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Development of food packaging bioplastic from potato peel starch incorporated with rice husk silica using response surface methodology comprehending central composite design

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Abstract

Rice husk and sweet potato peel are agricultural waste with high potential and economic interest. The utilization of these materials in product development will provide substantial improvement toward waste reduction. Therefore, this study aimed to develop a food packaging bioplastic using potato peel and rice husk. The optimization of three parameters (ratio of silica, the volume of glycerol and volume poured) was set in Design Expert Software version 13 to find the best formulation. The software set eighteen formulations to measure advanced bioplastic thickness, density, and moisture content. The optimum formulation exhibits thickness, density and moisture content with the value of 1.87 mm, 0.196 g/mL and 31.224%, respectively. In response surface methodology, bioplastic formulation was optimized using central composite design (CCD). The statistical model displayed an excellent fit with standard deviation, R^2 data. The R^2 for thickness was 0.8946, while 0.9516 for density and 0.96 for moisture content. These values were close to 1, indicating the significant effect on the tested conditions to get the optimum formulation.

1. Introduction

The food industry considers potatoes one of the most valuable crops for human consumption after wheat, rice and maize. In 2004, 336 megatons of potatoes were produced worldwide, continuously rising to 274 megatons made hugely from Europe and Asia (Majeed *et al*., 2017). Typically, the potato was peeled off before consumption, where the peel waste may range from 15% to 40% losses in production, depending on the peeling method. A massive amount of potato peel waste outgrowth the potato remains in the food industry annually. This leads to excessive waste and is still a concern for the waste management industry. Global potato production from 2004 until 2013 increased, as reported by Food and Agriculture Organization of the United Nations (FAO) in 2016 (Food, 2016). However, potato peel waste is classified as zero value in food manufacturing. In 2013, the waste emitted was more than 100 million tons leading to an environmental problem. The moisture content of potato peel is high, and it is susceptible to microbial infection. Therefore, it is often rejected and only utilized as a food supply for farming. This undermines a valuable resource of strong economic interest and chemical value regarding its antioxidant, antibacterial, apoptotic, anti-carcinogenic, and anti-inflammatory activities. Nevertheless, hemicellulose, lignin, starch, and fermentable sugar shift potato peel as a potential residue that can be converted into valuable goods and is being considered seriously for future applications (Dos Santos *et al*., 2016).

The critical residues during the rice milling process are rice husk (RH). Rice husk incineration led to ash from rice husk (RHA). Open burning is also intolerable to the public, leading to air pollution. This also encompasses greenhouse emissions and smoke (Goodman, 2020). Owing to its high silica content and the ample availability of RHA, it has stimulated considerable research interests at lower costs. Rice husks removed during the paddy milling process consist of 75% volatile organic matter, and 25% of the RH weight

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is incinerated into RHA (Prasad *et al*., 2001). RH is about 20% of the weight of rice paddy. RHA obtained from burning RH comprises an excessive percentage of silica (SiO_2) together with other trivial constituents considered impurities. Potassium oxide, calcium oxide, magnesium oxide, iron (III) oxide, aluminium oxide, sodium oxide, and others are the most common trace elements in RHA. RHA needs approximately 87% to 97% amorphous silica, some negligible quantities of alkalis, and some remainder components (Prasad *et al*., 2001).

Presently, approximately 20% of rice husk is utilized for practical reasons. For instance, rice straw is known to be converted into biodiesel, sheets, organic compost and hay. The rest is often burnt on wasteland, absorbed into the soil or applied as compost for the subsequent harvest. Notwithstanding, incorporating rice husks in farmland decomposes poorly and causes rice diseases. A study from India also stated that the fibrous content in rice husks might be dangerous to cattle feeding (Gidde and Jivani, 2007). In defiance of the potential of rice husk, it is only being recycled for low-value applications in contrast to its increasing production worldwide. The low-value applications are not in a systematic manner, and this may carry a disadvantage in the future. Therefore, various studies have been done to apply rice husk into a polymeric material as a filler and convert this waste into a valuable, environmentally friendly product.

In the early stages, manufacturers and researchers collaborated to develop photodegradable plastic. Still, the plastic is time-limited because its degradability property can only be done in the presence of sunlight. Plastic with long-term biodegradability is desired for composters and urban landfills. Plastic processing is then transferred to natural materials, with microorganisms and plants synthesizing many bio-based plastics. The main benefits of bio-based plastics are low carbon emissions, low production in labour costs, and reduced contamination due to increased compost ability. Amongst others, polyhydroxlalkanoate is a microbial-produced polymer, and polylactic acid (PLA) is a chemically synthesized polymer made from monomers extracted from agri-resources.

Nevertheless, plastic manufacturing by microbial fermentation is costly with the addition of strict bioreactor monitoring (Ismail *et al*., 2016). Therefore, most researchers and manufacturers see the potential of starch as a viable option for developing a sustainable bioplastic. This is due to the starch properties as a plant-based material with a high level of biodegradability and renewability. Starch is also low-cost and has a stable chemical compound for handling (Ismail *et al*., 2016). Usually, the source of starch used by researchers is banana peel, potato, cassava, corn, yam, and rice. These sources are abundant; thus, they are utilized to make bioplastic. However, due to the disadvantages of starch characteristics which are hydrophilic, undesirable mechanical and thermal properties, high fragility and high moisture absorption, the addition of plasticizers such as glycerol can increase the shelf-life and elasticity of the bioplastics. It also can reduce the formation of crystallinity and result in more functional properties as it is incorporated with different polymeric materials for various applications (Abdullah *et al*., 2019).

This research is conducted to study the properties of bioplastic made from potato peel starch and silica rice husk. Previously, the authors have developed bioplastic from cocoa pod husk cellulose incorporated with kenaf fibre (Azmin *et al*., 2022) and cocoa pod husk cellulose combined with sugarcane bagasse fibre (Azmin *et al*., 2020). Bioplastic properties, including thickness, density and moisture content, can be improved by incorporating silica from RHA into starch-based bioplastic. Using potato peel and rice husk as bioplastic could significantly improve the agriculture industry and help utilize and minimize waste in Malaysia.

2. Materials and methods

2.1 Extraction of starch from the potato peel

The procedure started with the cleaning process of potato peel. An amount of 650 g of potato peel was cleaned with distilled water and rinsed a few times to ensure dirt was removed. Then, it was ground using Philips's HR 2056/00 electrical blender. It was filtered using a muslin cloth. The filtration underwent centrifugation at 12000 rpm using Eppendorf Centrifuge 5810R for 10 mins. A 50 mL Falcon tube was used in this procedure. After centrifugation was finished, the supernatant was discarded. The precipitation was poured into a petri dish and dried at 50°C overnight in Memmert UF110 universal drying oven. After that, dried starch is ground by using an electrical blender. It was sieved using a sieve with a size range of 0.002 cm to 12.5 cm. The weight was obtained with Sartorius BSA4202S-CW weighing balance with a precision of 0.01 g before keeping the sample in a zip-lock bag until further usage (Bezirhan and Bilgen, 2019). A total of 25 g of dried starch was obtained.

2.2 Extraction of silica from the rice husk

The rice husk (40 g) was ground using Philips's HR 2056/00 electrical blender and sieved using a sieve to obtain a uniform size. The ground rice husk was placed in a beaker containing 386 g of distilled water and 7.65 mL of sulphuric acid under magnetic stirring for three hours at 80°C as an acid treatment to remove metallic

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impurities using Stuart US152D hot plate at power level two. After that, the residue of the treated rice husk was washed with deionized water by filtration with Whatman paper No. 41 and dried overnight at room temperature. Then, the dried rice husk was calcined in a Protherm ECO Series furnace at 800°C for 1 hr (Battegazzore *et al*., 2014). This method was repeated twice, and approximately 10 g of silica was obtained. Silica was sieved using a sieve with a size range of 0.002 cm to 12.5 cm and weighed using Sartorius BSA4202S-CW weighing balance with a precision of 0.01 g.

2.3 Preparation of silica/starch bioplastic

The silica/starch bioplastic (SSB) mixture was made using 17 mL of distilled water, 1 g of starch, 1 g of silica and 1 mL of glycerol with slight modification according to the method by Norsyafina *et al*. (2017). The formulation was done using Design Expert Software version 13. The factors accounted for this formulation are the ratio of silica, mass of glycerol and volume of mixture poured into the petri dish. There are 18 formulations generated by Design Expert Software.

2.4 Thickness of bioplastic

The thickness of each bioplastic sample was measured using a Spurtar Vernier-Calliper 1505555 with 0.02 mm precision. Each data was recorded in the mm unit. The measurement was taken at five different places and recorded an average value (Oluwasina *et al*., 2019).

2.5 Density of bioplastic

The density of each bioplastic sample was measured and calculated using Equation 1. All weight is measured by Sartorius BSA4202S-CW weighing balance with a precision of 0.01 g. The weight of the petri dish for each sample was taken beforehand. All data were recorded using a g/cm^3 unit. The method was done according to Maulida *et al*. (2016) with some modifications.

$$\text{Density } (g/cm^3) = \frac{\text{Weight of Petri dish + sample} - \text{weight of a petri dish}}{\text{volume poured into a petri dish}} \quad (1)$$

2.6 Moisture content analysis

The moisture content of each bioplastic sample was measured by recording the initial weight of the sample using an analytical weighing balance and placing it in the drying oven at 90°C overnight. The final weight is recorded after the sample cooled down at room temperature. Then, the moisture content was calculated using Equation 2 as applied by Venkatesh and Sutariya (2019).

$$\textit{Moisture content} (\%) = \frac{\text{The initial weight of the sample} - \text{final weight of the sample}}{\text{The initial weight of the sample}} \times 100 \quad (2)$$

2.7 Optimization of starch/silica bioplastic

The optimum formula was picked based on the best physical properties shown in each sample. One sample from the optimum formula was developed and underwent three analyses mentioned above. The data obtained were compared to the predicted mean in Design Expert.

3. Results and discussion

Composite central design (CCD) was chosen from response surface methodology (RSM) in Design Expert software version 13 to obtain optimum formulation based on desired factors and responses. In this research, an optimum formulation for this SSB is obtained based on the responses of thickness, density, and moisture content. Table 1 shows all data recorded for these three responses.

3.1 Thickness response analysis

In Table 2, the model summary statistics compared the suitable model for obtaining optimum formulation. In this response, a quadratic model is suggested. The R^2 value from this model is 0.8946, and the adjusted R^2 is 0.7761, which is deemed acceptable. However, the predicted R^2 is -0.7726 indicating the model is overfitting. A cubic model is not suggested as it is aliased.

The Model F-value of 7.55 implies the model is significant. There is only a 0.46% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. In this case, B, B^2, and C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. This means that the ratio of silica, the volume poured into a petri dish, the interaction between the ratio of silica and volume of glycerol (AB), the ratio of silica and volume poured into a petri dish (AC), the volume of glycerol and volume poured into a petri dish (BC), and interaction between the ratio of silica on each other (A^2) are insignificant terms. This data is recorded in Table 3.

The perturbation graph displays how the response changes according to each factor from a chosen reference point. This reference point is generated by Design Expert software. In the plot, factor A, the ratio of silica displays a small effect as it changes from the reference point. Therefore, it is acceptable to use factor B as the X1 - the axis, the volume of glycerol and factor C X2 - the axis, the volume poured into the petri dish and slice on factor A in Figure 1.

In contour and 3D surface plots, the response characteristics for this analysis are in the form of

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Table 1. Responses from design expert.

Std	Run	Factor 1 A: Ratio %	Factor 2 B: Volume of glycerol mL	Factor 3 C: Volume pour into a petri dish mL	Response 1 Thickness mm	Response 2 Density g/mL	Response 3 Moisture content %
10	1	5	6.7	8.5	1.5	0.44	37.92
16	2	5	2.5	8.5	3.0	0.38	46.27
9	3	13.4	2.5	8.5	3.0	0.30	19.38
11	4	5	2.5	4.3	2.0	0.25	52.78
2	5	10	0.0	6.0	1.0	0.08	51.96
18	6	5	2.5	8.5	3.0	0.38	46.27
6	7	10	0.0	11.0	0.5	0.10	1.76
12	8	5	2.5	12.7	1.0	0.34	48.49
15	9	5	2.5	8.5	3.0	0.38	46.27
4	10	10	5.0	6.0	3.0	0.61	46.17
14	11	5	2.5	8.5	3.0	0.38	46.27
5	12	0	0.0	11.0	1.0	0.10	3.57
7	13	0	5.0	11.0	3.0	0.45	49.29
1	14	0	0.0	6.0	0.5	0.09	3.70
8	15	10	5.0	11.0	4.0	0.42	35.70
17	16	5	2.5	8.5	3.0	0.38	46.27
3	17	0	5.0	6.0	3.0	0.82	36.99
13	18	5	2.5	8.5	3.0	0.38	46.27

Table 2. Model summary statistics.

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.3505	0.3981	0.2692	-0.0564	3.02	
2FI	0.3919	0.4088	0.0864	-1.3718	6.78	
Quadratic	0.1940	0.8946	0.7761	-0.7226	4.92	Suggested
Cubic	0.0000	1.0000	1.0000		*	Aliased

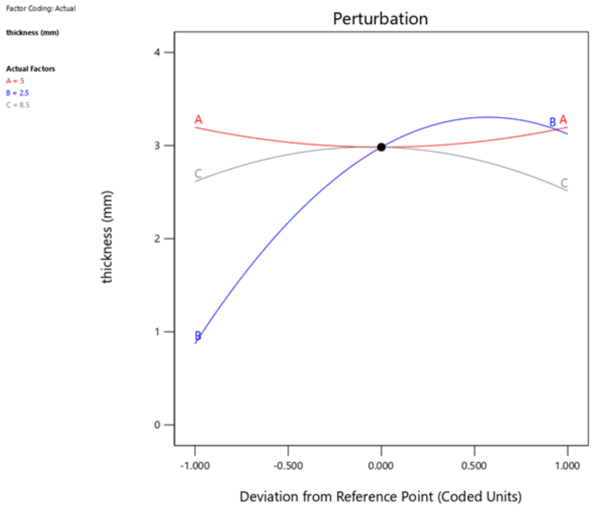

Figure 1. Perturbation plot for thickness response.

maximum response. The correlation between the two variables is that the higher the volume of glycerol added, the higher the thickness. The lower the volume pours into a petri dish, the lower the thickness. This is due to the function of glycerol as a plasticizer. It disrupts and restructures the intermolecular polymer chain networks and increases the thickness of bioplastic by converting all free volumes (Tarique *et al.*, 2021). This was similar to the study found by Nordin *et al.* (2020), where an increase in the volume of the mixture of bioplastic will simultaneously increase the thickness of the bioplastic film. The maximum response indicates that silica content is high. This also proves that the incorporation of silica adds more thickness to the bioplastic. This finding correlates with a study by Oluwasina *et al.* (2021), where silica from bamboo leaves was used. If the volume poured into the petri dish is 7.95 mL, and the volume of glycerol is 4.05 mL, then the thickness response will be 3.8 mm at maximum. This can be seen in Figures 2 and 3.

The comparison between models highlighted those linear, and quadratic models are suggested for this response and presented in Table 3. However, the quadratic model was chosen as the value for R^2, 0.9516, which is near 1.0000 compared to the linear model value. The R^2 value of a quadratic model is 0.9516, which is higher than the adjusted R^2. Therefore, it is acceptable. The predicted R^2 is 0.2784, indicating that the model is overfitting. The data is recorded in Table 4.

The Model F-value of 17.48 implies the model is significant. There is only a 0.02% chance that an F-value

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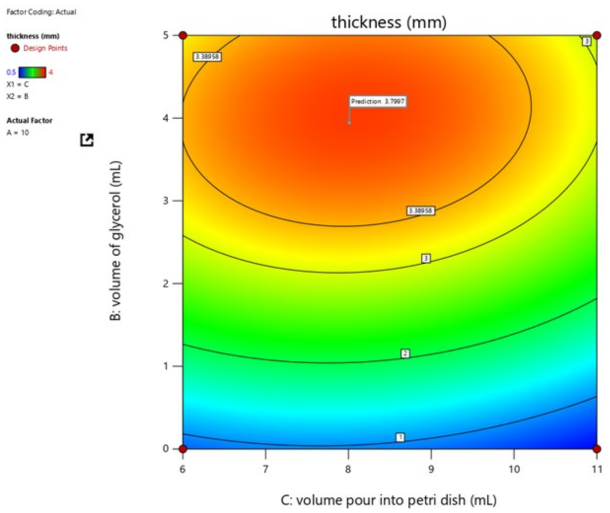

Figure 2. Contour plot for thickness response.

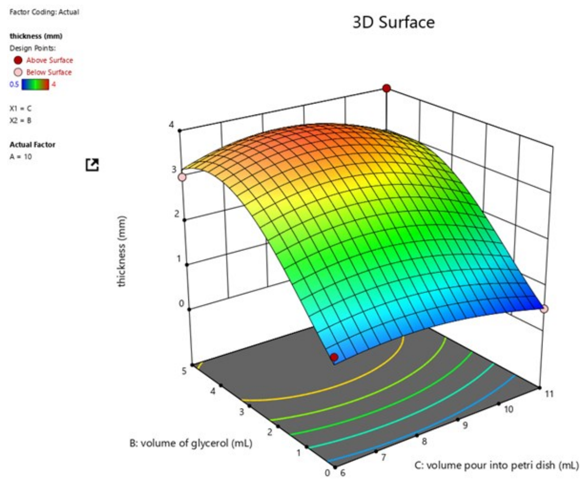

Figure 3. 3D surface plot for thickness response.

Table 4. ANOVA for density response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.4593	9	0.051	17.48	0.0002	significant
A-ratio of silica	0.0076	1	0.0076	2.61	0.1451	
B-volume of glycerol	0.3997	1	0.3997	136.87	< 0.0001	
C-volume pour into a petri dish	0.0024	1	0.0024	0.829	0.3892	
AB	0.0022	1	0.0022	0.7643	0.4075	
AC	0.0017	1	0.0017	0.5702	0.4718	
BC	0.0214	1	0.0214	7.33	0.0268	
A^2	0.0007	1	0.0007	0.2331	0.6422	
B^2	0.0668	1	0.0668	22.87	0.0014	
C^2	0.0044	1	0.0044	1.5	0.2558	
Residual	0.0234	8	0.0029			
Lack of Fit	0.0234	3	0.0078			
Pure Error	0	5	0			
Cor Total	0.4826	17				

this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. B, BC, and B^2 are significant model terms in this case. Values greater than 0.1000 indicate the model terms are not significant. This signifies that the ratio of silica, volume poured into a petri dish, the interaction between the ratio of silica and volume of glycerol (AB), the ratio of silica and volume poured into a petri dish (AC), the ratio of silica square (A^2) and volume poured into petri dish squared (C^2) are insignificant terms. This data is presented in Table 4.

The perturbation graph in Figure 4 shows that factor A, the ratio of silica, offers the least significant changes after passing through the reference point. Therefore, it is suggested that in factor B, the volume of glycerol is X1 - axis, and in factor C, the volume is poured into a petri dish as X2- axis and sliced on factor A.

Based on contour and 3D surface graphs, this displays the data in the form of maximum response. The correlation between the two variables can be determined when the volume of glycerol added increases and the

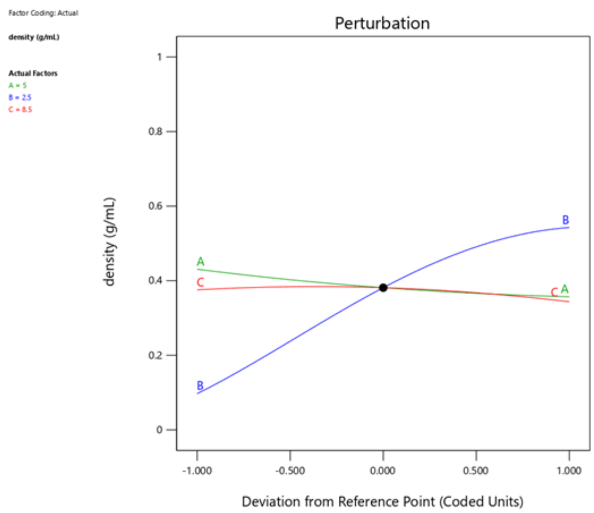

Figure 4. Perturbation plot for density response.

density of the bioplastic sample increases. This is because plasticizer expands the starch network structure and increases network density. This correlated with a study using cassava peel and sorbitol as plasticizers (Maulida *et al*., 2016). This statement is further proven by Dawam Abdu *et al*. (2018), who used sweet potatoes with glycerol. The research stated that density is strongly correlated with thickness. Therefore, the increase in bioplastic thickness will increase the density as well.

Furthermore, the study also explains where large particles such as silica may contribute to an increment in density. Besides that, glycerol was also in charge of interfering with the intermolecular bonding within polymer chains, resulting in a more compact arrangement of polymer structure. This decreases the volume of starch and increases the density of bioplastics (Razavi *et al*., 2015). Nonetheless, the book poured into the petri dish has little effect on the density value. The density decreases slightly when less volume is poured. This further enhances the relationship of density with thickness, as mentioned above. The highest prediction value for density response is 0.53 g/mL when 4.94 mL of glycerol is added as X1 - axis and 6.05 mL volume is poured into the petri dish as X2 - the axis. This data is displayed in Figures 5 and 6.

3.3 Moisture content response analysis

In Table 5, the model summary statistics for moisture content response suggested a quadratic model. The value for R^2 is 0.9600, and the adjusted R^2 is 0.9150, which is deemed acceptable. The predicted R^2 is 0.2589, which is low, indicating that the model is overfitting. A cubic model is not suggested as it is labelled aliased.

The Model F-value of 21.33 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB, AC, BC, A^2, and B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. This signifies that only the volume poured into the petri dish squared (C2) is insignificant. All data is recorded in Table 6.

In the perturbation plot, factor C volume poured into the petri dish shows the least significant changes when passing the reference point. Therefore, factor A ratio of silica as X1 - axis and factor B volume of glycerol as X2 - axis will be used and sliced on factor C in Figure 7.

In contour and 3D surface graphs, this data is presented in a maximum response form. The correlation between the factors is that the higher the amount of ratio silica added, the lower the moisture content. This is due to the interaction between glycerol within starch–silica matrix that decreases the availability of the hydroxyl group to form a bond with water. Then, this allows the matrix to create a less hygroscopic state. Nafchi *et al*. (2013) did this study using starch from potatoes and commercial silica. Comparing this result with a study done by Oluwasina *et al*. (2021), the study that used silica from bamboo leaves identified that the chemical state of silica might contribute when incorporated with a starch matrix that leads to less moisture. Higher hydrogen bonds are formed between silica – starch matrix and prevent free movement of water molecules interaction. The incorporation of silica replaces empty sites on starch matrix usually filled with water (Torabi and Mohammadi Nafchi, 2013) that also uses potato peel and commercial silica. However, the moisture content

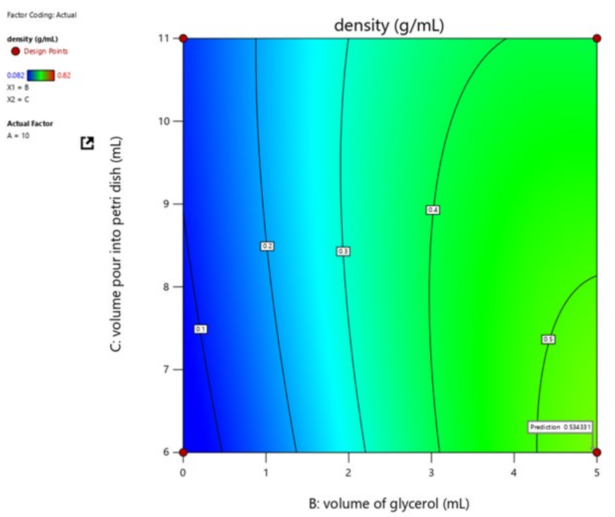

Figure 5. Contour lot for density response.

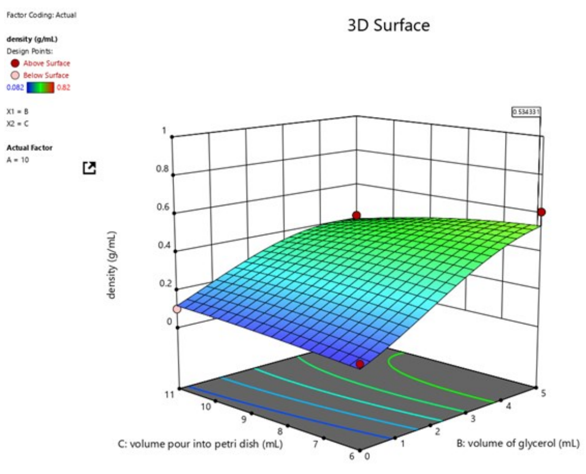

Figure 6. 3D surface plot for density response.

Table 5. Model summary statistics.

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	16.44	0.2637	0.1059	-0.4470	7432.90	
2FI	14.94	0.5219	0.2612	-1.3353	11995.88	
Quadratic	5.07	0.9600	0.9150	0.2589	3806.88	Suggested
Cubic	0.0000	1.0000	1.0000		*	Aliased

Table 6. ANOVA for moisture content response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4931.35	9	547.93	21.33	0.0001	significant
A-ratio of silica	187.78	1	187.78	7.31	0.0269	
B-mass of glycerol	1425.68	1	1425.68	55.50	< 0.0001	
C-volume pour into a petri dish	227.30	1	227.30	8.85	0.0177	
AB	323.34	1	323.34	12.59	0.0075	
AC	663.21	1	663.21	25.82	0.0010	
BC	340.08	1	340.08	13.24	0.0066	
A^2	939.98	1	939.98	36.59	0.0003	
B^2	674.07	1	674.07	26.24	0.0009	
C^2	58.36	1	58.36	2.27	0.1702	
Residual	205.50	8	25.69			
Lack of Fit	205.50	3	68.50			
Pure Error	0.0000	5	0.0000			
Cor Total	5136.85	17				

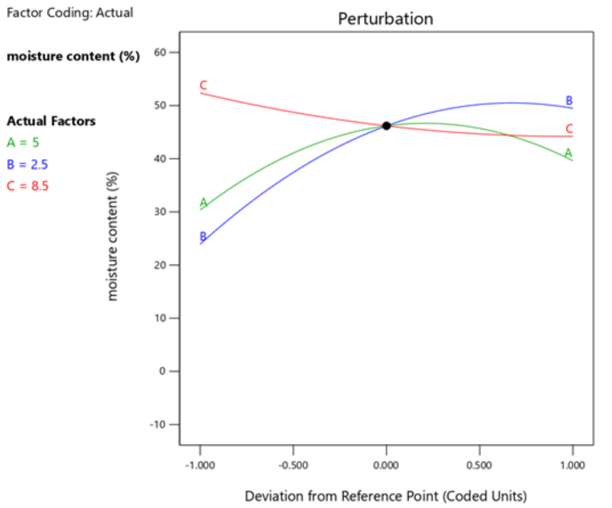

Figure 7. Perturbation plot for moisture content response.

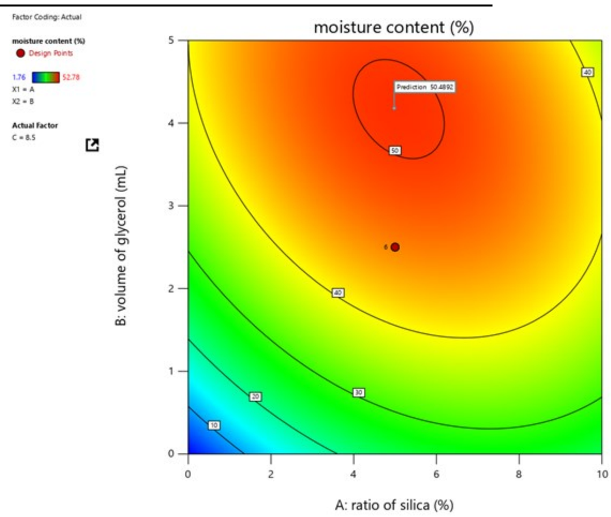

Figure 8. Contour plot for moisture content response.

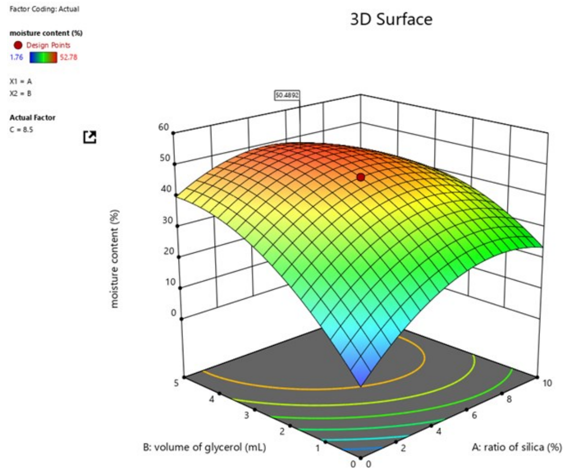

Figure 9. 3D surface plot for moisture content response.

increases by increasing the glycerol volume. This is due to the strong attraction of water molecules from hydroxyl groups in glycerol that allows the bioplastic to retain water and develop hydrogen bonds in the structure (Tarique *et al.*, 2021).

The prediction value for maximum moisture content response is 50.49%, with a ratio of silica added as X1 - axis is 4.98% and volume of glycerol added as X2 - axis is 4.97 mL. These trends are presented in Figures 8 and 9.

3.4 Optimization of starch/silica bioplastic

A numerical response optimization technique is used to obtain the optimum formulation for starch bioplastic incorporated with silica. The main goal for constrained optimization was to target the ratio of silica, minimize the volume of glycerol added, and find the volume poured into the petri dish (Mosisa and Vighneswara, 2021). These factors are keeping thickness and density within target and minimizing moisture content percentage as much as possible. The value is presented in Table 7.

After the parameters and constraints were selected, 22 solutions were generated. The average value from the 22 solutions was chosen for further analysis to analyze an optimum formulation. The average values for the

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Table 7. Constraints for optimization.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: ratio of silica	is target = 10	0	10	1	1	3
B: volume of glycerol	minimize	0	5	1	1	3
C: volume pour into a petri dish	is target = 8.5	6	11	1	1	3
thickness	is target = 1.83211	0.5	4	1	1	3
density	is target = 0.355153	0.082	0.82	1	1	3
moisture content	minimize	1.76	52.78	1	1	3

Table 8. Numerical optimization solutions.

No.	Ratio of silica	Volume of glycerol	Volume poured into a petri dish	Thickness	Density	Moisture content	Desirability	
1	10.000	0.962	8.627	1.870	0.196	31.224	0.737	Selected
2	10.000	0.960	8.609	1.870	0.196	31.332	0.737	
3	10.000	0.965	8.648	1.870	0.197	31.101	0.737	
4	10.000	0.967	8.666	1.870	0.197	30.992	0.737	
5	10.000	0.958	8.588	1.870	0.195	31.457	0.737	
6	10.000	0.971	8.698	1.870	0.198	30.804	0.737	
7	10.000	0.954	8.551	1.870	0.195	31.679	0.737	
8	10.000	0.975	8.732	1.870	0.199	30.611	0.737	
9	10.000	0.950	8.513	1.870	0.194	31.915	0.737	
10	10.000	0.978	8.756	1.870	0.199	30.471	0.737	
11	10.000	0.989	8.833	1.870	0.201	30.039	0.736	
12	9.932	0.969	8.651	1.870	0.197	31.305	0.735	
13	10.000	1.003	8.928	1.870	0.204	29.522	0.735	
14	10.000	1.010	8.971	1.870	0.205	29.293	0.735	
15	10.000	1.014	8.571	1.928	0.201	31.979	0.734	
16	9.889	0.981	8.728	1.870	0.199	30.997	0.734	
17	10.000	1.066	8.923	1.933	0.211	30.024	0.732	
18	10.000	1.100	9.085	1.940	0.216	29.232	0.729	
19	10.000	1.059	9.246	1.870	0.212	27.910	0.728	
20	10.000	1.176	9.413	1.949	0.226	27.770	0.718	
21	10.000	1.477	8.500	2.392	0.252	35.414	0.701	
22	10.000	0.736	9.174	1.561	0.177	25.733	0.697	

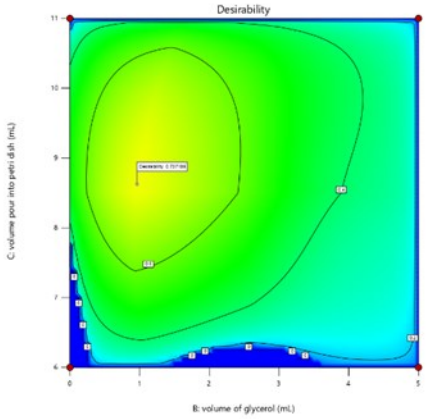
Table 9. Response prediction and confirmation.

Ratio of silica	Volume of glycerol	Volume poured into a petri dish
10	0.962248	8.62648
Responses		
Thickness	Density	Moisture content
2	0.2	31.75
1.8	0.27	30.15
2.1	0.2	31.3

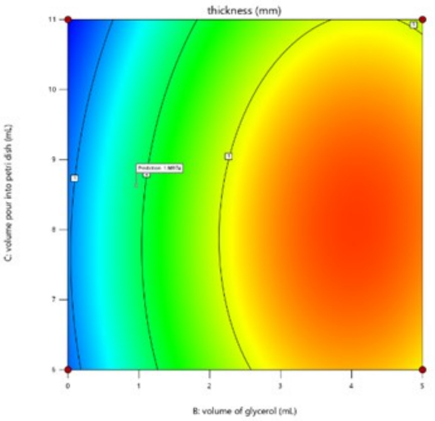
Table 10. Confirmation prediction.

Solution 1 of 22 Response	Predicted Mean	Predicted Median*	Std Dev	n	SE Pred	95% PI low	Data Mean†	95% PI high
Thickness	1.86974	1.83211	0.5278	3	N/A	1.01367	1.96466	2.89102
Density	0.19633	0.1934	0.0477	3	N/A	0.11777	0.22217	0.28769
Moisture content	31.2277	31.2277	5.06828	3	3.92881	22.1678	31.0667	40.2876

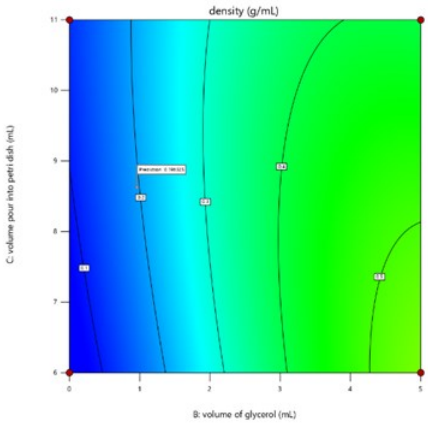
https://doi.org/10.26656/fr.2017.8(S2).75



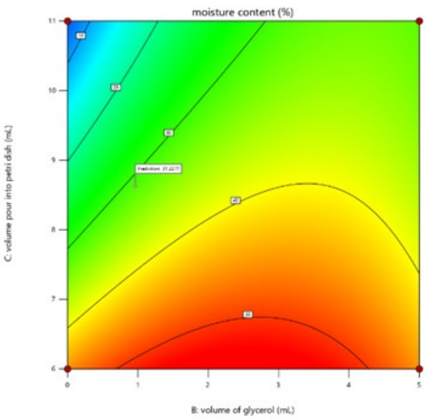
(a) Desirability



(b) Thickness

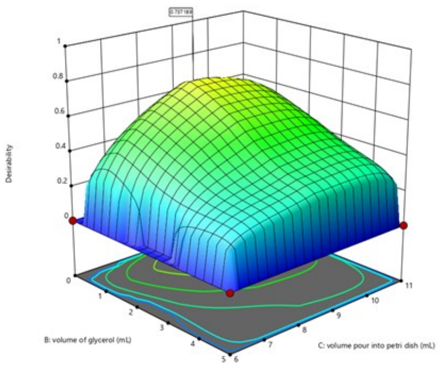


(c) Density

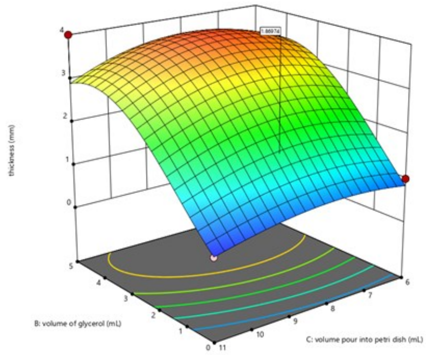


(d) Moisture content

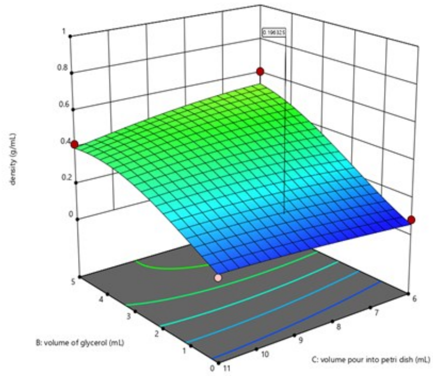
Figure 10. Contour Plot plot for optimization: (a) desirability, (b) thickness, (c) density, (d) moisture content.



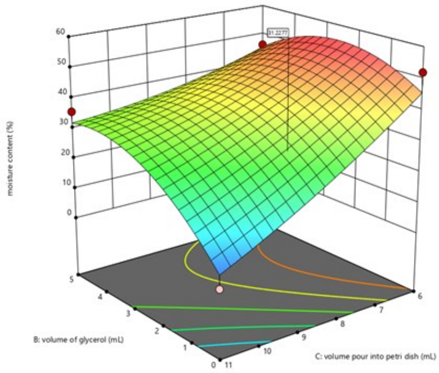
(a) Desirability



(b) Thickness



(c) Density



(d) Moisture content

Figure 11. 3D surface plot for optimization: (a) desirability, (b) thickness, (c) density, (d) moisture content.

three factors were the ratio of silica (10%), volume of glycerol (0.962 mL), and volume poured into a petri dish (8.627 mL) that will result in a thickness of 1.870 mm, density of 0.16 g/mL and moisture content of 31.224% as an optimum response. Table 8 presents the numerical optimization solutions. Solution one was chosen as the optimum formula.

The desirability for numerical optimization is 73.72% for overall responses to obtain the best criteria for SSB. The optimum value relatively closer to desirability (100%) is 73.72%. This means that the formulation is easy to achieve and yields better output availability. This optimization meets the best-desired criteria out of the 22 solutions.

Analyzing for the optimum formulation is to identify the best value in all factors to provide better responses. The X1 - axis is factor C volume poured into the petri dish, and X2 - axis is factor B of glycerol. The ratio of silica is constant, which is 10% according to solution one. This data can be analyzed on contour and 3D Surface plots presented in Figures 10 and 11 that show: a. desirability, b. thickness, c. density, and d. moisture content.

In order to generate response prediction, solution one is chosen as the optimum formula. The confirmation is done by running the solution one formula three times to obtain the average value. The ratio of silica use is 10%, the volume of glycerol is 0.962 mL, and the volume poured into the petri dish is 8.627 mL. The response value obtained three times was also recorded in the table. The data is presented in Table 9.

Based on Table 8, the optimum value obtained for all three responses is in between the range given. The mean for thickness response is 1.96466, density is 0.22217, and moisture content is 31.0667. Therefore, the model for the optimum formulation is confirmed in Table 10.

4. Conclusion

This study observed the relationship between three factors (ratio of silica, the volume of glycerol and volume poured into the petri dish) with responses (thickness, density and moisture content). The volume of glycerol and volume poured into the petri dish notably affects the thickness and density. However, the silica ratio and glycerol volume significantly affect the moisture content. The thickness increases as the volume of glycerol and volume poured into the petri dish increases. Furthermore, the density of SSB increases as the volume of glycerol and volume poured into the petri dish increases as well. This is also due to the silica content in the bioplastic.

Meanwhile, the moisture content decreases as a higher ratio of silica and increases when a higher volume of glycerol is added. Bioplastic from sweet potato peel starch incorporated with silica from rice husk was developed to find the optimum bioplastic by observing the thickness, density and moisture content properties. The quadratic model was chosen for all responses to exhibit a statistically significant model for all factors developed to explain the relationship between thickness, density and moisture with the three factors. SSB formulation was optimized using central composite design in response surface methodology, and the statistical model perfectly fits with R^2 data. The data for thickness $R^2 = 0.8946$, density $R^2 = 0.9516$ and moisture content $R^2 = 0.9600$ with low standard deviation, respectively, portray the significant effect on the conditions for the optimal formula. ANOVA results signify the impact of each factor was significant and quadratic models were chosen to predict the responses. The optimal formulation selected using numerical optimization exhibit a combined value of desirability (73.72%). The value of data means thickness (1.96466), density (0.22217) and moisture content (31.0667). The data mean for each response is aligned within the range of the predicted mean. Therefore, the optimal formula is confirmed.

Conflict of interest

The authors declare no conflict of interest.

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