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Durioplastics: Enhancing Durian (Durio zibethinus) Seed Starch Bioplastics via Cellulose Reinforcement from its Husk

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ABSTRACT

Bioplastics, derived from natural resources, are developed as an eco-friendly alternative to conventional petroleum-based plastics. The use of biopolymers in bioplastics enables faster degradation compared to petroleum-based plastics. Durian (Durio zibethinus Murr) seed starch and durian husk cellulose are one of the potential materials to make bioplastics. This study aims to evaluate starch-based and cellulose-based bioplastics, produced by combining starch and cellulose extracted from Durio zibethinus Murr with glycerol as a plasticizer. Four different samnples with varying compositions of the extracted starch and cellulose bioplastic properties were tested through four tests: elongation test,swelling test,flammability test, and biodegradability test. The results indicated that the properties of the bioplastics varied based on the composition of starch and cellulose, with each sample exhibiting distinct characteristics. The tests conducted on the samples revealed differences in flexibility, degradation rate, durability,and resistance to water. Statistical analysis further highlighted the significance of varying cellulose content in influencing these properties, suggesting the need for further optimization to achieve the desired balance of characteristics. Further details and analysis can be found in the full study.

I. Introduction

The Philippines produces an estimated 2.7million tons of plastic wvaste annually. A significant portion of this waste ends up in landfills and different bodies of water. According to WWF-Philippines (2024),2.15million tons of plastic waste, the third largest component of the country's solid waste, were generated in 2019 alone. However, only 9% of these plastics are recycled due to limitations in recycling high-value plastics, and 35% leaks out into the open environment.

One way to address this issue is to use bioplastics. Since they can form a continuous matrix and are an abundant and renewable resource, bioplastics are made from a combination of natural materials like cellulose and starch, which are biodegradable polymers based on natural polysaccharides. These materials are used as raw materials to create biodegradable films.With high biodegradability and the abundance of cellulose and starch in nature, bioplastics can be made.

Durian fruit (Durio zibethinus) is a seasonal fruit that is found in the tropics of the Philippines. Every year, the Philippines produces around 54,700 metric tons of durian, with the majority of production areas located in Mindanao. The flesh and seeds make up around 60 percent of the fruit, while the husk or skin which is generally considered waste material represents 40percent or 21,880 metric tons. Hence, every year, the country produces around 22,000metric tons of durian husk, which usually end up in the garbage dumps or worse, are just left along the sides of the streets to rot, according to data from the Department of Agriculture (2012).

High amounts of cellulose (50-60%) and lignin (5%), respectively, are found in durian husk. Numerous studies have made use of the cellulose found in durian husks.Ariyani's (2012) research on the usage of durian husk as a raw material for ornamental paper serves as one example. Another study by Mashuni (2021) used a mixture of 12%chitosan,2% glycerol, and 6% cellulose to generate bioplastic from chitosan and variants of durian husk cellulose as antibacterial food packaging. Tensile strength is 5.16, elongation is 3.01, thickness is 0.23, and biodegradation is 17.94 percent for this bioplastic.

Because durian seed has a large amount of starch (46.2%), it can also be used as a source for bioplastic due to its high carbonate content. A study by Jannah et al.(2021) combined glycerol as a plasticizer with the starch from durian seeds to develop a starch-based bioplastic. The bioplastic made from durian starch and 20% glycerol has an elongation of 13.3% and a strength of 50.28 MPa. Compared to other starches with a lower amylose percentage, those with a higher amylose concentration (30%) have excellent film-forming qualities, according to research by MMali et al. (2018) and Bae et al. (2019). Considering that the amylose content of durian starch is sufficiently high (27%), it can be utilized as a raw material for the production of biodegradable films.

In this study, the researchers will make a bioplastic made from durian husk cellulose and durian seed starch. Glycerol is added to make this biodegradable plastic. Glycerol as a plasticizer functions to increase elasticity by reducing the degree of hydrogen bonding and increasing the distance between polymer molecules (Wahyuningtiyas & Suryanto,2018). The researchers aim is to evaluate the properties of the bioplastics made from durian husk cellulose and durian seeds through four tests: elongation test, swelling test,flammability test, and biodegradability test

II. Materials and Method

a. Gathering of Materials

Durian husks and seeds were collected from fruit stalls along the road of Buhangin for cellulose and starch extraction. Chemicals such as sodium hydroxide, sodium hypochlorite, calcium hydroxide, acetic acid, and glycerol were sourced from a supply store in Uyanguren. In addition to these, distilled water, a stirrer, weighing scale, stove, parchment paper, measuring spoons and cups, and a blender were used in the process. The trays, pans, containers, and oven required for the experiment were provided by the researchers, ensuring that all procedures were conducted with the necessary equipment.

b. Preparation **and Extraction of Starch** from Durian **Seeds**

To begin the starch extraction process, the seeds were thoroughly washed to remove any dirt or debris. After cleaning, the outer layer of the seeds was peeled off. The peeled seeds were then cut into small, even pieces to make the next steps easier. This simple preparation was important to ensure a good amount of starch could be extracted.

Figure 1.Cutting the seeds

To remove the sap from the seeds, they were soaked in lime water for a period of 7 hours. This soaking process helped to break down the sap and other unwanted substances, making it easier to extract the desired starch Once the soaking was complete, the seeds were drained and thoroughly rinsed with clean water to remove any remaining traces of lime. After rinsing, the seeds were spread out and left to dry naturally under direct sunlight

Figure 2. Seeds soaked in limewater

Figure 3.Washing the ***seeds***

Figure 4.Drying the seeds

The dried seeds were mixed with distilled water in a container. This mixture was then blended well to create a smooth paste. Blending the seeds with water was important for breaking them down and releasing the starch. The result was a uniform mixture, making separating the starch from the solid parts easier.

Figure 5. Blending the seeds

The blended seeds were placed into a clean cloth for squeezing and filtering. This step was important to separate the liquid from the solid material. As the mixture was squeezed,the liquid, which contained starch, was collected,while the solid parts stayed in the cloth

Figure 6.Filtering the blended seeds

The filtrate was left to settle for 12 hours. The precipitate collected was then dried under the sunlight. Once dried, the starch was crushed and sieved to obtain small equal sizes.

Figure 7.Dried starch

Figure 8. Crushed starch

c. Preparation and Extraction of Cellulose from Durian Husks

The extraction of cellulose from durian husks was based on the integration of several established studies, with modifications applied by the researchers.

First, the durian rind, including the white inner layer, was thoroughly cleaned. The cleaned husks were then sun-dried for three days to reduce moisture content. After drying, the husks were soaked in water for five days to soften them for easier cutting Once softened, the husks were cut into smaller pieces.

Figure 9.Cleaning the durian husks

Figure 10. Sun-drying the husks.

Figure 11.Soaking the husks

Figure 12. Cut husks

The cut husks were then subjected to delignification by boiling them in 1000 ml of water containing 3% sodium hydroxide (NaOH)for 1-2 hours to remove lignin. After delignification, the husks were rinsed with distilled water to remove residual NaOH and dissolved lignin

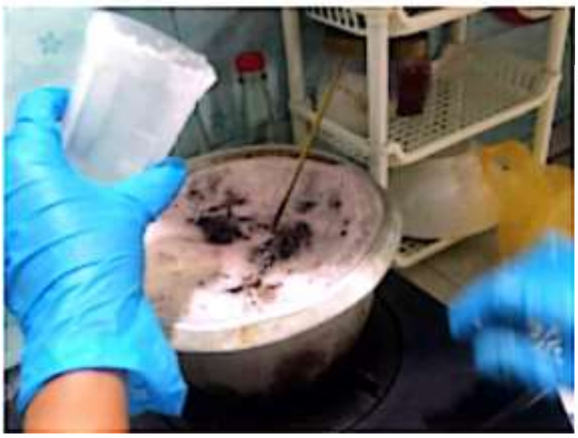

Figure 13. Boiling husks in 3% NaOH

Figure 14. Husks rinsing

Next, the delignified husks were bleached by boiling them in a 6% sodium hypochlorite (NaOCl) solution for 1-2 hours to further purify the cellulose. After bleaching, the husks were neutralized using acetic acid (CH COOH)and 95% ethanol, then rinsed with distilled water.The husks were either sun-dried or oven-dried until fully dried. Finally, the dried husks were ground into smaller, uniform pieces

Figure *15. Bleaching husks in 6% NaOCL*

Figure 16.Sun-dried cellulose

Figure 17.Ground cellulose

d. Formulation of Bioplastic

The bioplastic will be formulated using starch extracted from durian seeds and cellulose derived from durian husks, following a method adapted from Giestas (2021).The process will begin by preparing a bioplastic solution with a base ratio of 10 g starch, varying amounts of cellulose-1 g and 2 g-,10 mL of vinegar,and 10 mL of glycerin.

In a pot, the 10 g starch, 10 mL vinegar,10mL glycerin were mixed with 100 mL distilled water. The mixture was stirred thoroughly to avoid clumping. Next, the mixture was heated to 30℃ while stirring continuously for 10 minutes.

After this initial heating phase, 1 g or 2 g of cellulose was added to the solution they were assigned to, and it was stirred until the cellulose was evenly distributed throughout the mixture.

Figure 18. Mixing the bioplastic ingredients

The solution was then heated until it reached 75° , with continuous stirring to maintain a consistent texture. Once the solution became filmogenic, it was poured into a suitable container for drying and allowed to sun-dry for 5days.

Figure 19. Heating the mixture

Figure 20. Container assignation & sun-drying

Figure 21. Dried bioplastic

***Table** 1. Table 1. Variation of Bioplastic Formulations and Their Control Classification.*

Sample	Durian Seed Starch/corn starch (g)	Durian Husks Cellulose (g)	Glycerol (mL)	Vinegar (mL)	Water (mL)
S1	10	1	10	10	100
S2	10	2	10	10	100
S3	10	0	10	10	100
S4 (com starch)	10	-	10	10	100

e. Risk and Safety

The research involved chemical, biological, and physical risks. Sodium hydroxide and sodium hypochlorite, used in the cellulose extraction process, required PPE such as gloves and goggles to prevent burns and irritation. Potential microbial contaminants from durian husks and seeds were handled carefully. Physical risks from blenders, cutting tools, and drying ovens necessitated strict safety protocols All experiments were conducted in well-ventilated areas, and waste was disposed of according to safety regulations

f. Data Analysis

In this study, the properties of the bioplastics were evaluated through four tests: elongation test, swelling test, flammability test, and biodegradability test.

Elongation test

The method for evaluating elongation at break was adapted from the procedure described by Xometry (2024), with some modifications done by the researchers. Instead of using a tensile testing machine, a uniform force was applied to the bioplastic samples using varying weights of sand. Each sample was clipped at both ends:one end was used to hang the bioplastic, while the other end held a cellophane bag filled with sand The weight of the sand varied depending on how much the bioplastic stretched before breaking.

Before testing, the initial length of each sample was measured and gradually stretched until it broke under increasing tension. The elongation at break (%) was calculated by comparing the final length at breakage to the original length,allowing assessment of the bioplastics' ductility and tensile properties.

Elongation at Break=(Lf-LO/L0)100

*Swelling test (Water **Absorption)***

The method for evaluating water resistance (swelling) was adapted from the procedure described by Lazuardi and Cahyaningrum (2013) with some modification done by the researchers. Bioplastic samples were cut into 2x2 cm pieces and initially weighed (WO). The samples were then immersed in a beaker containing distilled water for 1 hour. After the immersion,the samples were removed, and any surface water was gently blotted with tissue. The samples were then reweighed to obtain the final weight(W).

Swelling(%)=(W1-Wo/Wo) 100

Flammability test

The flammability test was conducted to evaluate the burning rate of bioplastic samples. Before the test, each sample was prepared in a uniform shape and size. The length of the material to be burned was measured, and the sample was ignited at one end. The time it took for the flame to travel through a specific length of the material was recorded. The burning rate was calculated using the formula:

$$\textbf{Burning Rate} = \frac{\textbf{Length Burned (cm)}}{\textbf{Time (s)}}$$

Biodegradability test

Biodegradation testing was performed using the soil burial testtechnique, which relies on soil microorganisms to facilitate the degradation process Bioplastic samples were initially weighed (Mo), buried in soil, and left exposed to the open air. Observations were made every 2days fora period of 12 days. At the end of the observation period, the samples were reweighed to obtain the final weight (M1). The percentage of weight loss was calculated using the following formula:

Weight loss (%)=(Mo-M1/Mo) 100

For data analysis, descriptive statistics were first used to summarize the central tendency and variability of the test results for each bioplastic property. ANOVA (Analysis of Variance) was employed to determine if there were statistically significant differences in flexibility, water absorption, and biodegradability across different cellulose concentrations. If significant differences were found, post-hoc tests, such as Tukey's HSD (Honestly Significant Difference),were conducted to identify which specific cellulose concentrations differed from one another. This approach provided a detailed understanding of how varying cellulose concentrations impacted the performance and characteristics of the bioplastics.

III. Results and Discussion

Elongation Test Results

The elongation test was conducted to assess the ductility of bioplastic samples (S1 to S4). This was done by measuring the initial and final lengths of the samples after applying a controlled force. The percentage elongation was calculated to evaluate the material's ability to stretch before breaking

Table 2.1. Elongation (%) of each bioplastic replication.

Sample	Replication (#)	Initial length (cm)	Final length(cm)	Elongation (%)
S1(Durian seed starch-1g cellulose)	1	5	5.36	7.1%
	2	5	5.37	7.3%
	3	5	5.36	7.2%
S2(Durian seed starch-2g cellulose)	1	5	5.22	4.3%
	2	5	5.23	4.6%
	3	5	5.23	4.5%
S3(Durian seed starch only)	1	5	5.49	9.7%
	2	5	5.51	10.1%
	3	5	5.51	10.2%
S4 (Cornstarch)	1	5	5.39	7.8%
	2	5	5.41	8.2%
	3	5	5.40	8.0%

Table 22. The elongation percentages of the four bioplastic samples reveal clear differences in flexibility. Sample 3, made only from durian seed starch, exhibited the highest average elongation at 10.0%, indicating it could stretch the most. In contrast, Sample 2, which contains 2g of cellulose, had the lowest average elongation at 4.5%, meaning it was the least flexible. This suggests that adding more cellulose may decrease the ductility of the bioplastic. However, despite the lower elongation, S2's sturdiness could be beneficial for applications requiring a more rigid and durable material.

Table 2.2.A brief summary of the data collected during the experiment.

Descriptive Statistics

Descriptive Statistic

	elongation at break			
	S1	S2	S3	S4
Valid	3	3	3	3
Mssing	0	0	0	0
Mean	7.200	4.467	10.000	8.000
Std.Deviation	0.100	0.153	0.265	0.200
Mrimum	7.100	4.300	9.700	7.800
Maximum	7.300	4.600	10.200	8.200

Descriptives plots

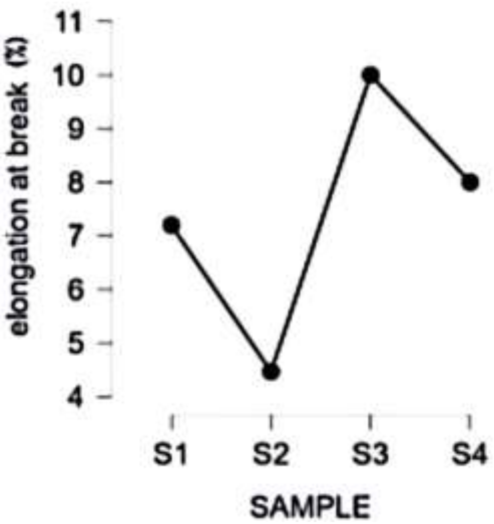

Figure 2.2. A visual representation of the summarized data.

The ANOVA results reveal a significant difference in the elongation percentages among the samples tested. The F-value of 439.907 and a p-value of <.001 indicate that these differences are statistically significant. This suggests that the composition of the bioplastic samples has a substantial impact on their elongation.

Table 2.3. Determining the F-ratio and p-value

ANOVA

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Cases	3av cf 5eames 0	Moas 8oaee		
SAMPLES	47,200	19,753	430,907	• .001
Res	0.287	0230		

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The Post Hoc Tukey's test reveals significant differences in elongation at break among the bioplastic samples. S1 (1g cellulose) exhibits a significantly higher elongation at break (7.1% to 7.3%)compared to S2 (2g cellulose), which has the lowest elongation at break (4.3% to 4.6%).Additionally, SI's elongation is less than that of S3 (durian seed starch only)and S4 (cornstarch),which show elongation percentages of 9.7% to 10.2% and 7.8% to 8.2%, respectively. Importantly, there is no significant difference in elongation between S3 and S4.

Table 2.4. A pairwise comparison between each sample's average elongation rate.

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		Mean Crnerescе	8E	t	F
S1	52	2733	0.155	17.625	0.001
	53	-2000	0.155	-13.116	*.001
52	24	-3800	0155	-5.176	0.004
	53	-5533	0.155	-36.000	0.001
	24	-1533	0.155	-22,001	• 001
53	54	2000	0.155	12.940	• .001

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These findings suggest thatincreasing cellulose content decreases the ductility of the bioplastic, resulting in lower elongation at break. Despite S2's reduced ductility, its lower elongation could make it more suitable for applications requiring higher durability and rigidity, where ductilityis less important but strength and resistance to deformation are critical.

Swelling Test Results

Water resistance testing for bioplastics was conducted using the water absorption (swelling)method. Swelling refers to the ability of the plastic to expand when immersed in a solution. Bioplastic samples were evaluated for their water resistance properties. Typically, a higher

water absorption capacity corresponds to lower water resistance, and vice versa

The table below illustrates the effects of varying concentrations of durian husk cellulose on the water absorption capacity of bioplastics. It also compares the results against bioplastics made purely from durian seed starch and cornstarch (without cellulose).

Table 3.1. Swelling (%) of each bioplastic replication.

Sample	Replication no.(#)	Initial weight (g)	Final weight after 1hr(g)	Swelling(%)
S1(durian seed starch -1g cellulo se)	1	0.52	0.64	23.08
	2	0.51	0.63	23.53
	3	0.50	0.61	22.00
S2(durian seed starch -2g cellulo se)	1	0.54	0.68	25.93
	2	0.53	0.67	26.42
	3	0.54	0.69	27.78
S3 (durian	1	0.42	0.49	16.67
	2	0.43	0.50	16.28
seed starch only)	3	0.42	0.49	16.67
S4 (corn starch)	1	0.40	0.46	15.00
	2	0.39	0.45	15.38
	3	0.41	0.47	17.50

Table 3.2 summarizes the water absorption capacity (swelling percentage) of the four bioplastic samples (S1 to S4). Sample S2, which contains 2g of cellulose, has the highest average swelling at 26.71%, while S3, composed of durian starch only, exhibits the lowest swelling at 16.54%. The results suggest that higher cellulose content corresponds to increased water absorption. Meanwhile, commercial plastic (S4)shows lower water absorption, with a mean of 15.96%, suggesting superior water resistance. The standard deviations indicate the variability in swelling, with S2 showing the greatest spread and S3 the least.

***Table 3.2. A brief summary of the data** collected **during** the experiment.*

Descriptive Statistics

Descriptive Statistics

	swelling(%)			
	S1	S2	S3	S4
Vialid	3	3	3	3
Missing	0	0	0	0
Mean	22.870	26.710	16.540	15.960
Std.Deviation	0.786	0.958	0.225	1.347
Minimum	22.000	25.930	16.280	15.000
Maximum	23.530	27.780	16.670	17.500

Descriptives plots

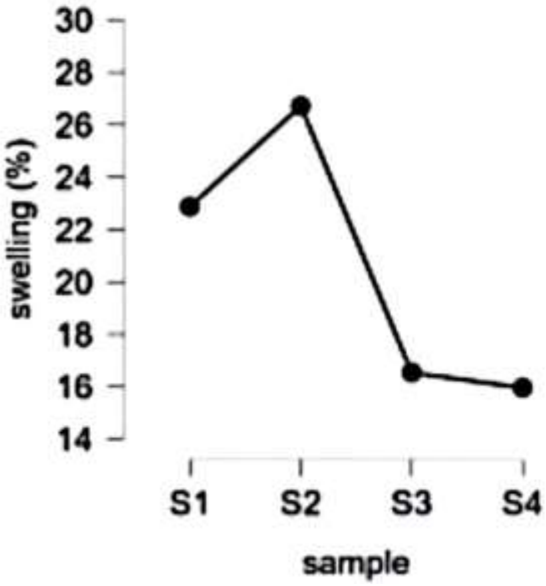

Figure 23. A visual representation of the summarized data.

The results of the ANOVA test (table 3.3) show a statistically significant difference between the swelling percentages of the different bioplastic samples, with an F-value of 94.604 and a p-value of < 001. This indicates that the

variations in swelling percentages between the samples are not due to chance.

Table 3.3. Determining the *F-ratio* ***and*** *p-value* **ANOVA**

ANOWA-SNelrg(%)

Cases	Sum of Squares	d	Mean Square	F	p
sarple	241.418	3	80.473	94.604	c.001
Residuals	6.805	8	0.851		

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Additionally, the Post Hoc Tests (Tukey's HSD)confirm specific differences. For instance, S2absorbed significantly more water than S3 and S4, with mean differences of 10.17% and 10.75% respectively ($p < .001$). However, S3and S4 showed no significant difference (p=0.866),suggesting that both almost have similar water absorption rates.

Table 3.4. A pairwise comparison ***between each*** *sample's average swelling percentage (%).*

Post Hoc Tests

Standard

Pest Hoc Compertsons-sampe

		Mea1 Oiference	SE	1	P2be
S1	S2	-3.640	0.753	-5.099	0.004
	S3	6.300	0.753	8.406	<.001
52	S4	6.910	0.753	9.176	<.001
	S3	10.170	0.753	13.505	<.001
	S4	10.750	0.753	14.275	<.001
S3	S4	0.500	0.753	0.770	0.856

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These findings indicate that the addition of cellulose to bioplastic formulations enhances water absorption, though higher water absorption correlates with lower water resistance, which might be a drawback in practical applications

Flammability Test Results

The burning rate test was conducted on bioplastic samples made from different compositions, evaluating their fire resistance by measuring the length burned over time. Burning rate, expressed in cm/s, indicates how quickly a material burns when exposed to fire. Lower burning rates suggest better fire resistance, while higher rates indicate faster consumption by flames.

The table below shows how each bioplastic sample performed in terms of burning rate across various points. These results provide insights into the fire resistance properties of bioplastics and how the addition of cellulose affects burning behavior.

Table 4.1. Burning rate of each bioplastic replication.

Sample	Relocation no.(#)	Lengt H Burne d(cm)	Time (5)	Burning Rate (cm/s)
S1 (durian seed starch -1g cellulose)	1	2.1	30.43	0.0690
	2	2.4	32.03	0.0749
	3	2.2	31.88	0.0690
S2 (durian seed starch -2g cellulose)	1	1.8	35.04	0.0514
	2	1.9	34.50	0.0551
	3	1.7	34.81	0.0488
S3 (durian seed starch only)	1	2.3	25.70	0.0895
	2	2.5	24.80	0.1008
	3	2.3	25.54	0.0901
S4 (corn starch)	1	2.3	24.90	0.0924
	2	2.6	25.57	0.1017
	3	2.5	25.21	0.0992

Table 4.2 summarizes the burning rates (in cm/s)of the four bioplastic samples (S1 to S4). Sample S4, made from corn starch, has the highest average burning rate at 0.098 cm/s, indicating the fastest burn rate among the samples. In contrast, S2, which contains durian seed starch with 2g of cellulose, exhibits the lowest average burning rate at 0.052 cm/s, suggesting improved fire resistance due to the higher cellulose content.

***Table** 4.2. A briefsummary of the data collected during the experiment.*

Descriptive Statistics

Descriptive Statistics

	Burning rate (cm/s)			
	S1	S2	S3	S4
Valid	3	3	3	3
Missing	0	0	0	0
Mean	0.071	0.052	0.093	0.098
Sid. Deviation	0.003	0.003	0.006	0.005
Minimum	0.069	0.049	0.089	0.092
Maximum	0.075	0.055	0.101	0.102

Descriptive plots

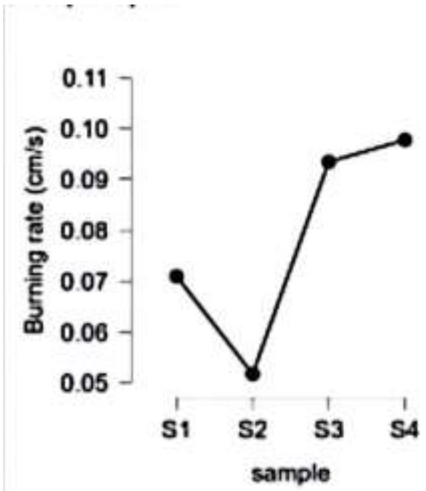

Figure 24. A visual representation of the summarized data.

The results of the ANOVA test (Table 4.3)indicate a statistically significant difference in the burning rates between the samples, as evidenced by an F-value of 64.151 and a p-value of less than.001. This suggests that the observed variations in burning rates among the samples are unlikely to be due to random chance.

***Table** 4.3. Determining the F-ratio and p-value* **ANOVA**

ANOMA-Euring rate (ons)

Cases	Sum of Squares	d	Mean Square	F	P
sample	0.004	3	0.001	64.151	<001
Resicuas	1.704x10	B	2130*10*5		

PAxte. Type II Sum of Squates

The Post Hoc Tests (Tukey's HSD) revealed notable differences in burning rates across the samples. S2, with the lowest burning rate, was significantly different from both S3 and S4,showing **mean differences** of **-0.042** cm/s and -0.046 cm/s, respectively (p <.001) However,no significant difference was observed between S3 and S4 (p = 0.762), indicating their burning rates are quite similar. The results suggest that S2 exhibited the best fire resistance, followed by S1, while S3 and S4 had the fastest burning rates.

By calculating the weight loss, we were able to determine the biodegradability rate for each bioplastic tested.

Table 4.4. A pairwise comparison between each sample's average burning rate.

Post Hoc Tosts Standard

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		Mean Deference	BE	1	P
51	52	0.019	0.004	5005	0.004
	83	-0.022	0.004	-6.970	0.002
	34	-0.027	0.004	-7,111	< 001
52	53	-0.042	0.004	-11.065	• 001
	54	-0.046	0.004	-12 208	• 001
83	84	-0.004	0.004	-1,141	0.677

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These results show that adding cellulose to bioplastic formulations effectively reduces the burning rate, significantly improving fire resistance. This positive outcome suggests that higher cellulose content enhances the material's safety in fire-prone applications, making it a valuable modification for bioplastics in practical uses requiring enhanced fire resistance.

Biodegradability Test Results

The biodegradability test was conducted using the soil burial method and observed over a duration of 12 days. The resarchers measured the initial and final weights of the bioplastic samples to assess the extent of decomposition.

Table** 5.1. Biodegradability (%) of each **bioplastic

Sample	Replication (#)	Initial Weight (g)	Final Weight (g)	Biodegradability (%)
S1 (Durian seed starch - 1g cellulose)	1	0.63	0.04	93.65
	2	0.64	0.05	92.19
	3	0.62	0.04	93.55
S2 (Duria n seed starch - 2g cellulose)	1	0.67	0.07	89.55
	2	0.67	0.07	89.55
	3	0.68	0.08	88.23
S3 (Duria n seed starch only)	1	0.59	0	100
	2	0.58	0.01	98.31
	3	0.59	0	100
S4 (Cornstarch)	1	0.59	0	100
	2	0.6	0.02	96.6
	3	0.61	0.02	96.72

The biodegradability percentages of the four bioplastic samples (S1 to S4) show clear differences in how well they break down.

Sample 3, made only from durian seed starch,has the highest average biodegradability at 99.15%, while S2, which contains 2g of cellulose, has the lowest at 89.11%. This suggests that more cellulose may lead to lower biodegradability. However, it's important to note that S2, despite its lower biodegradability, is more durable,which could be a positive attribute for applications requiring stronger,longer-lasting bioplastics.

***Table** 5.2. A brief summary of the data collected **during the** experiment* escriptive Statistics

	Blodegradation(%)			
	S1	S2	S3	S4
Valid	3	3	3	3
Missing	0	0	0	0
Mean	93.130	89.110	99.437	97.773
Sid.Devtation	0.816	0.762	0.976	1.929

Minimum	92.150	88.230	98.310	96.600
Maximum	93.650	89.550	100.000	100.000

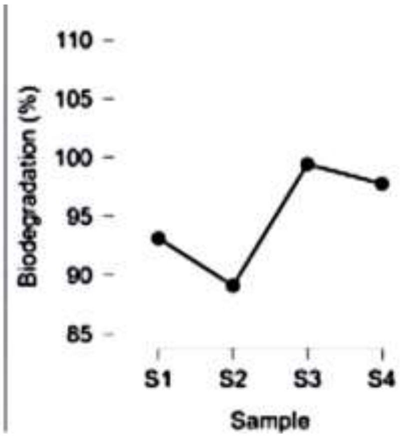

Figure 25. A visual representation of the summarized data.

The ANOVA results indicate a significant difference in the biodegradation percentages among the four bioplastic samples. The F-value of 44.248 and p-value of <.001 confirm that these differences are not due to random chance,leading to the conclusion that the composition of the bioplastic samples significantly affects their biodegradation rates.

Table 5.3. Determiningthe F-ratio and p-value

ANOMA-Bodegatabon(%)

Cases	Sum of Stuares	d	Mean Square	F	P
Sarpl:	196.466	3	65,489	44,245	<001
Resicuals	11.840	8	1.430		

Note.Type lI Sum of Squares

The Post Hoc Tukey's test reveals significant differences in the biodegradation rates among the bioplastic samples. S1 degrades significantly faster than S2 but slower than S3 and S4.Notably, S2 exhibits the slowest biodegradation rate, significantly lagging behind all other samples, including S3 and S4. Interestingly, there is no significant difference in biodegradation between S3 and S4.

***Table 5.4. A pairwise comparison between** each **sample's** average biodegradation rate.*

Post Hoc Compareons-Sample

		Mean Diference	SE	t	Prer
S1	S2	4.020	0.993	4.047	0.015
	S3	-6.307	0.993	-6.349	<001
S2	94	-4.643	0.993	-4.675	0.007
	S3	-10.327	0.093	-10.396	<001
	84	-8.663	0.993	-B.722	<001
S3	S4	1.663	0.503	1.675	0.395

Nore. Pwaiue adjusted lor comparing a tamly of 4

These findings suggest that adding cellulose reduces biodegradation, with more cellulose leading to slower breakdown rates. However,this means that while S2 has a slower biodegradation rate, it is also more durable and better for applications that need extra strength and it can be reused for various applications.

IV. Conclusion and Recommendations

In conclusion, the study on enhancing bioplastic using durian seed starch integrated with durian husks cellulose has provided valuable insights into these innovative materials. The results from the clongation, swelling, flammability, and biodegradability tests show that the composition of bioplastics significantly affects their properties and environmental impact. Sample S3, which consists only of durian seed starch, Showed excellent flexibility and biodegradability, breaking down quickly in the environment. On the other hand, Sample S2, containing 2g of cellulose, demonstrated lower flexibility but greater durability, emphasizing a balance between durability and water resistance.

Our statistical analysis revealed clear differences in the performance of the samples, emphasizing the need to optimize cellulose content to enhance bioplastic properties for specific uses These findings support the use of renewable materials like durian seed starch and encourage future advances in bioplastic development, contributing to more sustainable practices in material science.

The researchers recommend further investigation into the best balance of cellulose in bioplastics to improve their qualities for different applications. Future studies should consider using various amounts of cellulose with durian seed starch to enhance flexibility and biodegradability. Additionally, adding natural materials could improve the water resistance and fire safety of these bioplastics, making them more suitable for different uses.

We also suggest conducting field tests to see the long-term environmental impact of these bioplastics in real-life situations. This will help confirm their effectiveness and raise public awareness about sustainable materials. In summary, the potential of durian seed starch bioplastics as eco-friendly alternatives is clear,and with ongoing research and innovation, it could play a significant role in creating more sustainable materials

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