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Optimization of Edible Straw Characteristics from Kimpul Taro Starch and Patin Fish Skin Gelatin with Sorbitol Addition

Tasya Vyra Putri Ariyani*, Amalia Azzahroh, Sintha Soraya Santi

Department of Chemical Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Surabaya
***Corresponding author**: 21031010192@student.upnjatim.ac.id

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Abstract
The pervasive contamination resulting from plastic straw usage has necessitated the development of a resolution to address this predicament. One potential avenue for exploration is the development of an environmentally sustainable edible straw. The objective of this study is to design and evaluate the optimal materials and characteristics of an edible straw that complies with the Japanese Industrial Standard, which serves as an international benchmark. The independent variables employed in this study encompass the ratio of kimpul taro starch and catfish skin gelatin, along with sorbitol. These variables were analyzed using Central Composite Design (CCD) and Response Surface Methodology (RSM), with the assistance of Design Expert 13 software. The edible straw was produced through a mixing and casting process, using a ratio of catfish skin gelatin to kimpul taro starch of 5:5; 4:6; 3:7; 2:8; 1:9, along with the addition of plasticizers at varying concentrations of 0%; 0.4%; 0.8%; 1.2%; and 1.6%. The characteristics that were the focus of the analysis included thickness, tensile strength, elongation, solubility, and biodegradation rate. The findings of this study suggest that the edible straw under consideration is in accordance with the Japanese Industrial Standard and is deemed safe for utilization and ingestion.
Keywords: *edible straw; kimpul taro starch; catfish skin; optimization*

Abstrak
Tingkat polusi yang tinggi akibat sedotan plastik telah menimbulkan kebutuhan akan solusi untuk mengatasinya. Salah satu opsi yang dapat dipilih adalah mengembangkan sedotan ramah lingkungan yang dapat dikonsumsi. Penelitian ini bertujuan untuk merancang dan mengevaluasi bahan serta karakteristik optimal dari sedotan yang dapat dimakan agar sesuai dengan Japanese Industrial Standard sebagai standar internasional. Variabel bebas yang digunakan dalam penelitian ini meliputi perbandingan pati talas kimpul dan gelatin kulit ikan lele serta sorbitol, yang dianalisis menggunakan *Central Composite Design (CCD)* dan *Response Surface Methodology (RSM)* dengan bantuan perangkat lunak Design Expert 13. Sedotan yang dapat dimakan dibuat melalui proses pencampuran dan pencetakan, dengan rasio gelatin kulit ikan patin terhadap pati talas kimpul sebesar 5:5; 4:6; 3:7; 2:8; 1:9 serta penambahan plastisizer dengan berbagai konsentrasi, yaitu 0%; 0,4%; 0,8%; 1,2%; dan 1,6%. Karakteristik yang dianalisis mencakup ketebalan, kekuatan tarik, perpanjangan, kelarutan, dan tingkat biodegradasi. Kesimpulan dari penelitian ini menunjukkan bahwa semua karakteristik sedotan yang dapat dimakan memenuhi *Japanese Industrial Standard* serta aman untuk digunakan dan dikonsumsi.
Kata Kunci: *edible straw; kimpul taro starch; catfish skin; optimization*

1. Introduction

Indonesia is the country with the highest usage of plastic straws in the world with 93.2 million units of plastic straws per day. If disposed of improperly, plastic straws can accumulate in undesirable locations such as oceans and landfills, harming living organisms by releasing dioxins and microplastic pollutants. One of the steps that can be taken to reduce single-use plastic straw waste is to develop an environmentally friendly straw that is degradable and does not harm the environment because it is made from natural materials, the product is edible straw. Edible straw is a straw made from natural materials and has a fairly short degradation period so it is expected not to harm the environment and worsen pollution. Edible straw can even be consumed because it is plant-based so it is not harmful for consumption. When disposed of, edible straw also does not harm the environment because it can be decomposed by microorganisms in a fairly short time. Unlike plastic straws, edible straws are fully biodegradable and biodegradable [1]. Edible straws can be produced using flour or starch. To ensure optimal usability, they must possess specific characteristics, including resistance to breakage, insolubility at various beverage temperatures, and a neutral aroma and taste [2].

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Raw materials for making edible straw are abundantly available in Indonesia. Various tubers in Indonesia are very easy to find and can be processed into starch for the main source of polysaccharides forming edible straw polymers. Kimpul taro tubers are one of the commodities that have a production value of 40.30 tons in 2021 [3]. Kimpul taro tubers contain up to 15% amylose and up to 70% amylopectin [4]. The composition of amylose and amylopectin in starch determines the degree of solubility and gelatinization. Higher amylopectin content tends to make starch more moist, sticky, and less water-absorbent. Conversely, starches with high amylose content are drier, less sticky, and more hygroscopic (easily absorb water) [5]. The proportion of amylopectin and amylose also affects the expandability of the final product. Starch with a high amylopectin content tends to produce products that are elastic and not easily fragile. On the other hand, amylose plays a role in forming texture and durability against damage, but in excess levels it can cause a rigid and less elastic layer. Generally, to obtain good quality products, the required amylopectin content is 50% or more [6].

In addition, catfish production in Indonesia is also very abundant. According to Grahadyarini in 2023, the production of catfish in Indonesia reached 380,000 tons in 2022, which shows that the market for catfish has high potential [7]. However, the utilization of parts of catfish is not optimal enough. Patin fish is widely utilized for its meat as fillets and produces patin fish skin as a by-product. This catfish skin, if processed, can produce protein levels in the form of gelatin up to 91% [8]. Then, as an additional ingredient that serves to improve the characteristics of edible straw, sorbitol is used. Sorbitol is known as a plasticizer that is better than other types of plasticizers because it produces films with lower oxygen permeability. permeability. The addition of sorbitol is positively correlated with the percentage of strain or elongation. or elongation. In other words, the value of percentage strain or elongation increases with the addition of sorbitol [9]. Straw film has several characteristics that must be met in order to produce a good product that meets the standards. According to Japanese Industrial Standard 1975, the minimum elongation required is 10%, if the elongation is more than 50% the product is considered to have excellent elongation and for the minimum tensile strength to be met is 0.39 MPa.

Meanwhile, the film thickness should not exceed 0.25 mm. For biodegradation rate, the straw film should be able to degrade at least 60% within 6 months. In previous studies, a combination of starch and gelatin [10] and starch and sorbitol [11] have been used to make straw films, but the results obtained in several important aspects are still below JIS standards. In addition, research on optimizing the characteristics of edible straw is still rare. This optimization can be achieved using Response Surface Methodology (RSM), an approach designed to analyze how different factors influence a response. The primary objective of this method is to determine the optimal conditions for achieving the best possible results while aligning with the intended target.

Response Surface Methodology (RSM) consists of a set of statistical and mathematical techniques used for product design and improvement, process development, and operational optimization. It plays a vital role in formulating new products and refining existing designs. As a powerful tool for experimental design, data analysis, and process optimization, RSM focuses on understanding the impact of variables on a response to achieve optimal outcomes. Two key experimental designs within RSM are Box-Behnken Design (BBD) and Central Composite Design (CCD). More recently, optimization studies have also incorporated Central Composite Rotatable Design (CCRD) and Face-Centered Composite Design (FCCD) [12]. In this study, optimization steps are needed for the ratio factor of catfish skin gelatin: chimp taro starch and sorbitol concentration. This is because the ratio of catfish skin gelatin:chimp taro starch can affect several aspects such as thickness, elongation, and solubility. On the other hand, sorbitol concentration can also affect some characteristics of the edible straw produced.

2. Material and Methods

The following is a list of the main materials, equipment used, and procedural steps applied during the research.

2.1 Materials and Tools

This research was conducted from March to November 2024 at the Research Laboratory of the "Veteran" National Development University of East Java, Surabaya. This research uses several steps, the first is the preparation of taro starch, the second is the preparation of catfish skin gelatin, then the third is the synthesis of edible straw, then the fourth step is the process of analyzing product characteristics such as thickness, tensile strength, elongation, solubility, and biodegradation level, and the last step is processing the data and analysis results to determine the optimum results using Design Expert 13 software.The materials used in this study were fresh taro kimpul obtained from Keputran market, Surabaya, catfish skin obtained from PT Dimas Reiza Perwira, Surabaya, and sorbitol obtained from PT Sorini Indonesia as well as distilled water, glacial acetic acid, sodium hydroxide, and sodium chloride obtained from Arkitos Chemicals. The tools used in this research are analytical scales, 1000ml and 500 ml beaker glass, 250ml volumetric flask, 10ml measuring cup, magnetic stirrer, hot plate, and thermometer.

2.2 Experiment

The kimpul taro is peeled, then washed and cut to make it smaller, and then soaked in a 7.5% sodium chloride solution. For 1 kg of taro, 4 liters of solution are needed, and soaking is done for 1 hour to remove oxalate content. Then the taro is washed again with water and then blended with distilled water first, for 1 kg of taro 2 liters of distilled water is needed. The blended material is then filtered and the filtrate is allowed to settle for approximately 2 hours. Next, the sediment is dried in an oven at 60°C for 6 hours. When the ingredients are dry, they are then blended again with a blender until smooth and filtered with an 80-mesh sieve until a homogeneous taro starch is obtained [13].

2.2.1 Preparation of Catfish Skin Gelatin

After the catfish skin is weighed, it is washed with 0.8 N NaCl for 10 minutes, and then rinsed with running water. Then, a 0.2 N NaOH solution with a ratio of 1 kg of catfish skin requires 6 liters of solution is added and stirred for 30 minutes at a speed of 120 rpm at room temperature, and then rinsed with water until the pH is neutral. Furthermore, the catfish skin is re-soaked at room temperature with a 0.05 N concentrated acetic acid solution at a ratio of 1 kg of catfish skin to 6 liters of solution, this step is carried out three times. After that, extraction is carried out with distilled water for ten hours at a temperature of 60°C. The result is filtered three times with gauze and put in an oven at a temperature of 55°C until dry. Solid gelatin is then mashed to produce gelatin powder [8]

2.2.2 Synthesis Edible Straw

In the process of synthesizing edible straw from taro starch and catfish skin gelatin, the ingredients in the form of taro starch and catfish skin gelatin are first weighed in a predetermined ratio of taro starch to catfish skin gelatin. For mixing, catfish skin gelatin and kimpul taro starch are dissolved with 100 ml of distilled water and then go through a heating process using a hot plate magnetic stirrer for about 18 minutes while being heated to an operating temperature of 70 ° C and a stirring speed of 200 rpm. In the 15th minute, a predetermined amount of sorbitol is added, after the addition of sorbitol, the heating process is continued so that a gel-like consistency of the material is formed.

Furthermore, the product from the previous process in the form of a suspension from the heating is then molded into a 25 cm x 10 mm square. After molding, the material is then dried in an oven at an operating temperature of around 65°C with a drying time of 5 hours. After drying, the material then goes through a cooling process for 15 minutes so that the formed edible straw is easy to remove from the mold and then the straw film is rolled using an acrylic rod with a diameter of 0.8 mm [14].

2.2.3 Edible Straw Characterization, Analysis, and Optimization

The produced edible straw is then analyzed to evaluate its characteristics. The analysis includes measurements of thickness, tensile strength, elongation, solubility, and biodegradation rate, which are then compared to the Japanese Industrial Standard.

Thickness analysis is conducted using a screw micrometer (Mitutoyo) with an accuracy of 0.01 mm. The average thickness of the straw film is determined based on measurements taken from five different areas: four at the edges and one at the center [15].

Then the tensile strength analysis of a material is the maximum tensile force of a material on a film before the film is damaged or the material breaks. This tensile strength measurement is to assess the amount of force or strength required for the material to reach the maximum tensile point per unit area on the film area so that it stretches. This analysis uses ASTM D 882 with the equation.

$$\text{Tensile strength } (\sigma) = \frac{\text{Tensile force (F)}}{\text{Surface area (A)}} \quad (1)$$

Furthermore, for the elongation analysis or elongation percentage, it is the percentage of the change in the length of the film when the film layer is pulled until it breaks, then compared to the initial length of the film [16]. The percentage value of elongation is considered good if it exceeds 50% and is considered low if it is less than 10%. This analysis uses ASTM D 882 with the equation.

$$\text{Elongation } = \frac{\text{strain at break (mm)}}{\text{initial length (mm)}} \times 100\% \quad (2)$$

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For solubility analysis, a 2 x 10 cm sheet of straw film is placed in a container of water and then stirred manually to test solubility. The percentage of the film that dissolves in water after soaking for 12 hours indicates the solubility value. To determine the percentage of solubility, the following formula can be used.

$$\text{Solubility} = \left(\text{initial weight} - \frac{\text{final weight}}{\text{starting weight}}\right) \times 100\% \qquad (3)$$

Meanwhile, the biodegradation analysis serves to determine how long edible straw can decompose. The soil burial test method is used in this analysis where the straw film is weighed using an analytical balance to obtain the weight of the film $W1$. The straw film is then buried in the ground to a depth of approximately 10 cm for 7 days. After the 7th day is over, the sample is taken from the ground, then washed with distilled water and weighed again to obtain the weight of the film $W2$. The percentage of mass loss from the straw film can be determined using the equation.

$$\text{Biodegradation} = \left(\frac{\text{initial weight} - \text{final weight}}{\text{initial weight}}\right) \times 100\% \qquad (4)$$

After analyzing the characteristics, the data is then processed further with optimization using Response Surface Methodology using the Central Composite Design type in Design Expert 13 software to determine the most optimal results.

3. Results and Discussion

Optimization is carried out using two factors, namely the ratio between the gelatin of the catfish skin:kimpul taro starch and the concentration of sorbitol, as well as the response in the form of thickness, tensile strength, elongation, solubility, and biodegradation rate. Optimization uses the Central Composite Design model in Design Expert 13. Central Composite Design parameter are obtained, as listed in the following table

Table 1. Central Composite Design Parameter

Level	Factors	
	Catfish skin gelatin: Kimpul taro starch (gr)	Sorbitol concentration (%)
Low	0,1111	0
High	1	1,6

Furthermore, nine experimental variables are obtained, as listed in the following table.

Table 2. Data experimental with Central Composite Design optimization

Run	Independent Variables		Dependent Variables				
	Catfish skin gelatin: Kimpul taro starch	%Sorbitol	Thickness (mm)	Tensile strength (Mpa)	Elongation (%)	Solubility (%)	Biodegradation (%)
1	0,55555	1,2	0,21	7,1492	2,0316	36,7347	25,8900
2	0,1111	0,4	0,14	4,7656	7,9623	34,5455	16,8000
3	0,55555	0,4	0,1413	4,2075	16,9525	35,1852	13,1000
4	0,111	1,2	0,2067	36,7381	1,1047	8,5714	32,4300
5	1	0,4	0,1427	1,0832	2,6201	44,4440	5,9400
6	1	0,8	0,2273	1,2032	43,0157	48,7805	3,9200
7	0,55555	1,6	0,228	3,4876	26,6398	37,7049	26,2500
8	0,1111	1,6	0,2267	5,2958	4,8690	32,5000	32,9700
9	1	1,6	0,2293	3,3317	55,2211	64,7059	8,5100

Based on the data from the characteristic analysis, the highest thickness is obtained from a combination of a 5:5 ratio and a sorbitol concentration of 1.6%. Previous studies have also shown that an increase in the amount of gelatin and sorbitol leads to greater thickness. This occurs because adding more sorbitol to a solution with the same volume and mold area increases the total solid content, resulting in more solids settling during the formation of the edible film [17]. Additionally, higher concentrations of gelatin and protein contribute to an increase in total solids within the solution and enhance the viscosity of the edible suspension, as gelatin has the ability to bond with other components. A rise in the total solid content leads to a thicker edible film, while a higher solid concentration results in more polymers forming the edible film matrix [18].

Based on the data from the characteristic analysis, the highest tensile strength is obtained from the combination of a 1:9 ratio and a sorbitol concentration of 1.2%. Previous research also explains that the higher the concentration of starch added, the stronger the film network formed, requiring greater force to break the film [19]. Additionally, sorbitol at 1.2% is found to be the most optimal concentration. Studies have shown that excessive or insufficient sorbitol can disrupt hydrogen bonds between adjacent polymer molecules, leading to a decrease in tensile strength within the polymer chain when the amount of sorbitol exceeds or falls below the optimal limit [20].

For the elongation characteristic, the highest elongation is observed in the combination of a 5:5 ratio and a sorbitol concentration of 1.6%. Previous studies indicate that gelatin concentration influences elongation, where higher gelatin content results in greater elongation. This occurs because increased gelatin concentration, combined with sorbitol, enhances the stretching of the intermolecular space within the edible film matrix structure, improving flexibility and reducing brittleness [21]. The optimal sorbitol concentration is 1.6%, as excessive or insufficient sorbitol can interfere with hydrogen bonding between polymer molecules, reducing tensile strength while increasing elasticity beyond the optimal range [20].

Regarding solubility percentage, the highest solubility is recorded in the combination of a 5:5 ratio and a sorbitol concentration of 1.6%. Previous studies indicate that higher gelatin concentrations result in increased solubility. This trend is attributed to the ratio of fish skin starch to gelatin, where lower starch content leads to higher solubility in edible films. Conversely, a higher gelatin concentration increases the solubility of the straw film. Previous study also found that incorporating polysaccharide components reduces solubility, while a higher gelatin composition enhances it [22]. Furthermore, an increase in plasticizer concentration correlates with greater solubility [23]. Plasticizers enhance water solubility by disrupting interactions between biopolymer chains, modifying the polymer molecular network, and reducing starch network density through hydrogen bond interference.

For biodegradation percentage, the highest value is obtained from the combination of a 1:9 ratio and a sorbitol concentration of 1.6%. Research suggests that higher gelatin concentrations result in lower biodegradation percentages, indicating longer degradation times for the straw. A denser gelatin matrix reduces water interaction with organic materials, slowing the biodegradation process. Previous research reported that the extended degradation time of bioplastics with high gelatin content is due to the energy-intensive process microorganisms undergo to break down gelatin, which has a complex protein structure [24]. Additionally, an increase in plasticizer concentration accelerates biodegradation. Previous research found that higher sorbitol levels increase biodegradation rates since sorbitol readily absorbs water, promoting microbial and fungal activity on bioplastics [25].

Table 3 presents the response model suggested by Design Expert 13 software based on Analysis of Variance (ANOVA) using a linear model. The selection of this model is based on evaluating parameters such as Standard Deviation (Std. Dev.), R^2, Adjusted R^2 (Adj. R^2), Predicted R^2 (Pred. R^2), and Predicted Residual Error Sum of Squares (PRESS). The Std. Dev. value indicates data dispersion and how closely the data aligns with the mean; higher standard deviation values signify greater data variation and reduced accuracy relative to the mean. The linear model is chosen due to its smallest PRESS value compared to other models, ensuring more precise prediction estimates. Linear models are also preferred based on Adjusted R^2 and Predicted R^2 values. The Adjusted R^2 value assesses model fit with experimental data and should not differ significantly from Predicted R^2. A model is considered suitable when the difference between Adjusted R^2 and Predicted R^2 is less than 0.2. Additionally, a high R^2 value, close to 1, indicates a strong correlation between predicted and experimental data.

Table 3. Mathematical Model Analysis

Response	Math's model	Std. Dev	R^2	Adj. R^2	Pred. R^2	Adeq. Prec.	PRESS	F-value	P-Value
Thickness	Linear	0,0195	0,8279	0,7706	0,6149	8,9971	0,0051	14,43	0,0051
Tensile strength	Linear	0,1568	0,7073	0,6098	0,3182	6,2247	0,3437	7,25	0,0251
Elongation	Linear	11,22	0,7408	0,6544	0,4078	7,2216	1725,73	8,57	0,0174

Response	Math's model	Std. Dev	R^2	Adj. R^2	Pred. R^2	Adeq. Prec.	PRESS	F-value	P-Value
Solubility	Linear	10,15	0,6544	0,5391	0,0342	5,6539	1727,45	5,68	0,0413
Biodegradation	Linear	4,56	0,8780	0,8373	0,6677	12,0706	338,99	21,58	0,0018

The standard deviation (Std. Dev.) value describes the level of data dispersion and the extent to which the data approaches the mean. A higher standard deviation indicates greater data variation, suggesting that the data is less accurate in representing the mean. The predicted R^2 aligns well with the adjusted R^2, where the adjusted R^2 is particularly useful for comparing models with different numbers of terms, though this comparison typically occurs in the background during model reduction.

Adequate precision measures the range of predicted values at design points relative to the average prediction error. A ratio greater than 4 signifies that the model has sufficient discrimination ability. Furthermore, R^2 (Coefficient of Determination) quantifies the strength of the relationship between the model and the dependent variable [26]. Simply put, it represents the proportion of variation in Y that is explained by the X variables. A high R^2 value close to 1, indicates a strong correlation between the predicted and experimental data [27]. The interpretation of the R^2 value is as follows: a. 0.00–0.199: Very low relationship; b. 0.200–0.399: Low relationship; c. 0.400–0.599: Moderate relationship; d. 0.600–0.799: Strong relationship; e. 0.800–1.000: Very strong relationship. In ANOVA analysis, a low F-value for the model is undesirable, as it suggests that the variance is primarily due to random, unexplained disturbances (noise). The p-value ($p > F$) indicates the model's significance concerning the F-value. It represents the probability that a variable has no effect on the response for a given F-value. If $p > F$ is below 0.05, the model is considered significant, meaning there is only a 5% chance that the F-value results from noise. However, if $p > F$ exceeds 0.1, the model is deemed insignificant [28].

Based on the ANOVA analysis data obtained, the p-value in all responses is less than 0.05. This indicates that the mathematical model used, namely the linear model, significantly explains the relationship between the independent variables.

3.1. Thickness Response with RSM Analysis

The ANOVA analysis results for the thickness response of edible straw indicate that a P-value below 0.0500 signifies a significant model term, while a value exceeding 0.1000 suggests insignificance. The model used in this ANOVA has a P-value of 0.0051, indicating a noise level of only 0.5%. Meanwhile, the ratio factor has a P-value of 0.3069, and the sorbitol factor has a P-value of 0.0018. These results suggest that the ratio factor does not significantly affect the thickness of the edible straw, as its P-value exceeds 0.05. However, the sorbitol factor has a significant impact on thickness. Additionally, there is a variation of 0.0023 from the average response of 0.0004 that remains unexplained and is considered residual.

For the edible straw response, the R^2 value is recorded at 0.8279, placing it in the very strong interaction category. This indicates that the gelatin-to-starch ratio and sorbitol concentration significantly influence the edible straw thickness response. Furthermore, the adequate precision value obtained is 8.9971, which is well above 4, confirming that the model provides a reliable response and is expected to perform well in prediction. The RSM equation or model for gelatin:starch ratio and sorbitol concentration on thickness response is shown in the following equation

$$\text{Thickness} = 0.1931 + 0.0090A + 0.0418B \quad (5)$$

Description:
A= Gelatin:starch ratio
B = Sorbitol concentration

Based on **Figure 1**, the surface plot graph of the thickness response, considering the factors of the gelatin-to-starch ratio and sorbitol concentration, indicates that the highest thickness obtained is 0.2293 mm, occurring at a gelatin-to-starch ratio of 5:5 and a sorbitol concentration of 1.6%. The increase in sorbitol concentration leads to greater edible film thickness due to the higher total solids present in the solution, resulting in a thicker edible film.

Additionally, a higher gelatin ratio contributes to increased thickness, as the greater gelatin concentration raises the total solids in the solution and enhances the viscosity of the edible suspension. Figure 1 also illustrates the direct relationship between sorbitol concentration and edible straw thickness, showing that as the sorbitol concentration increases, the thickness also increases.

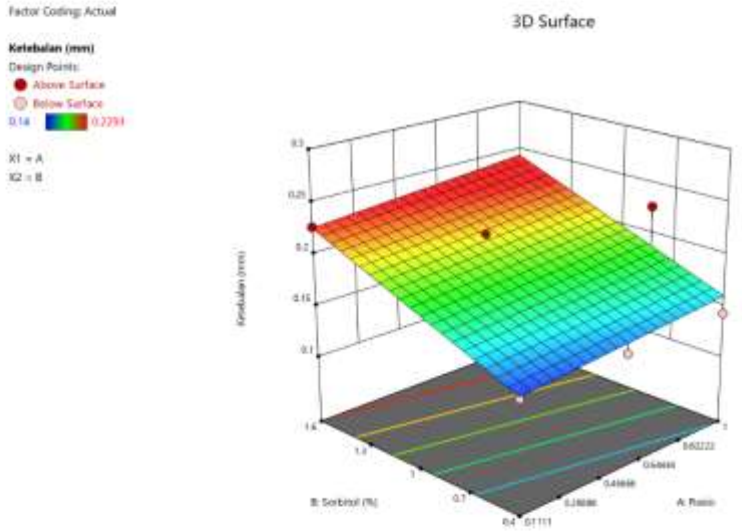

Figure 1. Thickness Response Surface

3.2. Tensile Strength Response with RSM Analysis

The ANOVA analysis results for the tensile strength response of edible straws indicate that a P-value below 0.0500 signifies a significant model term, while a value above 0.1000 suggests insignificance. The model used in this ANOVA has a P-value of 0.0251, indicating a noise level of only 2%. For individual factors, the ratio factor obtained a P-value of 0.0149, signifying a significant effect on tensile strength, whereas the sorbitol factor obtained a P-value of 0.2160, indicating no significant effect. Additionally, 0.1475 variations from the average response of 0.0246 remain unexplained and are considered residuals.

Regarding the edible straw response, the R^2 value is recorded at 0.6814, placing it in the strong interaction category. This suggests that the gelatin-to-starch ratio and sorbitol concentration significantly influence the tensile strength response. Furthermore, the adequate precision value obtained is 6.2247, which is well above 4, confirming that the model provides a reliable response and is expected to perform well in prediction. The RSM equation or model for the gelatin:starch ratio and sorbitol concentration against the tensile strength response is shown in the following equation

$$\text{Tensile strength} = 0.4176 + 0.4893A - 0.1445B \quad (6)$$

Description:
A = Gelatin:starch ratio
B = Sorbitol concentration

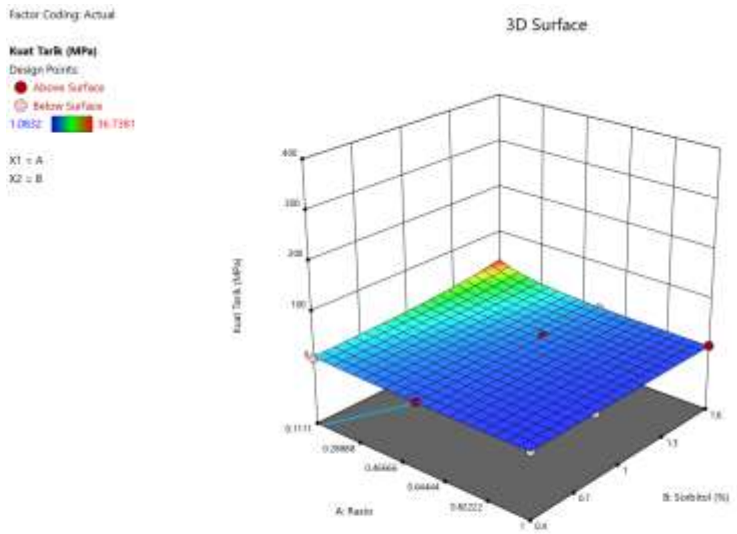

Figure 2. Tensile Strength Response Surface

Based on **Figure 2**, the surface plot graph of the tensile strength response, considering the gelatin-to-starch ratio and sorbitol concentration, shows that the highest tensile strength recorded was 36.7381 MPa at a gelatin-to-starch ratio of 1:9 and a sorbitol concentration of 1.6%. The tensile strength of edible straws is measured in MPa and is influenced by the starch-gelatin ratio and sorbitol concentration. The results indicate that as the gelatin concentration increases, the tensile strength decreases. This occurs because gelatin disrupts the bonds between adjacent molecules in the polymer chain, weakening the tensile strength while increasing the flexibility of the film. Fish skin gelatin is particularly effective in reducing internal hydrogen bonding and increasing molecular spacing, resulting in a smoother and more flexible film structure. Consequently, the tensile strength between molecules decreases as the molecular distance increases.

3.3 Elongation Response with RSM Analysis

The ANOVA analysis results for the elongation response in edible straws indicate that the model used has a P-value of 0.0174, meaning there is only 1% noise. In this analysis, a P-value below 0.0500 signifies a significant model term, while a value above 0.1000 indicates insignificance. The ratio factor obtained a P-value of 0.0063, demonstrating its significant impact on elongation, whereas the sorbitol factor had a P-value of 0.3600, suggesting it does not significantly affect elongation.

For the edible straw response, the recorded R^2 value of 0.7408 falls within the strong interaction category, indicating that the gelatin-to-starch ratio and sorbitol concentration significantly influence elongation. Additionally, the adequate precision value of 7.2116 confirms that the model provides a reliable predictive response, as it exceeds the threshold value of 4. The RSM equation or model representing the effect of the gelatin-to-starch ratio and sorbitol concentration on the elongation response is as follows:

$$\text{Elongation} = 20.28 + 18.91A + 4.45B \quad (7)$$

Description:
A = Gelatin:starch ratio
B = Sorbitol concentration

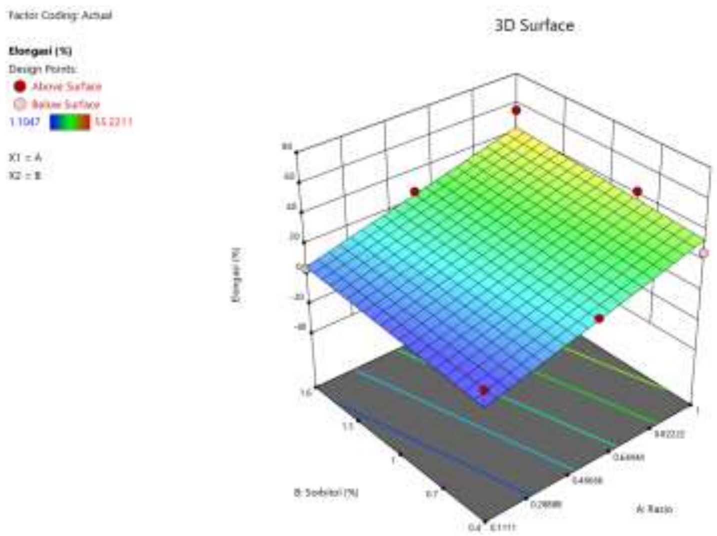

Figure 3. Elongation Response Surface

The surface plot graph in **Figure 3** illustrates the elongation response based on the gelatin-to-starch ratio and sorbitol concentration. The highest elongation value recorded is 55.2211, occurring at a gelatin:starch ratio of 5:5 and a sorbitol concentration of 1.6%. The graph demonstrates a direct proportionality between gelatin concentration and elongation. This aligns with existing literature, which states that higher gelatin concentrations lead to increased elongation values in edible films. The addition of gelatin enhances the flexibility of the edible film matrix by expanding the intermolecular space. When combined with sorbitol, this effect is further amplified, reducing brittleness and making the film more resistant to breaking.

3.4 Solubility Response with RSM Analysis

The ANOVA analysis for the solubility response of edible straws showed that the model had a P-value of 0.0413, meaning the level of noise was only 4%. Regarding individual factors, the gelatin-to-starch

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ratio significantly influenced solubility, as indicated by its P-value of 0.0152, while sorbitol concentration had no significant effect, with a P-value of 0.5512.

Additionally, the R^2 value for the edible straw response was recorded at 0.6544, classifying it as a strong interaction, which implies that the gelatin-to-starch ratio and sorbitol concentration play a key role in solubility. The adequate precision value of 5.6539 exceeded the benchmark of 4, confirming that the model ensures good predictive accuracy. The RSM equation or model for the gelatin:starch ratio and sorbitol concentration to solubility response is shown in the following equation

$$\text{Solubility} = 38.04 + 14A + 2.56B \quad (8)$$

Description:
A = Gelatin:starch ratio
B = Sorbitol concentration

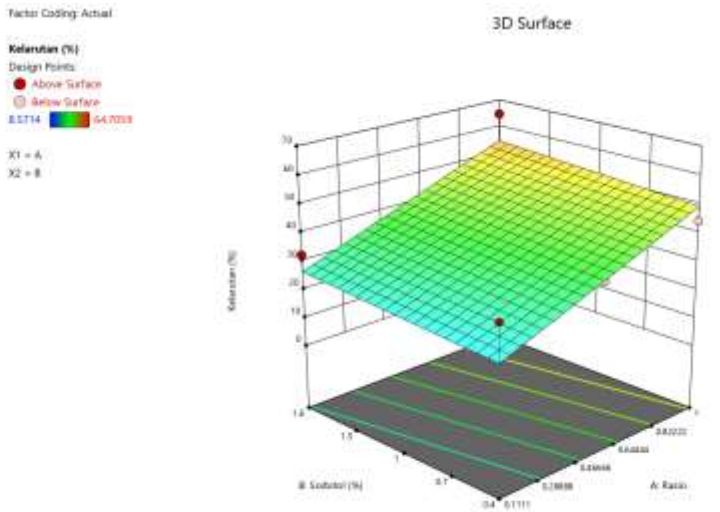

Figure 4. Solubility Response Surface

Referring to **Figure 4**, the response surface plot illustrates that gelatin concentration is positively correlated with solubility. This finding aligns with previous studies, which indicate that the solubility of edible films in water is influenced by the ratio of fish skin starch to gelatin. A lower starch concentration results in higher solubility, while an increase in gelatin concentration further enhances solubility. This occurs because higher gelatin content weakens molecular interactions in the edible film solution. Since gelatin possesses plastic-forming properties, its increased concentration contributes to greater solubility. Additionally, a high solubility value suggests that the edible film degrades easily in natural environments.

3.5 Biodegradation Response with RSM Analysis

The ANOVA analysis for the biodegradation response of edible straws revealed key findings. A P-value below 0.0500 indicates statistical significance, whereas values above 0.1000 suggest insignificance. The model used in this analysis yielded a P-value of 0.0018, signifying that noise accounts for only 0.1% of the variation.

Regarding individual factors, the gelatin:starch ratio had a P-value of 0.0018, and the sorbitol factor had a P-value of 0.0179. Since both values are below 0.05, it can be concluded that both factors significantly influence the biodegradation of edible straws. Furthermore, the R^2 value was recorded at 0.8780, classifying it as a very strong interaction. This confirms that the gelatin:starch ratio and sorbitol concentration substantially impact the biodegradation response. The adequate precision value of 12.0706 further supports the model's reliability, as it exceeds the threshold of 4, indicating strong predictive performance. The RSM equation or model for the gelatin:starch ratio and sorbitol concentration to biodegradation response is shown in the following equation

$$\text{Biodegradation} = 18.20 - 9.98A + 5.89B \quad (9)$$

Description:
A = Gelatin:starch ratio
B = Sorbitol concentration

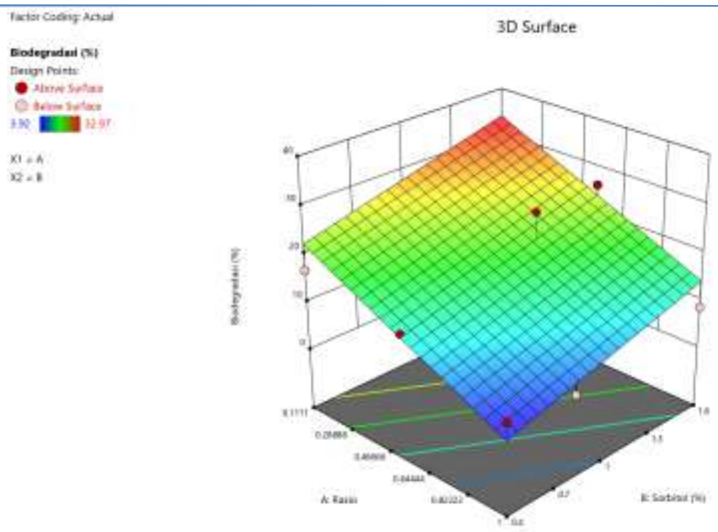

Figure 5. Biodegradation Response Surface

Based on Figure 5, the response surface plot graph illustrates that a higher gelatin concentration in the film leads to a decrease in biodegradation percentage. This occurs because gelatin forms a denser matrix, limiting water interaction with organic materials. Bioplastics with higher gelatin concentrations take longer to degrade. This is due to soil microorganisms requiring substantial energy to break down the protein structure, as gelatin has a relatively complex composition. Additionally, an increase in plasticizer concentration enhances biodegradation percentage. Higher sorbitol concentrations accelerate the biodegradation process. This is attributed to sorbitol's ability to absorb water, promoting microbial and fungal activity that facilitates bioplastic decomposition.

3.6 Optimization of Process and Conditions

This optimization aims to identify factor values that yield the most optimal response. The process is designed to achieve desired results based on specific parameters. These optimization parameters are adjusted to ensure that the edible film properties align with the Japanese Industrial Standard (JIS) 1975. The optimization process considers multiple target parameters, including upper and lower limits, along with the significance level of each independent variable, to determine the best combination of variables. The importance of these parameters is determined based on JIS standards, particularly for thickness, tensile strength, and elongation, which must comply with regulatory requirements. As shown in Table 4, the selected parameters define the recommended combination of conditions. The optimum condition is identified by the desirability value, where a value close to one (1.0) indicates the best match to the desired target. This desirability value serves as the key indicator in the optimization process, reflecting the accuracy of optimization and the model's ability to meet predefined parameters while achieving optimal conditions.

Table 4. Constraint and Importance

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Rasio	is in range	0.1111	1	1	1	3
B:Sorbitol	is in range	0.4	1.6	1	1	3
Ketebalan	maximize	0.14	0.2293	1	1	5
Kuat Tarik	maximize	1.0832	36.7381	1	1	5
Elongasi	maximize	1.1047	55.2211	1	1	5
Kelarutan	maximize	8.5714	64.7059	1	1	4
Biodegradasi	maximize	3.92	32.97	1	1	5

Table 5. Optimization Results

Number	Ratio	Sorbitol	Thickness	Tensile Strength	Elongation	Solubility	Biodegradation	Desirability	
1	**1.000**	**1.600**	**0.244**	**2.545**	**43.638**	**54.603**	**14.111**	**0.694**	**Selected**
2	1.000	1.582	0.243	2.523	43.506	54.527	13.935	0.692	

According to **Table 5**, the optimum solution for the conditions calculated using Design Expert 13 is presented. The optimization results indicate that the best conditions are achieved with a gelatin:starch ratio of 5:5 and a sorbitol concentration of 1.6%. Under these conditions, the produced edible straw has a thickness of 0.244 mm, a tensile strength of 2.545 MPa, an elongation of 43.63%, a solubility of 54.60%, and a biodegradation rate of 14.111%.

The desirability value obtained is 0.694, suggesting that the optimization results are fairly good, as this value is relatively close to 1. This aligns with the theoretical concept that a desirability value of 1 represents an ideal condition, as the desirability function measures how well the optimization solution meets the target response objectives. Based on the optimum results obtained, a comparison is made with the JIS 1975 standards to evaluate whether the resulting product meets the required specifications.

Table 6. Comparison of Product Characteristics and JIS Standards

	Ratio	Sorbitol	Thickness (mm)	Tensile Strength (Mpa)	Elongation (%)	Solubility (%)	Biodegradation/ 7 days (%)	Meet the characteristics/not
Result	1.000	1.600	0,244	2,545	43,638	54,603	14,111	Yes
JIS Standard			<0,25 mm	0,39	<10% bad; >50% very good	-	60%/6 months	

3.7 Morphology Analysis with SEM (Scanning Electron Microscope)

The edible straws resulting from this study were then selected based on the most optimum characteristics, which were then analyzed on the surface using the Scanning Electron Microscope (SEM) method. This analysis aims to see the surface image of a material and to depict the sample at a magnification of up to tens of thousands of times to see the size of the particles scattered on the sample. In the observation, magnifications of 500, 1000, 5000 and 10000 times are used to observe the detailed morphology of the film. The detailed morphology of the film is as follows.

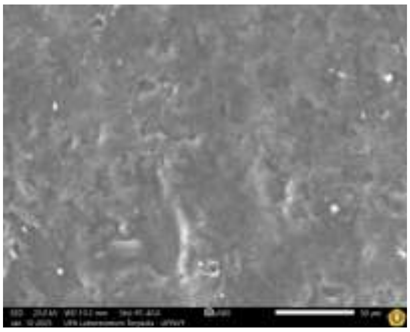

Figure 6. Edible Straw Surface with 500x Magnification

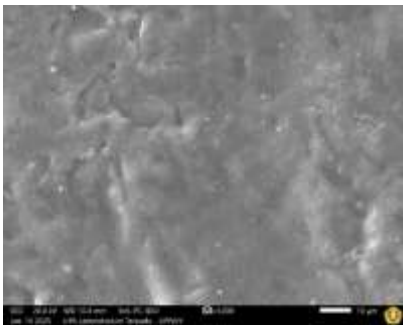

Figure 7. Edible Straw Surface with 1000x Magnification

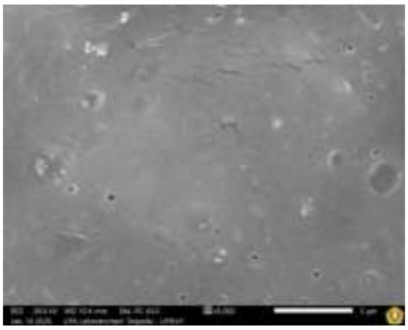

Figure 8. Edible Straw Surface with 5000x Magnification

Figure 9. Edible Straw Surface with 10000x Magnification

Based on surface analysis with a Scanning Electron Microscope, it can be seen that the optimum edible straw has a fairly dense surface with a homogeneous surface, indicating that the ingredients of taro starch, catfish skin gelatin, and sorbitol have been fairly well homogenized, although the texture is not yet smooth enough. Then at 10000 magnification, there are slight cracks which are thought to be caused by the catjang taro starch, the particle size of which is quite large, namely 80 mesh, so it is not completely dissolved. The loose structure and cracks in the fiber cause more water to be absorbed, resulting in cracks in the polymer

4. Conclusion

Based on the research results obtained, it can be concluded that the edible straw produced in this study has characteristics in the form of strong tensile value, elongation, solubility, biodegradation, and thickness that meet the commonly used international standard, namely the Japanese Industrial Standard. Optimum results were also obtained, calculated with Design Expert software, as well as the optimum ratio of this composite, namely a gelatin:starch ratio of 5:5 and a sorbitol concentration of 1.6%, which, from this ratio, obtained characteristics that fully met JIS standards.

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