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Prize Winner

Scientific Inquiry

Year 9-10

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Functionality of bioplastics: Investigating the physical and mechanical properties of algal bioplastics

How do different concentrations of agar and glycerine affect the physical and mechanical properties of algal bioplastics?

Chloe Yew

Scientific Report

Title

Functionality of bioplastics: Investigating the physical and mechanical properties of algal bioplastics

Research Question

How do different concentrations of glycerine and agar affect the physical and mechanical properties of algal bioplastics?

Background information

Burgeoning concerns regarding the severe depletion of fossil fuel resources along with the detrimental pollution of persistent conventional plastic accumulation in the natural environment motivate the investigation of renewable material production from green processes to replace petroleum-based plastics. Petrochemical plastic emits greenhouse gases over every phase of the plastic lifecycle, including extraction and transport, refining and manufacturing, and after-use and waste management. By 2050, oceans are forecasted to contain more plastics than fish by weight, and the cumulative greenhouse gas emissions from the plastic lifecycle will surpass 56 billion tonnes, constituting 10–15% of the annual global carbon budget (Global Alliance for Incinerator Alternatives and Zero Waste Europe, 2018). Plastic pollution is a massive crisis for our planet. In recent years, the development of renewable sources for edible packaging solutions and advancements in bioplastic technologies have contributed to the increase in popularity of algal bioplastic innovations through green technologies.

Aim

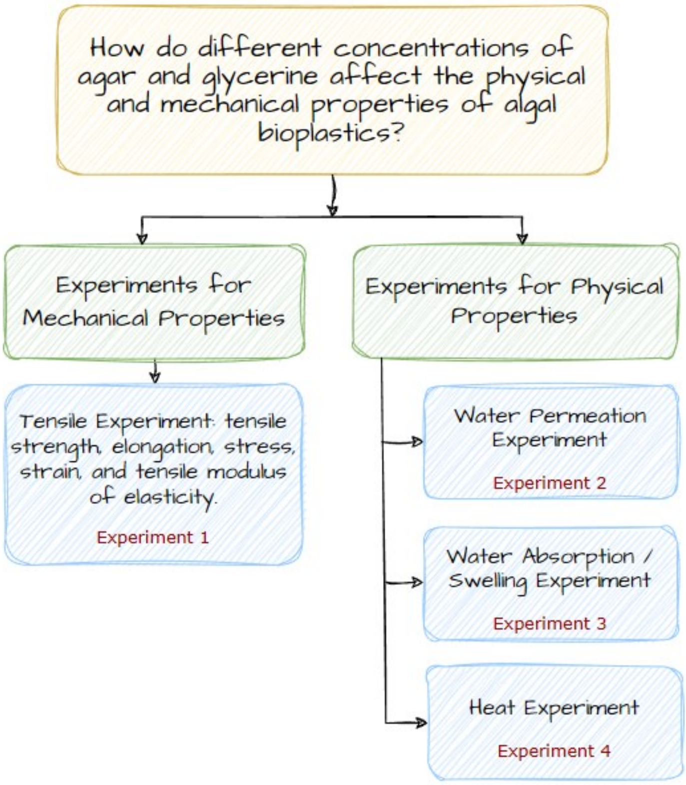
The first phase of this investigation was creating biodegradable polymers derived from algae using water, agar, and glycerine. Agar is a seaweed polysaccharide extracted from the cell walls of the red seaweeds, namely Gelidium and Gracilaria (A. Balamurugan et al. 2024). Glycerine, with a molecular formula of $C_3H_8O_3$, occurs naturally in plants through the fermentation of sugars in plants but can be produced from the hydrolysis of fats and lipids. Glycerine serves as a plasticiser, which increases the flexibility of plastics. Bioplastic formulations were created following multiple attempts to produce bioplastics using combinations of different ingredients.

In the second phase of the study, experiments were conducted to study the effect of different concentrations of agar and glycerine on the physical and mechanical properties of algal bioplastics. Of interest, mechanical properties comprising tensile strength, tensile elongation, stress, strain, and tensile modulus of elasticity, as well as physical properties including water permeability and water absorbency, were investigated. The functional properties of the home-made bioplastics were also compared with the commercially available compostable plastics. Qualitative and quantitative analyses were performed to evaluate which bioplastic is most suitable in terms of mechanical strength and flexibility, and whether algal bioplastic is a viable alternative to conventional plastics to tackle plastic pollution and climate change.

Hypotheses

Hypothesis 1:	An increase in agar concentration increases the tensile strength, stress, and modulus of elasticity in the bioplastics.
Hypothesis 2:	An increase in glycerine concentration increases the tensile elongation and strain but decreases the tensile strength, stress, and modulus of elasticity in the bioplastics.

Experiment flowchart



Terms	Definition
Tensile Strength	The load at which a plastic sample of a cross-sectional area can wisthstand when it is pulled apart under specified conditions.
Ultimate tensile Strength	The maximum load to which a plastic sample can withstand before it breaks under a tensile load.
Tensile Elongation	The degree to which a plastic sample can be elongated under a tensile load prior to failure.
Fracture point	Fracture point refers to the point where a plastic sample reaches the maximum strain and fractures.

Fracture/breaking strength	Ductile materials have a fracture strength lower than the ultimate tensile strength; whereas, in brittle materials, the fracture strength is equivalent to the ultimate tensile strength.
Stress	The force per unit area that acts on a plastic sample.
Strain	A measure of the elongation of a plastic sample under a tensile load.
Tensile modulus of elasticity (Young's modulus)	A measure of the tensile stiffness of a plastic sample before breaking or permanently deforming.
Water absorption capacity	The % weight increase of a plastic after immersion in water for a period of time.

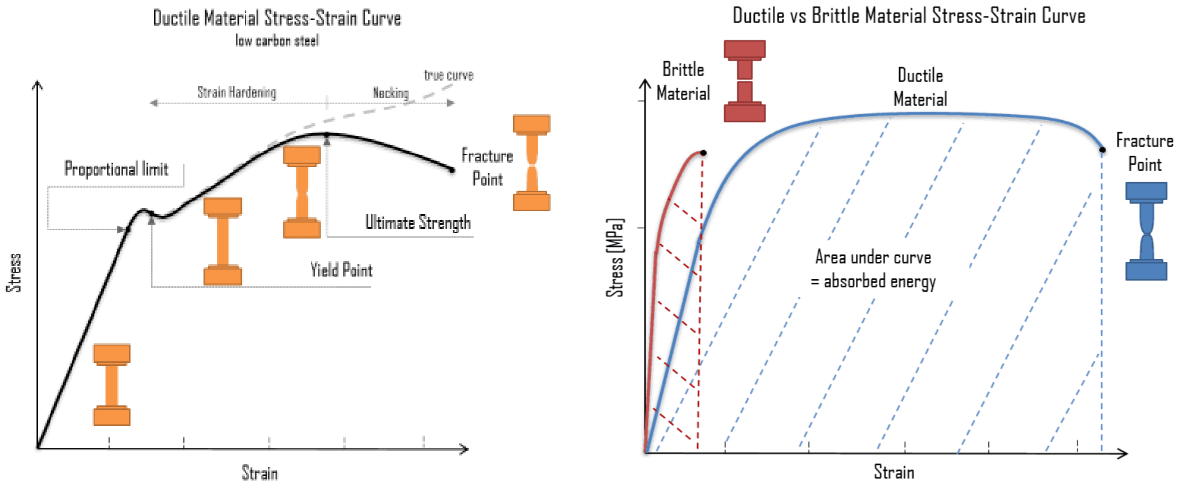


Figure 1. Understanding the stress-strain curves of materials (Fracture Point - Fracture Strength - Stress-strain Curve n.d.).

Variables

Independent and Dependent Variables

Independent Variables	Different concentrations of agar and glycerine
Dependent Variables	**Experiment 1:** Tensile Test: tensile strength, tensile elongation, stress, strain, and tensile modulus of elasticity **Experiment 2:** Water permeability **Experiment 3:** Water absorption: percentage of weight gain

Controlled Variables

Controlled variables are to ensure that this experiment is a 'fair test'.

Controlled variables	Method of Control	Reason
Size of bioplastic samples	Each bioplastic sample was measured and cut to either 80mm x 20mm (Experiment 1	Surface area of bioplastic sample is a factor that can affect tensile

	and 3) or 12cm x 12cm (Experiment 2) dimensions, using a ruler for precision.	properties and water absorption ability.
Measurement/observation time	The data was collected at the specified time intervals.	The data is collected at the same time for fair test to ensure the results are not observed at a random event. Different measurement/observation time may affect data reliability.
Environment	All the experiments were conducted in the same environment. The temperature range was 8°C to 20°C.	Different environment, such as temperature and humidity, may affect the quality of the bioplastics and all experiments.
Weighing scale, analytical balance, ruler, and infrared thermometer	The same equipment was used for measurement. The length of bioplastics is measured at eye level.	This is to minimise parallax and systematic errors and hence improve the accuracy of the data collected.
Amount of water (for Experiment 2)	10ml of water was measured and placed on each bioplastic sample using a syringe.	Different amount of water may affect the bioplastic's water permeability.
Source of bioplastic materials (agar and glycerine)	Agar and glycerine used to produce all bioplastic samples were sourced from the same brand and batch.	Different source of agar and glycerine may exhibit variability which may affect the quality of the bioplastics, and hence manifesting random errors in the data.
Volume and amount of water, agar, and glycerine	The amount of water was set consistent 200ml to produce the bioplastics samples. Following the set procedure, the amount of water, glycerine and agar were measured accurately using the analytical balance, weighing scale, and syringe.	The amount of water, agar, and glycerine are independent variables of investigation that affect tensile properties, water permeability, and water absorption ability.
Heat level for producing bioplastics	When heating the bioplastics, the stove knob was set consistent at low heat.	Varied heat levels when heating the bioplastic may affect their quality.
Experiments of trials	Trials were conducted with the same method and materials, and at the same period of time.	The procedure of the trials must be the same to produce valid and reliable results. In addition, five trials and three trials are used in Experiment 1 and 2 respectively to generate averaged data.

Uncontrolled Variables

Uncontrolled variables	Reason why it cannot be controlled and its effect on data
The time lapse for measurement/observation across the bioplastic samples	The time lapse for measurement/observation across the bioplastic samples occurs since time is consumed for preparing and measuring. Its effect on data is insignificant since there is

	no rapid change to their tensile properties, water permeability, or water absorption abilities in that short amount of time.
Temperature and heat fluctuations during heating time	Despite the stove being set on low heat, the temperature can fluctuate during heating, which can manifest intrinsic errors that can alter the quality of bioplastic samples, resulting in variability in the data. The effect on the data is insignificant since the stove knob is adjusted consistently in all bioplastic production.
Amount of sodium benzoate	The amount of sodium benzoate used as a preservative in bioplastic production may vary since the analytical balance was not used to regulate the portions precisely. However, this variation is expected to have a negligible impact on the data, given that the amount of sodium benzoate used was approximately consistent.
Thickness of the bioplastics	The thickness of the bioplastics is unable to be controlled due to limited resources and casting techniques. However, the same initial volume of water and tray size are used across all bioplastic samples. Different thicknesses of the bioplastics may vary their tensile properties and water permeability, which may subsequently lead to inconsistencies in the data.
Rate of loading weights during tensile testing	The variation in the rate at which weights are manually loaded during tensile testing may influence the tensile properties. However, this process is performed by a single tester, which could potentially normalise the rate of loading. Five trials are performed to reduce variability.

Equipment and Materials

Equipment and Materials (Producing bioplastics)			
	Materials	**Equipment**	**Personal Protective Equipment**
Producing bioplastics	▪ Agar ▪ Glycerine ▪ Water ▪ Sodium Benzoate	▪ Stove ▪ Metal Spoon ▪ Saucepan (16cm) ▪ Plastic trays (33cm x 33cm) ▪ Syringes (12ml) ▪ Digital Scale (0.1g) ▪ Analytical balance (0.001g) ▪ Labelling stickers ▪ Pen/Marker ▪ Plastic scraper ▪ Small plastic bags ▪ Scrub Pad	▪ Apron ▪ Safety glasses ▪ Safety gloves ▪ Surgical mask ▪ Enclosed footwear

Tensile Test	▪ Bioplastics	▪ Retort stand (60cm) ▪ Retort clamps ▪ Mohr clip ▪ Hoffman compression metal clamps x 2 ▪ Force meters (spring scales) 500g, 2kg ▪ S hooks x4 ▪ Slotted weights (50g x15, 100g x6, 10g x6) and a 1012g plate ▪ Calliper ▪ Ruler ▪ Cutter ▪ Chair ▪ Thick mat	▪ Apron ▪ Safety glasses ▪ Safety gloves ▪ Surgical mask ▪ Enclosed footwear
Water Permeability and Absorption Tests	▪ Bioplastics ▪ Water	▪ Beaker 100ml x43 ▪ Analytical balance (0.001) ▪ Elastic band x11 ▪ Ruler ▪ Cutter ▪ Tissue papers ▪ Forceps	▪ Apron ▪ Safety glasses ▪ Safety gloves ▪ Surgical mask ▪ Enclosed footwear
Heat Tests	▪ Bioplastics ▪ Water	▪ Stove ▪ Saucepan (16cm) ▪ Infrared thermometer	▪ Apron ▪ Safety glasses ▪ Safety gloves ▪ Surgical mask ▪ Enclosed footwear


Agar powder

Glycerine


Water


Sodium benzoate


Stove


Metal spoon


Saucepan (16cm)


Plastic trays
(33cm x 33cm)


Syringes (12ml)


Kitchen scale (0.1)


Analytical balance (0.001)


Labelling stickers


Pen


Plastic scraper

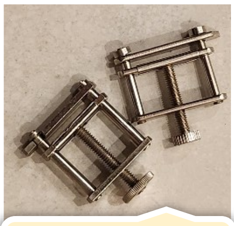

Scrub pad


Bioplastics


Retort stand (60cm)


Retort clamps


Mohr clip


Hoffman compression metal clamps


Force meters (spring scales) 500g, 2kgs


S hooks


Slotted weights


Calliper


Ruler

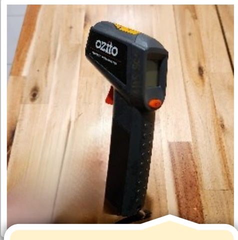

Cutter


Beaker (100ml)


Elastic bands


Tissue papers


Forceps

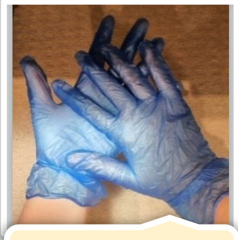


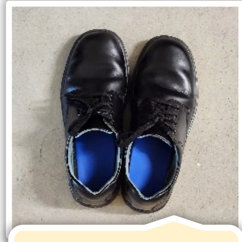
Infrared thermometer


Surgical mask


Safety glasses


Apron


Safety gloves


Enclosed footwear

Risk Assessment

Safety Precautions Prudent laboratory safety practices were followed. Chemical contact was avoided by putting on personal protective equipment, including an apron, safety glasses, safety gloves, enclosed footwear, and a surgical mask, to prevent inhalation of chemicals. Hair was tied back so that it did not come into contact with any chemicals. During observation, personal protective equipment was used to reduce the risk of contamination and biohazards, including mould growth. When cutting bioplastics, scissors and cutter knives were carefully handled to prevent cuts. The equipment and apparatus used in this experiment were carefully handled to prevent any incidents.
Environmental Consideration The experiment was conducted in compliance with the control measures for preparation, usage of laboratory materials, and disposal of chemical waste. There were no significant environmental considerations, as the equipment and actions used in this experiment presented no hazard or danger to the environment.
Ethical Consideration There were no significant ethical considerations, as the equipment and actions used in this experiment presented no harm to society or any individual.

Procedure

Phase 1. Producing the bioplastics.

STEP 1: Prepare the materials

1. 200 ml of water was measured and placed in the saucepan.

2. Glycerine was measured and placed in the saucepan using a syringe (Table 1).

3. Agar powder was measured using an analytical balance and placed in the saucepan using a spoon (Table 1).

4. A dash of sodium benzoate was placed in the saucepan using a small plastic spoon.

STEP 2: Heating and casting the bioplastics.

5. The mixture was stirred consistently with a spoon and cooked on the stove at low heat for 8 minutes or until thick.

6. The mixture was carefully poured and spread evenly in the tray. The trays were labelled appropriately (Table 1).

7. The bioplastics were left to be dry at room temperature.

8. The bioplastics were carefully peeled off the tray using the plastic scraper for easy manoeuvring.

***The saucepan was thoroughly washed using the scrub pad and water between producing various bioplastics.**

Table 1. Bioplastic formulations were achieved during the phase 1 of the study. Bioplastics of different textures were obtained by heating specified mixtures of different concentrations of agar and glycerine. The casting trays were labelled. A2 is the same as G2.

Bioplastics Label	Amount of Water	Solution	Concentration (%w/v)	Ratio of water : agar : glycerine
A1	200 ml	2.5g agar, 5ml glycerine	1.25% agar, 2.5% glycerine	80 : 1 : 2
A2	200 ml	5g agar, 5ml glycerine	2.5% agar, 2.5% glycerine	40 : 1 : 1
A3	200 ml	10g agar, 5ml glycerine	5% agar, 2.5% glycerine	40 : 2 : 1
A4	200 ml	15g agar, 5ml glycerine	7.5% agar, 2.5% glycerine	40 : 3 : 1
G0	200 ml	5g agar, 1.25ml glycerine	2.5% agar, 0.625% glycerine	160 : 4: 1
G1	200 ml	5g agar, 2.5ml glycerine	2.5% agar, 1.25% glycerine	80 : 2 : 1
G2	200 ml	5g agar, 5ml glycerine	2.5% agar, 2.5% glycerine	40 : 1 : 1
G3	200 ml	5g agar, 10ml glycerine	2.5% agar, 5% glycerine	40 : 1 : 2

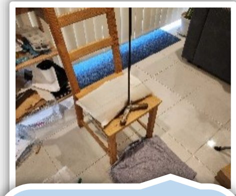
G4	200 ml	5g agar, 15ml glycerine	2.5% agar, 7.5% glycerine	40 : 1 : 3

Commercially available compostable bags were used for comparison.
B: Sourced from Campbelltown Council
C: Sourced from Coles
W: Sourced from Woolworths

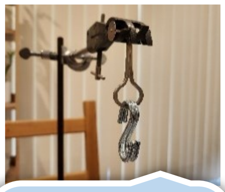
Phase 2. Experiments on the selected physical and mechanical properties of algal bioplastics

Experiment 1. Tensile Test

STEP 1: Setup the experiment

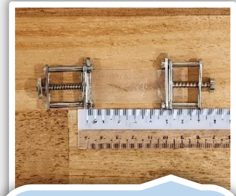


1. The retort stand is placed on a chair with a mat placed directly beneath it on the floor.



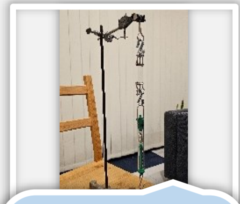
2. The clamps were securely fastened to the retort stand, followed by the placement of a Mohr clip within the clamps. Subsequently, two S hooks were attached to the clip.

3. The bioplastic sheets were measured and cut to strips of dimensions 80mm x 20mm using a ruler and cutter.

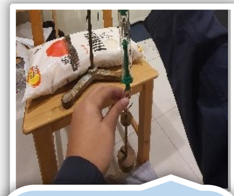


4. After measuring the bioplastic's thicknesses using the calliper, each end of the bioplastic samples was attached tightly in a Hoffman clamp, with a 50mm in between measured using a ruler.

STEP 2: Measure and record the bioplastic's tensile properties



5. One Hoffman clamp was hooked onto the two S hooks, followed by the placement of another two S hooks on the other Hoffman clamp, and a 2kg force meter on the S hooks.



6. The slotted weights were positioned on the hook of the force meter, with the weight incrementally increasing by either 10g or 50g depending on its tensile strength, starting from an initial weight of 100g.

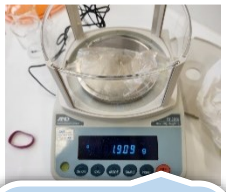
7. Each time a weight was added to the hook, the length of the bioplastic was measured at eye level and recorded using a ruler, until fracture occurred.

Data was gathered from five trials of each bioplastic sample.

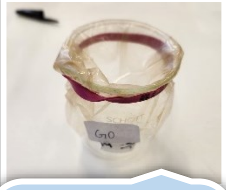
Experiment 2. Water Permeability

STEP 1: Setup the experiment

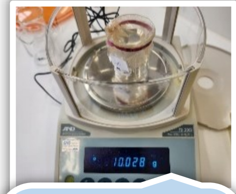
1. The bioplastic sheets were measured using a ruler and cut to strips of dimensions 12cm x 12cm using a cutter.



2. The weight of the bioplastics, beaker, water, and elastics were measured using the analytical balance.



3. The bioplastic was tied on top of the beaker around the rim using an elastic band and ruler to maintain an approximate depth of 3cm.



4. 10ml of water was added on the bioplastic using a syringe and an analytical balance.

STEP 2: Measure and record the bioplastic's water permeability

5. The beakers were labelled appropriately across all test samples.

6. The total weight of the setup was measured with an analytical balance, and recorded at time intervals of 1, 24, 25, and 48 hours.

Experiment 3. Water Absorption

Experiment 3. Water Absorption Procedure

1. The bioplastic sheets were measured using a ruler and cut to strips of dimensions 80mm x 20mm using a cutter.

2. The weight of each individual bioplastic were measured using the analytical balance.

3. Each bioplastic strip was placed in a 100ml beaker where 80ml of water was filled. Each beaker was labelled appropriately.

4. At time intervals of 2, 24, 26, and 48 hours, the bioplastics were gently wiped with tissue paper to remove any external water, after which their total weights were measured.

Data was gathered from three trials of each bioplastic sample.

Experiment 4. Heat Test

Experiment 4. Heat Test Procedure

1. 300ml of water was measured and placed in the saucepan using the digital scale.

2. Using a digital scale, bioplastics of each sample was measured and placed into the saucepan.

3. The stove was turned on at low heat, while an infrared thermometer was used to measure the bioplastic's temperature.

4. The process of melting the bioplastics was observed.

Processing and Analysing Data and Information:

Experiment 1: Tensile Test

Table 2. Mechanical properties of all bioplastics. Table 2 comprises of Tables 2a to 2f.

= Fracture point.

Table 2a. Mechanical properties of A1 bioplastics.

Weight (g)	A1 (1.25% agar, 2.5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	51	53	52	51	50
100	54	57	56	54	53
110	54	58	57	55	#
120	54	59	58	#	
130	54	59	59		
140	54	60	#		
150	55	60			
160	#	61			
170		62			
180		62			
190		#			

A1	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	160	190	140	120	110
Max stress (Pa)	1568.00	1862.00	1372.00	1176.00	1078.00
Max Strain (%)	7.84	16.98	13.46	8	6

Table 2b. Mechanical properties of A2/G2 bioplastics.

Weight (g)	A2/G2 (2.5% agar, 2.5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 1	Trial 4	Trial 1
0	50	50	50	51	50
100	50	51	52	52	52

150	51	52	52	52	53
200	52	54	53	53	53
250	53	54	53	54	54
300	54	56	54	54	56
350	55	57	55	55	58
400	56	58	56	56	#
410	56	59	57	56	
420	57	59	57	57	
430	58	60 #	57	57	
440	59		58	58	
450	59 #		58	58	
460			58	59	
470			59	59	
480			59	59	
490			59	59	
500			59	60	
510			#	60	
520				60	
530				60	
540				60	
550				61	
560				62	
570				62	
580				63 #	

A2/G2	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	450	430	510	580	400
Max stress (Pa)	4410.00	4214.00	4998.00	5684.00	3920.00
Max Strain (%)	18	20	18	23.53	16

Table 2c. Mechanical properties of A3 bioplastics.

Weight (g)	A3 (5% agar, 2.5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	51	52	50	52	50
100	52	53	51	52	51
150	53	53	52	52	52
200	53	54	53	53	52
250	54	54	54	53	53
300	55	55	55	53	53
350	56	56	55	54	54
400	57	56	56	54	55
450	59	57	58	56	55
500	60	58	59	56	56
510	61	58	59	56	57

520	62	58	60	56	57
530	62	58	60	56	57
540	63	58	61	56	57
550	#	59	61	57 #	57
560		60	61		58
570		61	61		58
580		61	61		58
590		61	62		58
600		62	62		59
610		#	62		59
620			63		#
630			63		
640			64		
650			64		
700			65		
720			65		
720			66		
730			68 #		

A3	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	550	620	730	550	620
Max stress (Pa)	5390.00	6076.00	7154.00	5390.00	6076.00
Max Strain (%)	23.52	19.23	36	9.62	18

Table 2d. Mechanical properties of A4 bioplastics.

Weight (g)	A4 (7.5% agar, 2.5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	50	50	53	51	50
100	51	50	53	51	51
150	51	51	53	51	51
200	51	51	53	51	51
250	51	51	54	51	52
300	51	51	54	52	51
350	52	51	54	52	52
400	52	51	54	52	52
450	52	51	54	52	53
500	52	52	54	52	53
550	52	52	54	53	53
600	53	52	54	53	53
650	53	53	55	53	53
700	53	53	55	53	54
750	54	53	55	53	54
800	54	53	55	53	54
850	55	54	55	53	55

860	55	54 #	55	53	55
900	55		56	53	55
950	55		56	53	55
1000	56		56	54	56
1050	56		56	54	56
1100	56		57	54	57 #
1150	58		57	54	
1200	58		57	55	
1250	58		58	55	
1312	59		58	55	
1362	60		58	55	
1372	#		58	55	
1412			59	55	
1462			60	56	
1512			60 #	56	
1562				57	
1612				57	
1662				57	
1712				58	
1762				58	
1812				59	
1862				59	
1912				60	
1962				61	
2012				61	
2062				62 #	

A4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	1372	860	1512	2062	1100
Max stress (Pa)	13445.60	8428.00	14817.60	20207.60	10780.00
Max Strain (%)	40	8	39.62	21.57	14

Table 2e. Mechanical properties of G0 bioplastics.

Weight (g)	G0 (2.5% agar, 0.625% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	50	50	50	51	52
100	50	51	50	50	52
150	50	52	50	50	52
200	50	52	50	51	52
250	50	52	50	51	52
300	50	52	50	52	52
350	50	52	51	52	53
400	51	53	52	52.5	53
450	52	54	52	53	54

500	52	54	53	53	54
550	53	55	53	54	55
560	53	55	53	54	55
570	53	55	53	54	55
580	53	55	54	54	55
590	53	55	54	54	55
600	53 #	55	54	55	55
650		55	55	55	55
700		56	56	57	56
710		57	57	57	56
720		58	57	57	56
730		58	57	57	56
740		59	#	57	56
750		59		57	#
760		60		57.5	
770		#		58	
780				58	
790				59	
800				59	
850				61	
900				62	
950				65	
960				66	
970				67	
980				67	
990				#	

G0	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	600	770	740	990	750
Max stress (Pa)	5880.00	7546.00	7252.00	9702.00	7350.00
Max Strain (%)	6	20	14	31.37	7.69

Table 2f. Mechanical properties of G1 bioplastics.

Weight (g)	G1 (2.5% agar, 1.25% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 1	Trial 4	Trial 1
0	51	50	50	51	50
100	52	50	50	52	50
150	52	50	50	52	51
200	53	52	50	52	51
250	54	52	50	52	52
300	54	52	52	53	52
350	55	53	52	54	53
400	56	54	53	54	53
450	57	55	53	55	54

500	58	55	54	55	54
510	58	55	54	55	54
520	58	55	54	55	54
530	59 #	56	54	55	54
540		56	54	55	54
550		56	54	55	55
600		57	54	56	56
650		58	56	57	57
660		58	56	57	57
670		58	56	57	57
680		59	57	57	57
690		59	57	57	57
700		#	57	57	58
710			57	58	#
720			57	58	
730			58	59 #	
740			58		
750			58		
800			59		
850			60		
900			62		
910			62		
920			62		
930			63		
940			62		
950			64		
960			64 #		

G1	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	530	700	960	730	710
Max stress (Pa)	5194.00	6860.00	9408.00	7154.00	6958.00
Max Strain (%)	15.69	18	28	15.69	16

Table 2g. Mechanical properties of G3 bioplastics.

Weight (g)	G3 (2.5% agar, 5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	52	52	51	53	51
100	54	55	54	55	54
150	56	57	55	57	55
200	57	59	57	58	57
250	59	62	58	59	59
260	59	62	59	60	60
270	60	62	59	60	60
280	60	63	60	61	60

290	60	63	60	62	60
300	61	63	#	62	61
310	61	64		63	62
320	61	65		63	62
330	62	#		64	62
340	62			#	63
350	63				63
360	#				#

G3	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	360	330	300	340	360
Max stress (Pa)	3528.00	3234.00	2940.00	3332.00	3528.00
Max Strain (%)	21.15	25	19.61	20.75	23.53

Table 2h. Mechanical properties of G4 bioplastics.

Weight (g)	G4 (2.5% agar, 7.5% glycerine)				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	52	51	50	51	53
100	57	54	54	56	56
110	57	55	54	56	56
120	58	55	55	56	57
130	58	56	55	56	57
140	59	56	56	56	58
150	59	57	56	57	58
160	60	58	57	58	59
170	60	59	58	59	59
180	61	61	58	59	60
190	61	61	58	59	61
200	62	62	59	61	62
210	62	63 #	60	62	64
220	63		62 #	64	65
230	64 #			64	68
240				65	70
250				68 #	71
260					#

G4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	230	210	220	250	260
Max stress (Pa)	2254.00	2058.00	2156.00	2450.00	2548.00
Max Strain (%)	23.08	23.53	24	33.33	33.96

Table 2i. Mechanical properties of B bioplastics.

Weight (g)	B				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	52	53	50	51	50
100	54	54	53	54	51
150	57	58	54	56	53
160	57	58	54	56	54
170	57	58	56	57	54
180	57	58	56	59	56
190	57	58	59	59	59
200	62	115	140	120 #	165 #
210	114	128 #	145		
220	125		145		
230	135		145		
240	156		145		
250	168		160		
260	178		185		
270	188		#		
280	212				
290	215				
300	228				
310	234				
320	239				
330	250				
340	263				
350	#				

B	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	350	210	270	200	200
Max stress (Pa)	3430	2058	2646	1960	1960
Max Strain (%)	405.77	141.51	270	235.29	230

Table 2j. Mechanical properties of C bioplastics.

Weight (g)	C				
	Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	50	50	52	51	49
100	52	52	54	53	51
150	54	54	55	55	53
160	54	56	57	56	53
170	54	56	58	58	54
180	54	58	60	60	54
190	54	170	115 #	#	56

200	58	195			185
210	#	197			190
220		206			195
230		215			197
240		220			200
250		224			205
260		232			217
270		238			#
280		245			
290		255			
300		267			
310		#			

C	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
Max tensile strength (g)	210	310	190	190	270
Max stress (Pa)	2058	3038	1862	1862	2646
Max Strain (%)	16	434	121.15	17.65	342.86

Table 2k. Mechanical properties of W bioplastics.

Weight (g)	W Length (mm)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	51	50	51	50	50
100	54	52	52	53	52
150	56	54	53	54	54
160	56	54	55	55	54
170	57	56	56	56	54
180	58	57	58	58	55
190	60	60	60	210	183
200	230	260	230	213	193
210	250	264	234	215	216
220	260	265	235	220	216
230	260	266	238	222	216
240	265	267	241	223	223
250	269	269	245	230	226
260	271	275	247	232	233
270	274	275	249	238	241
280	277	285	251	243	246
290	279	285	253	247	248
300	#	286	255	257	252
310		#	260	257	254
320			#	260	256
330				#	260
340					#

W	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Max tensile strength (g)	300	310	320	330	340
Max stress (Pa)	2940	3038	3136	3234	3332
Max Strain (%)	447.06	472	409.80	420	420

Table 3. Calculations of stress, strain, and Young's modulus.

Calculations		
Stress (Pa)	$\sigma = \frac{F}{A}$	σ = stress in Pa F = force applied (load) in newton (1g=0.0098N) A = cross-sectional area in square metre
Strain (%)	$\varepsilon = \frac{\delta l}{l}$	ε = strain δl = change in length l = original length
Young's modulus (E)	**Young's modulus (E)** = Gradient of the curve in the elastic region	

Table 4a. Mechanical properties of A1, A2, A3, and A4 bioplastics.

Tensile Strength	A1	A2/G2	A3	A4
Range of tensile strength (g)	110 - 190	400 – 580	550 - 730	860-2062
Average ultimate tensile strength (g)	144	474	614	1381
Average ultimate stress (Pa)	1411.2	4645.2	6017.2	13535.76
Average ultimate strain (%)	10.43	19.11	21.28	36

Table 4b. Mechanical properties of G0, G1, G2, G3, and G4 bioplastics.

Tensile Strength	G0	G1	G2/A2	G3	G4
Range of tensile strength (g)	600 – 990	530 – 960	400 – 580	300 – 360	210 - 260
Average ultimate tensile strength (g)	770	726	474	338	234
Average ultimate stress (Pa)	7546	7114.8	4645.2	3312.4	2293.2
Average ultimate strain (%)	15.81	18.68	19.11	21.62	27.58

Table 4c. Mechanical properties of commercially available compostable bags.

Tensile Strength	B	C	W
Range of tensile strength (g)	200-350	190-310	300-340
Average ultimate tensile strength (g)	246	234	320
Average ultimate stress (Pa)	2410.8	2293.2	3136.0
Average ultimate strain (%)	236.51	186.33	433.77

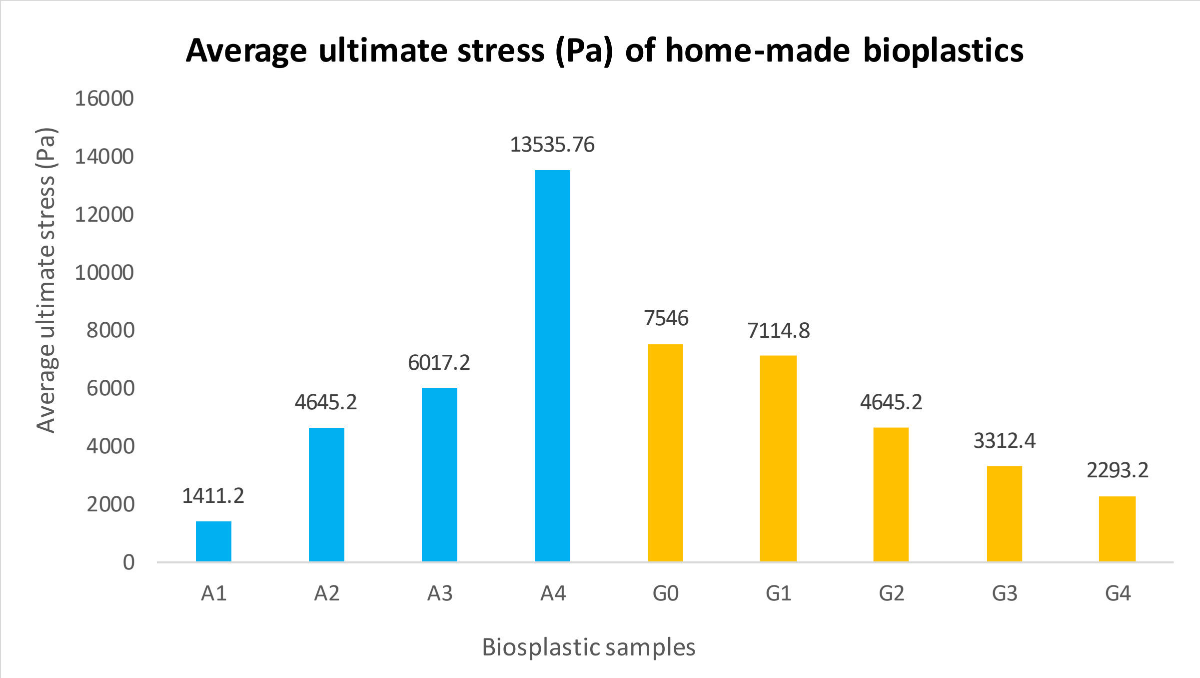


Figure 2a. This graph depicts the average ultimate stress for the five trials of A1, A2/G2, A3, A4, G0, G1, G3, and G4 samples.

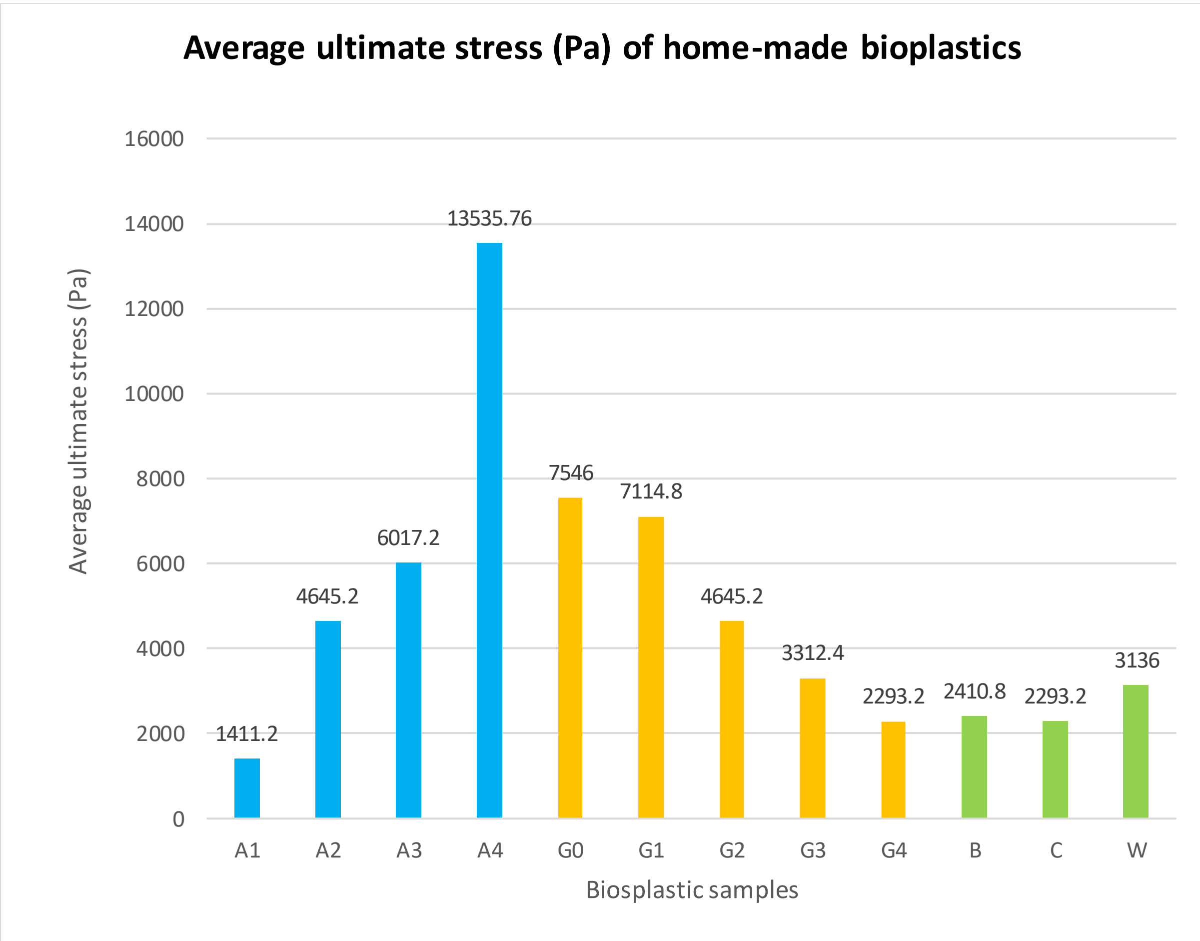


Figure 2b. This graph depicts the average ultimate stress for the five trials of A1, A2/G2, A3, A4, G0, G1, G3, G4, B, C, and W samples.

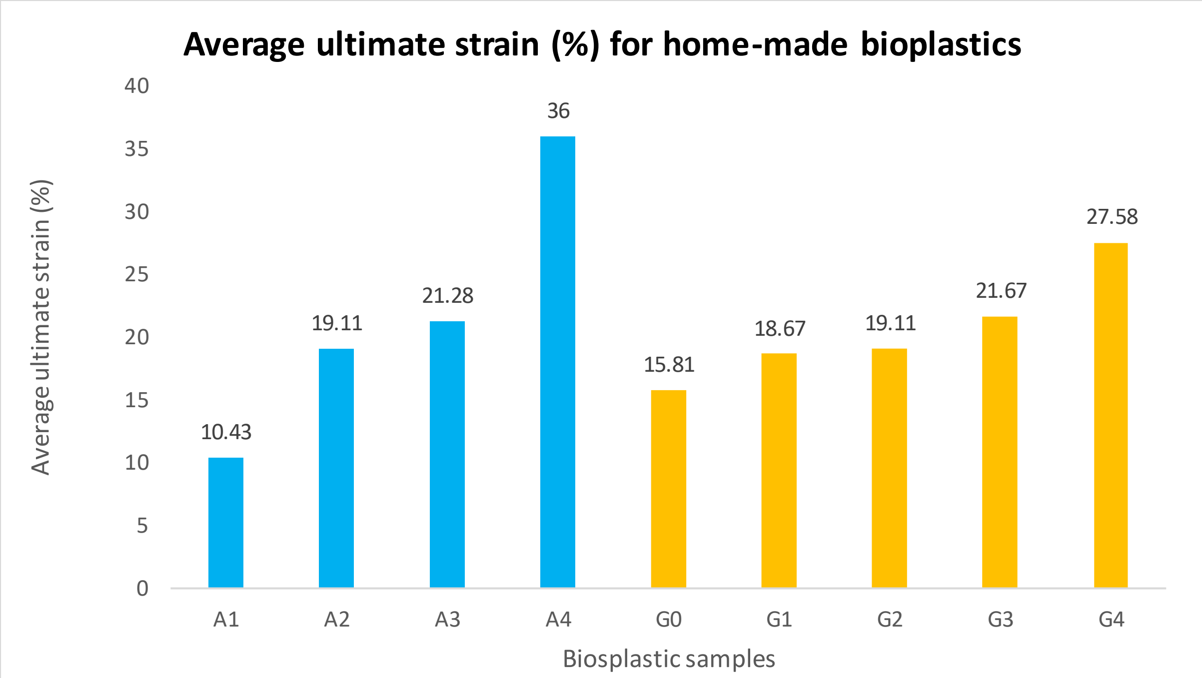


Figure 3a. This graph depicts the average ultimate strain for the five trials of A1, A2/G2, A3, A4, G0, G1, G3, and G4 samples.

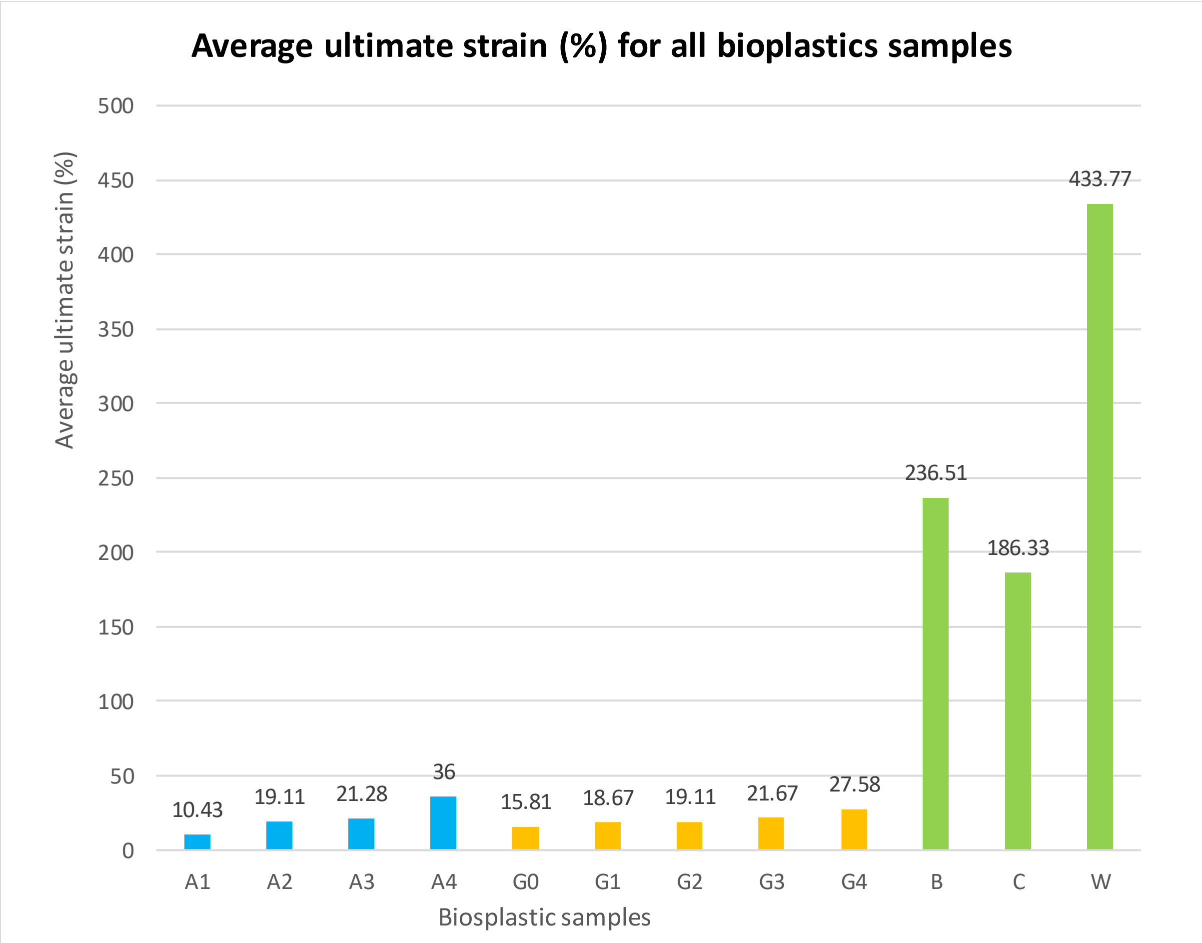


Figure 3b. This graph depicts the average ultimate strain for the five trials of A1, A2/G2, A3, A4, G0, G1, G3, G4, B, C, and W samples.

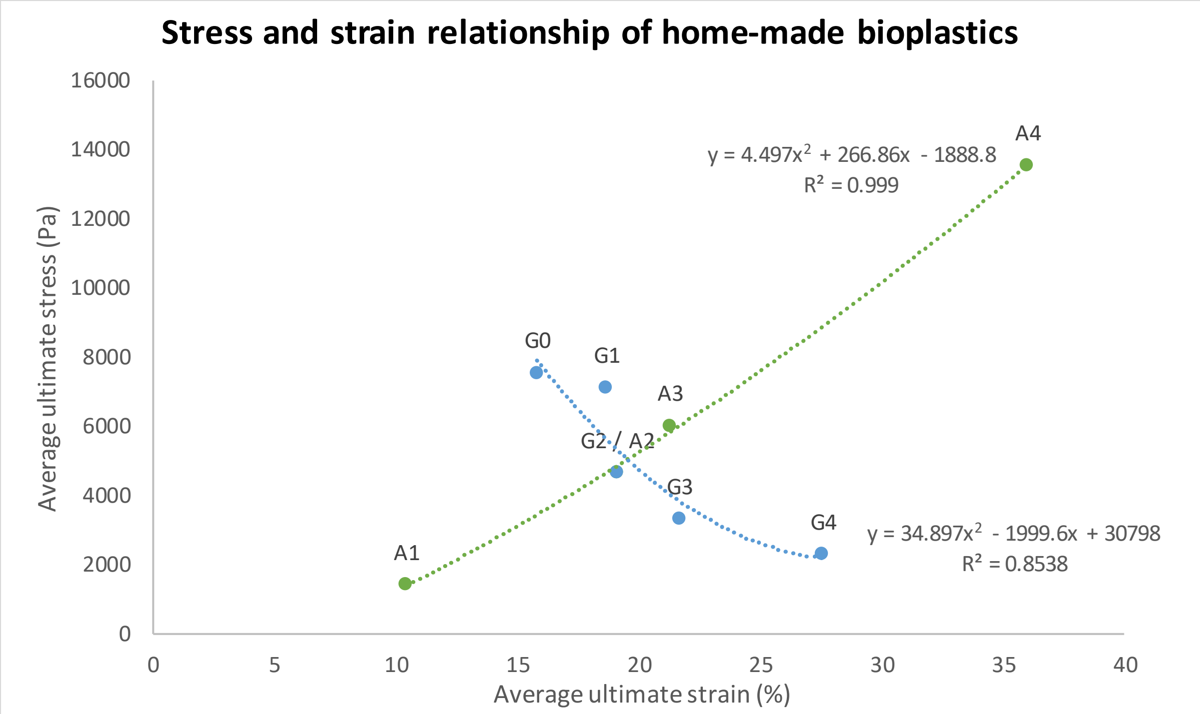


Figure 4a. This graph depicts the stress-strain relationships of A1, A2/G2, A3, A4, G0, G1, G3, and G4 samples.

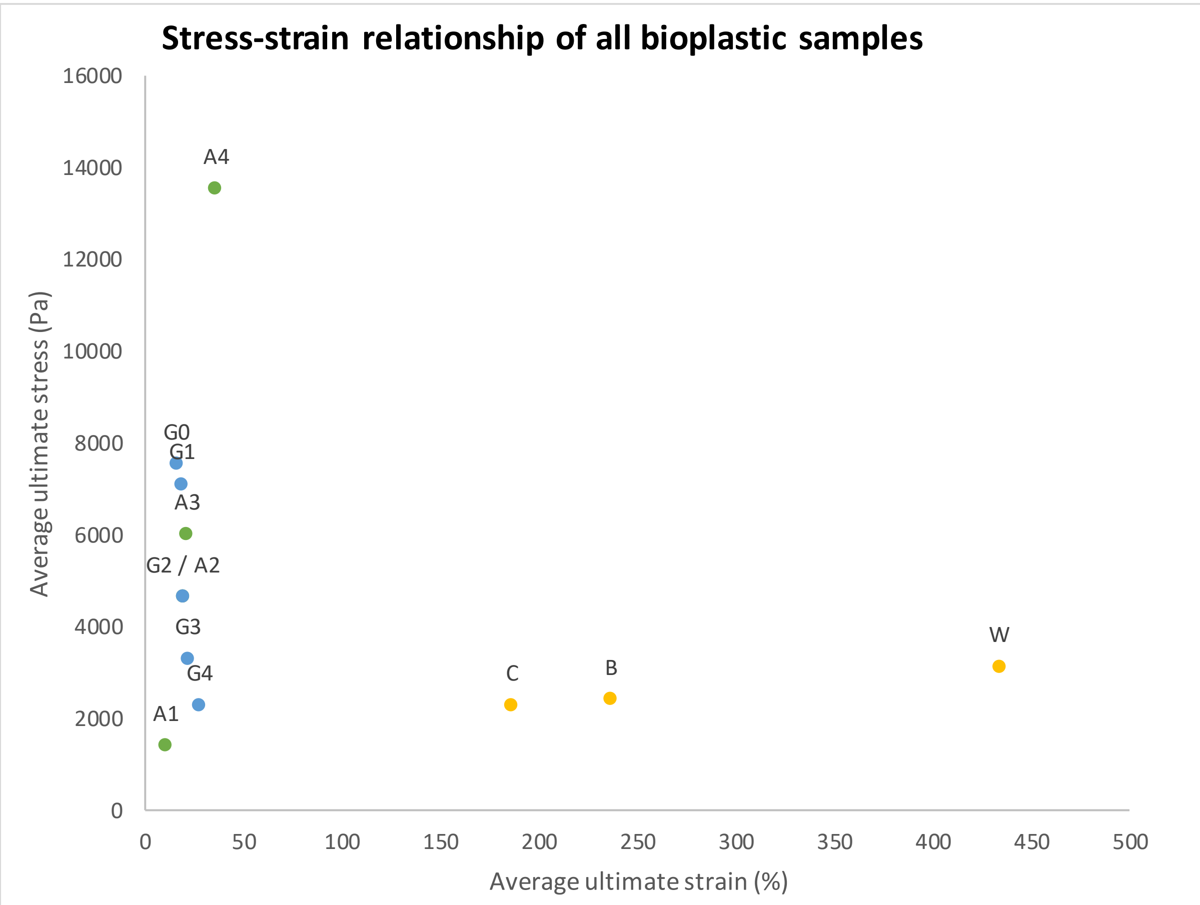


Figure 4b. This graph depicts the stress-strain relationships of A1, A2/G2, A3, A4, G0, G1, G3, G4, B, C, and W samples.

Table 5a. Order from greatest to least average ultimate stress value for A1, A2/A2, A3, A4, G0, G1, G3, and G4 bioplastics.

Order of stress value (greatest to least)	Bioplastic	Average ultimate stress value (kPa)
1st	A4	13535.76
2nd	G0	756.56
3rd	G1	711.48
4th	A3	601.72
5th	A2/G2	464.52
6th	G3	331.24
7th	G4	229.32
8th	A1	141.12

Table 5b. Order from greatest to least average ultimate stress value for A1, A2/A2, A3, A4, G0, G1, G3, G4, W, B, and C bioplastics.

Order of stress value (greatest to least)	Bioplastic	Average ultimate stress value (kPa)
1st	A4	13535.76
2nd	G0	756.56
3rd	G1	711.48
4th	A3	601.72
5th	A2/G2	464.52
6th	G3	331.24
7th	W	313.60
8th	B	241.08
9th and 10th	G4 and C	229.32
11th	A1	141.12

Table 5c. Order from greatest to least average ultimate strain value for A1, A2/A2, A3, A4, G0, G1, G3, and G4 bioplastics.

Order of strain value (greatest to least)	Bioplastic	Average ultimate stain value (%)
1st	A4	36
2nd	G4	27.5804
3rd	G3	21.617
4th	A3	21.2751
5th	A2/G2	19.106
6th	G1	18.675
7th	G0	15.813
8th	A1	10.4258

Table 5d. Order from greatest to least average ultimate strain value for A1, A2/A2, A3, A4, G0, G1, G3, G4, W, B, and C bioplastics.

Order of strain value (greatest to least)	Bioplastic	Average ultimate strain value (%)
1st	W	433.77
2nd	B	236.51
3rd	C	186.33
4th	A4	36
5th	G4	27.5804
6th	G3	21.617
7th	A3	21.2751
8th	A2/G2	19.106
9th	G1	18.675
10th	G0	15.813
11th	A1	10.4258

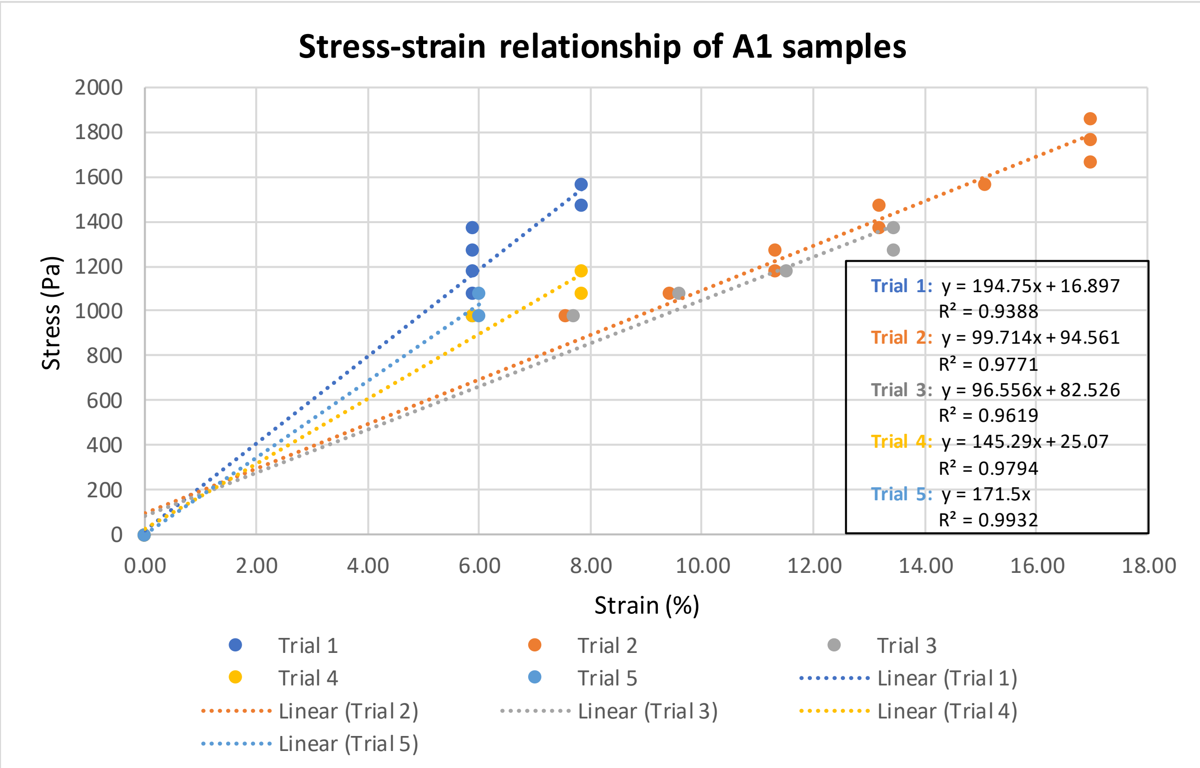


Figure 5a. This graph depicts the stress-strain relationship for the five trials of A1 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

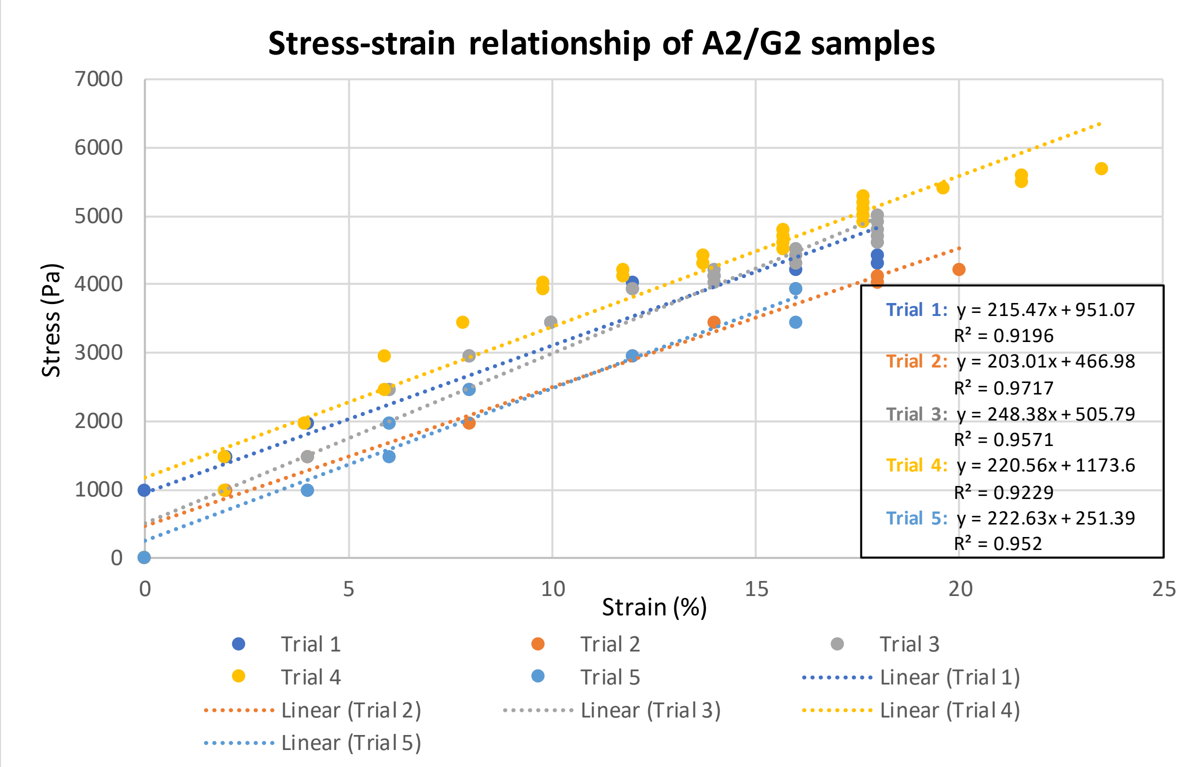


Figure 5b. This graph depicts the stress-strain relationship for the five trials of A2/G2 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

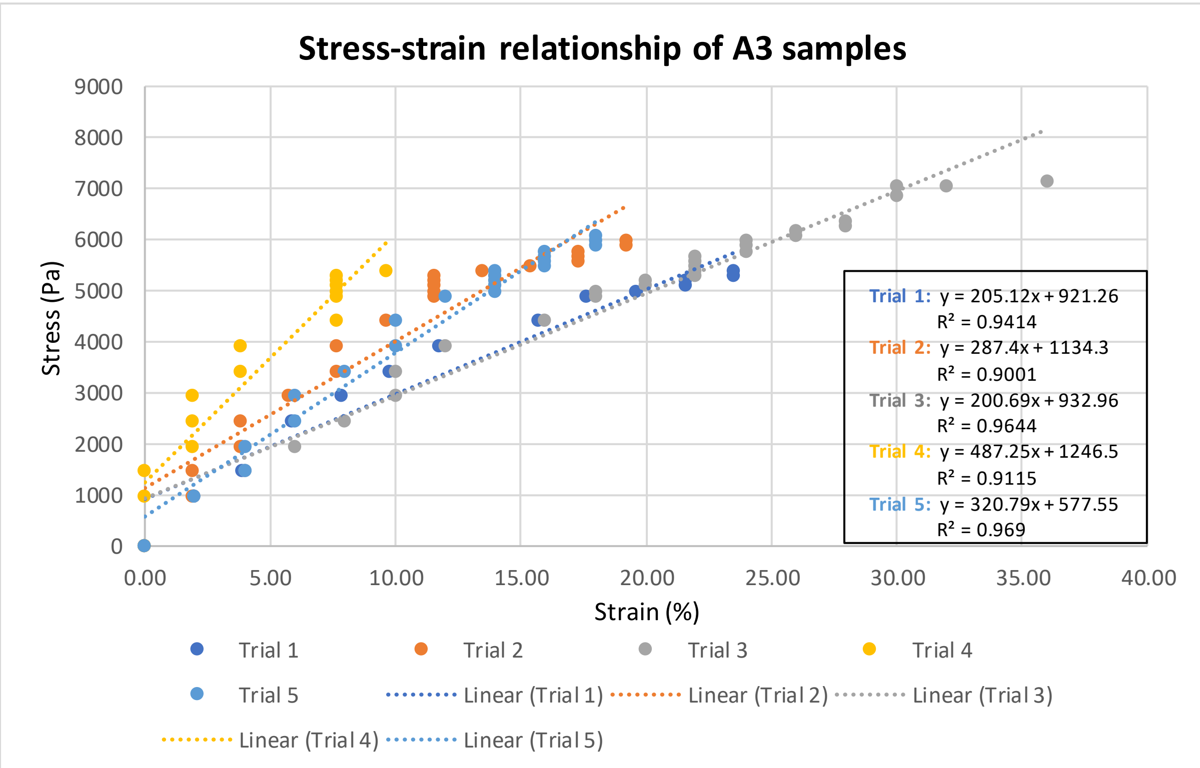


Figure 5c. This graph depicts the stress-strain relationship for the five trials of A3 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

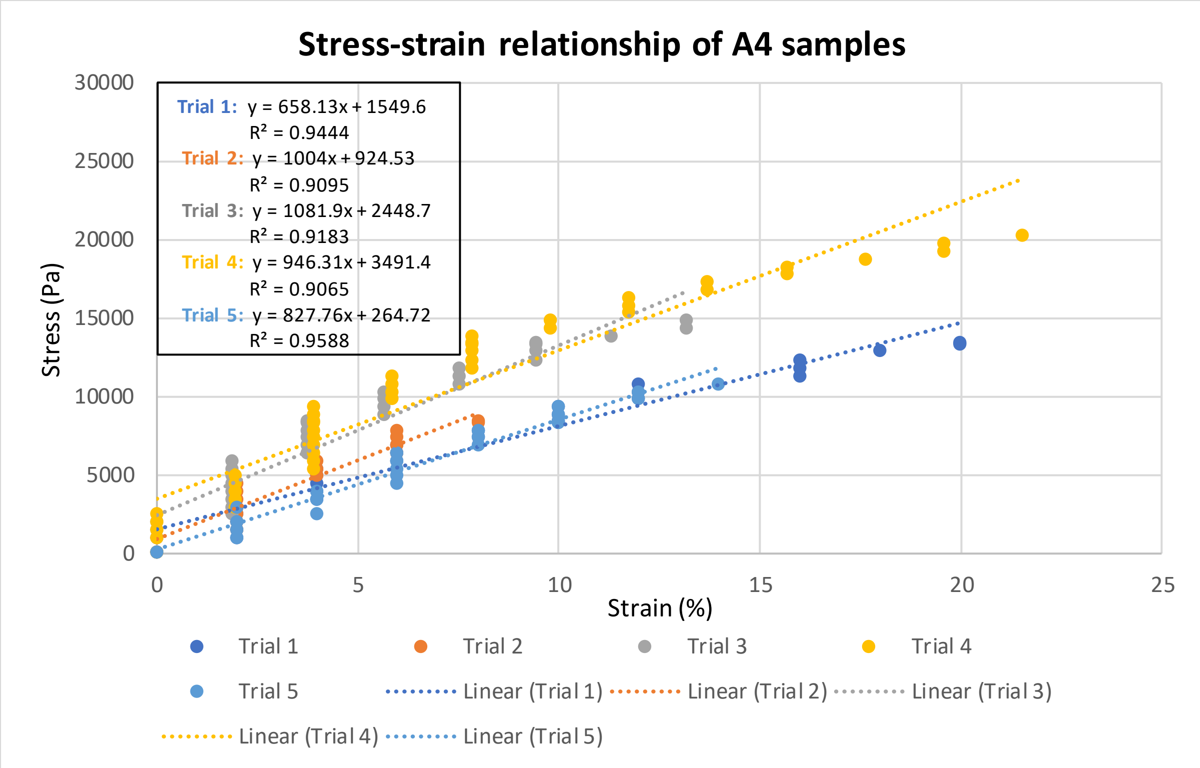


Figure 5d. This graph depicts the stress-strain relationship for the five trials of A4 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

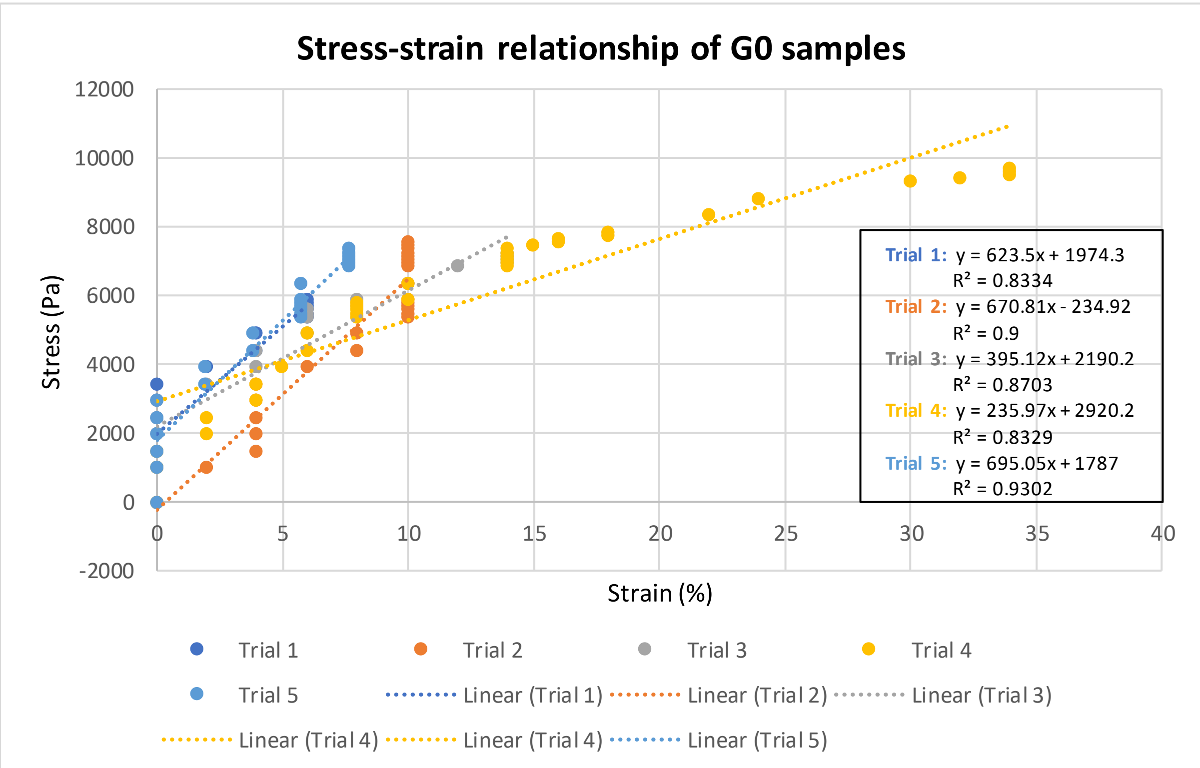


Figure 5e. This graph depicts the stress-strain relationship for the five trials of G0 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

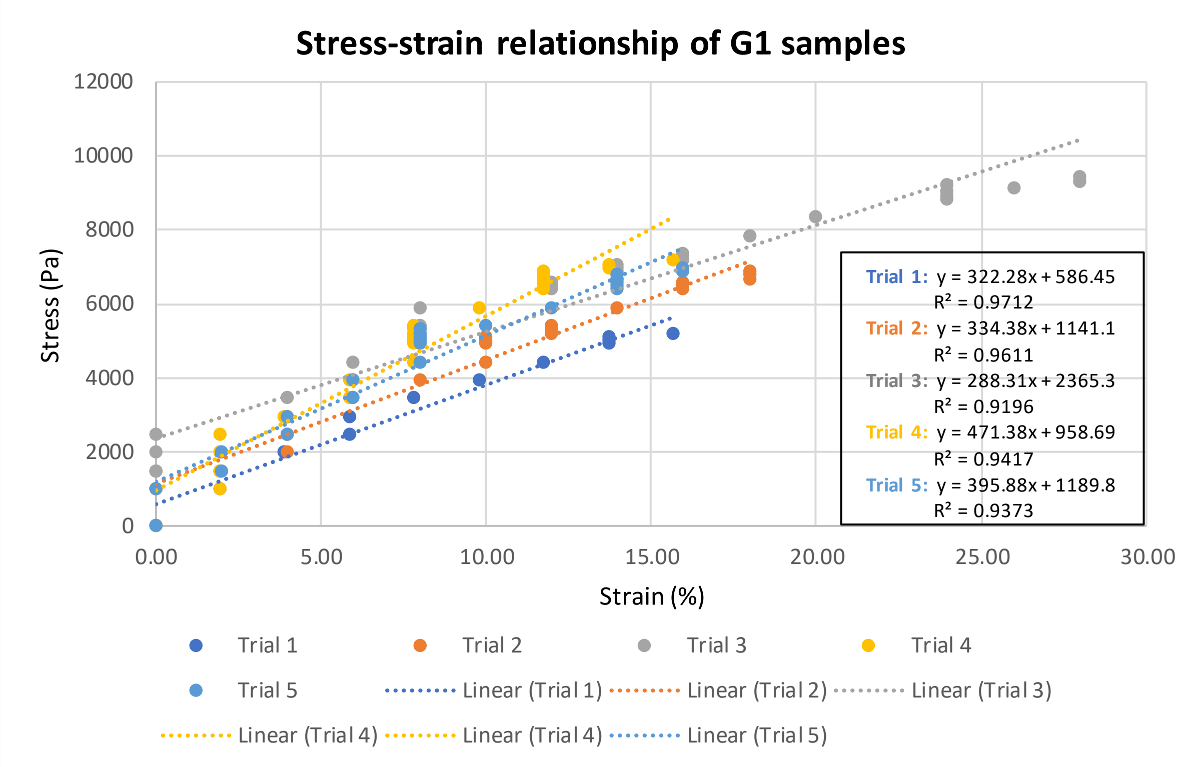


Figure 5f. This graph depicts the stress-strain relationship for the five trials of G1 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

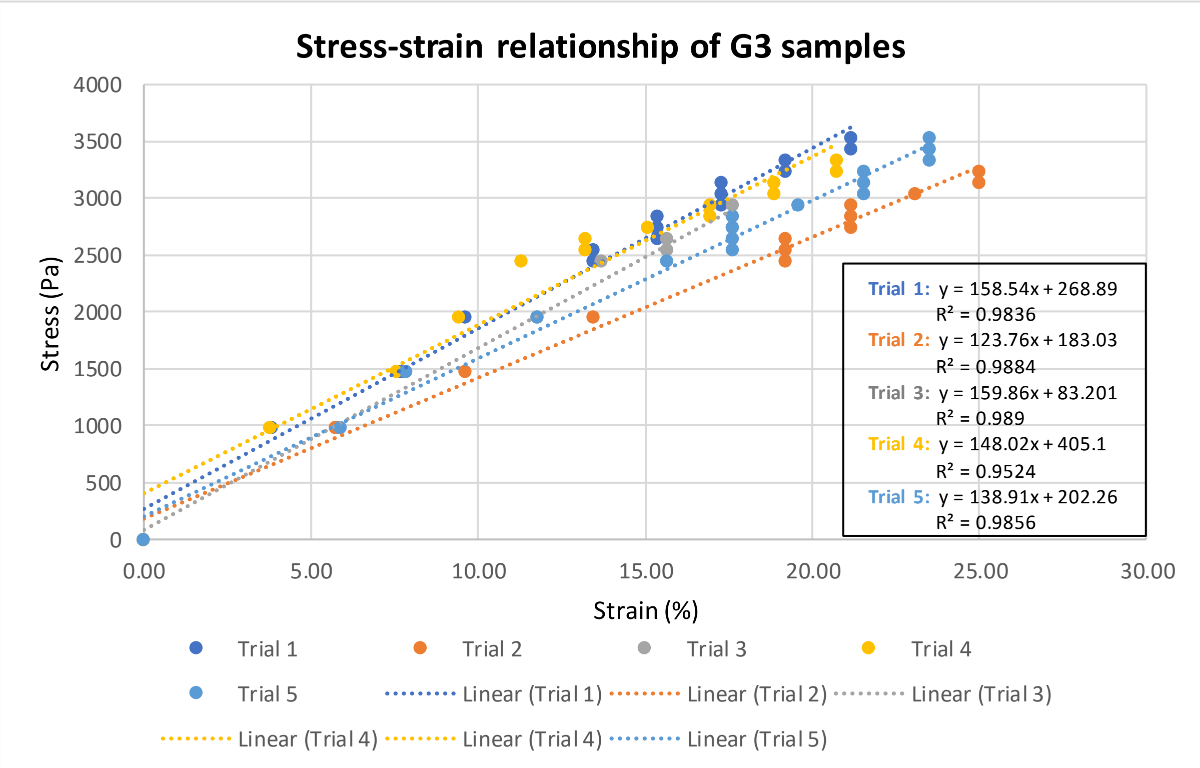


Figure 5g. This graph depicts the stress-strain relationship for the five trials of G3 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

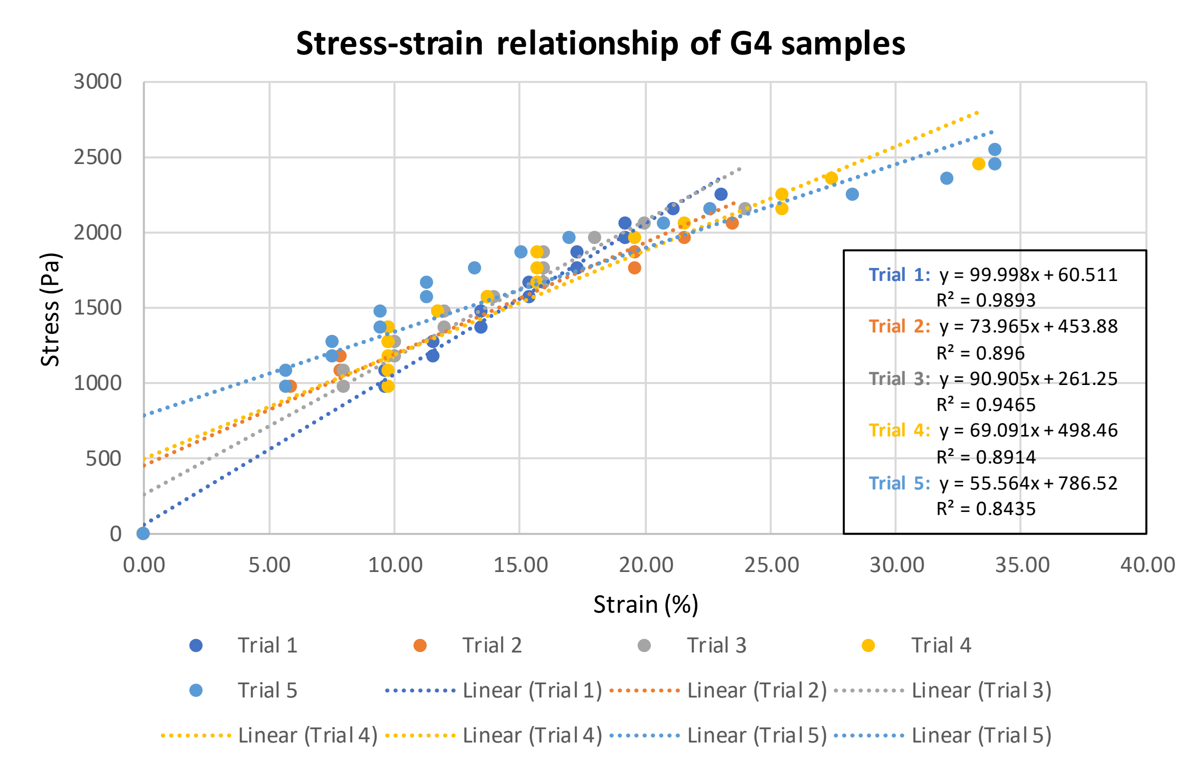


Figure 5h. This graph depicts the stress-strain relationship for the five trials of G4 samples, each represented by a corresponding linear trendline, equation, and R-squared value to calculate the Young's modulus of each trial.

Table 6. Tensile modulus of elasticity for A1, A2/A2, A3, A4, G0, G1, G3, G4 bioplastics.

Bioplastic	Young's modulus (E)	Ranking
A1	141.56	7
A2	222.01	5
A3	300.25	4
A4	903.62	1
G0	524.09	2
G1	362.45	3
G3	145.82	6
G4	77.9	8

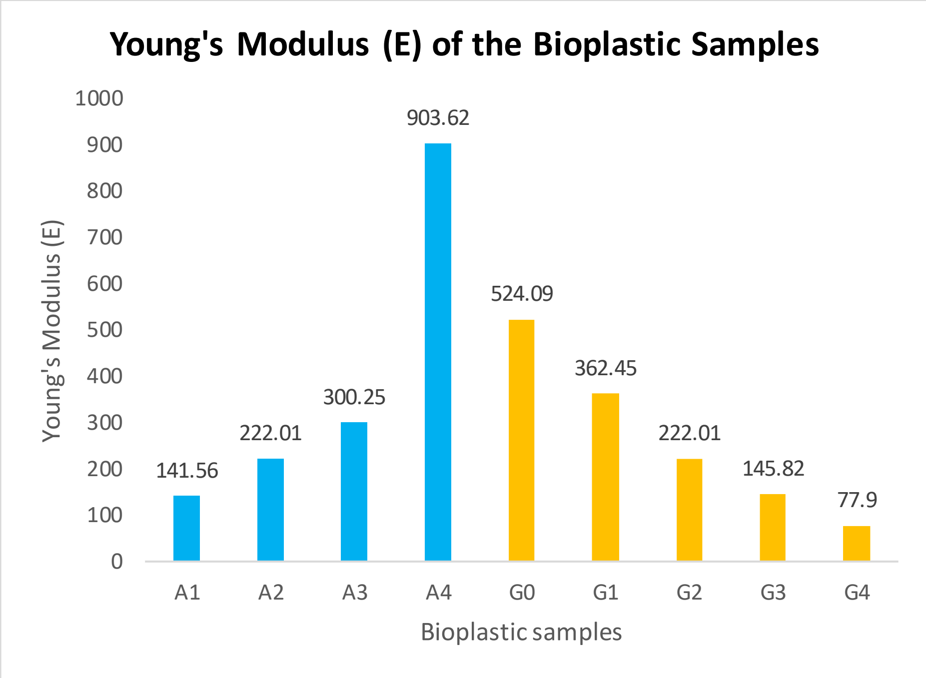


Figure 6. This graph depicts the average Young's modulus for A1, A2/A2, A3, A4, G0, G1, G3, G4 bioplastics.

Experiment 2: Water Permeability

Table 7a. Observations of water permeability for A1, A2, A3, and A4 bioplastics.

Observations	A1	A2	A3	A4
Beaker (g)	45.468	45.191	57.833	90.0
Test sample (g)	4.128	5.470	4.000	9.6
Rubber band (g)	0.847	0.896	0.809	-
Initial total weight after adding 10ml water	61.905	61.112	73.012	109.6
After 1 hour	56.598	61.005	72.964	109.6
After 1 day	55.299	51.690 little water seen in beaker	71.533	107.1
After 25 hours	55.176	51.475	71.376 (Permeation seen)	107.1
After 2 days	54.782	50.850	71.535	105.4
Test sample (g)	1.347	4.59	6.165	15.0
Water remains on sample (g)	No	No	6.437	2
Permeation	No	Yes, very little water seen in beaker	Yes, very little water seen in beaker	No

Table 7b. Observations of water permeability for G0, G1, G2, G3, and G4 bioplastics.

Observations	G0	G1	G2	G3	G4
Beaker (g)	45.621	45.621	55.788	45.632	50.427
Initial weight of bioplastic sample (g)	1.909	3.922	4.798	3.841	4.088
Rubber band (g)	0.930	0.865	0.877	0.873	0.542
Initial total weight after adding 10ml water (g)	61.396	59.559	71.407	60.359	64.902
After 1 hour (g)	61.055	58.369	67.147	60.301	61.391 Significant osmosis, outside beaker wall is wet
After 1 day (g)	59.971	55.360, little water (permeation) seen in beaker	64.868	55.980 Osmosis, permeation	54.985
After 25 hours (g)	59.830	55.177	64.693	55.269 Osmosis, permeation	54.730
After 2 days (g)	58.438	54.121	63.328	53.273	54.828
Test sample (g)	1.329	4.184	4.712	5.15	3.7
Water remains on sample (g)	9.135	3.293	1.64	1.295	No
Permeation	No	Yes, very little water seen in beaker	No	Yes, very little water seen in beaker	Yes, very little water seen in beaker

Table 7c. Observations of water permeability for B, C and W bioplastics.

Observations	B	C	W
Beaker (g)	48.024	43.907	54.934
Initial weight of bioplastic sample (g)	0.335	0.372	0.469
Rubber band (g)	0.855	-	1.366
Initial total weight after adding 10ml water (g)	59.560	55.038	66.291
After 1 hour (g)	59.169	54.983	66.254
After 1 day (g)	58.033	53.627	64.956 (Permeation seen)
After 25 hours (g)	58.010 (Permeation seen)	53.451	64.774
After 2 days (g)	57.758	53.000	62.794
Test sample (g)	0.386	0.645	0.864

Water remains on sample (g)	8.211	7.343	5.497
Permeation	Yes, very little water seen in beaker	No	Yes, very little water seen in beaker

Experiment 3: Water Absorption

Table 8a. Observations of water absorption for A1, A2, A3, and A4 bioplastics.

Average mass (g)	**A1**	**A2**	**A3**	**A4**
0 hr	0.161	0.270	0.386	0.442
48 hrs	0.171	0.340	1.195	1.615
Mass gain (g)	0.010	0.069	0.809	1.173
Water absorption rate (%)	6.00	25.65	209.59	265.46

Table 8b. Observations of water absorption for G0, G1, G2, G3, and G4 bioplastics.

Average mass (g)	**G0**	**G1**	**G2**	**G3**	**G4**
0 hr	0.107	0.114	0.270	0.354	0.565
48 hrs	0.312	0.153	0.340	0.780	1.277
Mass gain (g)	0.205	0.039	0.069	0.427	0.712
Water absorption rate (%)	191.90	34.21	25.65	120.64	126.08

Table 8c. Observations of water absorption for B, C, and W bioplastics.

Average mass (g)	**B**	**C**	**W**
0 hr	0.027	0.034	0.033
24hrs	0.039	0.027	0.052
Mass gain (g)	0.012	-0.007	0.019
Water absorption rate (%)	46.25	-19.80	56.57

Data analysis

Experiment 1

The tensile properties of bioplastics with varying agar concentrations are compared (Tables 2a-d, 4-5; Figures 2-4, 5a-d). A4 presents the greatest average ultimate tensile strength of 1381g, ultimate stress of 13,535.76Pa and ultimate strain of 36%, followed by A3, A2, while A1 exhibits the lowest average ultimate tensile strength of 144g, ultimate stress of 1411.2Pa and ultimate strain of 10.43%. Results indicate that bioplastics with higher agar concentrations are associated with greater average ultimate tensile strength, stress, and strain (R2 = 0.999) (Figure 4).

Upon analysing the tensile properties of bioplastics with varying glycerine concentrations, G0 displays the greatest average ultimate tensile strength of 772g and ultimate stress of 7565.6Pa, followed by G1, G2, G3, and lastly, G4 with the lowest average ultimate tensile strength of 234g and ultimate stress of 2293.2Pa (Tables 2e-h, 4-5; Figures 3-4, 5e-h). Reciprocally, G0 presents the lowest average ultimate strain of 15.81%, whereas G4 shows the highest average ultimate strain of 27.58%. The results reveal that increased glycerine concentrations increase strain but decrease tensile strength and stress (R2 = 0.854) (Figure 4).

Among the three commercially available bioplastics, W exhibits greater average ultimate tensile strength (320g), stress (3136Pa), and strain (433.77%) than B and C (Tables 2i-j, 4-5; Figures 3-4, 5i-j). Both B and C present comparable mechanical characteristics in terms of their average ultimate tensile strength, stress and strain. Their stress values are similar to those of G3 and G4. Their strain values (range: 186.33-433.77%) significantly surpasses those of home-made test samples (range: 10.43-36%). All three commercially available compostable plastics have substantial flexibility with much higher strain but generally lower stress values than other samples (Figure 4).

Comparing all the home-made bioplastics, A4 shows the greatest average ultimate stress and strain, while A1 has the lowest for both values (Tables 4, 5; Figure 2-4). Notably, results show an increase in stress values associated with increased agar concentrations, and a decline in stress values associated with increased glycerine concentrations. An increase in strain values is associated with increased glycerine concentrations and increased agar concentrations. In summary, an increase in agar concentration increases stress and strain in the bioplastics. However, an increase in glycerine concentration increases strain but decreases the tensile strength and stress in the bioplastics.

Young's Modulus of elasticity

The Young's modulus of elasticity, a measure of a material's stiffness, of each bioplastic sample is compared (Table 6, Figure 6). A4 exhibits the greatest elastic modulus of 903.62, followed by G0, G1, A3, A2/G2, G3, and A1, while G4 demonstrates the lowest value of 77.9. Overall, results illustrate that increased agar concentrations make the sample stiffer; however, increased glycerine concentrations reduce the material's stiffness.

Experiment 2 (Table 7)

No water permeation was observed in A1, A4, G1, G2, and C bioplastics. However, little water was seen permeating through bioplastics A2, A3, G0, G3, G4, B, and W in the beakers. Osmosis took place in G3 and G4 as water was observed along the outer beaker wall and water marks were seen on the table. Results indicate that the bioplastics samples are permeable to liquids to different extents.

Experiment 3 (Table 8)

All bioplastic samples absorb water with a weight gain of 6-265%. Results suggest that water absorbency increases with an increased agar concentration. Weight loss in sample C postulates that some portion of C may have dissolved in water.

Experiment 4

Observations on how bioplastic samples react with heat were made (Figure 7). When bioplastic samples were immersed in water, they became sticky, gluey, and softer when subjected to heat. Heat breaks down the molecular structure of the bioplastics. Continuous heating in the water makes the test samples decompose and dissolve in water faster. This finding supports that heat increases the decomposition rate of bioplastics when immersed in water.

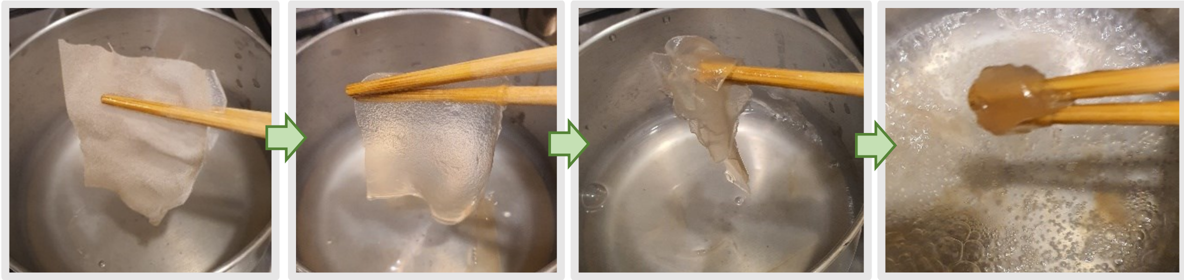


Figure 7. Heat increases the decomposition rate of bioplastics when immersed in water.

Discussion and Evaluation

Data discussion

The results of Experiment 1 support both hypotheses: an increase in agar concentration increases the tensile strength, stress, and modulus of elasticity in the bioplastics, and an increase in glycerine concentration increases the tensile elongation and strain but decreases the tensile strength, stress, and modulus of elasticity in the bioplastics (Figure 8).

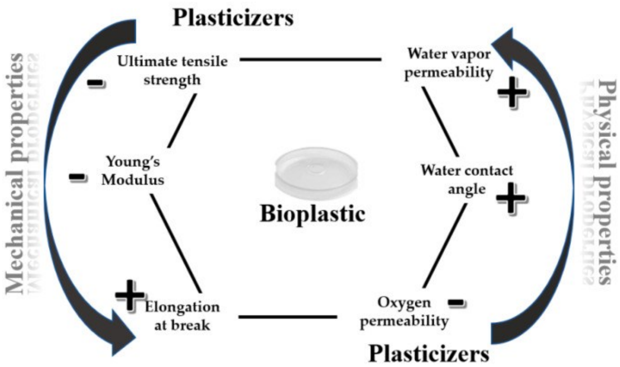


Figure 8. Effects of the plasticizers' addition on mechanical and physical properties of bioplastic materials (Acquavia et al. 2021).

The physical and mechanical properties of bioplastics depend on their chemical structure, the crystallinity of the material, the polymer's orientation, and the plasticisers or fibres that serve as reinforcements. Agar is a solidifying phycolloid agent and is widely used for its versatile applications due to its biocompatibility, high gelling ability, and film-forming properties (A. Balamurugan et al. 2024). As agar and water are mixed and heated, the two polysaccharides composing agar, agarose and agaropectin, undergo hydration and gelation (Acquavia et al. 2021). Water molecules penetrate the agar while the agar forms a three-dimensional hydrophilic structure that entraps water, resulting in the formation of a colloidal solution. In this investigation, increased agar concentration improves the material's tensile strength and elastic modulus, so the material becomes stronger and stiffer.

Glycerine is a plasticiser that is incorporated in the biopolymer synthesis to increase its extensibility, dispensability, flexibility, and elasticity. Based on the lubricant theory, plasticisers serve as internal lubricants by interspersing themselves and lowering the frictional forces between polymer chains (Acquavia et al. 2021). Alternatively, plasticization is viewed by the free volume theory as a means of increasing free volume, simultaneously assisting in explaining how a plasticiser reduces the glass transition temperature of a polymer (Acquavia et al. 2021). Conversely, the gel theory proposes that the rigidity of polymers originates from their three-dimensional structures, and plasticisers function by disrupting interactions between polymer chains such as hydrogen bonds and van der Waals or ionic forces (Acquavia et al. 2021). In this investigation, increased glycerine concentration improves the material's strain but reduces the tensile stress and elastic modulus; hence, the material becomes more flexible but weaker (Figure 8).

Addition of substance to improve bioplastic's functionality

Despite this study does not investigate the effects of additives, plasticisers, and cellulose, these substances can be implemented in agar polymer synthesis to enhance their properties and quality to suit certain applications, whereby the addition of these substances can produce various film characteristics and properties, physically, mechanically, and chemically. Polymers are permeable to gases, vapours, and liquids to various extents. For instance, the incorporation of arabinoxylan or glycerol improves moisture barrier efficiency but decreases the mechanical properties of biofilm. Another example is the addition of fish gelatine and TiO_2 nanoparticles, which increase the tensile strength, UV light barrier property, swelling ratio, and moisture content but decrease the water vapour permeability of biofilm (Abdul Khalil et al., 2016). Formulations of the bioplastics should be practical to produce desired functionality.

Comparison of bioplastics to commercially available compostable plastics

All samples of the compostable plastics exhibit significantly greater strain, characterised by increased plastic deformation once passing their yield strength, but lower tensile strength and stress than home-made bioplastics. However, the specific composition of the compostable plastics remains unknown.

Potentials of algal bioplastics

While in their early development, bioplastic innovations may not completely mimic the exceptional qualities of fossil-based plastic, including strength and durability. However, algae, one of the most abundant sources of biomass, is a promising candidate for scalable and sustainable, non-toxic bioplastic innovations to substitute harmful plastics. Exhibiting rapid and prolific growth, algae do not require freshwater, land, pesticides, or fertilisers to cultivate; therefore, competition with food supply is minimised. Algae are responsible for producing 70 to 90% of the Earth's total oxygen (Mouritsen 2017; Notpla 2023). While boosting marine habitat provision, including nutrient cycling, and reducing ocean acidification and eutrophication, algae is a potential carbon capture solution as it is capable of sequestering 20 times more atmospheric carbon dioxide than land forests (Notpla 2023; Sway 2023). Economically, algae cultivation provides employment opportunities and an economic boost to remote coastal communities in the seaweed supply chain living below the poverty line (Notpla 2023; Sway 2023). Algal bioplastics contribute towards a sustainable circular economy and bioeconomy. While the development of algal bioplastics is still in its early stages, further studies and continuous efforts are necessary to fulfil the vision of eliminating petroleum-based plastics and mitigating the severe issues of plastic pollution and climate change.

Impact of the investigation

The bioplastics produced exhibit characteristics including strength, flexibility, durability, and lightweight properties. The findings of this investigation could contribute to future studies in bioplastics. The valuable insights gained from this study, including the bioplastics' performance, particularly on the material's strength and flexibility, could guide initiatives to address and mitigate existing limitations. The potential advantages of bioplastics could be utilised to optimise their application in various sectors. With this perspective, the benefits of algae-based bioplastics can be leveraged to contribute to a more sustainable future.

Random errors

1. Parallax errors: measurements of the tensile elongation of bioplastic samples may be imprecise due to limitations in human eyesight and measurements using a ruler; however, this has a minimal effect on the data. A single assessor who follows a standardised procedure in a controlled condition may reduce inconsistency in measurement.
2. Despite the controlled tray size and volume of bioplastics, the varied thickness of the bioplastic samples produced (range 0.08–0.34 +/- 0.05mm) may affect data reliability. The relationship between thickness and tensile strength of the materials remains unknown, therefore, experimental testing is required.
3. The variation in the rate at which weights are manually loaded during tensile testing may influence the data reliability of tensile testing.

Systematic Error

Systematic errors can be minimised by using calibrated equipment that is reliable and functioning accurately, including analytical balance, digital scale, and ruler.

Limitations and improvement

1. A universal tensile testing machine can be used to ensure that the experiment is conducted under the same constant loading rate using a hydraulic system (Figure 9). Manually measuring the tensile strength and displacement of the bioplastics will not be required. A tensile testing machine can generate precise measurements efficiently. Alternatively, considering resource constraints, the use of calibrated image measurement utilising cameras and software programmes can obtain data with greater accuracy and efficiency compared to manual measurement.

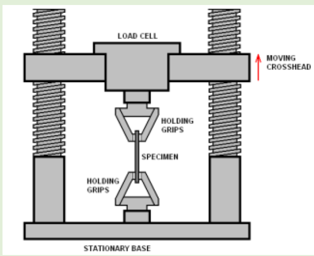


Figure 9. Tensile test machine (Kumar, 2017)

2. A better casting technique can be used to control the thickness of each bioplastic sample to reduce random errors and improve data reliability.
3. More trials of the experiment to obtain average values and testing more varied concentrations of the selected bioplastic's composition can be done to increase the reliability of the data.

Conclusion

The experiment supports both hypotheses: an increase in agar concentration increases the tensile strength, stress, and modulus of elasticity in the bioplastics, and an increase in glycerine concentration increases the strain but decreases the tensile strength, stress, and modulus of elasticity in the bioplastics. Replenishing life from sea to soil, algal bioplastics hold a bright future as a sustainable alternative to conventional plastics and play a vital role as one of the regenerative strategies to combat the staggering global plastic crisis and climate change. Ongoing research is warranted to develop algal bioplastics through green technologies to ensure that a circular economy and bioeconomy are successfully created for our society.

Word Count

- 1798 words
- Headings, titles, figure captions, tables, references, and journal are not included in the word count.

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Scientific Journal

01.05.2024 till 10/5/2024

Generating topic of interest/ Exploring potential topics:

General topic: Functionality of bioplastics: Investigating the physical and mechanical properties of algal bioplastics

Research question: How do different concentrations of agar and glycerine affect the physical and mechanical properties of algal bioplastics?

Discussion of ideas/ brainstorming:

Main interest: What qualities of bioplastics I have made and compare their qualities with the recently existing bioplastics in the industry.

Investigation: To create biodegradable polymers derived from algae and carry out experiments to test their properties to see which bioplastic is the most suitable and whether this algal bioplastic could be a viable alternative to conventional plastics to tackle plastic pollution.

Specific questions: How flexible and how strong is my bioplastics? Are they water resistant? In what extent do they absorb water? How do they react with heat and what are their melting points?

Impact of my investigation: My investigation outcome can provide values in the future study of bioplastics - to overcome the shortcomings and utilise the advantages of algal bioplastics.

Steps to do:
1. To create bioplastics of different formulations, of interest with different concentrations of agar and glycerine.
2. To investigate the effect of different concentrations of agar and glycerine on physical and mechanical properties of algal bioplastics
3. Data collection
4. Comparing with existing bioplastic products
5. Effect on society: future potentials
6. Complete report

13.05.2024 till 20/5/2024

Research and planning:

Independent variables:
- Make different bioplastics with different concentrations of agar and glycerine
  Concentration in %W/V

Dependent variables:
- Physical and mechanical properties of different algal bioplastics

Tests for the dependent variables:
- Mechanical properties: Tensile strength, stress, strain, Young's modulus of elasticity, fracture point
- Physical properties of interest:
  - Water resistance vs. water permeability
  - Water absorption: swelling test (Beaker test)
  - Thermal reaction

Notes:

Que: What are Mechanical Properties, Physical Properties and Chemical Properties?

Bioplastics can be distinguished into three categories: mechanical properties, physical properties and chemical properties.

Physical properties refer to observable or measurable characteristics of a material, i.e. the physical state of materials that are exclusive of their chemical composition or mechanical components. These properties encompass texture colour, texture, density, mass, melting and boiling points, and electrical and thermal conductivity.

Mechanical properties explain how a material reacts to external forces like pushing, pulling or twisting. Mechanical properties of material reflect the relationship between its response/deformation to an applied load or force. These mechanical properties determine the scope and limits of a material's functionality, as well as establish expected service life or performance, including strength, elasticity, plasticity, ductility, malleability, hardness, toughness, resilience, stiffness, toughness, and impact resistance.

Chemical properties describe how a material interacts with other materials in a given environment. These properties determine how the material behaves on a molecular level. Chemical properties are the basis for physical and mechanical properties.

Neither physical nor mechanical properties are constant; they change when exposed to various conditions, such as heat or loading rate. For example, elasticity (mechanical property) and density (physical property) are dependent on material temperature.

Definition:
- *Specific Gravity = The density of a plastic compared with the density of water. A higher number indicates a denser plastic.*
- *Water absorption = The % increase in the weight of a plastic when it is immersed in water for a specified period of time.*

The swelling capacity of a polymer is the amount of a liquid it can absorb. Two methods of swelling test: Beaker test method and Tea bag test method.

Definition:
- *Tensile strength = The load that a material with a particular cross-sectional area can withstand when loaded in tension under specified conditions.*
- *Yield strength = The point at which permanent (or plastic) deformation begins.*
- *Ultimate tensile strength = The maximum stress the material can withstand before it ultimately breaks under a tensile load*
- *Fracture / breaking strength = The point at which the material can no longer carry any more load and breaks.*
- *Tensile elongation = The degree to which a plastic test specimen can be stretched under a tensile load prior to failure.*
- *Young's Modulus of elasticity = A measure of the tensile (pulling) stiffness of a plastic material prior to breaking or permanently deforming.*

Biodegradable plastics
Biodegradable plastics are plastics that degrade or break down when exposed to sunlight or ultraviolet radiation, bacteria, certain enzymes, moisture or water, or wind abrasion. In certain circumstances, rodents, pests or insect attacks can also act as modes of biodegradation or environmental degradation. Examples: Starch-based, cellulose-based and soy-based plastics.

Bioplastics
Most plastics are products of petrochemicals; whereas, bioplastics are plastics produced substantially from renewable plant materials such as cellulose and starch. Bioplastics is a growing field due to the finite limits of petrochemical resources and the risk of global warming,

Reference:
Galus, S, Arik Kibar, EA, Gniewosz, M & Kraśniewska, K 2020, 'Novel Materials in the Preparation of Edible Films and Coatings—A Review', Coatings, vol. 10, no. 7, p. 674, viewed June 2024, <https://doi.org/10.3390/coatings10070674>.

Notes:

Water vapour permeability and mechanical resistance (tensile strength, Young's modulus and elongation at break) are commonly measured properties.

Composite films or coatings are prepared from the combination of two or more film-forming substances in order to obtain structures with modified physical, mechanical and barrier properties which are better than the single-component material. Thus in film-forming formulation various substances such as plasticizers, crosslinking agents, emulsifiers, and reinforcements are used to improve or modify the basic functionality of the material.

Different active compounds such as antimicrobials, antioxidant, colour agents, flavours, and nutraceuticals are incorporated into film-forming solution to improve the quality, stability, and safety of packed foods. Those ingredients may provide antibacterial, antifungal or antioxidant properties of edible material which may be produced by wet or dry methods.

Physical properties of plastic:
Plastic Type / Density (g/cm³) /Melting Point (°C) / Transparency / Flexibility / Hardness /Example Products
Polyethylene (PE) / 0.91-0.96 / 105-135 / Transparent /Flexible / Soft / Plastic bags, squeeze bottles

Chemical properties of plastic:
Plastic Type / Chemical Resistance / Flammability / Thermal Stability / Electrical Insulation
Polyethylene (PE) / Good / Flammable / Limited/ Excellent

Comparison of common plastic materials:
Plastic Type / Tensile Strength (MPa) / Young's Modulus (GPa) / Flexural Strength (MPa) / Impact Strength (J/m) / Elongation at Break (%) / Minimum Service Temperature (°C) / UL94 Fire Rating / Poisson's Ratio
Polyethylene (PE) / 15-40 / 0.1-0.9 / 10-40 / 10-100 / 200-1000 / -50 to 80 /V-2, HB / 0.42-0.4

Reference:
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20.05.2024 till 23/5/2024

Research and planning:

Notes:

Que: What is the standard test method of tensile testing?

The tensile tests were performed in accordance to the ASTM D882 - Standard Test Method for Tensile Properties of Thin Plastic Sheeting using a TESTOMETRIC M500 50-AT universal testing machine. For example, the bioplastic films were cut in strips of 100 mm x 20 mm. The test parameters were adjusted as follows: load cell of 100 N, grip distance of 50 mm and crosshead speed of 500 mm/min. 5 samples were tested.

Que: How to perform water absorption test?

Water absorption test was in compliance to the ASTM D570 (Standard Test Method for Water Absorption of Plastics). The test was performed to determine the control factors levels with the lowest water absorption. For instance, a repeated immersion test with two hours sampling was considered and a long-term immersion whereby the latter was weighed every 24 h until the three consecutives readings average was less than 1 % of the total increase in weight or 5 mg, which indicated saturation. The test specimens were cut in strips 76.2 mm (3 in.) x 25.4 mm (1 in.).
The percentage moisture content, ΔM (t) absorbed:
ΔM(t) = (Mass recorded at sampling time – initial mass)/ Initial mass × 100

Reference:
Water Absorption 24 Hour - (ASTM D570) Test of Plastics n.d., omnexus.specialchem.com, viewed June 2024, <https://omnexus.specialchem.com/polymer-property/water-absorption-24-hours#:~:text=What%20are%20the%20test%20conditions%20for%20water%20absorption%3F>.

26.05.2024

Notes:

Que: How to measure water vapour transmission rate (WVTR)?

ASTM E96/E96M (Standard Test Methods for Water Vapour Transmission of Materials)
Definition: Water Vapour Transmission Rate (WVTR) or Moisture Vapour Transmission Rate (MVTR) is the rate at which water vapour will permeate through solid material over a specific period of time.
Permeability: All polymers are permeable to gases and vapours to different extents.
Rate in Packaging: When referring to packaging, WVTR is the rate at which water vapours will permeate the package wall. WVTR is measured in mg/Day per area.

WVTR (water vapour transmission rate) is the steady state rate at which water vapour permeates through a film at specified conditions of temperature and relative humidity. Values are expressed in g/100 in2/24 hr in US standard units and g/m2/24 hr in metric (or SI) units. Test conditions vary, e.g. ExxonMobil has standardized to 100°F (37.8°C) and 90% RH, which is the most common set of conditions reported in North America.

Relevance to package performance
A critical function of flexible packaging is to keep dry products dry (potato chips, pretzels, fortune cookies, etc.) and moist products moist (cheese, muffins, chewing gum, etc.). Without protective packaging, products would quickly gain or lose moisture until they reached equilibrium with the environmental relative humidity around them, at which point crispy products would be soggy, and chewy products would be hard and dry.

WVTR is the standard measurement by which films are compared for their ability to resist moisture transmission, with lower values indicating better moisture protection. Only values reported at the same temperature and humidity can be compared, because transmission rates are directly affected by both of these parameters.

Two standards to measure WVTR of pharmaceutical container closure systems:
- *ASTM D7709 – Standard Test Methods for Measuring Water Vapour Transmission Rate (WVTR) of Pharmaceutical Bottles and Blisters*
- *USP <671> Barrier Protection Determination – Method 1, which is based on ASTM D7709*

Procedure for testing primary packaging (desiccant method):

- *Filling the test samples with a desiccant*
- *Weighing the samples and placing them into a climate chamber for 35 days*
- *Every 7 days, the samples are taken out and weighed*
- *The WVTR is determined by fitting a linear regression of the change in weight over time*

Principle:
The water vapour permeability of the package is defined as the rate at which water is transmitted into the package from the test atmosphere (Normally 90±2% RH at 37.8° C ± 1°C) surrounding it while a desiccant is sealed within.

Requirements (Equipment/Machinery/ Instrument and Chemicals/Material)
• Anhydrous calcium chloride
• Humidity Cabinet – It should have a provision for circulation of air
• Analytical balance - Readability of 0.0001g
• Oven

Steps:

- *Dry anhydrous calcium chloride in an oven at 200°C for 1 hour.*
- *Place known weight of the desiccant within the pack to be tested. The weight should be more than the half capacity of the pack. Prepare three such experimental samples.*
- *Label each pack as 1, 2, and 3. Seal the packs and record the weight for each pack.*
- *Pre-warm the sealed packets at 37.8°C. Place the warm samples in the test chamber/humidity cabinet maintained at 90±2% R H and 37.8±1°C.*
- *Remove one pack from the chamber after 24 hours, weigh and immediately place it back. Repeat the same for all packs.*
- *Repeat the above, till no change in the weight gain is observed.*

Reference:

- What is WVTR (Water Vapor Transmission Rate)? | LOG 2021, Pharma Primary Packaging, viewed June 2024, <https://logpac.com/what-is-wvtr-water-vapor-transmission-rate/#:~:text=Definition%3A%20Water%20Vapor%20Transmission%20Rate>.
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Notes:

Que: How to measure melting point?

The melting point of plastic is the temperature at which it transitions from a solid state to a liquid state. The melting point of plastic depends on various factors, including the type of plastic, chemical composition, and molecular structure.

Different types of plastics have different melting points. Some plastics have low melting points, such as thermoplastic plastics - polyethylene (PE) and polypropylene (PP), which melt between 110 to 175 degrees Celsius. On the other hand, other plastics, such as thermosetting plastics - epoxy and polyester, have higher melting points, ranging from 150 to 300 degrees Celsius.

The melting point of plastic can also be influenced by the chemical components of the plastic. For example, PE has a lower melting point compared to PP because PE has more branching in its molecular structure. The molecular structure of plastic can also impact the melting point. For instance, PE has a more linear molecular structure compared to PP, resulting in a lower melting point.

Que: How to determine the melting point of plastic?

Several different methods are used to determine the melting point of plastic. A common method involves using a mercury thermometer. This method entails heating the plastic in a small glass container and recording the temperature at the moment the plastic begins to melt.

Can the melting point of plastic be altered?

Yes, the melting point of plastic can be altered by adding various additives. For example, fillers often reduce the melting point of plastic.

In packaging applications, the melting point of plastic affects its suitability for containing food and beverages. Plastics with lower melting points are often used to package products that need to be stored at low temperatures, such as frozen foods. This is because plastics with low melting points can withstand cold temperatures without cracking or breaking. Plastics with higher melting points are typically used for packaging products that require high-temperature storage, such as hot beverages.

Que: What factors influence the melting temperature of plastic?

The melting temperature of plastic depends on several key factors, including:
- *The chemical structure of the polymer: Different types of plastics with different chemical structures have different melting temperatures. For instance, plastics containing a higher number of hydrocarbon groups tend to have higher melting temperatures compared to plastics with different functional groups.*
- *The degree of crystallinity: Crystalline plastics have higher melting temperatures compared to amorphous plastics. This is because the molecules in crystalline plastics are arranged in a specific order, making them more resistant to breaking apart.*
- *The mass ratio of components in the plastic: The melting temperature of plastic can also be influenced by the mass ratio of its components. For example, ABS plastic is a thermoplastic composed of three types of monomers: acrylonitrile, butadiene, and styrene. The mass ratio of these monomers affects the melting temperature of ABS plastic.*
- *Additives: Additives introduced into the plastic can impact its melting temperature. For example, heat stabilizers can be added to raise the melting temperature of the plastic.*

Reference:

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- What is the melting temperature of plastic? n.d., EuroPlas, viewed June 2024, <https://europlas.com.vn/en-US/blog-1/what-is-the-melting-temperature-of-plastic>.

Experimental design:

Experiment 1. To measure tensile strength – to test the usefulness of each plastic (how strong and flexible is the plastic?)

Equipment: Universal testing machine used for performing tensile testing, connected to software for data analysis

As testing machine is not available, the alternative is:
1. Retort stand with a Hoffman clamp that can hold the bioplastic sheet
2. S hooks – to hook the clips onto the clap at the top, to hook the weights at the bottom
3. Small weights in increments, e.g. 10g, 50g or 100g – to add to hook at the bottom end

Tensile test procedures:
1. Measure strips of material (e.g. 100mm in length)

2. Attach material in retort stand.
3. Add weights of 100g, 50g or 10g. at a time.
4. Measure increase in length.
5. Determine fracture point of each plastic.

Tensile test – dependent variables:
1. Tensile strength, mass (g) / force (N)
2. Fracture point = elongation at fracture = the amount of stress that breaks the plastic apart (mm)
3. Stress = force / surface area
4. Strain = change of length / initial length
5. Young's Modulus = gradient of the curve (to determine stiffness of the plastics)

Draw a graph of stress against strain. Analyse.

Experiment 2. To test water permeability (water resistance test) – is the plastic waterproof?

Equipment:
1. Beakers
2. Rubber band to secure the plastics on the top of the glass
3. Balance (measure up to 0.001g)

- Determine time interval for observation, 1 hour, 24 hours, 48 hours
- To observe and measure any water permeating through the test specimen into glass

Experiment 3. To perform swelling test – to test water absorption ability

Equipment:
1. Balance (measure up to 0.001g) is used as plastic is very light
2. Beakers

- Use a balance to determine the initial and final weights of plastics after absorption of water in the beakers

Swelling test (Beaker test method)
1. Record mass of the test specimen when dry
2. Place in a beaker of deionised water
3. Separate the swollen specimen using filter paper.
4. Measure mass at a specified time interval
5. Calculate the swelling capacity (%) = increase in mass/initial mass x 100

Experiment 4. Heat test to observe thermal reaction
1. Add water and place plastic into the cooking pot at room temperature.
2. Heat the cooking pot.
3. Observe behaviour of plastic at room temperature, 40C, 60 C, 90-100C using infrared thermometer.

23.05.2024 – 27.05.2024

Require lab equipment – to gain permission to borrow from lab
To contact with lab manager

1. Equipment to measure tensile strength
2. Equipment to examine water permeability
3. Equipment to test water absorption ability (swelling test)

Equipment to borrow from lab:

1. Retort stand with a clamp that can hold the plastic sheet.
2. Small weights in increments, e.g. 10g, 50g or 100g – to hook at the bottom end
3. S hooks x2 – to hook the clips onto the clap at the top, to hook the weights at the bottom
4. Weigh scale / balance
5. Trays - for casting
6. Beakers - to measure volume of liquid
7. Infrared thermometer – for heat test
8. Syringe

Notes:

Que: What are the tests out there for material functionality?

Degradation test (Soil burial Test)
The mass loss of the bioplastic film was considered as the index for biodegradation measurement. The soil burial test was carried out in a laboratory scale whereby the bioplastic at a depth of 75 mm in composting soil for aerobic conditions and incubated at room temperature.

The initial dried weight of each sample were recorded and a sampling period of 5 days was selected. The degree of disintegration was determined through the percentage of particles retained on a sieve of 2mm. The recovered pieces were washed, dried at 40 ± 2 ◦C and weighed to calculate the mass loss, in compliance to the ISO 20200:2015.
The percentage weight loss was determined:
% weight loss = Initial dry weight – weight after sampling time (5days) / initial dry weight × 100

Water vapour transmission test (WVT)
The WVT test was performed according to the ASTM E96/E96M (Standard Test Methods for Water Vapour Transmission of Materials), with some alterations. The desiccant method was selected for testing of the sample. The test specimen was weighed at 6h intervals until a constant weight was reached. The water vapour transmission, WVT was calculated: WVT = (G/t)/A, where G is the weight gain (g), t is the time tested (h), and A is the sample area (m2).

Testing methods for Tom Ford Prize Award – Tensile testing
To examine if the products align with industry standard performance specifications to ensure bioplastic solutions are capable of meeting the technical requirements for packaging system integration and for consumer end-use. Performance criteria included: Strength, Flexibility and Water vapour transmission.

Tensile properties
Purpose: To determine the strength and flexibility of sample materials and how they align with industry requirements for service-life performance.
Description: This test is to determine tensile properties of plastics in the form of thin sheeting and films (<s 1.0 mm (0.04 in.) In thickness). Samples were tested on a universal tensile tester (Shimadzu, 1kn load cell) equipped with 1-inch rubber grips for thin plastic films, with an initial grip separation of 4 inches (100 mm).
Key dependent variable(s): tensile strength at yield, tensile strength at break, elongation at yield, elongation at break and tensile modulus
Alignment with existing standards / test methods ASTM d882-18
At room temperature, approximately 22°c
Frequency of measurement: point-in-time evaluation
Sample preparation testing was conducted on films without any environmental exposure. Films were cut into a "dog bone" for use on the testing machine. Films were tested in Triplicate.

Compared with controls LDPE film (negative control)
Samples - weight, area, width, thickness, format
The test specimens consisted of strips of uniform width and thickness, at least 50 mm (2 in.) longer than the grip separation used. The nominal width of the specimens was > 5.0 mm (0.20 in.) or < 25.4 mm (1.0 in.).
The rate of separation was calculated from the required initial strain rate.

25.05.2024 – 29.05.2024

Searching for equipment for making bioplastics:

- Dehydrator 33cm x 33cm – for drying process
- Silicone trays 30cm x 60cm, 30cm x 45cm – for casting

Reference: bioplastics study

- Tan, SX, Ong, HC, Andriyana, A, Lim, S, Pang, YL, Kusumo, F & Ngoh, GC 2022, 'Characterization and Parametric Study on Mechanical Properties Enhancement in Biodegradable Chitosan-Reinforced Starch-Based Bioplastic Film', Polymers, vol. 14, no. 2, p. 278, viewed June 2024, <https://www.mdpi.com/2073-4360/14/2/278/htm#B10-polymers-14-00278>.
- Boey, JY, Lee, CK & Tay, GS 2022, 'Factors Affecting Mechanical Properties of Reinforced Bioplastics: A Review', Polymers, vol. 14, no. 18, p. 3737, viewed June 2024, <https://www.mdpi.com/2073-4360/14/18/3737>.
- Thana Teeraphantuvat, Kritsana Jatuwong, Praween Jinanukul, Wandee Thamjaree, Saisamorn Lumyong & Worawoot Aiduang 2024, 'Improving the Physical and Mechanical Properties of Mycelium-Based Green Composites Using Paper Waste', Polymers, vol. 16, Multidisciplinary Digital Publishing Institute, no. 2, pp. 262–262.

27.05.2024

To improve experimental design

- Use flat metal screw compressor clamps, callipers, spring scale
- Considering torsion test – tested, may not be relevant to plastic

29.05.2024 – 1.06.2024

Creating bioplastics – To design Pilot study

To select and compare different recipes: to decide the parameters for independent variables.

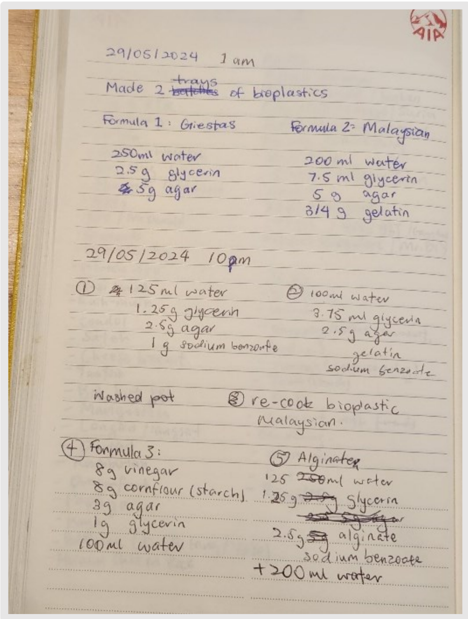
Note:

Calculating Percent Weight/Volume (% w/v):
A percent w/v solution is calculated using the gram as the base measure of weight (w): % w/v = g of solute/100 mL of solution.

Initial bioplastic formulations:

Recipe G: agar 250ml water 5g agar 2% w/v 2.5ml glycerine 1% w/v	Recipe C: starch and acetic acid 100ml water 3g agar 3% w/v 1ml glycerine 1% w/v 8g starch 8% w/v

	8g acetic acid 8% w/v
Recipe M: agar 800ml water 20g agar 2.5% w/v 30ml glycerine 3.75% w/v 3g gelatine 0.375% w/v	Considering Recipe C2 and C3 at a later stage if Recipe C works. Recipe C2: acetic acid water agar glycerine acetic acid
Recipe A: alginate 325ml water 2.5g alginate 0.77% w/v 1.25ml glycerine 0.385% w/v	Recipe C3: starch water agar glycerine starch



30.05.2024

Experiments for tensile testing:

1. Trials of using a spring scale for weight reading, or hand pull to generate force.
2. Measure the length of deformation at eye level as quickly as possible after addition of each weight.
3. Add initial weight of 100g, then 50g in increments, then 10g increments towards the fracture point.
4. The foldback clip is tilted one side, potentially reducing the vertical force. Solution: replaced with Mohr's clip.
5. The bioplastics thin sheets were observed fractured at top and bottom ends at its maximal tensile strength. This was different from the ideal testing method that producing fracture point in the middle of the material.

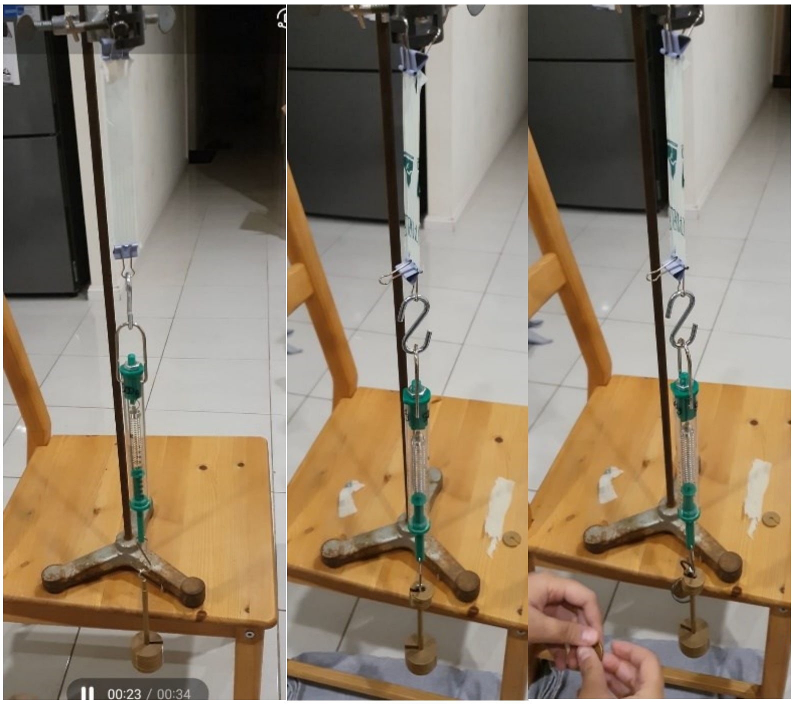
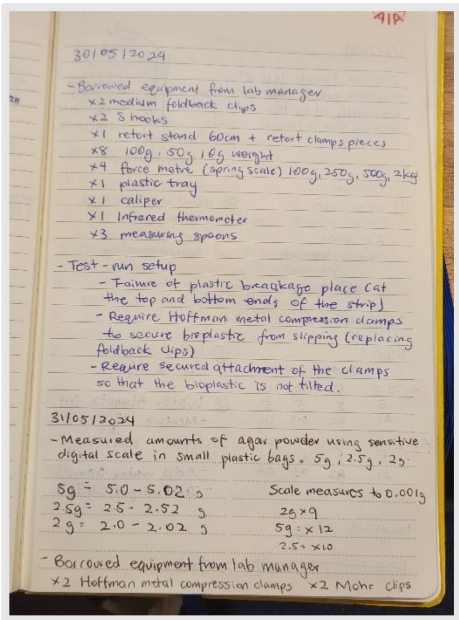


Figure. Conducting tensile testing experiment



30/05/2024

- Borrowed equipment from lab manager
  x2 medium foldback clips
  x2 S hooks
  x1 retort stand 60cm + retort clamps pieces
  x8 100g, 50g, 10g weight
  x4 force metre (spring scale) 100g, 250g, 500g, 2kg
  x1 plastic tray
  x1 caliper
  x1 Infrared thermometer
  x3 measuring spoons

- Test-run setup
  - Failure of plastic breakage place (at the top and bottom ends of the strip)
  - Require Hoffman metal compression clamps to secure bioplastic from slipping (replacing foldback clips)
  - Require secured attachment of the clamps so that the bioplastic is not tilted.

31/05/2024

- Measured amounts of agar powder using sensitive digital scale in small plastic bags. 5g, 2.5g, 2g.

5g = 5.0 - 5.02 g
2.5g = 2.5 - 2.52 g
2g = 2.0 - 2.02 g

Scale measures to 0.001g
2g x 9
5g = x 12
2.5 = x 10

- Borrowed equipment from lab manager
  x2 Hoffman metal compression clamps x2 Mohr clips

31.05.2024 -14.06.2024

I've skipped lunch to measure agar powder using analytical balance and conduct experiments in the lab.

Figure. Agar powder

1.06.2024 - 2.06.2024

Journey of creating own bioplastics!

Challenges faced:

1. Slow drying process – Solution: dry under sunlight (not suitable when windy and rainy), use heater to speed up heating process (different rate of shrinking observed), dehydrator however unavailable.
2. Potential of mold growth
   Observed some spotting mold growth as the bioplastics was wet and slow to dry. Solution: use preservative which showed good result
3. Difficulty to remove bioplastics sheets from the tray. Solution: to source for silicone tray which is soft and flexible
4. Controlled variables: amount of heating time affecting concentration, considering standardise the heating time and fire/heat intensity.

Results of pilot study:

The bioplastics of different formulations produced on 29.05.2024:

1. Bioplastics shrinks up to 1/3 of its original size after 3 days of drying and heating process. Bioplastics dries up slowly through evaporation depending on ambient temperature and humidity. Heating can speed up the drying process as well as shrinking rate.
   Controlled variables: amount of heating time affecting concentration, considering standardise the heating time and heat intensity.

Figure a. Recipe G shrinking to 1/3 size after 3 days of drying and heating.

Figure b. Recipe M shrinking slowly over 3 days under natural condition.

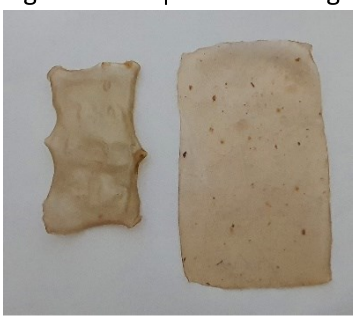


Figure c. Comparison of rate of drying and shrinking after 3 days under natural condition and combination of natural and heating condition.

2. Recipe M is more flexible than Recipe G due to higher concentration of glycerine it contains. With preservative added, no mold growth was observed in these samples.

Figure d. Both recipes G and M shrinking to 1/3 size with no mold growth after 3 days of drying and heating.

3. Recipe C produces rigid bioplastics which can be broken with higher force. Starch increases the hardness of bioplastics.

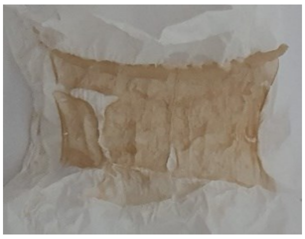


Figure e. Recipe S starch combination sheet is rigid and hard.

4. Recipe A alginate bioplastics is very colloidal and gluey, takes up a lot of water to dissolve and extremely slow to dry after casting. It appears as liquid and does not form a plastic after 3 days under natural condition. Heating improves drying process and leaves a very thin sheet. It appears flexible, however is hard to peel off due to its thinness. So, alginate will not be included in the experimental design. Solution: Use of calcium chloride spray to speed up drying – yet to explore this.

Figure f. Recipe A alginate sheet is very thin.

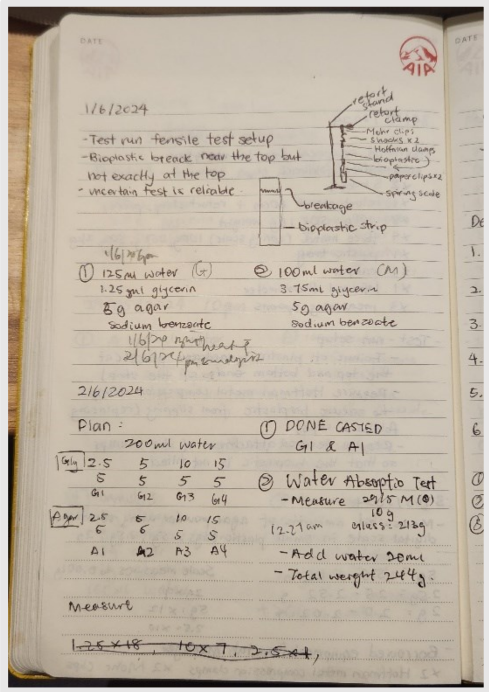
5. Next step: 01.06.2024 To make the bioplastic sheets with a much higher concentration of agar and analyse later.
6. Based on observation and outcome of the pilot study, different formulations of bioplastics using the parameters for independent variables are designed.

Table a. To investigate the effect of different concentration of agar on the properties of bioplastics

Recipe (w/vol)	**A1**	**A2**	**A3**	**A4**
Agar	1.25%	2.5%	5%	7.5%
Glycerine	2.5%	2.5%	2.5%	2.5%

Table b. To investigate the effect of different concentration of glycerine on the properties of bioplastics

Recipe (w/vol)	G0	G1	G2	G3	G4
Agar	2.5%	2.5%	2.5%	2.5%	2.5%
Glycerine	0.625%	1.25%	2.5%	5%	7.5%


1/6/2024

- Test run tensile test setup
- Bioplastic breack near the top but not exactly at the top
- uncertain test is reliable

1/6/24 6pm

① 125ml water (G)
1.25ml glycerin
5g agar
sodium benzoate

② 100ml water (M)
3.75ml glycerin
5g agar
sodium benzoate

2/6/2024

Plan:

200ml water

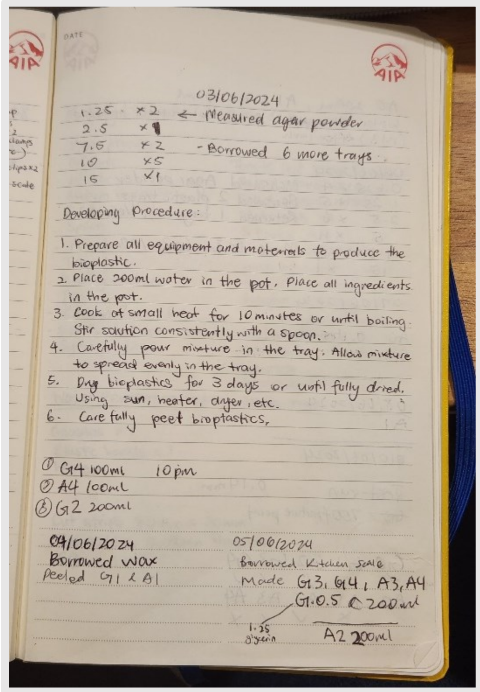
Gly	2.5	5	10	15
	5	5	5	5
	G1	G2	G3	G4
Agar	2.5	5	10	15
	6	6	5	5
	A1	A2	A3	A4

① DONE CASTED G1 & A1

② Water Absorptio Test
- Measure 29/5 M(①) 10g
12.21am glass: 213g
- Add water 20ml
- Total weight 244g.

Measure

~~1.25×18, 10×7, 2.5×4~~,


03/06/2024

1.25	×2
2.5	×
7.5	×2
10	×5
15	×1

← Measured agar powder

- Borrowed 6 more trays.

Developing Procedure:

1. Prepare all equipment and materials to produce the bioplastic.
2. Place 200ml water in the pot. Place all ingredients in the pot.
3. Cook at small heat for 10 minutes or until boiling. Stir solution consistently with a spoon.
4. Carefully pour mixture in the tray. Allow mixture to spread evenly in the tray.
5. Dry bioplastics for 3 days or until fully dried. Using sun, heater, dryer, etc.
6. Carefully peel bioplastics.

① G4 100ml 10pm
② A4 100ml
③ G2 200ml

04/06/2024
Borrowed wax
Peeled G1 & A1

05/06/2024
Borrowed Kitchen scale
Made G3, G4, A3, A4
G1 0.5 @ 200ml
1.25 glycerin
A2 200ml

3.06.2024

Start making bioplastics A1-4, G1-4 for experiments
Measure agar powder using analytical balance in the lab.

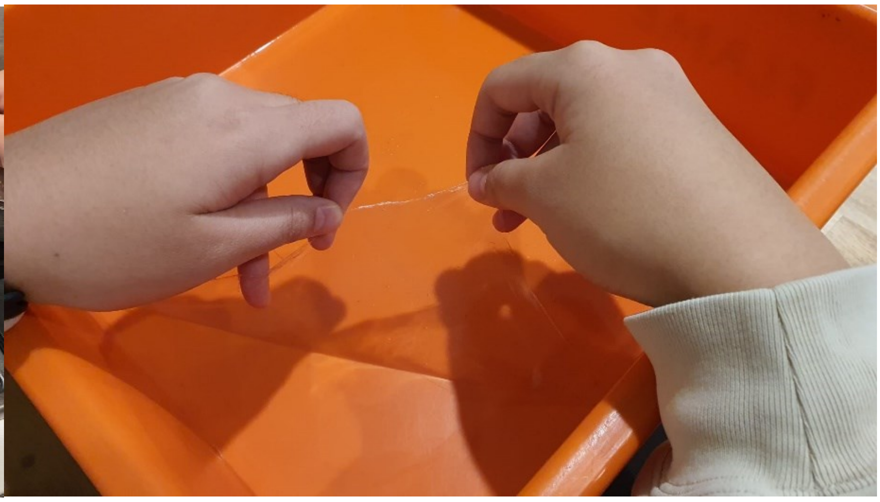



Figure. Making bioplastics

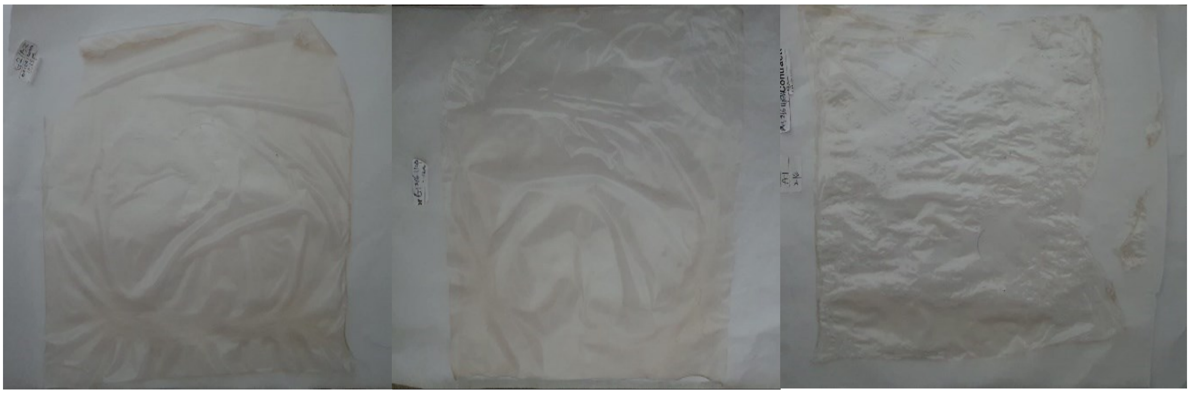


Figure. Drying bioplastics A1, A2/G2, G1 in order (2 days old)

2.06.2024

Experiments for tensile testing: To improve experimental design

- Use Mohr's clip to secure both ends of bioplastic thin sheets.
- Use double S hooks to prevent tilting of the clip. It works!

Figure. Improved version of tensile testing setup

1.06.2024 - 5.06.2024

Water permeability test using Recipe M – pilot study A

- Check each sample – any visible tear/cracks/imperfections?
- Weigh sample, glass and rubber band
- Add 20 ml of water

Figure. Water permeability test – pilot study A at the start

Results of pilot study A:

1. Osmosis was observed as water moves along outside the glass wall, 9g lost after 45 minutes, 1.5 hours, and 6 hours, 16g water lost after 2days. The sheet appears to have good permeability. Osmosis occurs when water leaks out of the edge of the sheets at the open end (16g after 1-2 days).
2. Water permeates through the sample slowly, but final weight of glass remains unchanged (213g). The water which leaks into the glass is a little bit.

3. Improvement: require sensitive balance

	Bioplastic sample	Glass	Rubber band	Whole system + 20 ml H2O
Initial weight	10g	213g	1g	244g

Measurement time	0	45 mins, 1.5 hrs	6 hrs	8.5 hrs	1 day 9 hrs, 1 day 17 hrs	1 day 19hrs. 1 day 10.5 hrs, 2 days
Weight	244	235	235	230	228	228
Weight loss due to osmosis	0	9	9	14	16	16

5.06.2024

Water permeability test using Recipe G3 – pilot study B

- Check sample
- Weigh sample, glass and the whole system
- Add 20 ml of water

Figure. Water permeability test – pilot study B before and after 1 hour.

Results of pilot study B (observed 3 days): similar to Results of pilot study A

1. A small amount of water permeates through the sample slowly into glass. The sheet has good hydrophilic properties and water permeability which is expected. Water leaks into glass. This assumes that the sample is porous in chemical composition; it has loose molecular structure that allows water molecules pass through. Additives or fillers can be added to bioplastics to make it resistant to water.
2. Osmosis was observed as water moves slowly along outside the glass.
3. The study will not examine the water barrier function for bioplastics with additives.

	Bioplastic sample	Glass	Rubber band	Whole system + 20 ml H2O
Initial weight	2.4g	212.4g	1g	236g
Final weight after 27 hrs	6g	212.4g	1g	223.8

Time	0	1 hr	1 day	2 days	27 hrs
Weight	236	235.7	227.7	224	223.8
Weight loss due to osmosis	0	0.3	8.3g	12g	12.2g

5.06.2024

Water permeability and water absorption test using sample M – pilot study C in lab

- Water permeates through the sample slowly into glass.
- Weight gain after immersion in water.

Figure. Water permeability test

Figure. Water absorption test

3.06.2024 - 6.06.2024

- Measure agar powder 0.625g, 1.25g, 2.5g, 5g, 10g , 15g
- Borrow equipment from lab.
    - Kitchen scale that measure up to 0.1g.
    - Additional trays
    - Wax

4.06.2024

Considering applying wax to the bioplastics to prevent water from being able to permeate through them. Any wax such beeswax, plant based wax, paraffin wax would be fine.

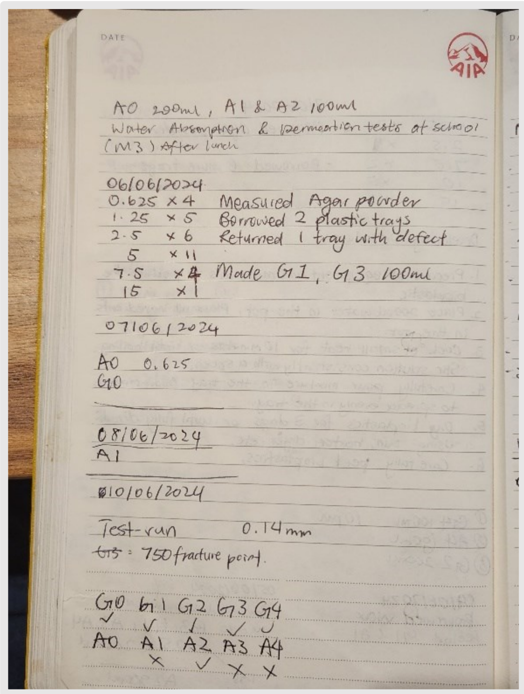
Next step: How to melt and apply the wax to the plastic?

- To consider: How to melt the wax for use, use a sponge brush to brush a layer of wax gently on bioplastic.

5.06.2024

Creating bioplastics samples for experiment 1.

Figure: Casting of bioplastics



AO 200ml, A1 & A2 100ml
Water Absorption & permeation tests at school (M3) After lunch

06/06/2024
0.625 × 4 Measured Agar powder
1.25 × 5 Borrowed 2 plastic trays
2.5 × 6 Returned 1 tray with defect
5 × 11
7.5 × 4 Made G1, G3 100ml
15 × 1

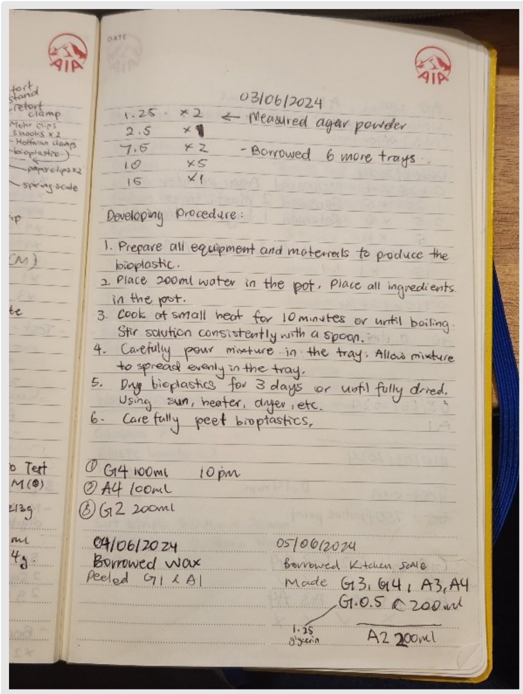
07/06/2024
A0 0.625
G0

08/06/2024
A1

10/06/2024

Test-run 0.74mm
~~G5~~ : 750 fracture point.

G0 G1 G2 G3 G4
✓ ✓ ✓ ✓ ✓
A0 A1 A2 A3 A4
× ✓ × ×



03/06/2024
1.25 × 2 ← Measured agar powder
2.5 × 1
7.5 × 2 - Borrowed 6 more trays
10 × 5
15 × 1

Developing Procedure:

1. Prepare all equipment and materials to produce the bioplastic.
2. Place 200ml water in the pot. Place all ingredients in the pot.
3. Cook at small heat for 10 minutes or until boiling. Stir solution consistently with a spoon.
4. Carefully pour mixture in the tray. Allow mixture to spread evenly in the tray.
5. Dry bioplastics for 3 days or until fully dried. Using sun, heater, dryer, etc.
6. Carefully peel bioplastics.

① G4 100ml 10pm
② A4 100ml
③ G2 200ml

04/06/2024
Borrowed wax
Peeled G1 & A1

05/06/2024
Borrowed Kitchen scale
Made G3, G4, A3, A4
G1.0.5 @ 200ml
1.25 glycerin
A2 200ml

10.06.2024

Figure. Bioplastics G1-4 and A1-4.

Figure. Tensile testing setup for samples A and B.

Notes:

The pascal (Pa) is an SI coherent derived unit defined as one newton per square metre (N/m2). It is used to quantify internal pressure, stress, Young's modulus, and ultimate tensile strength.

Sample A.

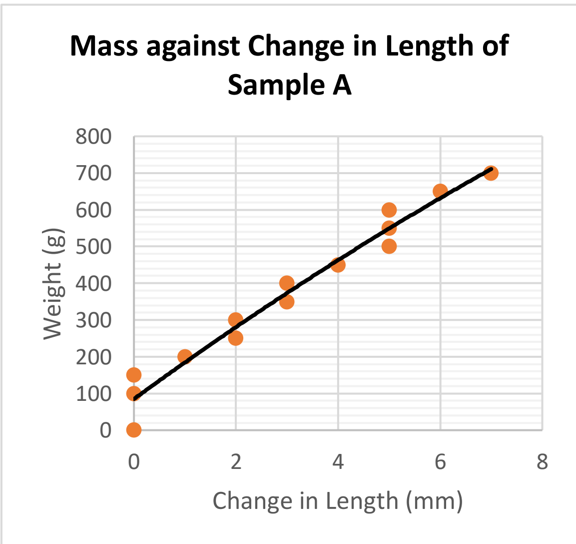
Surface area = 40 x 20mm = 0.04 x 0.02 = 0.0008 m2

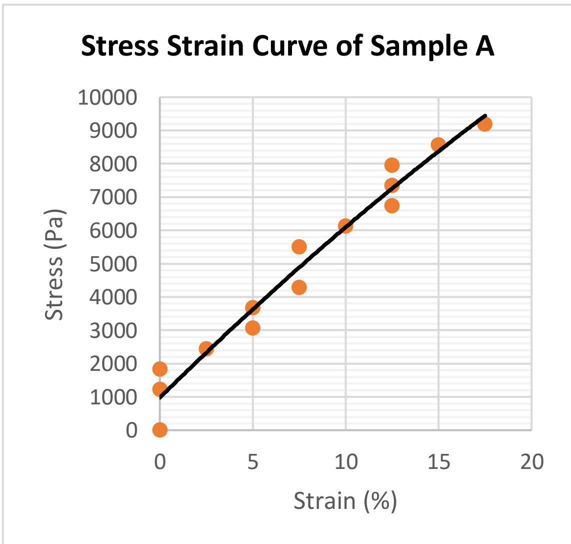
Thickness = 0.14mm

100g = 0.98N

W (g)	0	100	150	200	250	300	350	400	450	500	550	600	650	700	750
L (mm)	40	40	40	41	42	42	43	43	44	45	45	45	46	47	#
*L (mm)	0	0	0	1	2	2	3	3	4	5	5	5	6	7	#

W (g)	0	100	150	200	250	300	350	400	450	500
Stress (Pa)	0	1225	1837.5	2450	3062.5	3675	4287.5	4900	5512.5	6125
*L (mm)	0	0	0	1	2	2	3	3	4	5
Strain (%)	0	0	0	2.5	5	5	7.5	7.5	10	12.5





W (g)	550	600	650	700	750
Stress (mPa)	6737.5	7350	7962.5	8575	9187.5
*L (mm)	5	5	6	7	#
Strain (%)	12.5	12.5	15	17.5	#

Figure. Graph of the load applied against elongation and Stress Strain Curve of Sample A

Sample B.

Surface area = 26 x 20mm

Thickness = 0.24mm

W (g)	0	100	150	200	250	300	350	400	450	500	550	600
L (mm)	26	26	26	26	27	27	27	27	27	27	27	28
*L (mm)	0	0	0	0	1	1	1	1	1	1	1	2

W (g)	650	700	750	800	850	900	950	1000	1050	1100	1150
L(mm)	28	28	28	28	28	28.5	28.5	28.5	28.5	28.5	29
*L(mm)	2	2	2	2	2	2	2.5	2.5	2.5	2.5	3

W (g)	1200	1250	1300	1400	1500	2000
L (mm)	29	29	29	29	29.5	31.2
*L (mm)	3	3	3	3	3.5	5.2

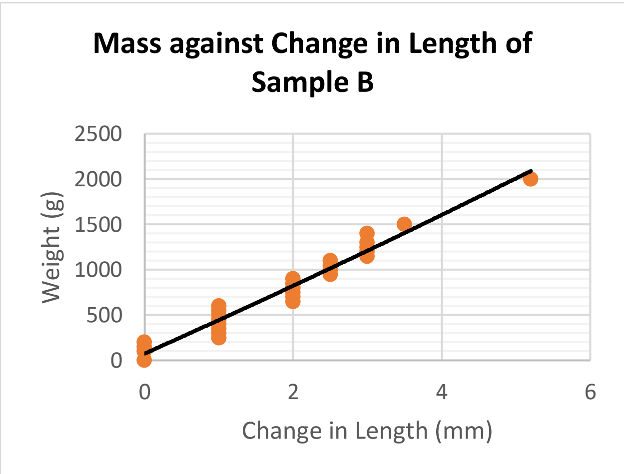


Figure. Graph of the load applied against elongation of sample B

10.06.2024 – 24.06.2024

Experiment 1: Tensile testing

Test specimen: Surface area = 50 x 20mm = 0.05 x 0.02 = 0.001 m2

100g = 0.98N

Results:

A1 Thickness 0.08mm +/- 0.05 mm Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 144g Range of tensile strength = 110 -190g Average max stress = 144Pa Average max strain = 10.43 %	**G0** Thickness 0.10 +/- 0.05 mm x2 Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 770g Range of tensile strength = 600 - 990g Average max stress = 7546Pa Average max strain = 15.81
A2 / G2 Thickness 0.10 +/- 0.05 mm x2	**G1** Thickness 0.08mm +/- 0.05 mm x2

Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 474g Range of tensile strength = 400 - 580g Average max stress = 4645.2Pa Average max strain = 19.11%	Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 726g Range of tensile strength = 530 - 960g Average max stress = 7114.8Pa Average max strain = 18.67%
A3 Thickness 0.18mm +/- 0.05 mm x2 Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 614g Range of tensile strength = 550 – 730 g Average max stress = 6017.2Pa Average max strain = 21.28 %	**G3** Thickness 0.28mm +/- 0.05 mm Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 338g Range of tensile strength = 300-360g Average max stress = 3312.4Pa Average max strain = 21.62%
A4 Thickness 0.16mm +/- 0.05 mm Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 1381g Range of tensile strength = 860 – 2062g Average max stress = 13535.76Pa Average max strain = 20.64%	**G4** Thickness 0.3-0.34mm +/- 0.05 mm Surface area = 0.05 x 0.02 = 0.001m2 Average max tensile strength = 234 g Range of tensile strength = 210 - 260g Average max stress = 2293.2Pa Average max strain = 27.58%

Special study on different thickness using samples of A4.
A4 – 2 samples
Thickness 0.052mm +/- 0.05 mm
Surface area 1a = 0.05 x 0.02 = 0.001m2
Surface area 1b = 0.05 x 0.017 = 0.00085m2
Average max tensile strength = 1275g
Range of tensile strength = 1250 – 1300g
Average max stress = 13575.88Pa
Average max strain = 36 %

Exp.	1a	2a
0	50	50
100	50	50
150	50	50
200	50	50
250	50	50
300	50	50
350	51	51
400	51	52
450	52	52
500	53	53
550	52	54
600	53	55
650	53	55
700	54	56
750	54	56
800	55	57
850	56	59
900	57	61
950	58	63
1000	60	65
1050	61	67
1100	62	68
1150	63	69
1200	64	70
1250	66	#
1300	#	
Thickness (mm)	0.052	0.052
Surface area (m2)	0.05 x 0.02	0.05 x 0.017

Max stress (Pa)	12740.00	14411.76
Max strain (%)	32	40

A4 with a higher shrinking rate – 3 samples from the same tray of A4
Thickness varies +/- 0.05 mm
Average max tensile strength = 1320.67g
Range of tensile strength = 1200 – 1300g
Average max stress = 29572.21Pa
Average max strain = 38.31 %

Exp.	1b	2b	3b
0	50	37	38
100	50	38	38
150	51	38	38
200	52	38	38
250	53	39	38
300	53	39	39
350	53	39	39
400	53	39	39
450	53	40	39
500	53	40	40
550	53	41	40
600	53	41	41
650	54	42	41
700	54	43	41
750	55	43	41
800	55	44	42
850	55	44	43
900	57	50	43
950	58	52	43
1000	59	53	44
1050	60	53	44
1100	61	53	45
1150	62	53	46
1200	66	53 #	47
1250	68		#
1300	69		
1362	71		
1412	73		
1462	74		
1512	#		
Thickness (mm)	0.072	0.076	0.042
Surface area (m2)	0.05 x 0.012	0.037 x 0.01	0.038 x 0.01
Max stress (Pa)	2469.6	3178.378	3223.684
Max strain (%)	48	43.2432	23.6842

B bag
Thickness 0.02mm +/- 0.05 mm
Surface area = 0.05 x 0.02 = 0.001m2
Average max tensile strength = 246g
Range of tensile strength = 200-350g
Average max stress = 2410.8KPa
Average max strain = 236.51%

W bag
Thickness 0.02mm +/- 0.05 mm
Surface area = 0.05 x 0.02 = 0.001m2
Average max tensile strength = 320g
Range of tensile strength = 300-340g
Average max stress = 3136KPa
Average max strain = 433.77%

C bag
Thickness 0.02mm +/- 0.05 mm
Surface area = 0.05 x 0.02 = 0.001m2
Average max tensile strength = 246g
Range of tensile strength = 190-310g

Average max stress = 2293.2KPa
Average max strain = 186.33%

11.06.2024 - 14.06.2024

Experiment 2: Water permeability test

- Conducted in lab

Experiment 3: Water absorption test

- Conducted in lab

Surface area = 0.05 x 0.02 = 0.01m2

Table: Result of water absorption test

Mass	A1a	A1b	A1c	Average
0 hr	0.167	0.158	0.158	0.161
2 hrs	0.165	0.157	0.157	-
24 hrs	0.192	0.182	0.182	-
26 hrs	0.170	0.159	0.165	0.161
48 hrs	0.180	0.169	0.163	0.171
Mass gain (g)	0.013	0.011	0.005	0.010
Water absorption rate (%)	7.78	6.96	3.16	6.00

Mass	A3a	A3b	A3c	Average
0 hr	0.373	0.503	0.282	0.386
2 hrs	0.863	0.913	0.602	-
24 hrs	1.118	1.215	0.813	-
26 hrs	1.166	1.250	0.907	-
48 hrs	1.262	1.317	1.006	1.195
Mass gain (g)	0.889	0.814	0.724	0.809
Water absorption rate (%)	238.34	161.83	256.74	209.59

Mass	A4a	A4b	A4c	Average
0 hr	0.468	0.479	0.379	0.442
2 hrs	1.152	1.218	0.975	-
24 hrs	1.514	1.478	1.231	-
26 hrs	1.596	1.481	1.361	-
48 hrs	1.645	1.705	1.496	1.615
Mass gain (g)	1.177	1.226	1.117	1.173
Water absorption rate (%)	251.50	255.95	294.72	265.46

Mass	G0a	G0b	G0c	Average
0 hr	0.090	0.111	0.120	0.107
2 hrs	0.190	0.220	0.235	-
24 hrs	0.252	0.307	0.279	-
26 hrs	0.260	0.317	0.279	-
48 hrs	0.279	0.337	0.321	0.312
Mass gain (g)	0.189	0.226	0.201	0.205
Water absorption rate (%)	210.00	203.60	167.50	191.90

Mass	G1a	G1b	G1c	Average
0 hr	0.154	0.126	0.062	0.114
2 hrs	0.172	0.144	0.075	-
24 hrs	0.208	0.157	0.087	-
26 hrs	0.211	0.159	0.093	-
48 hrs	0.211	0.16	0.088	0.153
Mass gain (g)	0.057	0.034	0.026	0.039
Water absorption rate (%)	37.01	26.98	41.94	34.21

Mass	G2a	G2b	G2c	Average
0 hr	0.207	0.379	0.225	0.270
2 hrs	0.216	0.508	0.255	-
24 hrs	0.230	0.535	0.256	-
26 hrs	0.230	0.535	0.257	-
48 hrs	0.220	0.543	0.256	0.340
Mass gain (g)	0.013	0.164	0.031	0.069
Water absorption rate (%)	6.28	43.27	13.78	25.65

Mass	G3a	G3b	G3c	Average
0 hr	0.398	0.225	0.438	0.354
2 hrs	0.620	0.315	0.673	-
24 hrs	0.732	0.375	0.840	-
26 hrs	0.800	0.389	0.897	-
48 hrs	0.890	0.423	1.028	0.780
Mass gain (g)	0.492	0.198	0.590	0.427
Water absorption rate (%)	123.62	88.00	134.70	120.64

Mass	G4a	G4b	G4c	Average
0 hr	0.570	0.460	0.665	0.565
2 hrs	0.962	0.616	0.924	-
24 hrs	1.169	0.775	1.157	-
26 hrs	1.280	0.824	1.284	-
48 hrs	1.345	0.876	1.611	1.277
Mass gain (g)	0.775	0.416	0.946	0.712
Water absorption rate (%)	135.96	90.43	142.26	126.08

Mass	Ba	Bb	Bc	Average
0 hr	0.026	0.027	0.027	0.027
2 hrs	0.028	0.027	0.027	-
24 hrs	0.036	0.037	0.044	-
26 hrs	0.031	0.034	0.033	-
48 hrs	0.040	0.030	0.033	0.034
Mass gain (g)	0.014	0.003	0.006	0.008
Water absorption rate (%)	53.85	11.11	22.22	28.75

Mass	Ca	Cb	Cc	Average
0 hr	0.035	0.032	0.034	0.034
2 hrs	0.030	0.029	0.029	-
24 hrs	0.029	0.026	0.026	0.027
Mass gain (g)	-0.006	-0.006	-0.008	-0.007
Water absorption rate (%)	-17.14	-18.75	-23.53	-19.80 ?dissolve in water

Mass	Wa	Wb	Wc	Average
0 hr	0.030	0.032	0.037	0.033
2 hrs	0.036	0.039	0.037	-
24 hrs	0.072	0.037	0.046	0.052
Mass gain (g)	0.042	0.005	0.009	0.019
Water absorption rate (%)	140.00	15.63	24.32	56.57

15.06.2024 – 25.06.2024

Results computed.
Comparison made across all bioplastic samples.

24.06.2024 -25.06.2024

Experiment 4: Heat test to observe thermal reaction

Pilot study for melting point test: fail to determine the melting point. Need to explore further.
Finding: Dry bioplastics alone does not melt when temperature increases from room temperature to 100C. It is postulated that they have a higher melting point than 100C.

When bioplastics samples are immersed in water:

- It becomes sticky and softer when subject to heat. Heat has changed the molecular structure of the bioplastics.
- Whilst immersion in water, continuous heating for 5 minutes makes it melt into colloidal state. Further constant heat makes the test samples dissolve in water. Thicker samples take longer time to dissolve in water. Higher heat and increased heating time speeds up the decomposition process. Bioplastics samples are easily compostable with heat.

Figure. Heating the bioplastics

17.06.2024 -27.06.2024

Complete Scientific Report …

Acknowledgement

- I acknowledge the lab manager, Jo who has been very supportive of borrowing lab equipment to conduct experiments both at home and in the lab.
- I appreciate the advice and feedback provided by Jo and my mother who assisted me in improving my experimental design.
- I am grateful to my parents who assisted me in purchasing materials and equipment for making bioplastics.

OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☑ Scientific Inquiry

This must be included with your report, log book or entry. One form per entry.

NAME: Chloe Yaan Yuit Yew ID: 0445-042

SCHOOL: Norwood International High School

Activity: Give a brief outline of what you are planning to do.

I am planning to study on the functionality of bioplastics through investigating the physical and mechanical properties of algal bioplastics. Biodegradable bioplastics derived from algae will be made using different concentrations of water, agar, glycerine, and sodium benzoate. Of interest, mechanical properties comprising of tensile strength, tensile elongation, stress, strain, and tensile modulus of elasticity, as well as physical properties including water permeability and water absorbency will be investigated.

Are there possible risks? Consider the following:

- **Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.**
- **Thermal risks: Are you heating things? Could you be burnt?**
- **Biological risks: Are you working with micro-organisms such as mould and bacteria?**
- **Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?**
- **Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead?**

Risks	How I will control/manage the risk
Thermal risks	The stove, oven, and heater will be handled with caution and care to prevent burns.
Electrical risks	Electrical appliances including heater, digital scale, and oven will be operated with caution and care.
Chemical risks	Chemicals such as acetic acid, potassium sorbate and sodium benzoate will be handled with care by wearing gloves to avoid direct contact.
Biological risks	The bioplastics products may consist of mold growth so gloves will be worn when interacting with bioplastics products.
Sharp risks	When cutting bioplastics products, scissors and cutter will be carefully handled to prevent cuts. Glassware equipment will be used carefully to prevent breakage and cuts.

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out.

RISK ASSESSMENT COMPLETED BY (student name(s)): Chloe Yaan Yuit Yew

SIGNATURE(S): Chloe Yew

☑ **By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.**

TEACHER'S NAME: Doris Yu

SIGNATURE: DATE: 31/5/2024