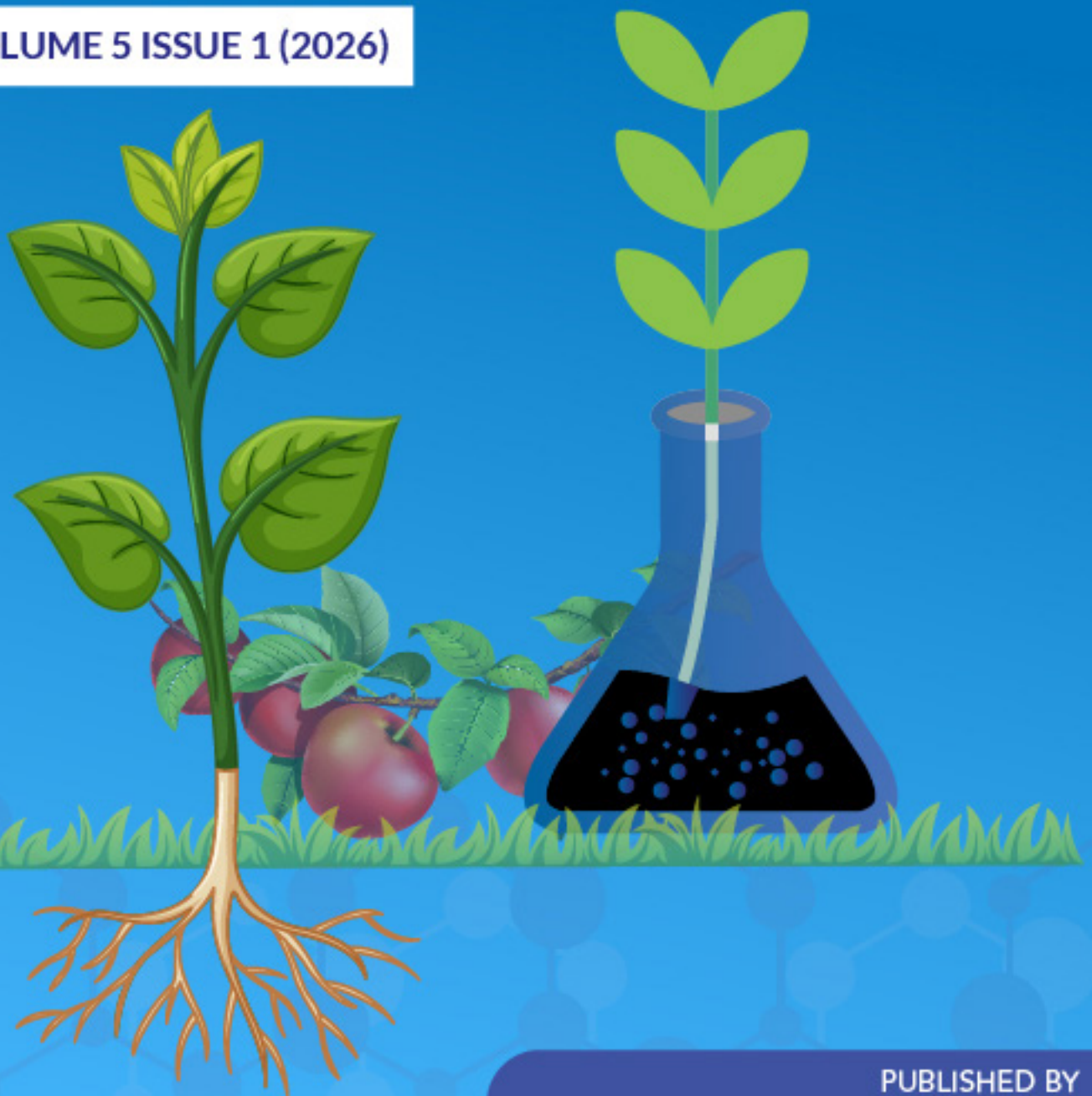




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Coconut and Strawberry in Functional Wine Development: A Review on Fermentation Dynamics, Nutritional Relevance, and Process Innovations

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ABSTRACT

Strawberry and coconut, both famed for their nutritional and functional virtues, are becoming novel substrates in fruit wines. Coconut, rich in electrolytes, vitamins, and antioxidants, and strawberry, famous for its high content of vitamin C, phenolics, and low glycaemic index, not only provide a rejuvenating substitute to conventional fruit wines but also substantial health advantages. The growing interest in these fruits stems from their ability to enhance the sensory character and nutritional quality of wines, favoured by an increasingly larger base of consumers who demand functional drinks and natural ingredients. Key fermentation variables, including the selection of yeast strains, fermentation temperature, and length, are addressed, as well as how they affect the alcoholic strength, flavor evolution, and quality of the wine. Particular focus is placed on reproducibility in winemaking, focus on meeting the requirements of batch-to-batch uniformity and standardized procedures to maintain product quality. Different processing methods of coconut and strawberry wines, including blending, co-fermentation, and enzyme treatment, are analysed to assess their performance in optimizing the final product's taste and texture. The review also investigates the sensory attributes of coconut and strawberry wines and how this impacts consumer preference and acceptability in various markets. The possibilities for scalability in production, as well as the problems of ensuring quality at increased scales of production, are also addressed. Lastly, this paper also mentions the increasing interest in these wines as functional foods, being marketed to a health-oriented consumer base, and aiding in the growth of the fruit wine industry.

INTRODUCTION

Winemaking is an ancient technology that has evolved into a lucrative biotechnology process. Ever since the dawn of civilization, the process of wine production has been a familiar one, evolving alongside the advancement of agriculture and human civilization. Wine has been produced from different raw materials to impart flavor or add significant chemical constituents (Nabin KHADKA *et al.*, 2024). Fruit wines are alcoholic drinks produced from fruits other than grapes; They can also contain extra Flavors extracted from fruits, flowers, and herbs. Fruit wines can either be still or sparkling. Fruits should possess high sugar and low acidity properties, which should be corrected when necessary (F. Matei *et al.*, 2016). Wine contains a range of nutrients that the human body requires, such as sugar, vitamins, amino acids, mineral elements, and polyphenols. These nutrients are blended with alcohol, organic acids, and fragrance compounds to impart the wine with a more specific sensory flavor and improved nutritional value (Giovanna Fia *et al.*, 2018). Starter culture usage during fermentation plays a central part in determining the final quality, flavor profile, and biochemical stability of fermented drinks, like wines. A specific selection of microbial species, such as *Saccharomyces cerevisiae*, plays a vital role in this process, as they regulate alcohol production, sugar utilization, and the release of bioactive compounds (A. Morata *et al.*, 2022; Guanfei Zhang *et al.*, 2018). Coconut

is a fruit of the coconut palm (*Cocos nucifera*) and is of the Arecaceae family. Coconut water (coconut liquid endosperm) ranks among the globe's most multi-purpose natural commodity (Jagadeesh U *et al.*, 2021). Coconut water, the endospermic liquid of the young green coconut, weighs about 25% of the nut. It is a transparent, colourless liquid with a slightly sweet and acidic flavor (pH ~5.6), and contains roughly 5% total soluble solids by weight (Mohan Naik *et al.*, 2020). Coconut water, which is a natural, high-value nutrient beverage with essential minerals, natural sugars, proteins, and vitamins present in it, is obtained from young green coconuts. It contains minerals, amino acids, phytohormones, and beneficial bioactive compounds like vitamin C, vitamin B, potassium, calcium, magnesium, sodium, glutamic acid, lysine, arginine, alanine, cytokinin, and more (Manita CHAUDHARY *et al.*, 2024). Such a fruit is the strawberry, being an excellent representative of a desired quality fruit with agreeable smells. Strawberry is a red and tasty fruit amongst other horticulture fruits that are currently farmed in India. Strawberries possess antioxidants, anti-inflammatory, antihyperlipidemic, and antiproliferative effects, and such actions directly correspond to the treatment of various chronic illnesses (Kaur Singh Nehra *et al.*, 2021). Strawberry consumption can contribute significantly to the improvement of folate status and the reduction in the prevalence of folate-related pathological disorders. (Sara Tulipani *et al.*, 2009). Strawberry (*Fragaria*

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sp.) is grown throughout the world. Aroma is one of the chief quality traits of the strawberry. Several volatile compounds like esters, terpenes, alcohols, ketones, and furans have been reported to be responsible for this strawberry aroma. (Jing Dong *et al.*, 2013; Perez *et al.*, Zabetakis *et al.*, 1997). This review will investigate the creation of fermented fruit wines from coconut and strawberry as new drinks, integrating traditional fermentation techniques with contemporary scientific methods. Such products provide functional health

benefits to health-oriented consumers and encourage sustainability by reducing post-harvest losses and extending the utilization of perishable fruits.

Nutritional Composition of Coconut and Strawberry as Raw Materials for Wine Production

Table 1: The comparative nutritional composition of coconut water and strawberry, both of which are being explored as alternative substrates for fruit wine production.

Table 1: Nutritional Composition of strawberries and coconut water

Nutrient	Strawberry	Coconut Water	References
Water	90.95	94.0	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Protein	0.67	0.72	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Energy (kcal)	32	19.0	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Total fat (g)	0.30	0.20	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Fiber	2.0	0.10	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Carbohydrate	7.98	4.0	(Mario Bezerra <i>et al.</i> ,2024; Yufeng Zhang <i>et al.</i> , 2024)
Sugar, Total (g)	4.86	4.86	(Hasnaa Sadik <i>et al.</i> ,2023; Isabela da Mota Leal Lemos <i>et al.</i> , 2023)
Sucrose (g)	0.47	6.36	(Hasnaa Sadik <i>et al.</i> ,2023; Isabela da Mota Leal Lemos <i>et al.</i> , 2023)
Glucose (g)	1.99	29.96	(Chadia Ouazzani <i>et al.</i> ,2023; Isabela da Mota Leal Lemos <i>et al.</i> , 2023)
Vitamin C (mg)	58.8	19.08	(Francesca Giamieri <i>et al.</i> ,2014; Pounce Djeumeni Hamilton <i>et al.</i> , 2024)
Potassium (mg)	153	1,932.57	(Mario Bezerra <i>et al.</i> ,2024; Beatriz Patricia Rocha <i>et al.</i> , 2024)
Calcium (mg)	34.94	279.93	(Hasnaa Sadik <i>et al.</i> ,2023; Beatriz Patricia Rocha <i>et al.</i> , 2024)
Magnesium (mg)	13	85.13	(Hasnaa Sadik <i>et al.</i> ,2023; Beatriz Patricia Rocha <i>et al.</i> , 2024)

LITERATURE REVIEW

Coconut Fermentation and Strawberry Dynamics

Fermentation of fruit substrates like coconut water and strawberry juice has been increasingly researched scientifically because of their distinctive biochemical content favoring microbial growth and functional enhancement. Coconut water is especially rich in natural sugars (glucose, fructose, sucrose), electrolytes (potassium, sodium, magnesium), and phytohormones like cytokinin’s that induce yeast metabolism and efficiency of fermentation (Zhang *et al.*, 2024; Rocha *et al.*, 2024). Some research indicates successful fermentation of coconut water by *Saccharomyces cerevisiae* strains, producing 7% to 10% ethanol content based on sugar content and inoculum size (Zhang *et al.*, 2018; Jagadeesh *et al.*, 2019). On the other hand, strawberry juice offers a natural source of fermentable sugars and phenolic richness. Nehra *et al.* (2021) and Hornedo-Ortega *et al.* (2017) in their research indicated that strawberry fermentation can yield wines with up to 12% (v/v) ethanol and enhanced antioxidant activity by polyphenol bioconversion. Non-*Saccharomyces* yeasts such as *Hanseniaspora uvarum* and *Torulasporea delbrueckii* are increasingly being utilized for their ability to contribute aromatic complexity to strawberry wines (Wang *et al.*, 2025; Padilla *et al.*, 2016).

Nutritional Significance and Bioactive Constituents

The nutritional composition of strawberry and coconut

water is the main contributor to the functional character of the end wines. Coconut water has high concentrations of potassium (up to 1,900 mg/L), magnesium, and calcium, which not only assist in fermentation but also the final drink, hence a rehydrating functional drink (Rocha *et al.*, 2024; Hamilton *et al.*, 2024). Strawberry is reported to have a high concentration of vitamin C (~59 mg/100 g), folates, and flavonoids such as anthocyanins, which are strong antioxidants (Giampieri *et al.*, 2014; Dong *et al.*, 2013). Through fermentation, strawberry polyphenolic compounds are subjected to enzymatic transformations, which increase their antioxidant activities and bioavailability. This has been reported to be responsible for cardiovascular protection and blood glucose regulation in moderate wine consumers (Badmi *et al.*, 2023; Zhao *et al.*, 2021). Fermented coconut water also preserves bioactive markers like cytokinins and amino acids, which impart anti-inflammatory and hydration activity (Mauro & Garcia, 2019).

Innovations in Process for Producing Fermented Fruit Drinks Process optimization has been highlighted in recent studies to preserve coconut and strawberry wines’ nutritional value and sensory characteristics. Low-temperature fermentation (15–18 °C), for example, preserves volatile aroma compounds like ethyl acetate, isoamyl alcohol, and phenylethyl alcohol in strawberry wines (Wei *et al.*, 2019; Lan *et al.*, 2024). Stress-resistant yeast strains like *S. cerevisiae* D254 have improved

ethanol yield and flavor stability in coconut wine production (Zhang *et al.*, 2018). In addition, enzyme-assisted extraction, co-fermentation technology, and stabilization by natural gum (e.g., xanthan and guar gum) have imparted greater viscosity, aroma preservation, and stability of the product (Mauro *et al.*, 2022). Multi-strain probiotics during the fermentation process of *Lactobacillus plantarum* have also been utilized to transform these wines into functional probiotic drinks with added benefits (Xu *et al.*, 2018; Doriya *et al.*, 2022).

Quality Control, Reproducibility, and Standardization

Repeatability during fermentation is a major challenge. Heterogeneity of raw materials, sugar levels, and microbial contamination can cause variable sensory characteristics and product quality. The importance of standardization of the yeast strain and pH adjustment by Padilla *et al.* (2016) was underscored to ensure reproducibility. The current protocols established by Romano *et al.* (2022) offer validated procedures to control the fermentative and chemical activity of *S. cerevisiae* strains, ensuring batch-to-batch reproducibility during commercial winemaking. Implementation of Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practice (GMP) is advocated to regulate the microbial contamination as well as optimize shelf-life achievement of fermented fruit drinks (Ross *et al.*, 2002; Behera *et al.*, 2018). Innovative application of E-palli-published technology advancements, such as food-grade

ethanol and pH level biosensors, are increasingly being accepted in applications in fermentation loops for real-time quality monitoring intentions (E-Palli Publisher, Doriya *et al.*, 2022).

This review was carried out following a systematic literature search method to provide peer-reviewed scientific data on the fermentation, nutritional value, and process innovation of coconut and strawberry in functional wine. The literature pertinent to the review was searched through combinations of specific keywords such as:

- “Coconut water fermentation,”
 - “Producing strawberry wine,”
 - “Dynamic fermentation,”
 - Nutritive value of fermented coconut
 - “Strawberry phenolics in wine,”
 - “Process innovations in fruit wine,”
 - Its connection to yeasts used in
 - “Non-Saccharomyces yeasts in strawberry wine.”
- Facts were pulled and thematically sorted into three broad categories:
- Fermentation Dynamics
 - Nutritional Value, and
 - Process Innovations.

Process Optimization in Fruit Wine Production: A Focus on Coconut and Strawberry

Table 2: Optimization of the process in strawberry wine making

Table 2: Key parameters influencing strawberry and coconut wine production

Parameter	Observation /Optimized Value	Fruit Type	References
Sugar Concentration	9% sugar in coconut water yielded 8.08% alcohol, pH 4.3, TSS 5.2 ° Brix, titrable acidity 0.72%	Coconut	Guanfei Zhang <i>et al.</i> , 2018
Yeast Strain	<i>S. cerevisiae</i> D254 produced the highest ethanol content in coconut wine	Coconut	Guanfei Zhang <i>et al.</i> , 2018
Inoculum Levels	6 – 12 % yeast inoculum altered fermentation efficiency and final alcohol content	Coconut	Guanfei Zhang <i>et al.</i> , 2018
Fermentation Duration	Alcohol content increased continuously during the 48-hour fermentation	Coconut	Guanfei Zhang <i>et al.</i> , 2018
Antioxidant Activity	Fermented enhanced DPPH, ABTS, FRAP-increased antioxidant potential	Coconut	Guanfei Zhang <i>et al.</i> , 2018
Fermentation Conditions	Optimal: 81 mg/L SO ₂ , 1g/L yeast, 20 degree C – enhanced aroma profile	Strawberry	Jianping Wei <i>et al.</i> , 2019
Aroma Compounds	Major esters: isoamyl alcohol, isoamyl acetate, ethyl hexanoate, ethyl octanoate	Strawberry	Jianping Wei <i>et al.</i> , 2019
Cultivar Selection	‘ZJ’ cultivar had more phenylethyl alcohol and aroma compounds	Strawberry	Jianping Wei <i>et al.</i> , 2019
Quality Parameters	Ethanol 11-12%, Vitamin C 5 – 6 g/L, Antioxidant Activity ~80%	Strawberry	Jianping Wei <i>et al.</i> , 2019

Case Study: Strawberry Pulp with and without Fermented Coconut Milk

Product Development and Optimization: Developed two fermented coconut milk beverages: a simple one (FC) and another with strawberry pulp (FCS). The optimum

formulation was 0.15% xanthan gum and 0.05% guar gum to achieve enhanced viscosity and prevent syneresis. (Carolina Saori Ishii Mauro *et al.*, 2022). FC and FCS both received high sensory approval scores, with scores across the globe >7.5 on a 9-point hedonic scale. Strawberry

pulp supplementation added to flavor and aroma but not to *Lactobacillus reuteri* LR 92's probiotic viability, which still maintained its viability at >74% following simulated digestion through the gastrointestinal tract. (Carolina Saori Ishii Mauro *et al.*, 2022). Incorporating stabilizers gave the product stability, and microbiological analysis ensured the drinks' safety for consumption by humans. The study concluded that fermented coconut milk beverages, especially those with fruit pulp, are acceptable functional foods with high consumer acceptability. (Maria Thereza Carlos Fernandes *et al.*, 2021)

Challenges

Coconut Water Wine

The main difficulty in making coconut water wine is its low sugar content, which must be supplemented to obtain the intended alcohol levels. A further complication is the perishable nature of coconut water, so processing must be carried out quickly to avoid spoilage. *Saccharomyces cerevisiae* strains have been used for fermentation to enhance the quality and storage life of coconut water wine (Guanfei Zhang *et al.*, 2018).

Strawberry Wine

Strawberry wine is beset by the high perishability of strawberries, which can result in spoilage if not treated immediately. Additionally, the process of fermentation has the potential to influence the composition of anthocyanins, resulting in color changes as well as a loss of antioxidant activity. Experiments have proved that fermentation procedures can reduce anthocyanin concentration in strawberry wine, thereby affecting its color and antioxidant capacity (Ruth Hornedo-Ortega *et al.*, 2017).

RESULTS AND DISCUSSION

Fermentation Kinetics of Coconut and Strawberry

The fermentation behavior of coconut water and strawberry juice is largely determined by their sugar, pH, and nutrient status. Coconut water, with a relatively lower sugar content (~6–8 g/L), generally requires added sugar to produce an acceptable alcohol level. Experiments using *Saccharomyces cerevisiae* D254 produced ethanol contents of up to 8.08%, best pH levels near 4.3, and titratable acidity of around 0.72% (Zhang *et al.*, 2018). Selection of yeast strains is needed to manage the rate of fermentation and the concentration of aroma compounds in coconut wines. Conversely, natural strawberry juice contains 12–18% fermentable sugars and phenolic compounds. This makes it an appropriate substrate for direct fermentation without supplemented sugar. The application of non-*Saccharomyces* yeasts like *Hanseniaspora uvarum* and *Torulaspora delbrueckii* has been reported to increase flavor complexity, while *S. cerevisiae* provides improved ethanol yield and fermentation stability (Wang *et al.*, 2025; Padilla *et al.*, 2016). Alcohol levels of 11% and 12% have been well established in optimized strawberry wine production (Nehra *et al.*, 2021).

Nutritional Value of Fermented Foods. Both coconut and strawberry contribute significant nutrients to the wine matrix. Coconut water contains high electrolyte levels, primarily potassium (approximately 1,900 mg/L), magnesium, calcium, and amino acids like glutamic acid and arginine (Hamilton *et al.*, 2024; Rocha *et al.*, 2024). Fermentation retains significant micronutrient content, so the drink is more worthy as a rehydrating functional beverage. Strawberries rich in vitamin C (~59 mg/100 g), polyphenols, and anthocyanins exhibit increased antioxidant activity after fermentation due to the release of bioactive metabolites (Giampieri *et al.*, 2014; Zhao *et al.*, 2021). Maintenance of that antioxidant activity after fermentation renders such fruit wines great nutraceuticals. Moreover, studies show that fermented strawberry products are enriched with increased bioavailability of phenolics and flavonoids, which are equivalent to anti-inflammatory and cardioprotective activities (Badmi *et al.*, 2023).

Innovations in the Wine Development Process

Different technological advancements have been investigated to enhance the quality and consistency of coconut and strawberry wines throughout fermentation. Low-temperature controlled temperature fermentation (~15–18°C) prevents the loss of volatile compounds and loss of aroma strength, particularly in strawberry wines (Wei *et al.*, 2019). Enzyme-aided extraction and stabilizers such as xanthan gum and guar gum have been employed to enhance mouthfeel, color stability, and viscosity in blended fruit wines (Mauro *et al.*, 2022). Probiotic co-cultures such as *Lactobacillus reuteri* and *Lactobacillus plantarum* have been studied to create fermented beverages that are probiotic as well as contain alcoholic attributes. Two-in-one beverages such as these optimize gastrointestinal health without the need to settle for appealing sensory qualities (Xu *et al.*, 2018; Doriya *et al.*, 2022).

Blending techniques have also been promising. Mixing coconut water with strawberry juice balances the coconut's lower sugar content with the strawberries' high antioxidant capacity. This combination enhances fermentability, aroma profile, and overall product acceptability (Khadka *et al.*, 2024). 6.4 Reproducibility and Standardization Problems: Reproducibility is one of the major problems of small- to medium-scale winemaking. Variation of raw material ripeness, sugar level, and microbial contamination affects batch-to-batch reproducibility. Standardization of yeast inoculum, pH management, and addition of nutrients is necessary for maintaining consistency of the kinetics of fermentation and product quality (Romano *et al.*, 2022; Padilla *et al.*, 2016). Process control equipment and real-time monitoring in the form of pH and ethanol biosensors are recommended for industrial applications.

Novelty of Research

This review is among the first to fully investigate the dual employment of coconut water and strawberry as substrates in functional wine production. Contrary to previous studies that address the individual coconut or

strawberry fermentation, this paper combines findings on fermentation dynamics, nutritional bioactivity, and process innovation in both fruits. The novel combination of this dual-substrate strategy emphasizes the synergistic potential for improving wine quality, antioxidant activity, and sensory attractiveness, providing a new avenue for the creation of health-focused alcoholic beverages.

Contribution to Knowledge

This review adds to the emerging science of functional fermented drinks by scientifically evaluating how strawberry and coconut, two nutrient-dense and lesser-utilized fruits, can be converted into high-value wine products. It collates key advances in yeast strain selection, fermentation optimization, and bioactive preservation, and adds the newest advances in co-fermentation and product stabilization. The research provides a fundamental structure for future experimental protocols and commercial scale-up options in tropical fruit wine production.

Satisfaction of Research Gap

Despite growing interest in fruit wines, there is a significant absence of comprehensive analysis on dual-substrate fermentation with coconut and strawberry. This review fills that gap by bringing together dispersed data into a unified discussion, describing both the inherent strengths and the possible synergistic effects of using these substrates in combination. It also points out limitations in existing methods, including reproducibility and supplementation with nutrients, while suggesting directions for future research in fermentation technology and functional enhancement for future beverages.

CONCLUSION

Wine production from coconut and strawberry offers a novel and potential application in the beverage market, where the tropical flavor profile of coconut is combined with the strong aroma and antioxidant content of strawberry. The review points out that difficulties in batch-to-batch reproducibility, quality control, and microbial stability are major challenges at the industrial level. Most notable findings indicate that fermentation conditions, such as strain choice, sugar maximization, and controlled environmental temperatures, play a key role in dictating the final product's sensory and nutritional properties. There is significant scope for technical advancements in fermentation methods, particularly in microbial strain engineering, process automation, and real-time quality control monitoring. More stringent quality assurance systems, such as the adoption of HACCP (Hazard Analysis and Critical Control Points) and GMP (Good Manufacturing Practices), would also help to guarantee product consistency and consumer protection during scale-up. The future offers great scope for research. Fortification with functional ingredients like vitamins, minerals, or polyphenols could boost the nutritional profile of coconut-strawberry wine. Modulation of

flavor-active compounds for sensory enhancement provides a route towards diversifying consumer interest. Further, infusing probiotic strains during fermentation might give rise to a new class of functional fermented drinks marrying the enjoyment of wine drinking with probiotic health benefits. Subsequent research aimed at maximizing fermentation kinetics, enhancing sensory profiles, and incorporating functional fortification would greatly enhance the commercial value and consumer appeal of coconut and strawberry wines.

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