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Research Article

Performance of superabsorbent polymer as admixture in hollow concrete blocks

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ABSTRACT

This study investigates the efficacy of superabsorbent polymer (SAP) waste as an admixture in producing hollow concrete blocks. Using the central composite design (CCD) of the response surface methodology (RSM), the concrete blocks were created by adjusting the SAP percentage from 0.05% to 0.25%, with a constant amount of cement and sand ratios ranging from 2.00 to 4.00. After 28 days of curing, the blocks were evaluated for their compressive strength, density, and water absorption capacity. Analysis of Variance (ANOVA) was used to analyze the data. The results showed that the created hollow concrete blocks at optimum condition exceeded the Philippine National Standard and ASTM Standard of 4.14 MPa for compressive strength on non-loadbearing concrete masonry, with theoretical properties of compressive strength of 8.20 MPa, density of 1900 kg/cm^3 and 5.28% water absorption at the optimized conditions after numerical optimization using the CCD. This innovation could reduce solid waste output and help the environment by using by-products from companies. This research provides valuable insights into sustainable construction materials and highlights the potential of using superabsorbent polymers in producing hollow concrete blocks.

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1. INTRODUCTION

In recent years, the world has faced various environmental challenges, including climate change and global warming, primarily caused by human activities. One environmental issue that has emerged is the disposal of Superabsorbent Polymers (SAP) generated by industries, which have detrimental effects on soil quality. Superabsorbent polymers are widely used materials known for their exceptional water absorption and desorption capacities [1]. However, a significant drawback of SAP is its non-biodegradability, leading to environmental pollution [2].

Typically found in products like diapers, adult incontinence items, and feminine hygiene products, superabsorbent polymers have been extensively used for their water-absorbing properties [3]. Several factors have driven ongoing research and development in advanced superabsorbent polymers. Superabsorbent polymer hydrogels can influence soil permeability, density, structure, texture, evaporation, and infiltration rates [4]. These polymers can

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be classified as either natural or synthetic, with synthetic variants gaining prominence due to their high absorption capacity, wider availability of raw materials, and extended durability. Their hydrophilic, non-toxic, biodegradable, and biocompatible properties make synthetic superabsorbent polymers highly suitable for various applications, including drug delivery, agriculture, bioremediation, firefighting, biosensors, food industries, thermal energy storage, and tissue engineering [5].

Incorporating superabsorbent polymers (SAP) as a novel component in the production of concrete materials offers promising opportunities for water regulation and control over the rheological properties of fresh concrete [6]. Hollow concrete blocks (HCB) remain widely used in the construction industry globally [7]. These blocks have gained popularity as substitutes for burnt clay brick masonry walls in developed and developing countries, playing a crucial role in modern construction practices [8]. Adding Superabsorbent Polymers (SAPs) to cementitious mixtures enhances the material's self-healing capabilities. When cracks occur, SAPs within the cracks expand upon contact with water, releasing the water to facilitate the hydration of unhydrated cement particles and the formation of calcium carbonate crystals [9]. However, excessive water absorption and the subsequent creation of excessive pores by SAP can adversely affect the strength of the cementitious material. Precise measurement of additional water absorption is vital to effectively minimize autogenous shrinkage, a critical consideration for structures prone to shrinkage and cracking [9].

By incorporating superabsorbent polymers in concrete production, autogenous shrinkage can be effectively reduced, and the hydration of cementitious materials can be facilitated, leading to enhanced concrete strength [10]. Considering the widespread reliance on water across various sectors, including construction, it becomes imperative to manage water availability and usage efficiently. Water plays a crucial role in the concrete mixing process and is also utilized for concrete curing in the construction industry. Curing, performed for specified durations such as 7, 14, or 28 days, significantly influences the strength and durability of structures. Exploiting SAP's reversible expansion and contraction properties when exposed to water and dry conditions can prove advantageous in concrete applications [11].

This study aims to utilize superabsorbent polymers to produce hollow concrete blocks (HCB). The effects of SAP admixture on various properties of HCB, including water absorption, density, and compressive strength, will be investigated. By exploring the potential of SAP in concrete manufacturing, this research contributes to sustainable construction practices. It provides insights into using waste materials to pursue environmentally friendly construction solutions.

2. MATERIALS AND METHODS

2.1. Collection and preparation of raw materials

The Superabsorbent Polymers (SAP) were collected at Mega Soft Hygienic Incorporated in Zone 3, Sinaloc, El Salvador City, Misamis Oriental, Philippines.

The raw ingredients utilized to make hollow concrete blocks are cement (CEM 1) with a fineness of 225 m²/kg, natural sand as fine aggregate with fineness that passes through 2.36 mm (Sieve No. 8), and superabsorbent polymers as an admixture. The researchers looked at the possibilities of increasing the characteristics of hollow concrete blocks by combining these materials.

After receiving the sample from its firm, the rejected by-product superabsorbent polymer (SAP) was examined immediately. The moisture content of the SAP was used to classify it initially. The SAP was employed as an admixture in producing hollow concrete blocks and was classified by particle size and moisture content. The moisture content of SAP was evaluated using the ASTM D 2974 process (Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils). The particle size of the SAP admixture was determined by drying it uncovered for at least 16 hours at 105 °C or until there was no change in mass of the sample following repeated drying periods of more than 1 hour. The sample pieces were removed from the oven, covered tightly, and cooled in a desiccator before weighing.

$$\text{Moisture Content (\%)} = \frac{(\text{wet mass} - \text{dry mass}) \times 100}{\text{wet mass}} \quad (1)$$

The SAP utilized in the experiment was a superabsorbent polymer as a white granular dry powder with particle sizes ranging from 0.8 to 1.0 mm. Cement and sand were purchased from Nailes Sand and Gravel Merchandise at Poblacion, Claveria, Misamis Oriental, Philippines. Sand and cement, which acted as binding ingredients for producing hollow concrete blocks, were also valuable in mixing. The cement used in the mixing was Ordinary Portland cement. Table 1 presents the technical information of the raw materials used in this study. Furthermore, Figure 1 shows the macrograph and micrograph of SAP adopted from the study of Cheng et al. [12].

Table 1. Technical Information of the Raw Materials Used

Material	Technical Information
Superabsorbent polymer (SAP)	Size: 0.8 to 1.0 mm
Sand	Fineness: 2.36 mm (Sieve No. 8)
Cement	Cement Designation: CEM 1
	Fineness: 225 m²/kg

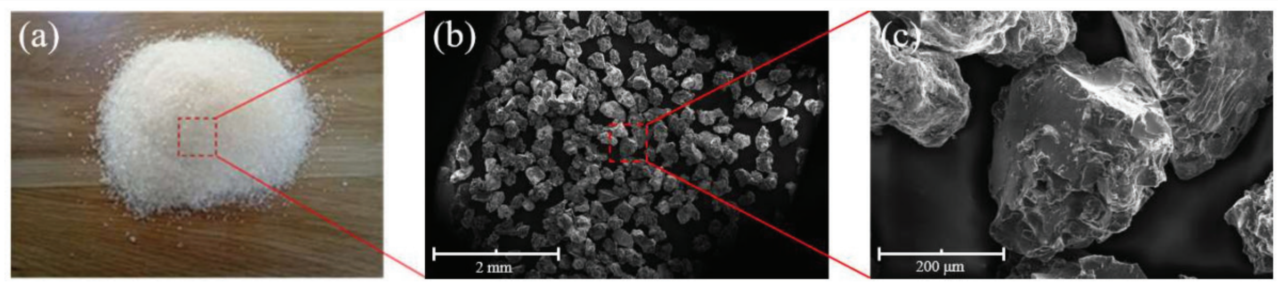

Figure 1. Image of the macrograph and micrograph of SAP as reported in the study of Cheng et al. [12].

2.2. Experimental Design

The researchers used the Central Composite Design (CCD) of the Response Surface Methodology (RSM) to establish the experimental mixtures. In addition to the essential components of the hollow concrete block mixture, superabsorbent polymer (SAP) was added as an admixture. Table 2 below depicts the low and high component ranges.

Using the values of the independent variables in Table 2, thirteen mixtures were generated, represented in different ratios in Table 3.

The proportion of 1.00 cement was kept consistent across all samples.

2.3. Procedure for Making the Hollow Concrete Blocks

Using the mixtures suggested by the central composite design (CCD), hollow concrete blocks were made through the respective proportions of the raw materials needed. The superabsorbent polymer (SAP) was mixed with cement, sand, and water to form a cementitious material until the mixture thickened and became homogeneous. Begin by adding water to the container that contains your cement and mixture. Use a rod to stir the mixture continuously. Keep adding water and stirring until the concrete mix reaches an easy consistency to pour into the hollow

Table 2. Experimental Range and Levels of Variables in Making Hollow Concrete Blocks

Variables	Coded Levels				
	-2	-1	0	1	2
Cement to Sand Ratio (CSR)	1:2	1:2.5	1:3	1:3.5	1:4
SAP (%)	0.05	0.10	0.15	0.2	0.25

Table 3. Experimental Mixtures with Values of Independent Variables in Hollow Concrete Blocks with Superabsorbent Polymers

Mixture	Ratio		
	Cement	Sand	SAP
1	1.00	4.00	0.15
2	1.00	3.00	0.15
3	1.00	3.00	0.15
4	1.00	2.50	0.10
5	1.00	3.00	0.25
6	1.00	3.00	0.15
7	1.00	2.00	0.15
8	1.00	2.50	0.20
9	1.00	3.50	0.10
10	1.00	3.00	0.15
11	1.00	3.50	0.20
12	1.00	3.00	0.05
13	1.00	3.00	0.15

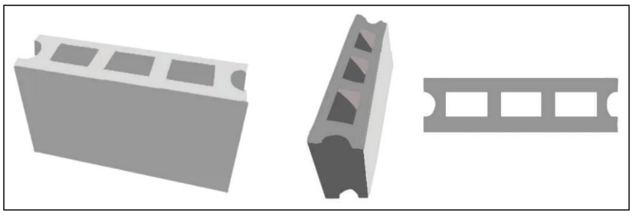

Figure 2. Hollow concrete block.

concrete block mold. It should be pliable and hold its shape when molded but still wet enough to spread quickly. This is a crucial step in making hollow concrete blocks, as the right consistency ensures that the blocks will be sturdy and hold their shape after they are removed from the mold. The mixture was then poured into the molder [40 cm (length) x 20 cm (width) x 4 in (thickness)] to produce the hollow concrete blocks as graphically shown in Figure 2, and compacted using pressure and jolting. The weight of the hollow concrete block ranged from 5,350 g to 6,850 g.

2.4. Product Testing

2.4.1. Water Absorption Analysis

At the USTP-Claveria Environmental laboratory, a water absorption test was performed. The following steps were used to determine the water absorption analysis procedure according to Kishore and ASTM C 140. ASTM C covers the physical properties of concrete masonry units. These properties include the absorption of the unit, density, moisture content, and as well as the compressive strength of the unit.

$$wt\% = \frac{w_m - d_m}{d_m} x100 \quad (2)$$

Where w_m equals the wet mass of the unit in kg, and dm equals the dry mass of the unit in kg. For 24 hours, three full-size blocks must be thoroughly immersed in clean water at room temperature. After removing the blocks from the water and allowing them to drain for one minute on a 10 mm or coarser wire mesh, visible surface water should be wiped with a damp towel, and the saturated and surface dry blocks should be weighed immediately. All blocks must be dried in a vented oven from 100 °C to 115 °C for at least 24 hours until two successive weighing at 2 hours demonstrate an increment of loss of not more than 0.2 percent of the specimen's last previously calculated mass.

2.4.2. Density Test

The density test was performed in the USTP-Claveria Environmental Laboratory. The mass and volume of the sample were determined to compute it. The density was calculated according to Equation 3.

$$\rho = \frac{m}{V} \quad (3)$$

Where m is the mass of the hollow block after drying to a constant mass in an oven, V is the volume of the hollow blocks after chilling the sample to ambient temperature, and the overall volume is estimated in cubic centimeters and translated to a cubic meter.

2.4.3. Compressive Strength

The compression test of the samples was conducted at the University of Science and Technology of Southern Philippines - Cagayan De Oro City. The compression sample was examined utilizing the Universal Testing Machine using ASTM C140/C140M or the Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. Figure 3 shows an image of the compressive testing of the hollow concrete blocks through the UTM.

Figure 3. Compressive Testing of the Hollow Concrete Blocks through the UTM .

Table 4. Properties of Superabsorbent Polymers

Material	Moisture Content	Particle Size
Superabsorbent Polymers (SAP)	3.1%	0.8 - 1.00 mm

3. RESULTS AND DISCUSSION

3.1. Properties of the Superabsorbent Polymer

The characteristics of Superabsorbent Polymers were determined using standard methods and are shown in Table 4.

The moisture content was calculated using the method indicated in Equation 1 by using an oven and setting it to 100-105 °C for 24 hours. The particle size of 0.8-1.0 mm was determined by sieving.

Due to osmotic pressure, SAPs can absorb up to 500 times their mass in aqueous solutions, forming a bloated hydrogel. SAPs are lengthy chains of linear polymers that are linked at multiple locations. They are employed as care articles or smart pills in the hygiene and medical industries, and they can even be used for firefighting or food packaging. It was just a matter of time before this polymer was used as a cement ingredient. SAPs can be utilized in cementitious materials to reduce autogenous shrinkage, alter the rheology of the fresh material to improve freeze/thaw resistance, self-sealing, and even promote autogenous healing [13]. Several studies have looked into the impact of SAP on mixing. Concrete and mortar, the hydrophilic feature of SAP piques curiosity since all the water absorbed will be chemically accessible to react with the cement. It can improve the hydration degree of cementitious matrices, reduce contraction, reduce micro-cracked development, and improve the durability of cement matrices [14].

3.2. Properties of the Hollow Concrete Blocks with SAP

The percentage proportion provided by Central Composite Design software was used to calculate the mixtures required to make a hollow concrete block with a volume of 2,601.77 cm^3.

Table 5 displays the physical and mechanical parameters, which include compressive strength, density, and water absorption of hollow concrete blocks created using the various proportions defined by the central composite design software.

Table 5 shows that mixture 7 had the highest compressive strength of 6.617 MPa, while mixture 9 had the lowest compressive strength of 3.327 MPa. However, aside from autogenous shrinkage, adding SAP to concrete can affect various concrete properties. SAP can boost hydration and increase strength [15]. As a result, regardless of the SAP dosage or the mixing sequence, all SAP-containing combinations have improved strength. This is because the basic liquid-binder ratio decreases when SAP is present, resulting in a denser interstitial structure that improves compressive strength. As a result, the impact of SAP dosage on strength is not always positive [16].

With a water absorption rate of 26.23%, mixture 13 was the most absorbent, and mixture 12 got the least water absorption capacity as a result of the small ratio of the SAP mixture. Due to osmotic pressure, SAPs can absorb up to 500 times their mass in aqueous solutions, forming a

Table 5. Physical and Mechanical Properties of HCB with SAP

Mixture	Test Results		
	Compressive Strength (MPa)	Density (kg/m^3)	Water Absorption (%)
1	5.840	2180	6.06
2	3.585	2630	25.17
3	3.927	2570	21.17
4	5.661	2230	11.48
5	5.960	2020	20.58
6	4.497	2570	21.68
7	6.617	2195	10.79
8	4.986	2470	18.96
9	3.327	2510	7.93
10	3.519	2590	23.10
11	5.765	2210	16.96
12	5.916	2100	3.70
13	3.658	2612	26.23

Table 6. Analysis of Variance of Response Surface Quadratic Model for Compressive Strength

Source	Sum of Squares	df	Mean Square	F Value	p-value
Model	14.83	5	2.97	16.81	0.0009[a]
A-Sand	0.8	1	0.8	4.56	0.0701[b]
B-SAP	0.29	1	0.29	1.62	0.2438[b]
AB	2.42	1	2.42	13.72	0.0076[a]
A^2	8.18	1	8.18	46.31	0.0003[a]
B^2	6.31	1	6.31	35.76	0.0006[a]
Residual	1.24	7	0.18		
Lack of Fit	0.59	3	0.2	1.24	0.4061[b]
Pure Error	0.64	4	0.16		
Cor Total	16.07	12			

$R^2 = 0.9231$

Adj $R^2 = 0.8682$

a=*significant;* b=*not significant*

bloated hydrogel. It was a matter of time until this polymer was also used as a cementitious material additive [17].

Meanwhile, mixture 2 had the highest density at 2630 kg/m^3, whereas mixture 5 had the lowest density at 2020 kg/m^3. A reduced density of lightweight concrete blocks, according to [18], results in cost reductions in terms of design flexibility, transportation, and handling.

3.3. Models in Predicting Hollow Concrete Block Properties

3.3.1. Compressive Strength

According to the fit summary analysis of the three attributes, the best-fit model in forecasting its values was quadratic. Equations 4-6 show the model equations where SAP is represented.

The analysis of variance (ANOVA) of the quadratic model for compressive strength of the hollow concrete block interpreted in Table 6 shows the model F-value of 16.81 implies the model is significant. There was only a 0.09% chance that a model "F-value" this large could occur due to the variability of the data. This indicated that the model's output values were correct. It can also be noted that the ANOVA showed that the variables A (Sand) and B (SAP) were not significant at 0.05 level of significance as their respective p-values were greater than 0.05. However, it can be noted that the interactive effect of these variables (A, B) significantly affected the compressive strength of the hollow concrete blocks, as evidenced by their significant p-values. This finding is consistent with the observations in previously published research, which states that the interactive effect of variables significantly impacts the compressive strength of concrete blocks [19].

The "Lack of Fit F-value" of 1.24 implied the Lack of Fit was insignificant relative to the pure error. There was a 40.61% chance that a "Lack of Fit F-value" this large could occur due to noise. A non-significant lack of fit is good because the model needs to fit.

It is also worth noting that the coefficient of determination value, R^2, was recorded as high at 0.9231, which determined that the regression model was 92.31% accurate based on the observed data. In other words, it can be interpreted that the generated model can support and explain the relationship between the experiment's actual and predicted values. To support this, the model-generated equation is presented in Eq. 4.

$$Y = 45.15282 - 19.52183A - 153.25844B + 31.12090AB + 2.38928A^2 + 209.94117B^2 \quad (4)$$

Y is the predicted compressive strength, A is sand, and B is the SAP. The model equation above is significant because it can determine an expected response based on the desired values of the independent variables of the experiment. The negative coefficients suggest that the factor tends to decrease the result of the predicted compressive strength, while the positive coefficients indicate otherwise. As observed in the equation, this interpretation is consistent with the results of the ANOVA of the quadratic model of the compressive strength, as shown above. Table 7 shows the actual and the predicted compressive strength values based on the generated model equation.

3.3.2. Effects of the Operating Variables to the Compressive Strength

As can be seen in Figure 5, it can be noted that the 3D surface plots showed a sagging graph. This means that a high compressive strength can be achieved at the combinations of low sand and SAP ratio and the high sand and SAP ratio. This could mean that the interaction of these two variables is significant in the compressive strength of the hollow concrete block, which is also proven by the important results of the interaction of the variables based on the

Table 7. Actual vs. Predicted Compressive Strength of the Hollow Concrete Blocks with SAP

Mixture	Mixture Components Ratio (wt. %)			Result	
	A Cement	B Sand	C SAP	Actual	Predicted
1	1	4.0	0.15	5.840	5.701
2	1	3.0	0.15	3.585	3.830
3	1	3.0	0.15	3.927	3.830
4	1	2.5	0.10	5.661	5.835
5	1	3.0	0.25	5.960	6.238
6	1	3.0	0.15	4.497	3.830
7	1	2.0	0.15	6.617	6.737
8	1	2.5	0.20	4.986	4.588
9	1	3.5	0.10	3.327	3.761
10	1	3.0	0.15	3.519	3.830
11	1	3.5	0.20	5.765	5.626
12	1	3.0	0.05	5.916	5.621
13	1	3	0.15	3.658	3.830

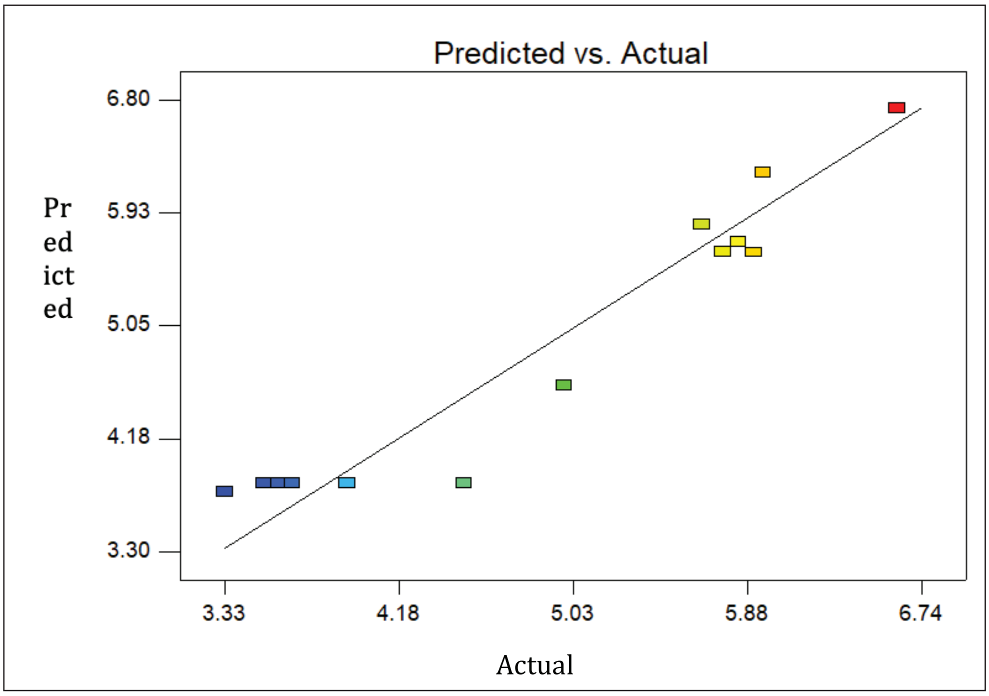

Figure 4. Diagnostic Graph on the Actual versus Predicted Compressive Strength of HCB with SAP.

ANOVA analysis. It can also be interpreted that the right ratio of sand and SAP is necessary so that each independent variable will not overpower the other.

3.3.3. Density

The best-fit model in forecasting its value was quadratic according to the fit summary analysis of the three attributes.

Table 8 shows that the model F-value of 265.19 implies the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to the variability of the actual results of the experiment. The "Lack of Fit F-value" of 0.15 implied the Lack of Fit is insignificant relative to the pure error. The lack of fit p-value suggests a 92.35% chance that a "Lack of Fit F-value" this large could occur due to noise. A non-significant lack of fit is good because it wants the model to fit. The "Pred R-squared" of 0.9879 is in reasonable agreement with the "Adj R-squared" of 0.9910.

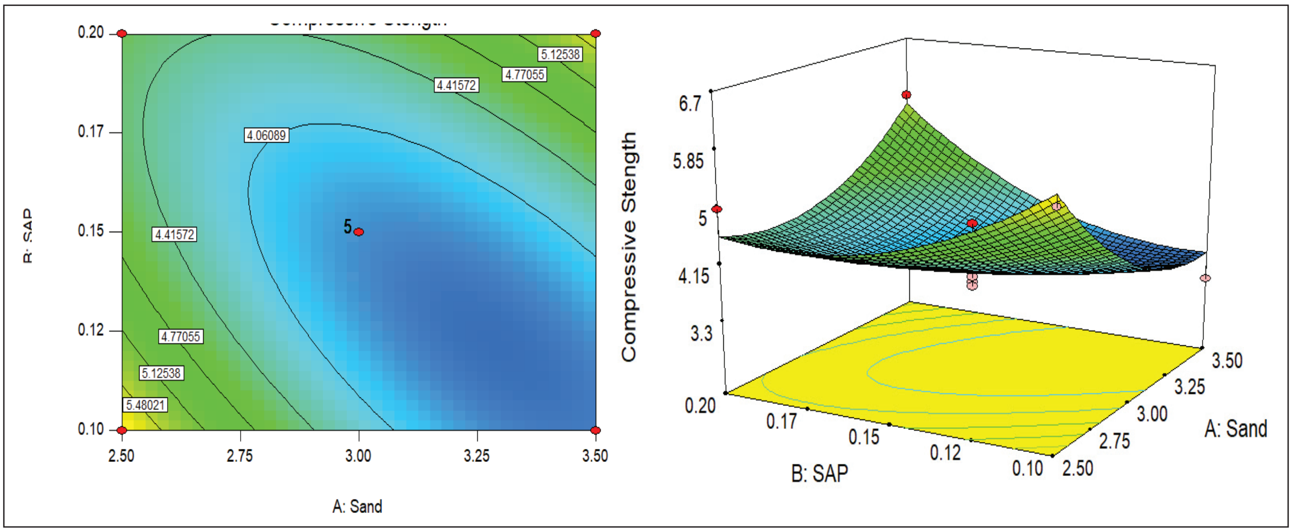

Figure 5. Contour and 3D Surface Plots of the Effects of Sand and SAP on Compressive Strength.

$$Y = -4644.578 + 3251.41954A + 31873.76437B - 5400AB - 407.18103A^2 - 53468.10345B^2 \quad (5)$$

Y is the expected density, A denotes the sand, and B represents the SAP. The model equation above is critical because it can anticipate a response based on the desired values of the experiment's independent variables. The negative coefficients indicate that the component has a propensity to reduce the expected density result, while the positive coefficients indicate the opposite. This interpretation is compatible with the results of the ANOVA of the quadratic density model, as shown in the equation. Based on the developed model equation, Table 9 illustrates the actual and predicted density values, which are graphically shown in Figure 6.

3.3.4. Effects of the Operating Variables on the Density

As can be seen in Figure 7, it can be noted that the contour and 3D surface plots show that with low amounts of sand, if the amount of SAP is increased, there is also a notable increase in the density of the hollow concrete blocks. Meanwhile, when SAP is low, and the amount of sand is increased, an increasing trend in the density of the HCB is also noted. Furthermore, it can be observed that the interaction of both variables, sand and SAP, have a significant effect on the trend of the density of the concrete. Looking back at equation 5, the coefficient of AB as the interaction of the variables is negative, which means that the interactive effect of SAP and sand on the hollow concrete block is the reduction of the density. This idea is consistent with the

Table 8. Analysis of Variance of Response Surface Quadratic Model for Density

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	587929.08	5	117585.82	265.1877	< 0.0001 [a]
A-Sand	8.3333333	1	8.3333333	0.018794	0.8948 [b]
B-SAP	4033.3333	1	4033.3333	9.096254	0.0195 [a]
AB	72900	1	72900	164.4091	< 0.0001 [a]
A^2	237436.81	1	237436.81	535.484	< 0.0001 [a]
B^2	409413.85	1	409413.85	923.3386	< 0.0001 [a]
Residual	3103.842	7	443.40599		
Lack of Fit	316.64195	3	105.54732	0.151474	0.9235 [b]
Pure Error	2787.2	4	696.8		
Cor Total	591032.92	12			
$R^2 = 0.9947$					
Adj $R^2 = 0.9910$					

a=*significant;* b=*not significant*

Table 9. Actual vs. Predicted Density of the Hollow Concrete Blocks

Mixture	Mixture Components Ratio (%)			Results	
	A. Cement	B. Sand	C. SAP	Actual	Predicted
1	1	4.0	0.15	2230	2241.98
2	1	3.0	0.15	2510	2510.31
3	1	3.0	0.15	2470	2475.31
4	1	2.5	0.10	2210	2203.64
5	1	3.0	0.25	2195	2187.76
6	1	3.0	0.15	2180	2184.43
7	1	2.0	0.15	2100	2095.26
8	1	2.50	0.20	2020	2021.93
9	1	3.50	0.10	2630	2593.28
10	1	3.0	0.15	2590	2593.28
11	1	3.5	0.20	2612	2593.28
12	1	3.0	0.05	2570	2593.28
13	1	3.0	0.15	2570	2593.28

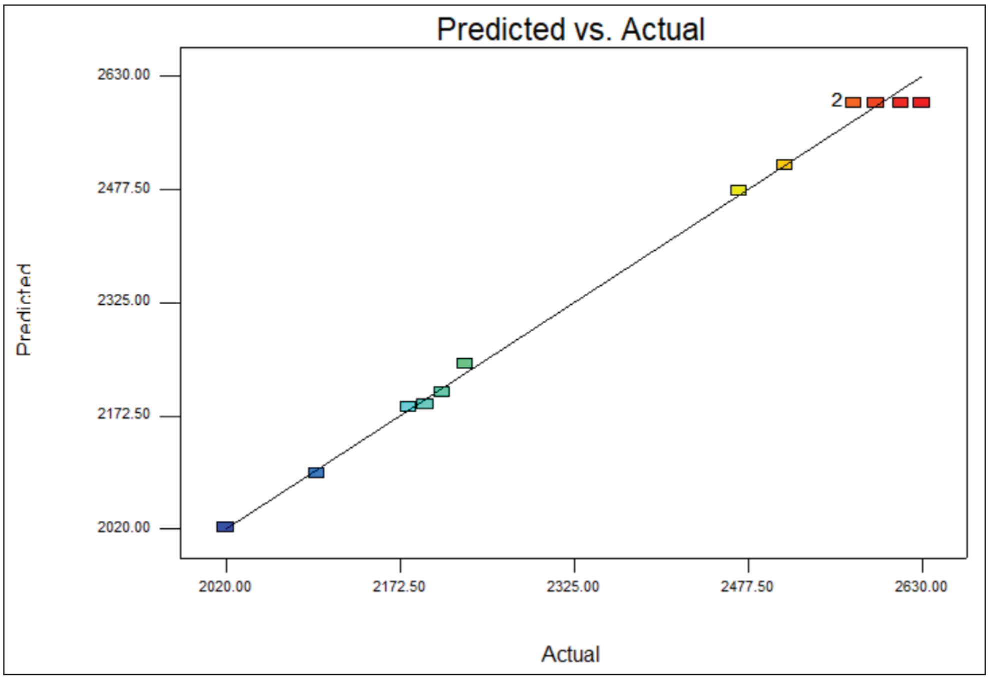

Figure 6. Diagnostic Graph on Actual versus Predicted Density.

findings of a previous study, which observed that adding SAP to the concrete mixture reduces the density, considering that SAP is less dense [14]. This observation can also be explained by the results of the analysis of variance for the density, as presented in Table 8 above.

3.3.5. Water Absorption

According to the fit summary analysis of the three qualities, quadratic was the best-fit model for forecasting its values. Table 10 shows the analysis of variance (ANOVA) of the Response quadratic model for water absorption.

The Model F-value of 20.12 implies the model is significant. There is only a 0.05% chance that a "Model F-value" this large could occur due to noise. In this case, B, A^2, B^2 are significant model terms. This means that factor B (SAP) significantly affects the water absorption quality of the hollow concrete blocks, which is not surprising because of the absorbent property of the superabsorbent polymer. The "Lack of Fit F-value" of 1.79 implies the Lack of Fit is insignificant relative to the pure error. The p-value also suggests a 28.83% chance that a "Lack of Fit F-value" could occur due to noise. The "Pred R-Squared" of 0.7046 is in

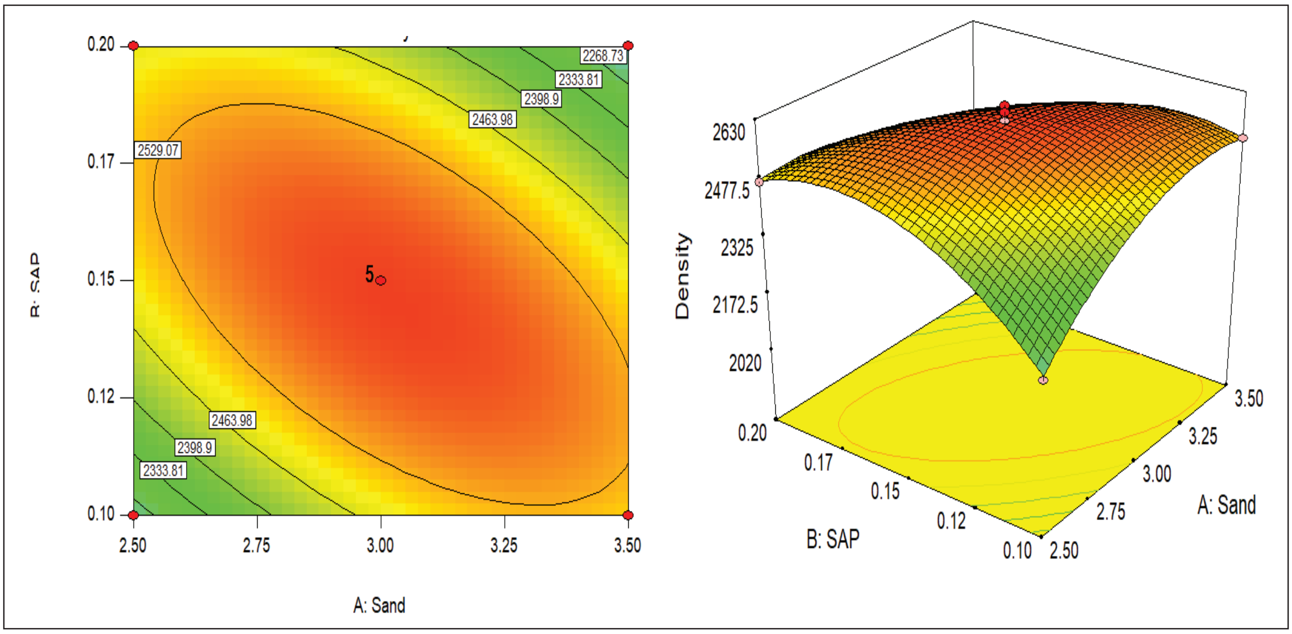

Figure 7. Contour and 3D Surface Plots of the Effects of Sand and SAP on Density.

Table 10. Analysis of Variance of Response Surface Quadratic Model for Water Absorption

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	644.1686	5	128.8337	20.11658	0.0005[a]
A-Sand	18.77501	1	18.77501	2.9316	0.1306[b]
B-SAP	210.5894	1	210.5894	32.88222	0.0007[a]
AB	0.600625	1	0.600625	0.093784	0.7683[b]
A^2	333.2671	1	333.2671	52.03758	0.0002[a]
B^2	190.712	1	190.712	29.77849	0.0009[a]
Residual	44.83049	7	6.404355		
Lack of Fit	25.69189	3	8.563963	1.789883	0.2883[b]
Pure Error	19.1386	4	4.78465		
Cor Total	688.9991	12			
$R^2 = 0.9349$					
Adj $R^2 = 0.8885$					

a=*significant;* b=*not significant*

reasonable agreement with the "Adj R-Squared" of 0.8885. The equation below describes the quadratic model equation of water absorption.

$$Y = -138.71619 + 86.70282A + 383.48075B + 15.50000AB - 15.25491A^2 - 1153.99138B^2 \quad (6)$$

Y represents the expected water absorption, A represents the sand, and B represents the SAP. The above model equation is crucial because it can anticipate a response based on the desired values of the experiment's independent variables. The negative coefficients indicate the opposite. This interpretation is compatible with the results of the ANOVA of the quadratic model of water absorption, as shown in the equation. Based on the developed model equation, Table 11 illustrates the actual and predicted water absorption values, which are graphically shown in Figure 8.

3.3.6. Effects of the Operating Variables on the Water Absorption

As can be seen in Figure 9, it can be observed that a change in the amount of sand only had a little effect on the water absorption quality of the hollow concrete block. At the same time, the increase in the same property was evident, while there was an increase in the amount of SAP. This

Table 11. Actual vs. Predicted Water Absorption of the Hollow Concrete Blocks

Mixture	Mixture Components Ratio			Results (%)	
	A. Cement	B. Sand	C. SAP	Actual	Predicted
1	1	4.0	0.15	11.48	13.38
2	1	3.0	0.15	7.93	10.10
3	1	3.0	0.15	18.96	20.98
4	1	2.5	0.10	16.96	19.26
5	1	3.0	0.25	10.79	9.88
6	1	3.0	0.15	6.06	4.87
7	1	2.0	0.15	3.70	2.71
8	1	2.5	0.20	20.58	19.47
9	1	3.5	0.10	25.17	22.63
10	1	3.0	0.15	23.1	22.63
11	1	3.5	0.20	26.23	22.63
12	1	3.0	0.05	21.68	22.63
13	1	3.0	0.15	21.17	22.63

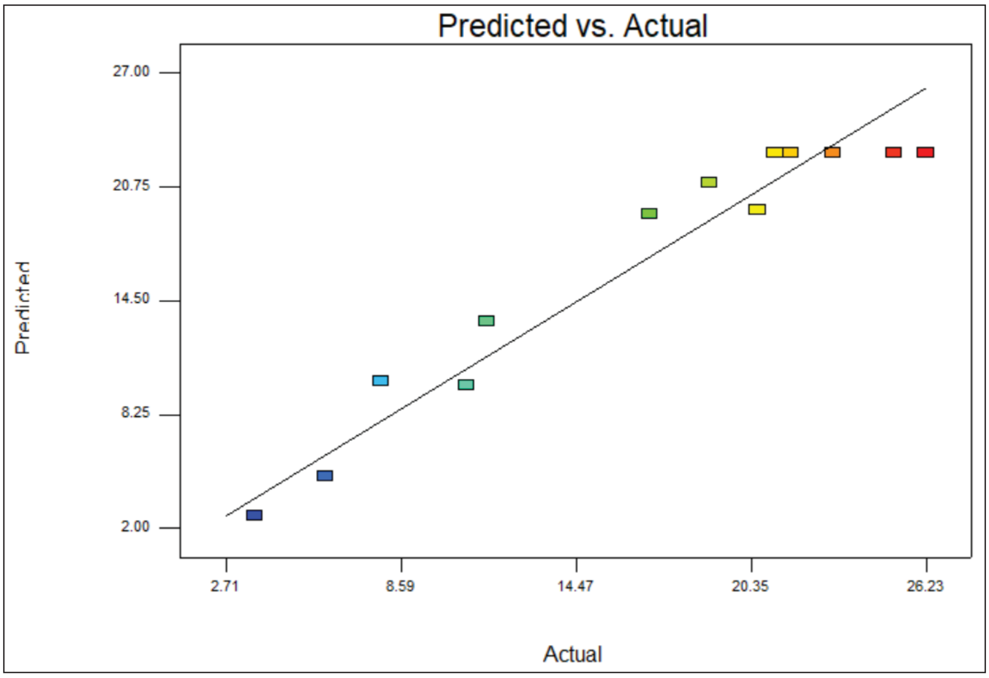

Figure 8. Diagnostic Graph on the Actual versus Predicted Water Absorption.

can be explained by the absorbent property of the superabsorbent polymer, as discussed previously in this paper. The same observation can be noted in a previous study where the addition of SAP increases the water absorption of the concrete [14]. The same observation can also be justified by the results of the analysis of variance (ANOVA) of the mixture quadratic model of the water absorption property of the HCB, as presented in Table 10, where the sand was not significant, and the SAP was substantial in affecting the water absorption quality of the hollow concrete blocks.

3.4. Theoretical Optimized Conditions for Compressive Strength, Density, and Water Absorption

Through the central composite design of the Design Expert 7.0 software, numerical optimization was done following the goals indicated in Table 12.

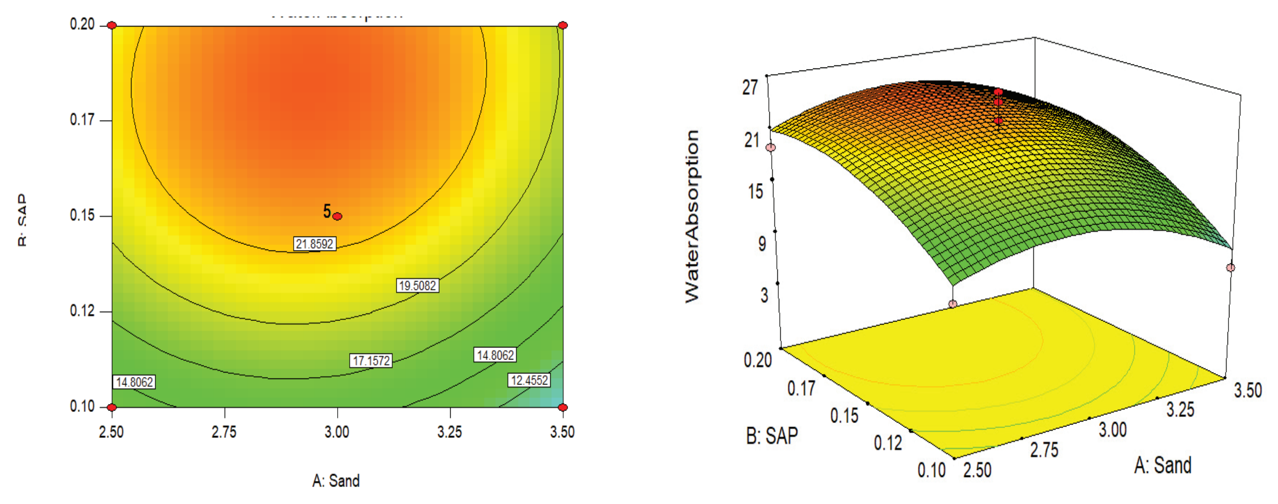

Figure 9. Contour and 3D Surface Plots of the Effects of Sand and SAP on Water Absorption.

Table 12. Numerical optimization criteria in the theoretical optimization of the production of hollow concrete blocks

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
SCR	is in range	2.0	2.5	1	1	3
SAP	is in range	0.1	0.15	1	1	5
Compressive Strength	maximize	5	20	1	1	5
Density	is in range	1900	2400	1	1	3
Water Absorption	minimize	3.7	15.0	1	1	3

Table 13. Theoretical Compressive Strength, Density, and Water Absorption of the hollow concrete blocks after numerical optimization

Solution	Operating Variables		Compressive Strength (MPa)	Density (kg/cm^3)	Water Absorption (%)	Desirability
	SCR	SAP				
1	2.00	0.110	8.20	1900	5.28	0.360
2	2.01	0.109	8.18	1900	5.38	0.357
3	2.04	0.105	8.13	1900	5.65	0.350

The sand-to-cement ratio (SCR) ranged from 2.0 to 2.5, considering that the experiment results showed that a desirable value of the properties identified was achieved at a lower SCR. The same consideration was considered in the SAP loading, which ranged from 0.1 to 0.15. The compressive strength was maximized because this study aims to have a good-quality hollow concrete block. The density was held from 1900 to 2400 concerning the ASTM standards. Finally, water absorption was minimized since it is not ideal for a hollow concrete block to have a high water absorption capacity. It may lead to decreased durability, increased risk of cracking, and reduced insulation properties.

Table 13 presents the theoretical results of an experiment investigating the effect of two operating variables, sand-to-cement ratio (SCR) and superabsorbent polymer (SAP) content, on concrete blocks' compressive strength, density, and water absorption. The table shows the values of these three output variables for three experiments with different values of the two input variables. The desirability values are calculated based on the target values for each output variable. A desirability value of 1.0 indicates that the experiment met all the target values, while a value of 0.0 indicates that the experiment did not meet any of the target values. A higher desirability value suggests that the suggestsiment is closer to meeting the target values. The

Table 14. The Philippine National Standard and the American Standard for Testing Materials for Hollow Concrete Blocks as Compared to This Study

Standards	Compressive Strength (MPa)	Water Absorption (%)	Density (kg/m³)	Reference
Philippine National Standard				
Load-bearing	11.7 – 13.1	Not more than 10% by mass	< 1680 (LW) 1680 to < 2000 (MW) > 2000 (NW)	[20,21]
Non-Load-bearing	4.14	Not more than 10% by mass	< 1680 (LW) 1680 to < 2000 (MW) > 2000 (NW)	[20,21]
American Standard for Testing Materials				
Load-bearing	11.7 – 13.1	max of 24.01%	< 1680 (LW) 1680 to < 2000 (MW) > 2000 (NW)	[22,23]
Non-Load-bearing	4.14	max of 24.01%	< 1680 (LW) 1680 to < 2000 (MW) > 2000 (NW	[23,24]
This Study	8.20	5.28%	1900	

Legend: LW-lightweight, MW-medium weight, NW-normal weight

table shows that increasing the sand-to-cement ratio (SCR) and decreasing the superabsorbent polymer (SAP) content generally leads to a decrease in compressive strength and density but an increase in water absorption. The desirability values for each experiment indicate that Solution 1 is the most desirable among the three, as it has the highest desirability value of 0.360. This suggests that the SCR of 2.00 and the SAP content of 0.110 used in Solution 1 produced concrete blocks closest to the target values for compressive strength, density, and water absorption as set in the criteria.

Theoretically, solution 1 will produce a compressive strength of 8.20 MPa, density of 1900 $kg/cm^{3,}$ and 5.28% water absorption, which all pass the Philippine National Standard (PNS) and the American Standard for Testing Materials (ASTM) for non-load-bearing hollow concrete blocks. Table 14 compares the theoretical properties of this study's hollow concrete blocks against the PNS and ASTM.

The qualities of the hydraulic cement paste, which is the active element of Portland cement concrete (PCC), are significantly responsible for the concrete's attributes and performance. Superabsorbent polymer admixtures are the components that interact in the hydrated cementitious system by physical, chemical, and physical-chemical action, modifying one or more properties and conferring specific beneficial effects to concrete, such as enhanced durability, improved workability and increased strengths, when added in small amounts (usually less than 3% wt.) to the concrete batch, immediately before or during mixing [25]. The SAPs occupy space during the manufacture of a concrete mixture. Internal cure water generated during cement hydration due to self-desiccation was utilized for further hydration and autogenous shrinkage reduction. Due to the decline in relative humidity, the water in the SAP was released into the cementitious matrix [13]. Adding various water-soluble organic polymers to new concrete batches significantly increases workability while providing strengths comparable to non-admixture concrete and several advantages over casting concrete [25].

4. CONCLUSION

This study has successfully demonstrated the potential of superabsorbent polymer (SAP) as an admixture in producing hollow concrete blocks. By adjusting the SAP percentage from 0.05% to 0.25% and maintaining constant cement and sand ratios ranging from 2.00 to 4.00, various blocks were produced and subjected to rigorous testing. The results were promising, with the blocks exceeding the compressive strength requirement set by the Philippine National Standard, thereby confirming their structural integrity and potential for load-bearing applications. Specifically, the blocks achieved a compressive strength of 8.20 MPa, significantly higher than the standard of 4.14 MPa for non-loadbearing concrete masonry. In addition to their impressive strength, the blocks exhibited a density of 1900 kg/cm^3 and a water absorption capacity of 5.28% at the optimized conditions after numerical optimization using the central composite design (CCD). These properties further attest to their durability and suitability for various construction applications. Beyond its technical contributions, this research also underscores the importance of sustainability in construction practices. Utilizing SAP as an admixture offers a practical solution to reducing solid waste and repurposing industrial by-products. This aligns with the industry's growing emphasis on sustainable construction materials and environmentally friendly practices.

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CONFLICT OF INTEREST

The authors declared no potential conflicts of interest concerning this article's research, authorship, and/or publication.

DATA AVAILABILITY STATEMENT

All graphs and data obtained or generated during the investigation appear in the published article.

AUTHOR'S CONTRIBUTIONS

Phoebe Love Candano: Drafted and wrote the manuscript and performed the experiment and result analysis. Assisted in analytical analysis. **Kate Rose Elorde:** Assisted in drafting and writing the manuscript and performed the experiment and result analysis. Assisted in analytical analysis. **Irl Rica Ann Mejos:** Assisted in drafting and writing the manuscript and performed the experiment and result analysis. Assisted in analytical analysis. **Rhoe James Cabada:** Assisted in the drafting and writing the manuscript and performed the experiment and result analysis. Assisted in analytical analysis. **Val Irvin Mabayo:** Supervised the experiment's progress and helped in the results analysis and manuscript preparation.

ETHICS

There are no ethical issues with the publication of this manuscript.

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