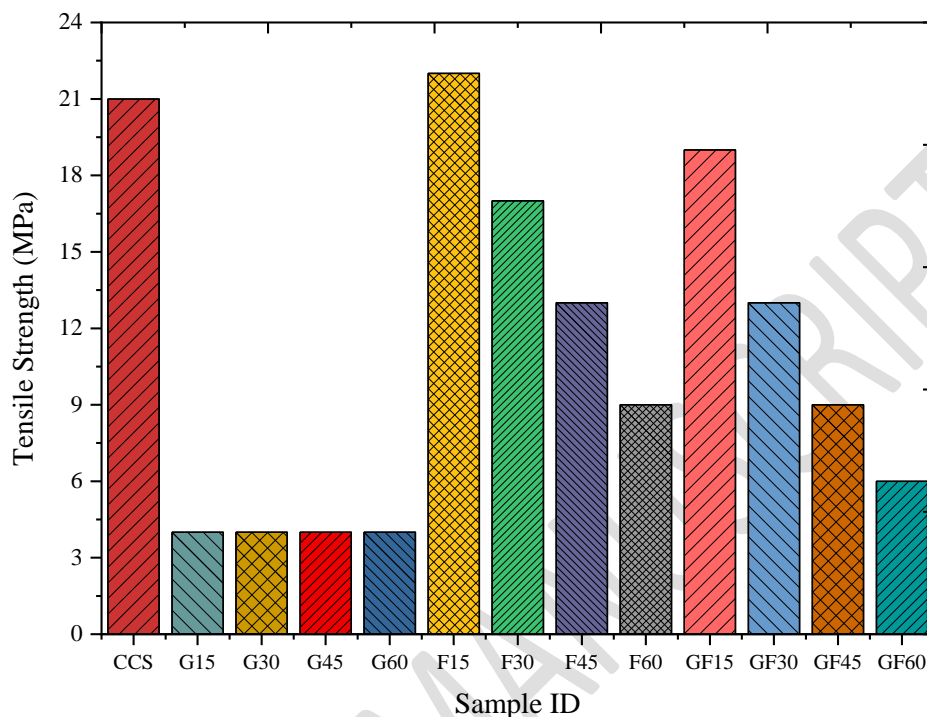
282  
283 Figure 7. Water absorption of bioplastic films

## 284 5.2 Mechanical properties

### 285 5.2.1 Tensile strength

286 At various dosages, the tensile strength, elongation at break, and Young's modulus of different  
287 plasticized films were evaluated. Figure 8 illustrates the effect of varying concentrations of  
288 various plasticizers on the tensile strength of CS films. The tensile strength of the F-plasticized  
289 film was 22.55 MPa at a concentration of 15%, the tensile strength of the FG plasticized film  
290 was 16.65 MPa, and the tensile strength of the G-plasticized film was 5.09 MPa. The findings  
291 confirmed the research [31], which revealed that F-plasticized CS film had greater tensile  
292 strength when compared to other plasticizers. Tensile strength was considerably diminished  
293 when the concentration of plasticizer was increased. The increase in plasticizer concentration  
294 from 15% to 60% decreased the tensile strength of the F-plasticized film from 22.55 to 8.67 MPa  
295. G-film's tensile strength reduced from 5.09 to 2.75 MPa in comparison, and FG-film's reduced  
296 from 16.65 to 4.52 MPa. In multiple investigations studies [18,22], the tensile strength of starch-  
297 based films decreased in response to an increase in plasticizer concentration. The incorporation  
298 of plasticizers increased the formation of hydrogen bonds between the starch molecules and the

299 plasticizers, thereby weakening the intra molecular interactions between the starch chain  
300 molecules [32].



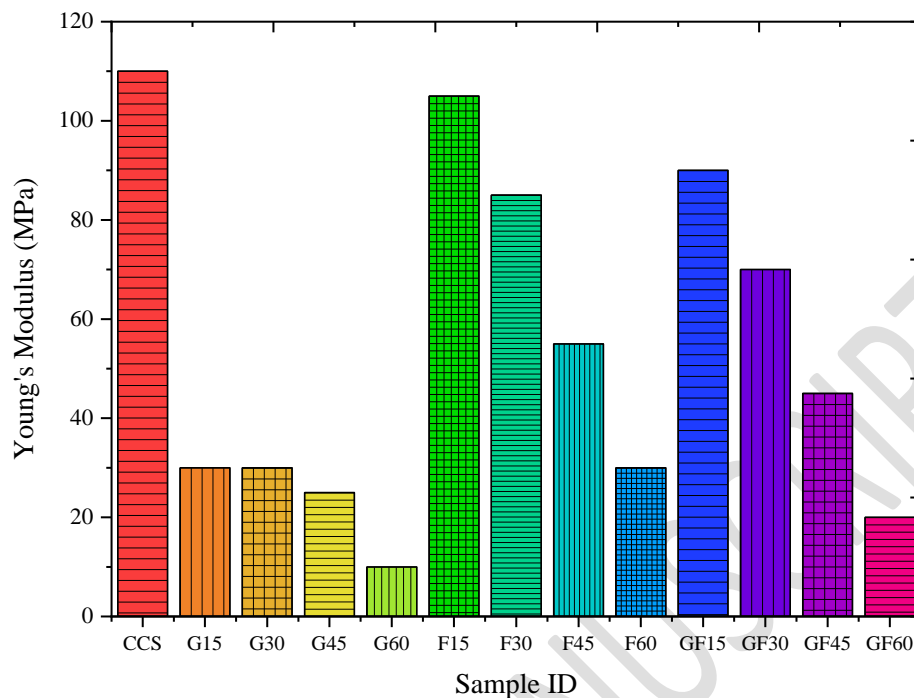
301

302 Figure 8. Tensile strength of bioplastic films

303 Young's modulus analysis was performed to evaluate the stiffness of the films, with a high  
304 Young's modulus indicating a material with a high degree of rigidity. According to Figure 9, F-  
305 plasticized films exhibited the highest Young's modulus, followed by FG plasticized films and G-  
306 plasticized films, in that order. Across all tested plasticizers, a decrease in tensile modulus was  
307 observed as plasticizer concentration increased from 30% to 60%, indicating that increasing  
308 plasticizer content made films less rigid. The rigidity of hydrophilic films decreases with  
309 increasing plasticizer concentration [33]. This behavior may be attributable to the structural  
310 modifications of the starch network that occurred when plasticizers were added and the film  
311 matrix became less dense [31].

312



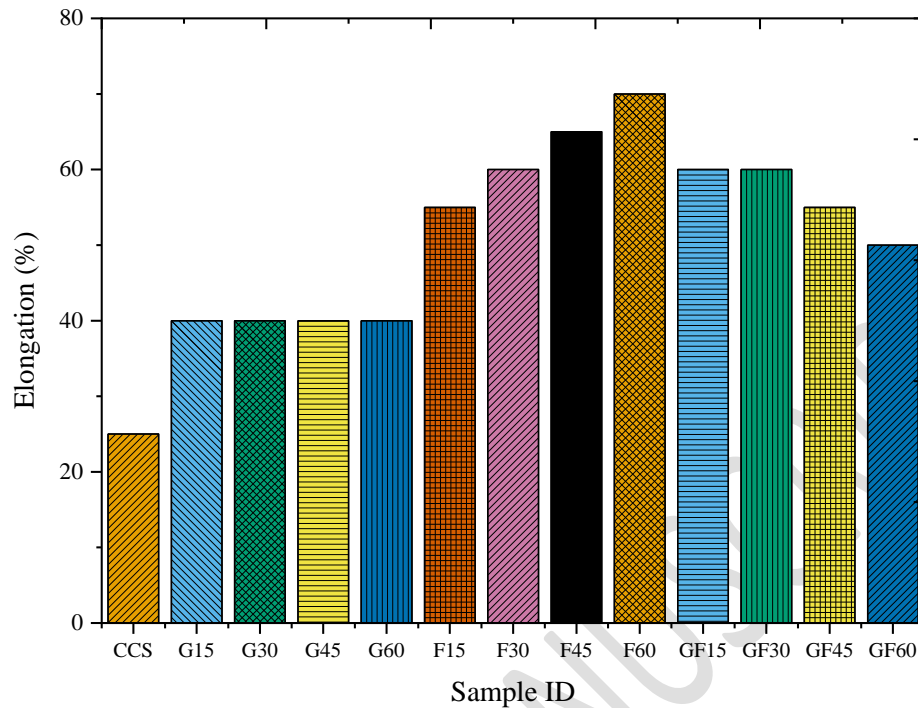


313

314 Figure 9. Young's modulus of bioplastic films

315 Figure 10 displays that the F-plasticized and FG-plasticized films had greater elongations at  
 316 break than the G-plasticized film. The elongation at break for F plasticized films was, however,  
 317 increased by the plasticizer concentration. In contrast, when the plasticizer content was raised  
 318 from 15 to 60%, a decrease in elongation at break was seen in FG-plasticized  
 319 films. However, for G-films, where elongation at break values of 37.13% and 35.24% were  
 320 reported at glycerol plasticizer concentrations of 150% and 60%, respectively, the effect of  
 321 plasticizer concentration on elongation at break was not statistically significant.  
 322





323

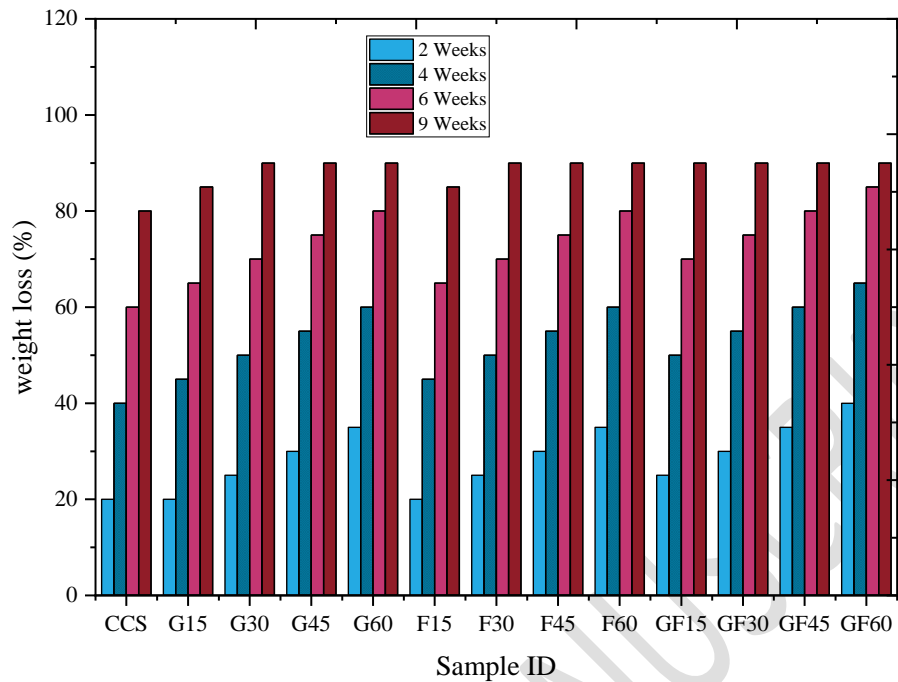
324 Figure 10. Elongation at break of bioplastic films

### 325 5.3 Environmental characteristics

#### 326 5.3.1 Biodegradability

327 By measuring the value of material reduced in weight over time, it is possible to determine the  
 328 rate of biodegradation caused by moisture in the soil and microorganisms [34]. The weights  
 329 before and after the test are compared to evaluate the amount of degradation in the soil burial  
 330 test. After nine weeks of interment, all the composites dropped more weight than two and four  
 331 weeks of degradation. The material lost more weight due to the increased number of  
 332 microorganisms present during the extended period the item was buried in the soil [35]. The  
 333 maximum weight loss of about 82% is achieved after 9 weeks of soil burial with fructose  
 334 addition.

335



336

337 Figure 11. Biodegradability of bioplastics at 2,4,6,9 weeks

### 338 6. Conclusions

339 This research aims to develop an approach to producing environmentally friendly and  
 340 biodegradable plastic. Evaluations are made for physical, mechanical, and biodegradability  
 341 characteristics. The test results have led to the following conclusions:

- 342 • Corn starch films without plasticizers were fragile and hard to remove from the casting  
 343 surface. Thus, using plasticizers facilitated reducing breakability and increasing the  
 344 flexibility of CS films. Plasticizers of various types and dosages were employed to study  
 345 the influences of CS films. The results revealed that the type and amount of plasticizers  
 346 affected the thickness, density, and strength of the CS film.
- 347 • Gradually increasing the plasticizer concentration from 15% to 60% decreased the water  
 348 absorption capability of the films, but it increased the film weight and thickness  
 349 irrespective of the plasticizer form.
- 350 • F-plastic films exhibited lower moisture, solubility, and water absorption when compared  
 351 to G and FG-plasticized films. Regarding physical and mechanical qualities, F-plasticized  
 352 films demonstrated maximum efficiency. With a tensile stress of 22.55 MPa, the F15-  
 353 plasticized films exhibited good mechanical strengths.

354 • Corn starch, fructose, and glycerol content can be optimized to improve the properties  
355 and applications of corn-based bioplastics. Furthermore, fillers must be added to improve  
356 the characteristics of corn-based bioplastics.

357 **7.Potential Limitations of Cornstarch-Based Bioplastic**Most of the cornstarch-based  
358 bioplastics have inferior tensile strength, flexibility, and toughness compared to  
359 petroleum-based plastics. Even though plasticizers improve flexibility, they tend to lower  
360 strength and create inconsistencies in performance. Because cornstarch is hydrophilic, the  
361 bioplastic has high water absorption, which compromises dimensional stability and  
362 usability under humid or wet conditions. Production of cornstarch-based bioplastics is  
363 still quite costly, especially when scaled up for industrial applications, making them less  
364 competitive with traditional plastics. While the bioplastic performs well in controlled  
365 composting conditions, its degradation may be retarded in less friendly environmental  
366 conditions, such as marine or landfill settings.

## 367 **References**

- 368 1. Nik Baihaqi, N.M.Z.; Khalina, A.; Mohd Nurazzi, N.; Aisyah, H.A.; Sapuan, S.M.; Ilyas,  
369 R.A. Effect of Fiber Content and Their Hybridization on Bending and Torsional Strength of  
370 Hybrid Epoxy Composites Reinforced with Carbon and Sugar Palm Fibers.  
371 *Polimery/Polymers*2021, 66, 36-43, doi:10.14314/POLIMERY.2021.1.5.
- 372 2. Supian, A.B.M.; Sapuan, S.M.; Jawaid, M.; Zuhri, M.Y.M.; Ilyas, R.A.; Syamsir, A.  
373 Crashworthiness Response of Filament Wound Kenaf/Glass Fibre-Reinforced Epoxy  
374 Composite Tubes with Influence of Stacking Sequence under Intermediate-Velocity Impact  
375 Load. *Fibers Polym.*2022, 23, 222-233, doi:10.1007/s12221-021-0169-9.
- 376 3. Rana, K.I. Usage of Potential Micro-Organisms for Degradation of Plastics. *Open J.*  
377 *Environ. Biol.*2019, 4, 007-015, doi:10.17352/ojeb.000010.
- 378 4. Ilyas, R.A.; Sapuan, S.M.; Asyraf, M.R.M.; Dayana, D.A.Z.N.; Amelia, J.J.N.; Rani,  
379 M.S.A.; Norrahim, M.N.F.; Nurazzi, N.M.; Aisyah, H.A.; Sharma, S.; et al. Polymer  
380 Composites Filled with Metal Derivatives: A Review of Flame Retardants. *Polymers*  
381 *(Basel)*.2021, 13, doi:10.3390/polym13111701.
- 382 5. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, Use, and Fate of All Plastics Ever Made.  
383 *Sci. Adv.*2017, 3, 25-29, doi:10.1126/sciadv.1700782.
- 384 6. Jang, Y.C.; Lee, G.; Kwon, Y.; Lim, J. hong; Jeong, J. hyun Recycling and Management  
385 Practices of Plastic Packaging Waste towards a Circular Economy in South Korea. *Resour.*  
386 *Conserv. Recycl.*2020, 158, 104798, doi:10.1016/j.resconrec.2020.104798.
- 387 7. Suriani, M.J.; Rapi, H.Z.; Ilyas, R.A.; Petru, M.; Sapuan, S.M. Delamination and  
388 Manufacturing Defects in Natural Fiber-Reinforced Hybrid Composite: A Review. *Polymers*  
389 *(Basel)*.2021, 13, 1-24, doi:10.3390/polym13081323.

- 390 8. Hazrati, K.Z.; Sapuan, S.M.; Zuhri, M.Y.M.; Jumaidin, R. Extraction and Characterization  
391 of Potential Biodegradable Materials Based on Dioscorea Hispida Tubers. *Polymers*  
392 (Basel).2021, 13, 1-19, doi:10.3390/polym13040584.
- 393 9. Bernaerts, T.M.M.; Gheysen, L.; Foubert, I.; Hendrickx, M.E.; Van Loey, A.M. The  
394 Potential of Microalgae and Their Biopolymers as Structuring Ingredients in Food: A  
395 Review. *Biotechnol. Adv.*2019, 37, 107419, doi:10.1016/j.biotechadv.2019.107419.
- 396 10. Omran, A.A.B.; Mohammed, A.A.B.A.; Sapuan, S.M.; Ilyas, R.A.; Asyraf, M.R.M.; Kolor,  
397 S.S.R.; Petru, M. Micro-and Nanocellulose in Polymer Composite Materials: A Review.  
398 *Polymers (Basel)*.2021, 13, 1-30, doi:10.3390/polym13020231.
- 399 11. Syafiq, R.; Sapuan, S.M.; Zuhri, M.Y.M.; Ilyas, R.A.; Nazrin, A.; Sherwani, S.F.K.;  
400 Khalina, A. Antimicrobial Activities of Starch-Based Biopolymers and Biocomposites  
401 Incorporated with Plant Essential Oils: A Review. *Polymers (Basel)*.2020, 12, 1-26,  
402 doi:10.3390/polym12102403.
- 403 12. Chan, J.X.; Wong, J.F.; Petru, M.; Hassan, A.; Nirmal, U.; Othman, N.; Ilyas, R.A. Effect of  
404 Nanofillers on Tribological Properties of Polymer Nanocomposites: A Review on Recent  
405 Development. *Polymers (Basel)*.2021, 13, 1-47, doi:10.3390/polym13172867.
- 406 13. Jumaidin, R.; Diah, N.A.; Ilyas, R.A.; Alamjuri, R.H.; Yusof, F.A.M. Processing and  
407 Characterisation of Banana Leaf Fibre Reinforced Thermoplastic Cassava Starch  
408 Composites. *Polymers (Basel)*.2021, 13, doi:10.3390/polym13091420.
- 409 14. Diyana, Z.N.; Jumaidin, R.; Selamat, M.Z.; Ghazali, I.; Julmohammad, N.; Huda, N.; Ilyas,  
410 R.A. Physical Properties of Thermoplastic Starch Derived from Natural Resources and Its  
411 Blends: A Review. *Polymers (Basel)*.2021, 13, 5-20, doi:10.3390/polym13091396.
- 412 15. Ghanbarzadeh, B.; Almasi, H.; Entezami, A.A. Improving the Barrier and Mechanical  
413 Properties of Corn Starch-Based Edible Films: Effect of Citric Acid and Carboxymethyl  
414 Cellulose. *Ind. Crops Prod.*2011, 33, 229-235, doi:10.1016/j.indcrop.2010.10.016.
- 415 16. Waterschoot, J.; Gomand, S. V.; Fierens, E.; Delcour, J.A. Production, Structure,  
416 Physicochemical and Functional Properties of Maize, Cassava, Wheat, Potato and Rice  
417 Starches. *Starch/Staerke*2015, 67, 14-29, doi:10.1002/star.201300238.
- 418 17. Ibrahim, M.IJ.; Sapuan, S.M.; Zainudin, E.S.; Zuhri, M.Y.M. Extraction, Chemical  
419 Composition, and Characterization of Potential Lignocellulosic Biomasses and Polymers  
420 from Corn Plant Parts. *BioResources*2019, 14, 6485-6500, doi:10.15376/biores.14.3.6485-  
421 6500.
- 422 18. Sanyang, M.L.; Sapuan, S.M.; Jawaid, M.; Ishak, M.R.; Sahari, J. Effect of Plasticizer Type  
423 and Concentration on Tensile, Thermal and Barrier Properties of Biodegradable Films Based  
424 on Sugar Palm (*Arenga Pinnata*) Starch. *Polymers (Basel)*.2015, 7, 11061124,  
425 doi:10.3390/polym7061106.

- 426 19. Zentou, H.; Rosli, N.S.; Wen, C.H.; Abdul Azeez, K.; Gomes, C. The Viability of Biofuels  
427 in Developing Countries: Successes, Failures, and Challenges. *Iran. J. Chem. Chem.*  
428 *Eng.*2019, 38, 173-182.
- 429 20. Shahabi-Ghahfarrokhi, I.; Goudarzi, V.; Babaei-Ghazvini, A. Production of Starch Based  
430 Biopolymer by Green Photochemical Reaction at Different UV Region as a Food Packaging  
431 Material: Physicochemical Characterization. *Int. J. Biol. Macromol.*2019, 122, 201-209,  
432 doi:10.1016/j.ijbiomac.2018.10.154.
- 433 21. Hazrol, M.D.; Sapuan, S.M.; Zainudin, E.S.; Zuhri, M.Y.M.; Wahab, N.I.A. Corn Starch  
434 (Zea Mays) Biopolymer Plastic Reaction in Combination with Sorbitol and Glycerol.  
435 *Polymers (Basel)*.2021, 13, 1-22, doi:10.3390/polym13020242.
- 436 22. Ibrahim, M.I.J.; Sapuan, S.M.; Zainudin, E.S.; Zuhri, M.Y.M. Physical, Thermal,  
437 Morphological, and Tensile Properties of Cornstarch-Based Films as Affected by Different  
438 Plasticizers. *Int. J. Food Prop.*2019, 22, 925-941, doi:10.1080/10942912.2019.1618324.
- 439 23. Vieira, M.G.A.; Da Silva, M.A.; Dos Santos, L.O.; Beppu, M.M. Natural-Based Plasticizers  
440 and Biopolymer Films: A Review. *Eur. Polym. J.*2011, 47, 254-263,  
441 doi:10.1016/j.eurpolymj.2010.12.011.
- 442 24. Versino, F.; López, O. V.; García, M.A. Sustainable Use of Cassava (Manihot Esculenta)  
443 Roots as Raw Material for Biocomposites Development. *Ind. Crops Prod.*2015, 65, 79-89,  
444 doi:10.1016/j.indcrop.2014.11.054.
- 445 25. Mali, S.; Grossmann, M.V.E.; García, M.A.; Martino, M.N.; Zaritzky, N.E. Effects of  
446 Controlled Storage on Thermal, Mechanical and Barrier Properties of Plasticized Films from  
447 Different Starch Sources. *J. Food Eng.*2006, 75, 453-460,  
448 doi:10.1016/j.jfoodeng.2005.04.031.
- 449 26. Zhang, Y.; Han, J.H. Mechanical Properties of High- Amylose Rice and Pea Starch Films as  
450 Affected by Relative Humidity and Plasticizer with Monosaccharides and Polyols. *Food*  
451 *Eng. Phys. Prop.*2006, 69, 449-454.
- 452 27. Basiak, E.; Lenart, A.; Debeaufort, F. How Glycerol and Water Contents Affect the  
453 Structural and Functional Properties of Starch-Based Edible Films. *Polymers (Basel)*.2018,  
454 10, doi:10.3390/polym10040412.
- 455 28. Cerqueira, M.A.; Souza, B.W.S.; Teixeira, J.A.; Vicente, A.A. Effect of Glycerol and Corn  
456 Oil on Physicochemical Properties of Polysaccharide Films - A Comparative Study. *Food*  
457 *Hydrocoll.*2012, 27, 175-184, doi:10.1016/j.foodhyd.2011.07.007.
- 458 29. Bagde, P.; Nadanathangam, V. Mechanical, Antibacterial and Biodegradable Properties of  
459 Starch Film Containing Bacteriocin Immobilized Crystalline Nanocellulose. *Carbohydr.*  
460 *Polym.*2019, 222, 115021, doi:10.1016/j.carbpol.2019.115021.
- 461 30. Kochkina, N.E.; Lukin, N.D. Structure and Properties of Biodegradable Maize

- 462 Starch/Chitosan Composite Films as Affected by PVA Additions. *Int. J. Biol.*  
463 *Macromol.*2020, 157, 377-384, doi:10.1016/j.ijbiomac.2020.04.154.
- 464 31. Edhirej, A.; Sapuan, S.M.; Jawaid, M.; Zahari, N.I. Effect of Various Plasticizers and  
465 Concentration on the Physical, Thermal, Mechanical, and Structural Properties of Cassava-  
466 Starch-Based Films. *Starch/Staerke*2017, 69, 1-11,  
467 doi:10.1002/star.201500366.
- 468 32. Hazrati, K.Z.; Sapuan, S.M.; Zuhri, M.Y.M.; Jumaidin, R. Effect of Plasticizers on Physical,  
469 Thermal, and Tensile Properties of Thermoplastic Films Based on Dioscorea Hispida Starch.  
470 *Int. J. Biol. Macromol.*2021, 185, 219-228, doi:10.1016/j.ijbiomac.2021.06.099.
- 471 33. Mali, S.; Grossmann, M.V.E.; Garcia, M.A.; Martino, M.N.; Zaritzky, N.E. Microstructural  
472 Characterization of Yam Starch Films. *Carbohydr. Polym.*2002, 50, 379-386,  
473 doi:10.1016/S0144-8617(02)00058-9.
- 474 34. Alamjuri, R.H.; Yusof, F.A. Biocomposite of Cassava Starch-Cymbopogan Citratus Fibre:  
475 Mechanical, Thermal and Biodegradation Properties. 2022, 1-19.
- 476 35. Jumaidin, R.; Sapuan, S.M.; Jawaid, M.; Ishak, M.R.; Sahari, J. Thermal, Mechanical, and  
477 Physical Properties of Seaweed/Sugar Palm Fibre Reinforced Thermoplastic Sugar Palm  
478 Starch/Agar Hybrid Composites. *Int. J. Biol. Macromol.*2017, 97, 606-615,  
479 doi:10.1016/j.ijbiomac.2017.01.079.
- 480