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ARTICLE

Bio-convertibility of fermentative vert wine: a comparative study of blue-green algae, pineapple, and longan fruits

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ABSTRACT

This research delves into the innovative fermentation of wines using blue-green algae (spirulina), pineapple, and longan fruit. Traditional wine consumption, often synonymous with alcohol content, has seen a shift in value and health appeal with the infusion of spirulina. The fermentation process was monitored using both single and mixed cultures of *Saccharomyces cerevisiae* until it achieved 12% alcohol content. Sensory evaluations by fruit wine consumers revealed gender-based preferences in the acceptability of tangerine wine formulations. Specifically, females showed a higher liking for 5 out of 9 wine formulas, with sugar and acidity playing pivotal roles in flavours preference. Three distinct algae wine recipes were fermented at room temperature, with chemical analyses post-fermentation indicating standard pH levels for wine (3.0 - 4.0). Among them, the seaweed-pineapple blend was the standout, with a pH of 3.55 and a 72.96% approval rate among taste testers. The economic analysis highlighted the pineapple-seaweed variant's high production cost, though pure spirulina wine boasted the most significant return on investment. In conclusion, pineapple-infused spirulina wine emerges as a frontrunner in terms of taste, standard adherence, and economic viability, presenting a solution to the regional fruit surplus.

1. Introduction

Over the last 10,000 years, humans began producing beverages like beer and wine by fermenting sugars from grains and fruits. While grapes are favored in wine production due to their inherent balance of juices, other fruits like bananas and pineapples are also used. Grape cultivation dates back to ancient times and played a pivotal role in transitioning humans from nomadic hunter-gatherers to settled farmers (Ogodo et al., 2015). Wine, a complex hydro-alcoholic solution, contains a variety of compounds believed to offer health benefits. Factors such as geography ("terroir") and cultivation methods impact its composition.

Significant compounds in wine include polyphenols and resveratrol (Buja, 2022). The total phenolic content varies between red and white wines. Additionally, melatonin found in wine might contribute to its health advantages. Distinct from distilled liquors like whiskey, wine is predominantly produced from fruits and has a longstanding reputation as a beverage with potential health benefits (Gavahian et al., 2022). For ages, wine has been a popular alcoholic beverage. It's believed to positively impact cardiovascular health. Light-to-moderate wine consumption has been linked to higher high-density lipoprotein cholesterol levels, reduced platelet clumping, and enhanced fibrinolysis.

Furthermore, it's inversely related to ischemic heart disease,

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and its influence on blood pressure typically shows a J-curve in studies. These benefits are due to wine's key components: ethanol and polyphenols. Consumed in moderation, wine can boost blood circulation, enhance memory, lower Alzheimer's risk, and possibly reduce Parkinson's onset (Haseeb et al., 2019). It can also combat respiratory pathogens, enrich food flavors, and enhance overall cardiovascular well-being. The production of fruit wines results in substantial by-products, such as wastewaters, lees, and solid residues like pomace, peels, and seeds from fruits like apples, bananas, and berries. As the wine industry expands, there's an increasing emphasis on its sustainability throughout the entire supply chain (Bandinelli et al., 2022). This is because the industry both impacts and is influenced by its environmental surroundings.

Adopting sustainable practices can address many environmental concerns and has the added advantage of gaining consumer approval. Specifically, wines labeled as organic are often perceived as healthier and more eco-friendly, thereby boosting their market value (Traversac et al., 2011). To address the broad environmental implications of wine production, it's vital to assess and improve the entire wine supply chain, from raw material sourcing to product distribution. Recent research on sustainability in the wine sector underscores its significance, with many studies examining specific facets of the wine supply chain.

In the Asia-Pacific region, there are more than 100 businesses engaged in microalgae production, collectively yielding well over 400 tonnes annually. Asia houses roughly 90% of these algae cultivation facilities. Key commercially grown microalgae varieties encompass *Chlorella*, *Spirulina*, *Dunaliella*, and several others. The majority of this algal output is sold as health supplements, primarily in tablet or capsule form (Lee, 1997). Additionally, algal products and extracts are incorporated into items like noodles, wines, drinks, cereals, and beauty products.

Delving into the realm of microalgae, *Spirulina*, known scientifically as *Arthrospira*, emerges as a noteworthy blue-green algae variant. This nutrient powerhouse is renowned for its rich protein content and its arsenal of essential amino acids that are not innately produced by the human body. Past research underscores spirulina's therapeutic properties, asserting its efficacy in addressing conditions from diabetes to ocular diseases like glaucoma (Wu et al., 2016). Recognizing spirulina's multifaceted benefits, our study sought to seamlessly integrate it into wine products. This integration not only elevates the wine's nutritional matrix but also endows it with a distinct flavor palette, catering to the evolving tastes of wine aficionados. To further optimize the fermentation process, Maltitol, a natural low-calorie sweetener found in various fruits and seaweeds, was employed as a substitute for traditional sugars (Martău et al., 2020). This choice was influenced by Maltitol's ability to modulate blood glucose levels and support digestive health.

Within the broader spectrum of Cyanobacteria, *Spirulina* spp. is categorized as a Gram-negative bacterium. Predominantly harnessed as a human dietary supplement, it also finds application in animal feed. Among its 35 known species, *Spirulina platensis* stands out for its suitability for both human and animal dietary purposes (AlFadhly et al., 2022; Palanisamy et al., 2023). The study also integrates the essence of tropical fruits into the wine

matrix. Pineapple, brimming with vital nutrients (Casabar et al., 2019) as well as the enzyme bromelain, is versatile, finding its way into fresh consumption or processed forms like canned pineapples and dried variants (Mohsin et al., 2020). Another pivotal ingredient is Longan, a fruit of economic significance (Nguyen et al., 2020). Renowned for its multifunctionality, it's consumed fresh, transformed into delicacies like longan wine, and offers a rich nutrient profile encompassing vitamins, minerals, and amino acids. The utilization of algae in viticulture is currently understudied and there are few reports in the literature assessing its effect on avoiding grapevine diseases and improving grape and wine quality (Gutiérrez-Gamboa et al., 2021). The primary yeast species plays a crucial role in wine fermentation (Khammee et al., 2021). Historically, this species was favored as a starter for alcoholic fermentation because of its excellent fermentative characteristics (Manmai et al., 2019; Manmai et al., 2022). This research aims to refine spirulina-based offerings to align with consumer tastes and to diligently develop a method for crafting spirulina-infused wine.

2. Material and methods

2.1 Equipment

In the experimental process, fermentation took place in tanks larger than 6 liters, fitted with an airlock and silicone stopper. Straining was achieved using muslin or filter fabric. A hydrometer or refractometer measured sugar and alcohol content, while temperatures were monitored with a thermometer. The final product was bottled and sealed with corkscrews.

2.1 Experimental designs

In this study, three unique spirulina wine recipes were crafted: Pure spirulina wine, Longan-spirulina wine, and Pineapple-spirulina wine. The Feedstock preparation process was exhibited in Figure 1. The winemaking process commenced with the addition of algal powder to a bucket or pot, followed by the introduction of 2.5 liters of water and 250 grams of Maltitol syrup. Wine yeast was then incorporated and allowed to dissolve. To initiate fermentation, the container was shielded from external contaminants and placed in a dark environment, maintaining a temperature range of 18-28°C over 3 days.



Figure 1. Feedstock preparations (a) algae, (b) pineapple, and (c) longan fruits

Within 4-12 hours, visible bubbles and a distinct aroma indicated successful fermentation. After a 3-day period, the blend was strained to discard residues, after which citric acid and

additional Maltitol syrup were added. Depending on the specific wine variant, either seaweed combined with pineapple juice or longan juice was introduced to the fermentation vessel, taking up to 75% of its capacity.

2.4 Fermentation

Laboratory fermentation steps are demonstrated in Figure 2. During primary fermentation, an airlock was installed on the fermentation tank, which was kept in a consistent, dark setting at 20-28°C. Every 4-5 days, a fraction of the mixture was removed, mixed with Maltitol syrup, and then reintroduced to the primary blend, a procedure that was reiterated after five days. Fermentation's completion spanned between 30 to 60 days, characterized by the cessation of bubble emergence from the airlock and the settlement of sediment. The clarified wine was then separated from this sediment.

Post-fermentation, the wine's alcohol content was evaluated, with the possibility of enhancement using ethanol or vodka. Finally, the wine was bottled, sealed, and stored at 2-16°C. It is recommended to age the wine for 4-9 months for the best flavor development. Additionally, the wine underwent chemical analysis to ascertain its pH and alcohol content. A sensory assessment was conducted using the 9-point Hedonic scale, assessing parameters like color, aroma, texture, and taste. Furthermore, its antioxidant attributes were determined via the DPPH method, utilizing 2,2-diphenyl-1-picrylhydrazyl as a reagent, celebrated for its straightforwardness and accuracy.



Figure 2. Laboratory fermentation steps

2.5 Analytical methods

The wine underwent chemical analysis to ascertain its pH and alcohol content. A sensory assessment was conducted using the 9-point Hedonic scale, assessing parameters like color, aroma, texture, and taste. Furthermore, its antioxidant attributes were determined via the DPPH method, utilizing 2,2-diphenyl-1-picrylhydrazyl as a reagent, investigated for its straightforwardness and accuracy.

2.6 Economical value assessment

Costs and revenues in the production year that consider both fixed and variable costs according to Vachiraporn and

Vachiraprance's methods (2004) are as follows:

Total cost $TC = TFC + TVC$

TC = Total cost, total cost

TFC = Total Fix cost, fixed cost

TVC = Total Variable cost Variable cost

Total revenue $TR = Q_y P_y$

TR = Total Revenue

Q_y = (ton) Quantity of Output

P_y = Average aquatic price/kg sold by farmers

Net Income = $TR - TVC$

TR = Total Revenue

TVC = Total Variable Cost

Net Profit = $TR - TC$

TR = Total Revenue

TC = Total Cost

Net remuneration rate from property = $\frac{(Net\ Profit \times 100)}{Total\ assest\ of\ costs}$

Payback Period = $\frac{Total\ cost}{Average\ annual\ net\ return}$

Break-even Break-Even point = $\frac{TC}{TC - TVC}$

Gross margin ratio = $\frac{Net\ worth \times 100}{TVC}$

Analysis of variable and fixed costs according to the reporting method of Abhisit (1989):

Variable cost = aquatic breeding + aquatic feed + medicines and chemicals for aquatic diseases + electricity + fuel + labor (household wages) Equipment cost + investment opportunity cost
Fixed cost = depreciation of materials and equipment + land use rental tax + loan interest + pond improvement depreciation + investment opportunity cost + shrimp pond depreciation
Analysis of the opportunity cost of fixed capital and the determination of material depreciation according to Abhisit method (1989) as follows:

$$D = \frac{(p-s)}{L}$$

Assign D = Yearly Depreciation

P = Property Capital Price

S = Smbre value of the property

L = Property lifespan

3. Results and discussion

3.1 The essence of fermentation: yeast's transformative impact

Fermentation has been used for millennia to produce alcoholic beverages, bread, and other products. Biochemically, it involves converting carbohydrates like sugar into alcohols or acids, with yeast, for example, turning sugar into alcohol for energy. Before its workings were understood, humans unknowingly utilized

fermentation (Bhuyar et al., 2021; 2022; Kongchan et al., 2022). In the mid-1800s, Louis Pasteur first studied it scientifically, showing living cells were responsible (Ramaraj and Unpaprom, 2019). *Saccharomyces cerevisiae*, a widely used yeast, plays a key role in making beverages like wine and beer. These yeasts thrive in various environments, especially on fruits, which naturally provide essential nutrients (Casabaret al., 2019). Yeasts have diverse shapes and are identified through microscopic, microbiological, and biochemical tests. They mainly reproduce asexually through budding, ensuring genetic consistency, which is crucial for industrial fermentation (Kongchan, et al., 2022; Vu et al., 2017). Yeasts can ferment many sugars and withstand acidic conditions. There are two primary groups: *Saccharomyces* and non-*Saccharomyces*. *S. cerevisiae* is the most popular for beer and wine production due to its adaptability and fermentation efficiency. Wine's aroma is multifaceted, arising from the grape variety, fermentation process, and aging method (Maicas, 2020). Wine quality is deeply connected to fermentation, influenced by the microbial makeup, and chosen strains. This study aims to analyze yeast diversity and the properties of Sangiovese red wines from biodynamic and organic farming.

3.1 Wine fermentation process

From the three wine fermentation experiments conducted, the process was initiated by boiling chopped algal biomass. Once boiled, the mixture was filtered, retaining only the liquid. For the longan variant, dehydrated longan was used, requiring it to be boiled separately. The resulting mixtures were transferred to fermentation tanks, where nutrients and yeast were added. Fermentation was allowed to proceed at 18 °C for 7 days. After this period, the wine mixtures were transferred to freezers for sludge removal. After an additional week, distinct characteristics of each wine type emerged:

- The spirulina-only wine developed a clear color.
- The spirulina-pineapple variant exhibited a slightly cloudy appearance, attributed to the fibrous nature of pineapples.
- The spirulina-longan wine exhibited a darker hue, which can be attributed to the use of dehydrated longan rather than fresh longan. Dehydrated longan is inherently sweeter, influencing the coloration of the wine.

Table 1. Antioxidant test, pH, and methyl alcohol measurements

Wine Type	Acidity-Alkali (pH)	Methyl Alcohol (ppm)	DPPH (mg Vitamin C/ml)
Algae wine	3.47	25.59	0.1569
Longan-algae wine	3.94	29.59	0.2360
Pineapple-algae wine	3.55	77.51	0.2156

Note: pH Benchmark: 3.0 - 4.0 Methyl alcohol acceptable range: 38-100 mg/l.

Following this, the clear wine from each variant was siphoned off using a hose and processed using a centrifuge. Before bottling, 1.2 grams of KMS was added to each wine as a disinfectant. This

methodology is in alignment with the findings from the study by Sirikhansaeng et al. (2020) on the chemical and sensory properties of okra wine and mulberry-infused okra wine. The following results were obtained from antioxidant testing, acidity-alkali (pH) measurements, and methyl alcohol content presented in Table 1.

3.2. Analysis of the chemical properties of wine

Wine samples were subjected to an in-depth analysis of their chemical properties at the LEP Institute for Quality Inspection and Product Standards. This examination encompassed assessments of their acidity-alkalinity (pH), methyl alcohol concentration, and antioxidant capability. The findings concerning acidity and alkalinity, based on the pH scale, for the three wine formulations were as follows:

- Formula 1, which is based on Longan-infused algae, registered a pH value of 3.94.
- The Pineapple-infused algae variant, referred to as Formula 2, had a pH value of 3.55.
- Lastly, Formula 3, which is purely algae-based, presented a pH reading of 3.47.

It's noteworthy to highlight the methyl alcohol content. Using a reference range of 38-100 mg/l, the pineapple-infused wine notably showed a peak value of 77.51 mg/l. A pivotal element of the analysis was the DPPH (2,2-diphenyl-1-picrylhydrazyl) test, which was specifically used to measure the antioxidant potential of the wines. This method stands out due to its efficiency, swift execution, and impeccable precision (Fernández-Pachón et al., 2014). The role of antioxidants is undeniably critical in reducing the risk of several ailments, prominently including conditions like cancer, cardiac diseases, and fatty vein thrombosis. A breakdown of the results revealed the following: (a) The seaweed wine that was combined with longan took the lead in antioxidant capacity, measuring at 0.2360 mg of Vitamin C/ml, (b) the wine infused with pineapple and seaweed marked its antioxidant potential at 0.2156 mg of Vitamin C/ml, and (c) the wine made exclusively with seaweed trailed behind the other two, exhibiting a noticeably reduced antioxidant potential.

3.3 Survey results on satisfaction with vert wine, a health-oriented algal wine

As health concerns grow among consumers, there's a noticeable shift towards healthier food and drink choices. However, studies indicate that health-related claims on US food products have inadvertently caused more confusion (Higgins and Llanos, 2015). Consumers find it challenging to interpret nutritional details and differentiate between varying levels of scientific backing for these claims. This has led to a degree of skepticism toward the authenticity of such health statements on food items. When looking at red wine consumer demographics, there's an even split, with females comprising 50% and males the other 50%. A deeper dive into the age demographics revealed a younger consumer base; 94% of them were aged between 20 to 25

years, followed by 25-30 years at 2%. The age groups 30-39 and 40-49 each constituted 2% of the surveyed group. In terms of educational background, a significant 94% of the respondents had completed primary education, while 6% held master's or doctoral degrees (Table 2).

Table 2. Analyzes the relationship between personal factors and attitudes toward healthy algae wines

Attitude	P-value			
	Personal factors			
	Sex	Age	Education level	Occupation
Product value	.489	.080	.298	.051
Product price side	.120	.398	.270	.147
Distribution Channels	1.000	.781	.803	.524
Marketing Promotion	.483	.301	.200	.162

Professionally, a vast majority of vert wine consumers, at 94%, were students. Government officials and employees followed at 6%. Delving into drinking habits, 68% of the respondents consumed wine less than 1-2 times per month. Those who drank wine more than 1-2 times a week accounted for 14%, 1-2 times a month were 10%, and 8% drank wine 1-2 times a week. Regarding the social aspect of wine consumption, 78% of the surveyed consumers preferred to enjoy their wine with close friends or colleagues, while 20% sometimes drank alone. A minimal 2% reported drinking wine primarily with family members.

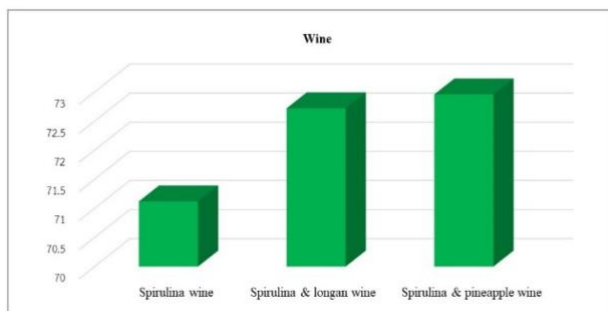


Figure 3. Sensory quality test results

In exploring the occasions when consumers are most likely to consume wine, 42% indicated special events or significant days, 30% mentioned celebrations, and 28% preferred weekends. As for their wine preferences, 32% of the consumers favored wines made from local fruits, followed closely by red wine at 28%, white wine at 20%, sweet wine at 8%, sparkling wine at 8%, and rosé at 4%. Lastly, when asked about their motivations for consuming wine, 34% cited socializing as their primary reason. This was followed by 24% who drank for the taste, another 24% for stress relief, 16% for the aroma, and a smaller 2% drank wine primarily for its health benefits.

3.4 Sensory evaluation of algal wine varieties

A sensory evaluation was conducted with 50 tasters to assess three distinct seaweed wine recipes based on clarity, color, aroma, and taste. Sensory quality test results are shown in Figure 3. The results revealed that seaweed wine infused with pineapple emerged as the most preferred with an overall score of 72.96%. This was closely followed by the longan-infused seaweed wine and pure seaweed wine, both scoring 72.72%. In terms of individual attributes like clarity, color, aroma, and taste, pure seaweed wine achieved a score of 71.12%.

3.4 Demographics and preferences of vert wine consumers

A comprehensive survey was executed to understand the preferences and habits of Vert Wine consumers. Key findings include:

- **Gender Distribution:** The consumer base had a balanced gender distribution with 50% females and 50% males.
- **Age Group:** The largest demographic was aged between 20 to 25 years (94%). The age groups 25-30, 30-39, and 40-49 represented 2%, 2%, and 2%, respectively.
- **Education:** 94% of the consumers had completed primary education, while 6% had achieved master's or doctoral degrees.
- **Occupation:** A vast majority (94%) were students, followed by government employees (6%).
- **Consumption Habits:** 68% drank wine less than 1-2 times/month, followed by those drinking more than 1-2 times/week (14%), 1-2 times/month (10%), and 1-2 times/week (8%).
- **Social Setting and occasion:** 78% preferred drinking with friends or colleagues, 20% drank alone, and a mere 2% enjoyed wine with family. Special events (42%) topped the list, followed by celebrations (30%) and weekends (28%).
- **Wine Preferences:** 32% favored wines made from local fruits, 28% preferred red, 20% white, 8% sweet, 8% sparkling, and 4% rosé.
- **Motivation:** 34% consumed wine for socializing, 24% for its taste, 24% for stress relief, 16% for aroma, and 2% for health benefits.

Table 3. Cost of producing healthy algal wine recipes Spirulina (cost per fermentation 1 bucket)

List	Cash cost	Non-cost Cash	Combine	Percent
Fixed costs				
Basin	-	3.33	3.33	0.30
Fermentation tank	-	9.17	9.17	0.84
Thin white fabric	-	3.5	3.5	0.32
Cistern	-	0.42	0.42	0.04
Pot	-	8.32	8.32	0.76
Wine set	-	55.5	55.5	5.08
Variable costs				
Granulated sugar	60	-	60	5.49
Spirulina	396	-	396	36.26
Multitool	287	-	287	26.28
Yeast	29	-	29	2.65
Dried longan	240	-	240	21.97
Total cost			1092.20	100
Cost price per bottle (500 ml.)			109.22	

Table 4. Cost of producing healthy algal wine recipes Pineapple-infused Spirulina (cost per 1 bucket of fermentation)

List	Cash cost	Non-cost cash	Com-bine	Percent
Fixed costs				
Basin	-	3.33	3.33	0.39
Fermentation tank	-	9.17	9.17	1.07
Thin white fabric	-	3.5	3.5	0.41
Cistern	-	0.42	0.42	0.05
Pot	-	8.32	8.32	0.97
Wine set	-	55.5	55.5	6.57
Variable costs				
Granulated sugar	60	—	60	7.04
Spirulina	396	—	396	46.44
Multitool	287	—	287	33.65
Yeast	29	—	29	3.40
Total cost			852.74	100
Cost price per bottle (500 ml)			85.27	

Table 5. Cost of producing healthy algal wine with longan Spirulina recipe (Cost per Fermentation 1 Bucket)

List	Cash cost	Non-cost Cash	Combine	Percent
Fixed costs				
Basin	-	3.33	3.33	0.95
Fermentation tank	-	9.17	9.17	2.62
Thin white fabric	-	3.5	3.5	1.00
Cistern	-	0.42	0.42	0.59
Pot	-	8.32	8.32	4.75
Wine set	-	55.5	55.5	16.00
Fruit blender	-	13.25	13.25	3.79
Variable costs				
Granulated sugar	60	—	60	4.89
Spirulina	396	—	396	32.30
Multitool	287	—	287	23.41
Yeast	29	—	29	2.36
Pineapple	286	-	286	24.61
Total cost			1,161.77	100
Cost price per bottle (500 ml)			116.18	

3.5. Economic analysis of algal wines

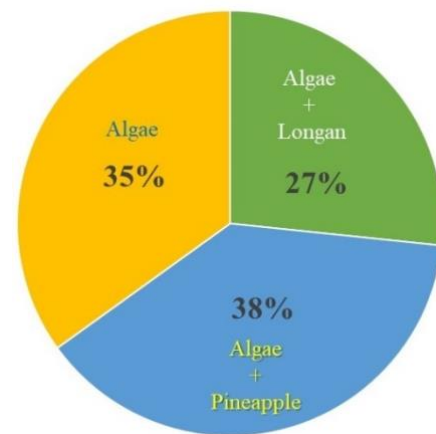
The production costs associated with the three variants of spirulina wine serve as a vital marker for profitability and economic viability as presented in Tables 3 to 5, as well as Figures 4 and 5. Here's a detailed breakdown of the economics behind these wine recipes. When considering ROI, a clear hierarchy emerges: The pure spirulina formula, being the least expensive to produce, offers the highest returns. The longan-infused recipe, with its moderate costs, sits at the second spot in terms of ROI. The pineapple-infused spirulina wine, with the highest production costs, understandably provides the lowest returns.

Variable costs variation: The variable costs differ more substantially between the recipes. The cost of Spirulina remains relatively consistent across all recipes at around 46.44%, 32.30%, and 36.26% respectively. The inclusion of different fruits, pineapple, and dried longan, introduces significant variable costs, at 24.61% and 21.97% respectively.

Total production cost and cost per bottle: Pineapple-infused spirulina wine incurs the highest production cost at Baht 116.177 per bottle. This can be attributed to the addition of pineapples, which constitute 24.61% of the total cost. The longan-infused spirulina wine comes in second at Baht 109.22 per bottle, while the plain spirulina wine is the most economical at Baht 85.27 per bottle. This variation highlights the significant impact of the additional fruits on production costs.

Profit and economic value: Given the selling price is fixed at 149 baht per bottle, the net profit for each bottle would be the difference between this selling price and the production cost. While the spirulina wine recipe yields the highest profit, the pineapple-infused variant appears to be the least profitable. The difference in production cost and the selling price is not as wide as the other variants.

Comparative analysis with traditional wines: Upon comparison with grape wines, the three spirulina wine variants present a more economical production model. The fundamental reason for this cost efficiency is the intrinsic nature of spirulina. Being a microalgae, spirulina can be cultivated in-house, offering savings in procurement. Fixed costs comparison: From the three tables provided, it's evident that certain fixed costs remain consistent across the spirulina wine production process, irrespective of the recipe variant. For example, the cost for items like the Fermentation Tank, Thin White Fabric, and Wine Set do not vary significantly between the three recipes. The Wine Set, in particular, stands out as a significant fixed cost in the production of each type of wine, with percentages of 6.57%, 16%, and 5.08% for spirulina, pineapple-infused spirulina, and longan-infused spirulina respectively.

**Figure 4.** Fixed costs analysis

Economical insights: One of the remarkable takeaways from these tables is that spirulina wines are more economical than traditional grape wines. This economical edge is attributed to the relatively low cost of spirulina which can be self-cultivated, reducing the need for external sourcing and associated expenses. Additionally, the use of local fruits like pineapple and longan not only enhances the flavor profile of the wines but also provides an avenue for managing the oversupply of these fruits in northern regions.

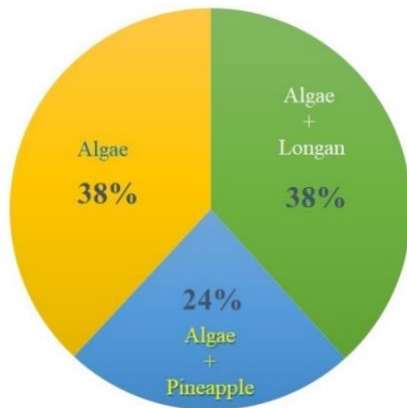


Figure 5. Variable costs analysis

3.6 Marketable innovations in winery implementation

Embracing sustainable practices is paramount in ensuring current needs are met without jeopardizing the prospects of future generations. Integrating these principles within the winery domain can offer both ecological and economical advantages. Our latest product, crafted from grape must, stands out with its low alcoholic content, merging both sustainability and social responsibility (Canovi and Pucciarelli, 2019). This distinctive characteristic can serve as a potential game-changer in the alcoholic beverage market. Moreover, leveraging the varied consumer perceptions, shaped by their unique past experiences, can be a valuable asset in crafting effective marketing and communication strategies for the product (Gueddari-Aourir et al., 2022). Marketable products of wines are displayed in Figure 6. Consequently, while all three spirulina wine recipes are economical and offer producers a good return, each recipe presents its own set of advantages and trade-offs.



Figure 6. Marketable products of wine varieties

For maximum profitability, producers might lean towards the pure spirulina recipe. However, those looking to introduce unique

flavors and cater to specific market preferences might opt for fruit-infused recipes, even if they come with slightly higher production costs.

Moreover, the strategic use of local fruits, like pineapple and longan, offers a twofold advantage. Firstly, they infuse the wine with distinct flavors catering to local palates. Secondly, given their abundant availability in the northern regions, they provide an economic solution to fruit overproduction issues, benefiting both producers and local fruit growers. In summary, while each spirulina wine variant has its unique cost structure, its collective production offers a viable and profitable alternative to traditional wine manufacturing.

4. Conclusion

In an investigation into the fermentation of algae wine, three distinct recipes underwent fermentation at room temperature over seven days. Post-fermentation, the wines were analyzed for their chemical properties, specifically their acidity and pH levels. The results showed that all three variations maintained a pH within the standard wine fermentation range of 3.0 – 4.0. Notably, the seaweed-pineapple blend had a pH of 3.55, making it the most preferred among a group of 50 taste testers, securing an approval rate of 72.96%. The longan-seaweed variant followed closely with an approval of 72.72%, while the pure seaweed wine had 71.12%. Statistical analysis of the sensory test results, using the t-test, revealed significant differences among the wines. From an economic perspective, while pineapple-infused seaweed wine had the highest production cost per bottle, the return on investment was the highest for pure spirulina wine. To summarize, the study reveals that the pineapple-infused spirulina wine is the most promising variant in terms of consumer preference and adherence to wine standards. Its production is also economically viable, given the low-cost nature of spirulina and the accessibility of local fruits like pineapple and longan, which can also address the issue of fruit surplus in the region.

Conflict of Interest Declaration

The authors assert that there are no conflicts or personal affiliations that might be construed as impacting the outcomes shared in this research.

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