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ORIGINAL ARTICLE

The Effect of Sucrose and Yeast Extract on Total Phenolic, Flavonoid, and Anthocyanin of Lactic-Acid-Fermented Mangosteen Fruit Peel (*Garcinia mangostana* L.)

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ABSTRACT

Objectives: This study aimed to determine the most suitable concentration of sucrose and yeast extract (SYE) and its impact on the levels of total phenol, flavonoid, and anthocyanin (TPFA) for lactic acid fermentation in mangosteen fruit peel.

Materials and Methods: In this study, the primary components were mangosteen fruit peel, SYE, and lactic acid bacteria starter. The experimental design was conducted using the Factorial Design method. The colorimetric method was used to determine the total phenol (Folin-Ciocalteu reagent) and total flavonoid ($AlCl_3$ reagent). In addition, the differential pH method was used to determine the total anthocyanins using KCl and the CH_3COONa reagent.

Results: The addition of SYE during the fermentation of mangosteen fruit peel significantly increased the concentrations of TPFA compared with the control (*p* value of 0.0001). The high sucrose concentration and low yeast extract produced the highest TPFA levels in mangosteen rind fermentation.

Conclusion: The use of SYE affects the levels of TPFA in lactic acid-fermented mangosteen fruit peel, with the most suitable concentrations obtained using sucrose (45 g/L) and yeast extract (2.5 g/L).

Keywords: Fermentation, *Garcinia mangostana* fruit peel, sucrose, yeasts

INTRODUCTION

Herbal products are parts of plants intended for health use according to their properties and can be developed into medicinal products, food supplements, and cosmetics.[1-3] One of the plants that can be developed into herbal products is the mangosteen fruit (*Garcinia mangostana* L.). It has health benefits for the body and is dubbed the Queen of Fruits.[4] The amount of waste generated by the mangosteen processing industry is considerable, as approximately 60% of the mangosteen fruit is made up of inedible fruit peel.[5] Mangosteen fruit peel extract has been reported to contain many phenolic compounds that can help overcome health issues such as cancers, tumors, diabetes, hypertension, inflammation, and skin aging.[6-8]

The extraction process is one of the important steps that need to be determined by a researcher to obtain the desired bioactive compounds.[9,10] Fermentation is one of the natural extraction processes involving microorganisms and enzymatic processes that result in the degradation of plant cell walls

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so that phytochemical components can be released from the matrix.[11] Lactic acid fermentation has been shown in previous studies to significantly enhance the nutrient and phytochemical profile of the substrate.[12-14] A different research also suggested that lactic acid fermentation on mulberry fruit substrate significantly influences the levels of total phenol, flavonoid, and anthocyanin (TPFA) compounds.[15,16] In addition, lactic acid fermentation also causes the fermentation environment to become acidic, which correlates with the release of bioactive compounds and by-products of fermentation.[17,18] Several factors that influence the fermentation of lactic acid are the source of carbon and nitrogen, in particular their type and concentration. The carbon source used in this research is sucrose, and the nitrogen source is yeast extract.[19,20] In another study, a sucrose concentration of 15-45 g/L was used as a carbon source, and yeast extract of 2.5-7.5 g/L was used as a nitrogen source during fermentation.[19] However, the fermentation of mangosteen peel has not been widely studied as an advanced processing step to increase phytochemical components; therefore, further studies are necessary. This study aimed to determine the most suitable concentration of sucrose and yeast extract (SYE) and its impact on the levels of TPFA for lactic acid fermentation in mangosteen fruit peel.

MATERIALS AND METHODS

Mangosteen fruit peel dry simplicia (*G. mangostana* L.) was purchased from the Center for Post-Harvest Processing of Medicinal Plants (Bali, Indonesia). Other materials provided at the Unud Forensic and Criminology Laboratory included SYE, lactic acid bacteria starter, potassium chloride, sodium acetate trihydrate, hydrochloric acid, aluminum chloride, ethanol, quercetin standard, gallic acid standard, Folin-Ciocalteu, and distilled water. All materials used were of analytical grade.

Mangosteen fruit peel fermentation

The concentrations of SYE used varied; sucrose with a concentration range of 15-45 g/L and yeast extract with a concentration range of 2.5-7.5 g/L were designed with Design Expert Software using the Regular Two-Level 2^2 Factorial Design method. The design of the experiment is listed in Table 1.

Fermentation was performed on 100 g of dried simplicia of mangosteen fruit peel, SYE lactic acid bacteria starter, and water in an Erlenmeyer flask. The fermentation runs on a shaker at 100 rpm at room temperature for 4 days, equipped with an airlock. Sampling for analysis was performed at 96 hours of fermentation. The sample was centrifuged for 20 minutes at 5 C˚ and 6000 rpm. In preparation for further analysis, the samples were collected and stored at a low temperature.

Total phenolic content (TPC) determination

TPC was determined using the Folin-Ciocalteu reagent and NaOH in a colorimetric method. The sample was placed into a vial, and 10% *v/v* Folin-Ciocalteu solution was added and allowed to stand for 8 minute. 1% *v/v* NaOH solution was added and incubated for 1 hour. A blank solution was prepared in the same manner without the addition of the test solution. A ultraviolet (UV)-vis spectrophotometer was used to determine the absorbance of each solution at a wavelength of 730 nm. TPC was calculated using the linear regression equation and expressed in mg gallic acid equivalents per liter (mg GAE/L).

Total flavonoid content (TFC) determination

TFC was determined using a colorimetric technique with $AlCl_3$ and CH_3COONa reagents. The sample was put into a vial, and ethanol, $AlCl_3$ 10%, CH_3COONa 1M CH3COONa, and water. Shaken and incubated at room temperature for 30 minutes. Similarly, a blank solution was prepared without using the test solution. A UV-vis spectrophotometer was used to determine the absorbance at a wavelength of 425 nm. TFC was calculated using the linear regression equation and expressed in mg QE/L.

Total anthocyanin content (TAC) determination

The sample was initially dissolved in KCl buffer at pH 1, which was used to establish the proper dilution factor for the sample. The sample was placed into several different vials. While the remaining vials received a pH 4.5 buffer solution (0.4 M CH_3COONa), the other vials received a pH one buffer solution (0.025 M KCl). After incubation for 15 minutes, the absorbance of all test solutions was measured at 520 and 700 nm. The quantity of all anthocyanins was calculated using the following calculation:

$$TAC = [(A_{520}-A_{700})_{pH1.0}-(A_{520}-A_{700})_{pH4.5}]/(\varepsilon \times l) \times \text{molecular weight (MW)} \times \text{dilution factor (DF)} \times 1000$$

where TAC stands for TAC (mg Cyanidin-3-glucoside/L), A stands for absorbance of each wavelength at a different pH, stands for molar absorptivity coefficient (26.900 L/mol.cm), MW stands for molecular weight (449.2 g/mol), DF stands for dilution factor, l stands for path length in cm (1 cm), and 1000 stands for the factor of conversion from g to mg.

Table 1. Mangosteen peel fermentation run using the factorial design method: regular two level 2^2

Run	Level		Concentration	
	A: Sucrose	B: Yeast extract	Sucrose (g/L)	Yeast extract (g/L)
1	-1	-1	15	2.5
2	-1	+1	15	7.5
3	+1	-1	45	2.5
4	+1	+1	45	7.5

Statistical analysis

In this study, experimental design was used using the Regular Two Factorial Design 2^2 method. Determination of the optimum conditions based on the highest response of TPC, TFC, and TAC levels during 96 hours of fermentation. The effect of SYE and their optimum levels to be used in mangosteen rind fermentation were analyzed using analysis of variance (ANOVA) integrated in the design expert software with several parameters, such as *f* value, *p value*, R squared, Predicted R squared and Adeq Precision. In addition, the influential factors in fermentation can be described in a linear equation.[21]

RESULTS

TPC determination

The link between the standard concentration of gallic acid and its absorbance was calculated in this study and the equation y= 0.0094 x 0.1317 was obtained, as shown in Figure 1. The results of the TPC determination are shown in Table 2.

TFC determination

The link between the standard concentration of quercetin and its absorbance was calculated in this study, and the equation y= 0.0077 x 0.4372 was obtained, as shown in Figure 2. The results of the TFC determination are shown in Table 3.

TAC determination

The results of the TAC determination are shown in Table 4.

Analysis

All data inputted and analyzed using ANOVA can be seen in Table 5.

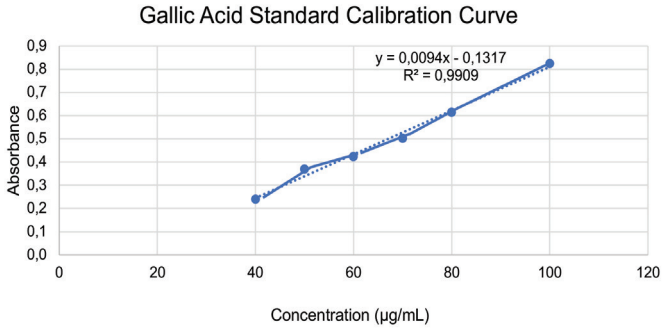

Figure 1. Gallic acid standard calibration curve

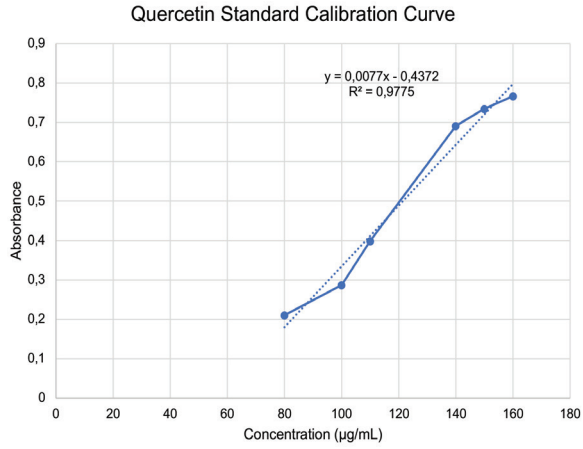

Figure 2. Quercetin standard calibration curve

Table 2. Results of the TPC determination of lactic acid-fermented mangosteen fruit peel

Sample	Replication	TPC (mg GAE/L)	Average value of the TPC (mg GAE/L) ± SD
Non-fermented mangosteen fruit peel (control)	1	592.65	593.62 ± 0.84
	2	593.93	
	3	594.25	
Run 1	1	665.96	666.10 ± 0.16
	2	666.10	
	3	666.28	
Run 2	1	684.47	684.47 ± 0.21
	2	684.26	
	3	684.68	
Run 3	1	791.91	792.20 ± 0.33
	2	792.13	
	3	792.55	
Run 4	1	681.06	681.17 ± 0.18
	2	681.06	
	3	681.38	

TPC: Total phenolic content, GAE: Gallic acid equivalents, SD: Standard deviation

DISCUSSION

Mangosteen fruit peel fermentation

Fermentation of mangosteen fruit peel was carried out using four Erlenmeyer, each filled with 100 g of mangosteen fruit peel dry simplicia, sucrose at a concentration between 15 and 45 g/L, yeast extract at a concentration between 2.5 and 7.5 g/L, and lactic acid bacteria starter at a concentration as high as 10 mL. The elements needed by lactic acid bacteria for growth and reproduction are carbon and nitrogen sources, which can be obtained through SYE.[19] Fermentation runs at room temperature, which is around 30 C˚ with constant stirring, where temperatures between 30 and 40 C˚ are ideal for promoting the development of lactic acid bacteria.[22] Constant stirring during fermentation was also performed on a shaker at

Table 3. Results of TFC determination of lactic acid-fermented mangosteen fruit peel

Sample	Replication	TFC (mg QE/L)	Average value of the TFC (mg QE/L) ± SD
Non-fermented mangosteen fruit peel (control)	1	200.13	200.03 ± 0.10
	2	200.05	
	3	199.92	
Run 1	1	239.17	239.37 ± 0.19
	2	239.43	
	3	239.53	
Run 2	1	252.94	253.01 ± 0.33
	2	252.73	
	3	253.38	
Run 3	1	311.48	311.28 ± 0.19
	2	311.27	
	3	311.09	
Run 4	1	301.77	301.94 ± 0.96
	2	301.09	
	3	302.98	

TFC: Total flavonoid content, QE: Quercetin equivalent, SD: Standard deviation

Table 4. Results of TAC determination of lactic acid-fermented mangosteen fruit peel

Sample	Replication	TAC (mg C3GE/L)	Average value of the TAC (mg C3GE/L) ± SD
Non-fermented mangosteen fruit peel (control)	1	3.45	3.49 ± 0.03
	2	3.51	
	3	3.52	
Run 1	1	4.67	4.67 ± 0.04
	2	4.64	
	3	4.71	
Run 2	1	3.53	3.58 ± 0.05
	2	3.58	
	3	3.62	
Run 3	1	6.60	6.64 ± 0.21
	2	6.45	
	3	6.88	
Run 4	1	2.08	2.14 ± 0.05
	2	2.19	
	3	2.15	

TAC: Total anthocyanin content, SD: Standard deviation

100 rpm. Constant stirring at 100 rpm will improve lactic acid bacteria's rate of growth during fermentation.[23]

With microbes, the process of fermentation helps break down organic macromolecules into simpler ones.[9] The purpose of fermentation on mangosteen peel is to increase the phytochemical components contained in it, namely phenol group compounds, flavonoids, and anthocyanins, which produce fermentation by-products in the form of lactic acid, which has many benefits. The production of organic acids that make the environment acidic will increase the solubility of phenolic compounds in water. The optimal pH in the extraction process of phenol compounds is in acidic conditions in the 3.0-5.3 pH range. The degradation of phenolic compounds is directly related to the pH level.[24]

In lactic acid fermentation, sucrose first undergoes hydrolysis to become the simplest sugar, namely glucose. Hexokinase, phosphogluconolactonase, and epimerase enzymes were produced by lactic acid bacteria and play a role in converting glucose through a series of chemical modifications. It also enters the phosphoketolase pathway and undergoes new chemical modifications to produce pyruvate, which can then be converted to lactic acid by the enzyme lactate dehydrogenase. The nitrogen source used in fermentation, namely yeast extract, also contains many nutrients in the form of vitamins, amino acids, and pyruvate so this will also affect the proliferation of lactic acid bacteria.[25]

The fermented mangosteen fruit peel samples were then subjected to phase separation using a centrifuge at 6000 rpm for 20 minutes. Centrifugation is performed to separate yeast extract, lactic acid bacteria, and powdered simplicia so that the fermentation process can be stopped. Sample centrifugation has a working principle, namely the application of centrifugal force and sedimentation to separate particles based on their specific gravity or density. The centrifugation results will separate two phases, namely, the supernatant and pellet. The supernatant is the result of centrifugation with a lower specific gravity than the pellets, whereas the pellets are the result of centrifugation with a higher specific gravity than the supernatant. The pellet is at the bottom of the centrifugation tube.[26] Water has a density of 0.99 g/mL, sucrose has a density of 1.6 g/mL, and yeast extract has a density of 1.4 g/mL. This shows that compared with water, SYE have a larger density. The components of sucrose, yeast extract, and simplicia will be at the bottom of the tube.

Table 5. Data analysis

Source	*f* value	*p* value	
Determination of the TPC			
Model	218642.77	< 0.0001	Significant
A-Sucrose	244356.76	< 0.0001	
B-Yeast extract	139042.57	< 0.0001	
AB	272698.57	< 0.0001	
Determination of the TPC			
Model	22933.01	< 0.0001	Significant
A-Sucrose	66446.12	< 0.0001	
B-Yeast extract	109.11	< 0.0001	
AB	2243.79	< 0.0001	
Determination of TAC			
Model	826.88	< 0.0001	Significant
A-Sucrose	16.24	0.0038	
B-Yeast extract	1796.47	< 0.0001	
AB	667.93	< 0.0001	

TPC: Total phenolic content, TFC: Total flavonoid content, TAC: Total anthocyanin content

TPC determination

The Folin-Ciocalteu and NaOH reagents were used in the spectrophotometric method to measure TPC levels. The basic principle of this method is the oxidation of phenolic-hydroxyl groups. Folin-Ciocalteu reagent will oxidize phenol and reduce heteropoly acids into a molybdenum-tungsten (Mo-W) complex. When the sample is treated with the Folin-Ciocalteu reagent, a greenish-yellow hue is produced, which indicates a phenolic compound. The amount of phenolic compounds present correlates exactly with the amount of blue color produced by this reaction.[27-29] TPC is expressed in mg GAE/L.

Compared with the control group in this study, the TPC of the lactic acid-fermented mangosteen fruit peel was significantly higher. Lactic acid bacteria produce several enzymes like β-glycosidase that play a role in β-glycoside hydrolysis, as well as the production of decarboxylase, esterase, hydrolase, and reductase, which have a significant influence on increasing the phenolic levels in mangosteen fruit peel fermentation.[30-32] In addition, it is also influenced by the constant stirring carried out during fermentation. According to previous research, constant stirring during fermentation causes hydrolysis of the glycoside bond but does not degrade the phenolic aglycone.[33] The increase in phenolic components is also caused by an

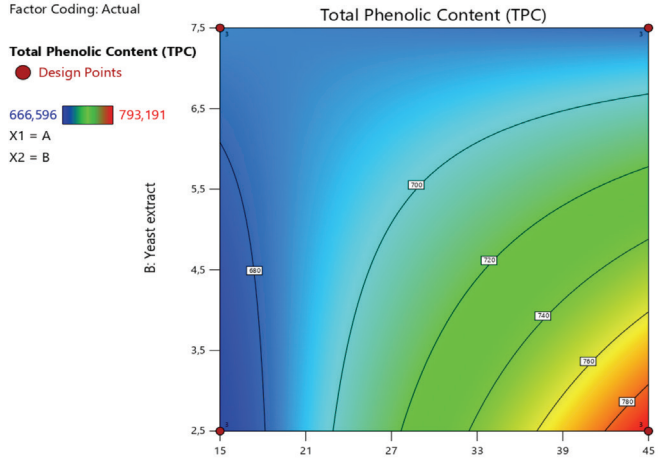

Figure 3. Contour plot of the relationship between SYE concentration in mangosteen fruit peel fermentation to its TPC

TPC: Total phenolic content, SYE: Sucrose and yeast extract

increase in extraction ability and the release of phenolic compounds from bound forms to free forms.[34] The contour plot of the relationship between SYE concentration in mangosteen fruit peel fermentation and its TPC is shown in Figure 3.

Based on the *p* value of 0.0001, the contour plot of the TPC test results of mangosteen (*G. mangostana* L.) fruit peel fermentation with different amounts of SYE showed significant results. This value indicates that the mathematical model used to calculate the TPC of the fermentation products can accurately capture the real conditions. The following linear equation represents the total phenol test results from the factorial design calculation.

y= 6.36 (A) +16.66 (B) -0.83 (A*B)

Where y= TPC; A= sucrose; B= yeast extract; and A*B= interaction between SYE. Based on the equation obtained, it can be interpreted that an increase in the SYE components can increase the total phenol content during fermentation. However, the interaction between the two can reduce the total phenol content. The resulting *R squared* value is 1.000, and the resulting pred *R squared* value is 1.000. This indicates that the predicted value is the same as the *R* value generated in actual experiments. The resulting Adeq Precision value is 1016.4183. Adeq Precision is required to measure the noise level of an experiment, and this value is expected to be more than 4.

TFC determination

The UV-vis Spectrophotometric technique with an $AlCl_3$ and CH_3NOONa reagent was used in this study to determine the TFC. The basic principle behind the use of this method is the high affinity to bind $AlCl_3$ metal ions to form Al (III)-flavonoid chelates. The addition of $AlCl_3$ will cause the OH group on C3 and C5 to form a stable complex, causing the solution to turn yellow. Furthermore, the addition of CH3NOONa is known to create an acidic atmosphere that will form a complex compound so that the solution turns pink, where the absorbance will be measured.[35] TFC was measured at a wavelength of 425 nm using quercetin standards and $AlCl_3$ and CH_3NOONa reagents. TFC is expressed as the amount of quercetin in milligrams per liter of sample (mg QE/L) or mg quercetin.

A significant difference was found between the TFC of the lactic acid-fermented mangosteen fruit peel and the control group. The increase in flavonoid compounds is caused by changes in the environment, which becomes more acidic because of organic acid synthesis by lactic acid bacteria, which triggers the release of bound flavonoid components and increases their availability in water in their free form.[36] Figure 4 shows the contour plot showing the relationship between the concentration of SYE in mangosteen fruit peel fermentation and the total amount of flavonoids present.

Based on the p value of 0.0001, the contour plot of the TFC test results of mangosteen (*G. mangostana* L.) fruit peel fermentation with different amounts of SYE showed significant results. This value indicates that the mathematical model used to calculate the TFC of the fermentation results can accurately capture the real conditions. The following linear equation shows the results of the factorial design calculation for the total flavonoid assay.

y= 2.768 (A) +4.957 (B) -0.148 (A*B)

Where Y is the TFC; A is sucrose; B is yeast extract; and A*B is the interaction between SYE. According to the equation, an increase in the SYE components can increase the TFC during fermentation. However, the interaction between the two can decrease the TFC. The resulting R squared value is 0.999, as is the resulting pred R squared value. This means that the predicted value is the same as the R value obtained from the experiments. The resulting Adeq Precision value is 434.3983. Adeq Precision is required to measure the noise level of an experiment, and this number is predicted to be greater than 4.

TAC determination

The difference in absorbance caused by the change in anthocyanin structure due to pH changes drives the differential pH technique used to measure the TAC. Anthocyanins in strongly acidic conditions at pH 1 have a colored flavellum cation (oxonium) form, whereas those in weak acidic conditions at pH 4.5 have a pseudo base carbinol (hemiketal) form that does not produce color.[37,38] At pH 4.5, most anthocyanin monomers are in the hemiketal state; however, polymerized anthocyanins and non-enzymatic browning pigments are not reversible to pH changes and must be omitted from absorbance calculation.[37,39] As a result, the difference in absorbance values between pH 1 and 4.5 at the maximum wavelength of the anthocyanins is directly proportional to the anthocyanin content.[37]

In comparison with the control group, the mangosteen fruit peel's TAC was considerably greater. The use of sugar and yeast extract during fermentation contributes to the increase in TAC. Pyruvate from the fermentation process and yeast extract is converted to acetaldehyde during sucrose glycolysis, which acts as a terminal electron acceptor in the production of ethanol. Pyruvate and acetaldehyde are produced in the cytoplasm of yeast extracts and metabolized simultaneously,

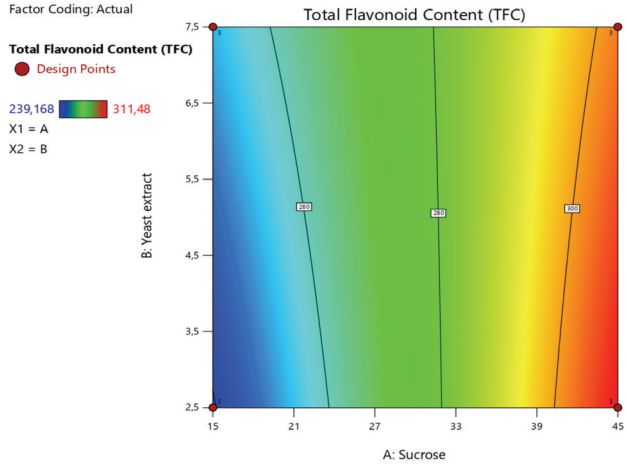

Figure 4. Contour plot of the relationship between SYE concentrations in mangosteen fruit peel fermentation to its TFC

TFC: Total flavonoid content, SYE: Sucrose and yeast extract

with pyruvate being decarboxylated to acetaldehyde or used to produce acetyl CoA. However, some of them will diffuse out of the cell and become reactive, allowing them to attack other molecules and facilitate the transition of anthocyanins into various derivative compounds such as proanthocyanins. The most important anthocyanin derivatives in the fermentation products are proanthocyanidin. Pyruvate and anthocyanins react to form proanthocyanidin carboxy compounds (visitin type A), whereas acetaldehyde and anthocyanins react to form anthocyanin 3-O-glycoside-4-vinyl (visitin type B).[40] However, compared with the control group, run 4 had lower numbers of total anthocyanins. This is due to the degradation of anthocyanin compounds through hydrolysis by glucosidase and polyphenol oxidase enzymes, which break the glycoside bond between the aglycone and glycine groups. The hydrolysis process converts anthocyanin molecules to the chalcone form and ultimately to aldehydes and phenolic acids. As a result, the component identified as cyanidin-3-glucoside on the spectrophotometer was lower in the test group than in the control group. Figure 5 shows a contour plot of the relationship between sugar and yeast extract concentrations in mangosteen fruit peel fermentation and TAC.

The contour plot of the TAC test results of mangosteen (*G. mangostana* L.) peel fermentation with varying amounts of SYE indicates significant results based on a p value of 0.0001. This figure shows how the equation model used can describe the actual conditions for calculating the TAC of the fermentation results. The results of the factorial design calculation for the total anthocyanin assay are shown in the linear equation below.

$$Y = 0.12\,(A) + 0.12\,(B) - 0.02\,(A*B)$$

Where Y is the TAC, A is sucrose, B is yeast extract, and A*B is the reaction between the two. Based on the equation found, it can be deduced that during fermentation, an increase in the components of yeast extract and sucrose can lead to an increase in the total amount of anthocyanins. However, the combined anthocyanin content may decrease because of their interaction. The *R squared* value obtained is 0.9968, whereas the pred *R squared* value obtained is 0.9928. This shows that the *R* value obtained from the actual experiments and the predicted value is identical. 68.2291 is the derived Adeq Precision value. To quantify the noise level of an experiment, Adeq Precision is required, and this value is expected to be greater than 4.

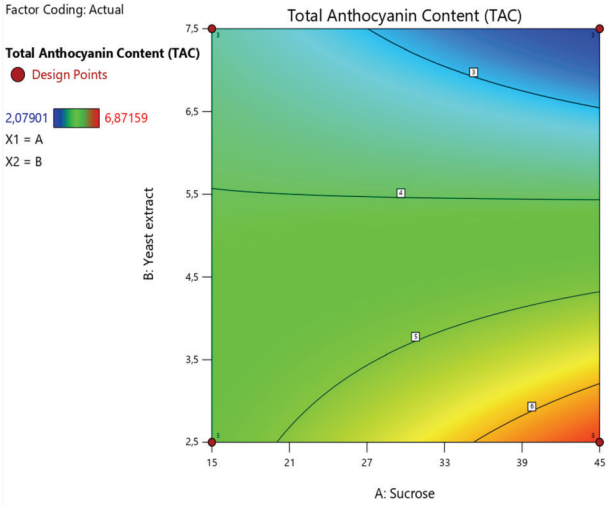

Figure 5. Contour plot of the relationship between SYE concentration in mangosteen fruit peel fermentation to its TAC

TAC: Total anthocyanin content

CONCLUSION

The use of sucrose as a carbon source at a high concentration (45 g/L) and yeast extract as a nitrogen source at a low concentration (2.5 g/L) resulted in a significant increase in total phenol, flavonoid, and anthocyanin levels compared with the control group. An increase in the components of yeast extract and sucrose can increase the concentrations of total phenol, flavonoids, and anthocyanin. However, their interaction may decrease its concentration.

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Ethics

Ethics Committee Approval: Not required.

Informed Consent: Not required.

Authorship Contributions

Concept: I.M.A.G.W., E.I.S., Design: P.S.Y., I.M.A.G.W., Data Collection or Processing: K.D.A.P., G.A.D.P., Analysis or Interpretation: K.D.A.P., E.I.S., P.S.Y., Literature Search: K.D.A.P., Writing: K.D.A.P., G.A.D.P.

Conflict of Interest: No conflict of interest was declared by the authors.

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