ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol. Technol. Aliment. 24(1) 2025, 67–76
www.food.actapol.net pISSN 1644-0730 eISSN 1898-9594 http://doi.org/10.17306/J.AFS.001272

ORIGINAL PAPER

Received: 13.08.2024
Accepted: 27.11.2024

OPTIMIZATION OF FRUIT WINE PRODUCTION FROM PINEAPPLE (*ANANAS COMOSUS* (L.) MERR.) USING *SACCHAROMYCES CEREVISIAE* RV002

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ABSTRACT

Background. Pineapple, also known as *Ananas comosus*, is ranked third in terms of production among tropical fruits. It is renowned for its distinctive aroma and numerous health benefits. As well as being an alcoholic beverage, wine is similarly well-known for its appealing flavor and health advantages. Grapes and other kinds of fruits, including pineapple, can be used as raw materials for wine production.
Materials and methods. Initial conditions, including total soluble solids, pH, and yeast inoculation concentrations, were optimized to maximize efficiency after fermentation. Fermentation time was also investigated, and the effectiveness of scaling up fermentation by 10 times was investigated.
Results. The optimized initial conditions include a pH of 4.5, the addition of sugar to bring the total soluble solids to 23°Brix, and inoculation of the pineapple juice with 0.04% (w/v) yeast. An investigation into the effect of fermentation time on wine production revealed no significant difference in the ethanol content after 8, 10, and 12 days of fermentation, which were determined to be 13.72%, 13.81%, and 14.12% (v/v), respectively. Similarly, no significant difference was observed between the 1-L scaled and non-scaled treatments, which resulted in ethanol contents of 13.55% and 14.62% (v/v), respectively.
Conclusion. Based on the validation of the optimization models, which demonstrated their high efficiency and consistency during ethanol production, the initial conditions specified in the results were selected. Due to the insignificant differences in results between treatments, 8 days was determined to be the most appropriate fermentation time. Finally, it was concluded that the fermentation process could be scaled up tenfold in volume without any adverse impact on wine production.

Keywords: alcoholic fermentation, *Ananas comosus*, fruit wine, pineapple, *Saccharomyces cerevisiae*

INTRODUCTION

Wine is a well-known and ancient alcoholic beverage with an appealing flavor and potential health benefits. Its flavor and aroma results from many interactions between various chemical compounds and sensory receptors (Styger et al., 2011). The chemical profile of a wine is derived from many factors, and the raw materials (normally grapes) used for the fermentation process are one of those factors. It is noticeable that

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besides grapes, many other fruits have been used as raw materials for the fermentation process, and alcoholic beverages produced with these fruits are called fruit wines (Saranraj et al., 2017).

Pineapple is a tropical fruit ranked third in global tropical fruit production after bananas and citrus (Ali et al., 2020). It is widely recognized for its distinctive aroma and numerous nutritional benefits (Hossain et al., 2015). Pineapple is rich in vitamins and minerals, including potassium, copper, manganese, calcium, magnesium, vitamin C, β-carotene, thiamin, B6, and folate, as well as soluble and insoluble fiber and bromelain (Hossain et al., 2015). It can be consumed fresh and is notable for its high moisture, sugar content, vitamin C content, and low crude fiber, which significantly contribute to its suitability for fermentation (Hossain, 2016). Owing to these properties, pineapple, like many other fruits, can be used as a key ingredient in the production of alcoholic beverages.

Commonly, *Saccharomyces cerevisiae* has been commercialized as dry yeast, which is used in various forms of winemaking (Mendoza et al., 2018). In Vietnam, these commercial yeast sources are widely used for wine and breadmaking, valued for their convenience and simplicity.

Typically, the investigation of the effects of one factor on fermentation involves varying the factor of interest while keeping the other factors constant. However, this approach often fails to capture the total impact of all aspects of the process and can be time-consuming. Optimized experimental design models provide an alternative approach in which the impact of multiple factors can be evaluated simultaneously and optimal conditions can be determined through statistical modeling, which is more efficient. In addition, using software to design experiments helps reduce the total number of experiments whilst ensuring overall process optimization. Previous studies on the optimization of fruit wine fermentation conditions include research on wine made from mango (Kumar et al., 2009), mulberry (Wang et al., 2013), apple (Peng et al., 2015), and longan (Liu et al., 2018).

In this context, the present study focuses on the optimization of fruit wine production using pineapple as the primary ingredient and the yeast strain *Saccharomyces cerevisiae* RV002 for fermentation.

MATERIALS AND METHODS

Materials and chemicals

Materials

Pineapple was purchased from a local market in Can Tho City, Vietnam. The *Saccharomyces cerevisiae* RV002 used in the experiment was a commercial strain (Angel Yeast Co., Ltd.).

Chemicals

Dinitrosalicylic acid (DNS, Merck, Germany), $KNaC_4H_4O_6.4H_2O$ (Merck, Germany), $NaHSO_3$ (Xilong, China), Na_2CO_3 (HiMedia, India), citric acid (Merck, Germany), and NaOH (Xilong, China) were from commercial suppliers.

Preparation of pineapple juice

The procedure for preparing pineapple juice was a modified version of the method described by Shukla et al. (2013). All steps were performed at room temperature. First, the pineapple was washed carefully, and the crown and peel of the fruit were removed. The flesh of the fruit was cut into small pieces for easy blending and to remove the core. After blending, the pineapple juice was filtered to remove any excessive residue before being used in further applications.

Overall procedure

After filtration, the fruit juice was diluted with distilled water to a desired dilution ratio of 1:2 v/v. The total soluble solids and pH of the juice were then adjusted by adding sugar, citric acid, or Na_2CO_3 to establish appropriate initial conditions for fermentation. The juice was then pasteurized with 140 mg/L $NaHSO_3$ for 2 hours to eliminate undesirable microorganisms. Subsequently, the desired concentration of *Saccharomyces cerevisiae* RV002 was inoculated into the pasteurized juice, which was covered with food wrap. The inoculated juice was then left to ferment at room temperature (28–30°C) for the specified period. The fully fermented juice was evaluated based on several parameters, including ethanol content, pH, Brix, and reducing sugar content.

The ethanol content of the product was determined using a distillation method based on the procedure described by Nguyen and Nguyen (2005). First, 100 mL of the fermented product was added to a round-bottomed

flask. The flask was then connected to the distillation system and heated, causing the alcohol to evaporate. The evaporated alcohol was cooled and condensed back into liquid form to obtain pure ethanol. An alcoholmeter and thermometer were used to measure the ethanol content, and the results were compared with a hydrometer alcohol chart to estimate the ethanol content.

The carbohydrate content and pH of the product were measured using a hand refractometer (Atago Mater-T 2312, 0-33°Brix, France) and a pH meter (Hanna HI2002-02, Romania).

The reducing sugar content was evaluated using the DNS method. A mixture of 2 mL of the product and 2 mL of DNS solution was placed in a water bath, heated and then allowed to cool. A UV-Vis spectrophotometer (Genesys 10-S, Thermo Fisher Scientific Inc.) was used to measure the absorbance of the product at a wavelength of 540 nm. The results were compared to the standard curve, prepared using glucose, to calculate the reducing sugar content of the product (Miller, 1959).

Optimization of wine production from pineapple

The optimization of wine production from pineapple was based on the Central Composite Design (CCD) model and carried out with three replicates (Kayaroganam, 2021). The factors used in the optimization were total soluble solids (TSS), pH, and yeast inoculation concentration (YC). The CCD model, designed using Design-Expert 11.0, included 20 treatments, comprising 6 central points and 6 axial points (Kumar et al., 2009). The factors and levels used in the CCD are displayed in Table 1. After fermentation, ethanol content, pH, TSS, and reducing sugar content were evaluated as previously described.

Table 1. Factors and levels for central composite design (CCD)

Factors	Levels				
	–α	–1	0	1	+α
pH	3.7	4	4.5	5	5.3
Total soluble solids, °Brix	18	20	23	26	28
Yeast concentration, %	0.023	0.03	0.04	0.05	0.057

Investigation of the effects of fermentation time on wine production from pineapple

The treatment with optimal efficiency was selected to investigate the effects of different fermentation times on wine production from pineapple. All treatments followed the procedure described by Van Rooney and Tromp (1982). After yeast inoculation, the juice was left to ferment for 4, 6, 8, 10, or 12 days. In addition, all treatments were carried out in triplicate, and their yields after fermentation—including pH, TSS, reducing sugar content and ethanol content – were evaluated.

Investigation of the efficiency of 1-L scaled-up wine production from pineapple

The juice volume was scaled up from 100 mL to 1 liter. The initial conditions for the scaled-up fermentation process, including pH, TSS, and yeast inoculation concentration, were identical to those in the 100 mL fermentation process. The yields after scaled-up fermentation were evaluated as described above.

Sensory evaluation of wine made from pineapple

Wine produced under optimal conditions was filtrated using the vacuum method after 8 days of fermentation, and its sensorial qualities were then assessed according to Vietnam Standard 3217:79, which includes indicators of clarity and color, aroma, and taste (Vietnam National Standard TCVN 3217:79, 1979).

RESULTS AND DISCUSSION

Optimization of wine production from pineapple

The optimization of process factors to maximize the alcohol content of wine from pineapple fruit was achieved using a central composite design (CCD), which is a type of response surface methodology. The CCD included full factorial cores encompassing three numeric factors. These numeric factors featured low and high factorial levels, low and high axial levels, and center points. The results of the design matrix, along with the response data, are presented in Table 2.

Based on the data presented in Table 2, the ethanol content was affected by pH, Brix level, and initial yeast concentration during the fermentation process.

After 8 days of fermentation, the results show that the pH, Brix, and reducing sugar content all tended to decrease in all treatments. This decline reflects sugar

Table 2. Results of pH, TSS, ethanol content, and reducing sugar content after fermentation in optimally designed treatments

Treatment	Initial conditions			Post-fermentation			
	pH	TSS °Brix	YC %	pH	TSS °Brix	Ethanol % v/v	Reducing sugar g/100 mL
1	3.7	23	0.04	$3.64^{g} \pm 0.09$	$8.67^{c} \pm 0.58$	$11.54^{d} \pm 0.33$	$6.64^{cd} \pm 0.69$
2	4.0	20	0.03	$3.86^{f} \pm 0.01$	$5.00^{e} \pm 0.00$	$11.91^{cd} \pm 0.49$	$4.98^{def} \pm 0.09$
3	4.0	20	0.05	$3.88^{f} \pm 0.01$	$5.00^{e} \pm 0.00$	$11.92^{cd} \pm 0.00$	$4.87^{def} \pm 0.12$
4	4.0	26	0.03	$3.90^{f} \pm 0.01$	$10.33^{b} \pm 0.58$	$12.11^{bcd} \pm 0.32$	$9.20^{b} \pm 0.47$
5	4.0	26	0.05	$3.90^{f} \pm 0.02$	$10.67^{b} \pm 0.58$	$12.29^{bcd} \pm 0.32$	$9.08^{b} \pm 0.47$
6	4.5	18	0.04	$4.47^{a} \pm 0.00$	$5.00^{e} \pm 0.00$	$10.11^{e} \pm 0.65$	$5.34^{def} \pm 0.32$
7	4.5	23	0.023	$4.44^{a} \pm 0.05$	$7.00^{d} \pm 0.00$	$13.06^{abc} \pm 0.00$	$5.43^{def} \pm 0.08$
8	4.5	23	0.04	$4.16^{e} \pm 0.01$	$7.67^{cd} \pm 0.58$	$13.90^{a} \pm 0.49$	$4.92^{def} \pm 0.06$
9	4.5	23	0.04	$4.17^{e} \pm 0.04$	$8.00^{cd} \pm 0.00$	$13.62^{a} \pm 0.00$	$5.11^{def} \pm 0.17$
10	4.5	23	0.04	$4.21^{cde} \pm 0.01$	$7.67^{cd} \pm 0.58$	$13.90^{a} \pm 0.27$	$4.73^{ef} \pm 0.21$
11	4.5	23	0.04	$4.21^{de} \pm 0.03$	$7.00^{d} \pm 0.00$	$13.05^{abc} \pm 0.49$	$4.48^{f} \pm 0.29$
12	4.5	23	0.04	$4.19^{de} \pm 0.05$	$7.33^{d} \pm 0.58$	$13.62^{a} \pm 0.00$	$4.42^{f} \pm 0.12$
13	4.5	23	0.04	$4.21^{cde} \pm 0.01$	$7.67^{cd} \pm 0.58$	$13.62^{a} \pm 0.00$	$4.56^{f} \pm 0.52$
14	4.5	23	0.057	$4.45^{a} \pm 0.01$	$7.33^{d} \pm 0.58$	$12.77^{abc} \pm 0.00$	$4.78^{ef} \pm 0.58$
15	4.5	28	0.04	$4.17^{e} \pm 0.01$	$14.33^{a} \pm 0.58$	$13.05^{abc} \pm 0.49$	$16.57^{a} \pm 1.95$
16	5.0	20	0.03	$4.26^{bcd} \pm 0.01$	$5.00^{e} \pm 0.00$	$11.25^{de} \pm 0.66$	$5.52^{def} \pm 0.09$
17	5.0	20	0.05	$4.30^{bc} \pm 0.02$	$5.00^{e} \pm 0.00$	$11.16^{de} \pm 0.59$	$5.29^{def} \pm 0.13$
18	5.0	26	0.03	$4.32^{b} \pm 0.02$	$11.00^{b} \pm 0.00$	$13.06^{abc} \pm 0.00$	$8.44^{b} \pm 0.41$
19	5.0	26	0.05	$4.33^{b} \pm 0.03$	$10.67^{b} \pm 0.58$	$13.15^{ab} \pm 0.66$	$7.57^{bc} \pm 0.61$
20	5.3	23	0.04	$4.18^{de} \pm 0.03$	$8.00^{cd} \pm 0.00$	$12.11^{bcd} \pm 0.32$	$6.35^{cde} \pm 0.73$

The data are the means of three replicates of each treatment. Different lowercase letters indicate significantly different values within each column at p-value < 0.05.

consumption by yeast, which converts sugars into ethanol and by-products. The pH of all treatments decreased compared with the initial pH due to CO_2 and organic acids formed during fermentation. The Brix level after fermentation also decreased compared with the initial adjusted Brix level, indicating that some sugar was used by the yeast to increase biomass (Bergman, 2001) and convert sugar into ethanol (Dickinson and Kruckeberg, 2006). Moreover, the reducing sugar content after fermentation was consistent with the recorded TSS value, reflecting efficient yeast metabolism. Decreased values of pH, Brix, and reducing sugar content are often observed in fruit wine fermentation. This result is also consistent with Idise (2012) and Balogun et al. (2017). The results of analysis of variance (ANOVA) and statistical significance are presented in Table 3.

The ANOVA results show that the model has a p-value less than 0.0001, indicating that it is statistically significant and effectively explains the variations in the response variable. As shown in Table 3, the p-values for B (total soluble solids), AB (interaction between pH and total soluble solids), A^2 (quadratic effect

Table 3. Analysis of variance (ANOVA) of the model

Source	Sum of Squares	df	Mean Square	F-value	*p*-value	
Model	19.41	9	2.16	22.64	< 0.0001	significant
A-pH	0.1332	1	0.1332	1.40	0.2644	
B-TSS	6.35	1	6.35	66.68	< 0.0001	
C-YC	0.0065	1	0.0065	0.0681	0.7994	
AB	1.30	1	1.30	13.69	0.0041	
AC	0.0045	1	0.0045	0.0474	0.8321	
BC	0.0153	1	0.0153	0.1607	0.6969	
A^2	5.45	1	5.45	57.17	< 0.0001	
B^2	7.09	1	7.09	74.41	< 0.0001	
C^2	0.7584	1	0.7584	7.96	0.0181	
Residual	0.9528	10	0.0953			
Lack of Fit	0.4711	5	0.0942	0.9780	0.5094	not significant
Pure Error	0.4817	5	0.0963			
Cor Total	20.36	19		R^2	0.9532	
Std. Dev.	0.3087		Adjusted R^2		0.9111	
Mean	12.56		Predicted R^2		0.7903	
C.V., %	2.46		Adeq Precision		14.3446	

of pH), B^2 (quadratic effect of total soluble solids), and C^2 (quadratic effect of yeast concentration) are all less than 0.05, suggesting that these terms have significant effects on the outcome. Additionally, the F-value and p-value for the lack of fit are estimated to be 0.9780 and 0.5094, respectively, indicating that there is no significant lack of fit. This lack of significant fit further suggests that the model adequately fits the data, with observed errors likely arising from random noise rather than model inadequacy. In addition, the closer the coefficient of determination R^2 is to 1, the stronger the correlation between the experimental and predicted values (Umeh et al., 2015). The regression model was found to be very significant in this investigation (R^2 = 0.9659). Myers et al. (2016) pointed out that to evaluate the effectiveness of the model, not only R^2 but also adjusted R^2 and predicted R^2 should be evaluated. The predicted R^2 of 0.7903 was in reasonable agreement with the adjusted R^2 of 0.9111, which indicates that the model (which included pH, TSS and yeast concentration) explained 91.1% of the variation in ethanol content. The remaining variation can be attributed to other factors and random errors. Adeq Precision measures the signal-to-noise ratio, with a ratio greater than 4 considered desirable. In this study, the ratio was 14.345, indicating an adequate signal.

The correlation between Brix, pH, and yeast concentration was demonstrated through a regression equation built using Design Expert 11.0 software, achieving 95% reliability. The regression equation is as follows: Ethanol = +13.62 + 0.0988A + 0.6820B – 0.0218C + 0.4038AB – 0.0237AC + 0.0437BC – $0.6148A^2$ – $0.7014B^2$ – $0.2294C^2$.

The model equation can be presented in both actual and coded formats. Both formats represent mathematical forms of alcoholic wine production. The coded

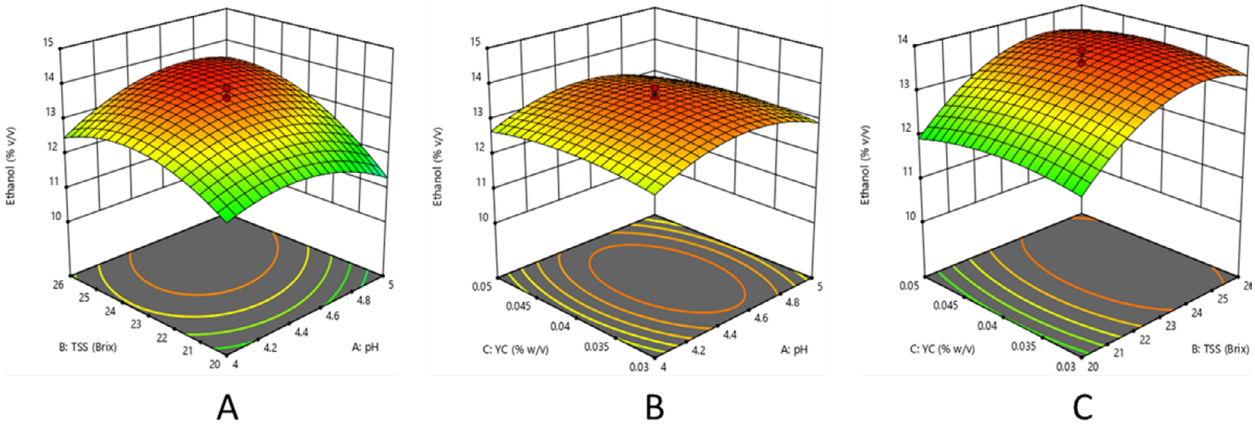

Fig. 1. Response surface and contour plots for the ethanol content of pineapple wine. (a) interactive effect of pH and TSS; (b) pH and yeast concentration; (c) TSS and yeast concentration

format can only be used for response prediction because it omits the units of measurement for the factors. This coded equation is useful for comparing the factor coefficients to identify the relative impact of each factor. The equation in terms of actual factors allows predictions about the response at given levels of each factor, with these levels expressed in their original units.

The influence of the factors on the ethanol content is depicted in 3D response surface plots of the ethanol content, shown in Figure 1. The red areas represent the highest ethanol content, whereas the green areas indicate lower values. The interaction between pH and Brix significantly affected the ethanol content of pineapple wine, whereas the interactions between pH and YC or Brix and YC were not significant (Table 3). As shown by the 3D plot in Figure 1, the ethanol content increased within a certain range; however, further increases in both pH and TSS reduced the amount of ethanol produced.

Based on the experimental results, the software proposed optimal treatments for the dependent variable ethanol, with corresponding predicted values. From the 30 proposed treatments, the three treatments yielding the highest ethanol content were selected, and experiments were conducted to verify the actual ethanol content compared to the predicted values (Kumar et al., 2009). The results of the three selected treatments are presented in Table 4.

The actual values obtained in the experiment differed from the model's predicted ethanol content of 13.60–13.64% v/v by only 0.08–0.64%. These results confirm that the optimized conditions described by the model are consistent with experimental outcomes and have practical significance. Notably, the standard deviation of the actual ethanol content was estimated at 0.17 for treatment 1 and 0.02 for treatment 2, indicating that treatment 2 yields the expected ethanol content more consistently than the other treatments. Taking this into consideration, it is more appropriate to conclude that the initial conditions of treatment 2 represent the optimal conditions. These conditions comprise a pH of 4.5, 23°Brix, and yeast inoculation at 0.04% (v/v).

Table 4. Results for the theoretical and experimental ethanol content

Treatment	pH	TSS °Brix	Yeast concentration % v/v	Theoretical ethanol % v/v	Experimental ethanol % v/v
1	4.47	25	0.039	13.64	13.72 ±0.17
2	4.50	23	0.040	13.62	13.62 ±0.02
3	4.46	23	0.041	13.60	12.96 ±0.34

Table 5. Results for ethanol content, TSS, pH, and reducing sugar content after 12 days of fermentation with optimal initial conditions

Fermentation time (days)	After fermentation			
	pH	TSS °Brix	Ethanol % v/v	Reducing sugar g/100 mL
4	4.31^{a} ±0.01	14.67^{a} ±0.58	7.14^{c} ±0.58	13.84^{a} ±0.25
6	4.26^{b} ±0.01	12.00^{b} ±1.00	9.39^{b} ±0.49	11.39^{b} ±0.86
8	4.18^{c} ±0.01	7.67^{c} ±0.29	13.72^{a} ±0.17	6.29^{c} ±0.65
10	4.15^{d} ±0.02	7.00^{c} ±0.00	13.81^{a} ±0.17	5.56^{c} ±0.19
12	4.09^{e} ±0.01	5.33^{d} ±0.58	14.12^{a} ±0.00	5.27^{c} ±0.56

The data are the means of three replicates of each treatment. Different lowercase letters indicate significantly different values within each column at p-value < 0.05.

Investigation of the effects of different fermentation times on wine production

The results for pH, carbohydrate, reducing sugar content, and ethanol content are illustrated in Table 5. Overall, the carbohydrate content of all treatments decreased after 12 days of fermentation, mirroring reductions in pH and reducing sugar content. Conversely, ethanol content increased for all treatments over the same period. The reductions in carbohydrate content and pH can be explained by the process of ethanol production. *Saccharomyces cerevisiae* converts sugar into ethanol, carbon dioxide, and other end-products, contributing to the final chemical composition and sensory quality of the wine (Fleet, 1990). This process is evident in the changes observed in carbohydrate and ethanol content from day 4 to day 12 of fermentation. Specifically, the decrease in carbohydrate content from 14.67°Brix on day 4 to 5.33°Brix on day 12 demonstrates the conversion of sugar into ethanol by *S. cerevisiae*, which caused the ethanol to increase from 7.145% (v/v) on day 4 to 14.12% (v/v) on day 12. From day 8 to day 12, there was no significant difference in the ethanol content, which was 13.72% (v/v) on day 8, 13.81% (v/v) on day 10, and 14.12% (v/v) on day 12.

This may be because the ethanol content in wine becomes sufficiently high to affect the biological processes of yeast cells (Stanley et al., 2010). Furthermore, the carbon source is gradually depleted during fermentation. Carbon sources are essential for ethanol production, and a shortage of carbon prevents significant ethanol production (Díaz-Nava et al., 2017). Therefore, an 8-day fermentation period is most appropriate for wine production from pineapple, as further fermentation becomes inefficient.

Efficiency of 1-liter scaled-up wine production from pineapple

Table 6 presents the results for pH, carbohydrate content, ethanol content, and reducing sugar content of the 10-fold scaled-up and normal treatments after 8 days of fermentation under optimal initial

Table 6. Results for pH, TSS, ethanol content, and reducing sugar content of the scaled-up (1 L) and normal (100 mL) treatments after 8 days of fermentation under optimal initial conditions

Initial conditions (pH - TSS - YC)	Volume	After fermentation			
		pH	TSS °Brix	Ethanol % v/v	Reducing sugar g/100 mL
4.5 – 23 – 0.04	1 L	4.19	9.00	13.55	6.67
	100 mL	4.20	8.00	13.62	5.24

conditions. Despite the procedure being scaled up 10 times, the carbohydrate content and pH after fermentation decreased relative to their levels before fermentation, as observed in the normal treatment, which means that scaling up the procedure does not negatively affect ethanol production. The results show no significant difference in ethanol content between the scaled-up (1 L) and normal (100 mL) treatments, with ethanol contents of 13.55% (v/v) and 13.62% (v/v), respectively. In addition, a comparison of the scaled-up and normal treatments revealed no significant difference in pH, carbohydrate content, or reducing sugar content, confirming that scaling up the fermentation process by 10 times has no adverse effect on ethanol production.

Sensory evaluation of wine made from pineapple

The sensory qualities of the pineapple wine, namely clarity and color, aroma, and taste, were scored between 4.0 and 4.8 out of 5.0, as shown in Table 7. The average score was 18.36, within the range of 15.2 to 18.5 required for a good grade. Therefore, the product was classified as meeting the requirements of Vietnamese Standard TCVN 3127:79 and was graded as having good quality.

Although vacuum filtration was the only filtration method used for this product, it achieved a turbidity score of 4.0/5.0, indicating minimal cloudiness. It was still reported to be slightly cloudy because no additional clarification treatments were applied during the wine-making process. Besides filtration, other methods such as spontaneous sedimentation, centrifugation, or the addition of clarifying agents (Ma et al., 2020) can be used to treat turbidity. It is notable that not only particulates but also some soluble substances, including aroma components, coloring matter, and polymerized tannins, are removed when adding clarifying agents during the wine-making process (Ma et al., 2020). For this reason, vacuum filtration was the only treatment used to reduce the turbidity of the wine in this study. Nevertheless, further research into the effect of adding clarifying agents is suggested, as it may enhance product quality.

As noted, recent studies have demonstrated that the color of pineapple juice comes from its carotenoid content. Interestingly, the color of the original pineapple juice and the fermented product are identical, indicating that the fermentation process did not affect the color of the liquids. Liquid color is an important criterion in modern fermentation due to the high demand for the organoleptic properties of wine (Gómez-Plaza et al., 2002). Here, we did not analyze the color change of wine during long-term storage, which is an essential aspect of wine preservation. Color changes due to chemical and photo-oxidation can be prevented using food additives, which should be investigated in future studies (Thungbeni et al., 2020).

Organic acids, including succinic acid, lactic acid, acetic acid, and pyruvic acid, are commonly found in

Table 7. Sensorial evaluation of pineapple wine according to TCVN 3217:79

Criteria	Sensorial evaluation results				Standard requirements (TCVN 3217:79)
	Average score	Weight coefficient	Score with weight coefficients	Remarks	
Clarity and color	4.0	0.8	3.2	Clear, slightly cloudy; color specific to the product	The liquid is clear, without opaque states and solids. The color of the material is specific.
Aroma	4.8	1.2	5.8	Clear and specific aroma	Harmonious, fragrant, and completely specific for fermented wine products.
Taste	4.7	2.0	9.4	Slightly sweet and sour	Harmonious, mellow, good posture, and completely specific to the product.
Total average score with the impact coefficient			18.36	Grade: Good	Good grade (15.2–18.5)

wine and are the products of yeast metabolism during the wine-making process (Chidi et al., 2018). The decrease in carbohydrate sources after fermentation, along with the reduction in pH caused by the production of organic acids, contributes to the slightly sweet and sour flavor of the wine. In this study, the pH levels of the wine samples were determined to be around 4.0, a level associated with improved organoleptic scores. This pH range is also favored by most wine producers, as pH levels at 3.0–4.0 enhance wine longevity due the presence of anthocyanins (Forino et al., 2020). As discussed, future investigations into the aging process should consider suitable storage conditions, including temperature, moisture, and light intensity.

CONCLUSION

Based on the analysis of the optimization model, the optimal initial conditions for pineapple wine fermentation were identified as a pH of 4.5, sugar addition to achieve 23°Brix as a carbon source, and the inoculation of 0.04% (v/v) yeast into the pineapple juice. Considering the outcome values after fermentation, 8 days was selected as the most appropriate duration to achieve the highest efficiency. The ethanol content after scaling up the treatment 10-fold was 13.55% (v/v), which was not significantly different from the 13.62% (v/v) ethanol content of the normal treatment. It is therefore possible to conclude that scaling up the fermentation process by 10 times in volume did not affect the efficiency of ethanol production.

ACKNOWLEDGMENTS

The authors would like to thank the Institute of Food and Biotechnology of Can Tho University, Vietnam for their generous support.

DECLARATIONS

Data statement
All data supporting this study has been included in this manuscript.

Ethical Approval
Not applicable.

Competing Interests
The authors declare that they have no conflicts of interest.

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