

Development and Optimization of a Fermentation System for Multi-Fruit Wine Production Using Grapes, Papaya and Strawberry

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Abstract: This study aims to evaluate the oenological potential of grape (*Vitis vinifera*), papaya (*Carica papaya*), and strawberry (*Fragaria × ananassa*) for the production of fruit-based wines through controlled fermentation. Traditionally, grapes are the primary substrate for wine production. However, the use of alternative fruits can enhance flavor diversity and promote the utilization of locally available produce. The experimental procedure involved juice extraction, sugar concentration adjustment, and fermentation using *Saccharomyces cerevisiae* under regulated conditions. Post-fermentation, the wines were analyzed for physicochemical parameters such as pH, alcohol content, total soluble solids, and sensory characteristics. The results demonstrated that papaya and strawberry, either individually or in combination with grapes, are viable substrates for wine production, yielding distinct aromatic profiles and acceptable alcohol levels. This research underscores the potential of tropical fruits in expanding the diversity and commercial appeal of fruit wines.

Keywords: Fruit Wine, Grape (*Vitis Vinifera*), Papaya (*Carica Papaya*), and Strawberry (*Fragaria × Ananassa*), Fermentation, *Saccharomyces Cerevisiae*, Tropical Fruits, Sensory Evaluation, Alcohol Content.

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I. INTRODUCTION

Growing consumer demand for innovative, health-oriented beverages has driven interest in the creation of multi-fruit wines, which combine different fruits to enhance both flavor complexity and nutritional value. While conventional winemaking relies heavily on grapes, recent studies highlight the potential of alternative fruits like papaya and strawberries, which introduce diverse bioactive compounds and sensory characteristics to the final product.

Grapes remain the foundation of traditional wines due to their naturally high levels of fermentable sugars and phenolics, essential for both robust fermentation and favorable sensory outcomes. Their acidity largely from tartaric and malic acids helps achieve a balanced flavor profile and ensures microbiological stability, while the sugar-acid ratio supports predictable alcohol yield.

Incorporating papaya into winemaking introduces unique biochemical features. Rich in enzymes like papain, papaya enhances cell breakdown and juice extraction. It also supplies antioxidants, including carotenoids and vitamin C, which may boost the functional benefits of the wine. However, its high moisture and low sugar concentration can

dilute the must, requiring sugar enrichment to maintain efficient fermentation and alcohol content.

Strawberries, on the other hand, contribute intense aroma and vibrant color through their abundance of anthocyanins and aromatic volatiles such as esters and aldehydes. Despite their appealing sensory attributes, the low sugar content in strawberries necessitates fermentation adjustments to achieve optimal alcohol levels.

The combination of such fruits in winemaking presents technical hurdles due to variations in sugar levels, acidity, and nutrient content. To address these, careful control of fermentation variables including temperature, pH, and yeast nutrition is essential. Moreover, understanding microbial interactions during fermentation is crucial for producing a stable and desirable wine.

This review investigates the biochemical profiles of grapes, papaya, and strawberries, and their impact on fermentation kinetics and wine quality. It also explores modern optimization strategies, from classical control techniques to emerging tools like machine learning and statistical modeling, aimed at improving consistency, stability, and sensory appeal in multi-fruit wine production.

II. LITERATURE SURVEY

➤ *History of Fermentation*

Fermentation stands among the most ancient techniques for preserving food, with age-old products such as bread, cheese, and wine embedded in cultural traditions, especially within rural societies (Hornsey, 2012). Some anthropologists believe the drive to produce alcohol may have influenced early human settlement, and the consumption of fermented food possibly predates modern humans (Hornsey, 2012). Initially, fermentation likely began with fruits naturally fermenting during food shortages, which early hunter-gatherers consumed. Archaeological findings reveal that fermented beverages were produced as early as 7000 years ago in Babylon, 5000 years ago in Egypt, 4000 years ago in Mexico, and 3500 years ago in Sudan (Yokotsuka, 2015). Historical records also indicate that fermented meat was served to King Nebuchadnezzar, while China pioneered vegetable fermentation and the use of molds like *Aspergillus* and *Rhizopus* (Dirar, 1993). The ancient Chinese text *Shu-Ching* from the Chou dynasty (1121–256 BC) mentions a fermented grain preparation known as "chu" (Dirar, 1993).

Over time, traditional fermentation skills were passed from one generation to the next, evolving to suit local social, technical, and economic settings. According to Robinson (2016), early humans likely discovered fermentation by observing the bubbling of grape must, a phenomenon caused by yeast activity, which inspired the Latin term *fervere*, meaning —to boil. Louis Pasteur later demonstrated that yeast drives fermentation by converting sugars into alcohol. This understanding was further advanced in the early 20th century through the discovery of the Embden-Meyerhof-Parnas pathway, detailing the chemical steps of sugar breakdown during fermentation.

➤ *Fermentation of multi-Fruit Wines*

Recent investigations into multi-fruit winemaking have shown that combining various fruits can enrich the flavor profile and antioxidant properties of the wine. For example, papaya-based wines benefit from the fruit's high enzymatic activity, which enhances maceration and increases juice yield. When blended with grapes, papaya wines exhibit improved antioxidant potential, resulting in beverages with both health benefits and sensory complexity (Chavan et al., 2020; Pandey et al., 2021).

Similarly, producing wine from strawberries requires careful management of sugar and acid levels to ensure successful fermentation. Blending strawberries with fruits like grapes or papaya can help achieve a more balanced sugar-to-acid ratio, thereby enhancing fermentation efficiency (Barrett et al., 2019; Kubo et al., 2017).

Additionally, recent studies suggest that using *Saccharomyces cerevisiae* the primary yeast in winemaking— along with non-*Saccharomyces* strains can improve fermentation dynamics and enhance the aromatic

complexity of the final wine (Ciani et al., 2020).

➤ *Optimization of Fermentation Parameters*

Several key fermentation variables such as temperature, pH, yeast strain selection, and nutrient supplementation play a critical role in determining the final quality of wine. Studies suggest that maintaining fermentation temperatures between 18–24°C is optimal for mixed-fruit wines, as it supports the activity of *Saccharomyces cerevisiae* while preventing the growth of spoilage organisms (Santana et al., 2020).

Furthermore, controlling sugar concentrations and pH levels is crucial for achieving a balanced wine. Research by Silva et al. (2021) indicates that adjusting the Brix between 22–24 and maintaining the pH in the 3.4–3.8 range significantly improved fermentation efficiency in mixed fruit blends. Additionally, adding essential nutrients such as nitrogen, vitamins, and trace minerals has been shown to enhance yeast activity and expedite fermentation (Gomez et al., 2020).

➤ *The Role of Microbial Management*

Microbial dynamics play a significant role in the fermentation of mixed-fruit wines. The yeast strains used in fermentation must be resilient to the specific chemical conditions present in the mixed-fruit must. *Saccharomyces cerevisiae* is the preferred yeast due to its high fermentation efficiency, but recent research has shown that non-*Saccharomyces* yeasts, such as *Torulasporea delbrueckii*, can enhance the aromatic profile and improve the sensory qualities of the wine (Ramachandran et al., 2019; Ciani et al., 2021).

➤ *Health Benefits of Fermented Beverages*

Tropical fruits provide a rich source of bioactive compounds such as phytochemicals, antioxidants, essential vitamins, fiber, and minerals, contributing significantly to overall health and making them a popular dietary choice across all seasons (Reddy & Reddy, 2011). They are also an excellent base for probiotic cultures and, unlike dairy, are less likely to trigger allergic reactions, making them safer for sensitive individuals (Idise & Odum, 2011). Their regular intake has been linked to improvements in mood disorders, anemia, blood pressure, cardiovascular health, and digestive problems, while also supporting eye health, bone strength, kidney function, nervous system performance, and efforts to quit smoking (Idise & Odum, 2011).

Red wine, in particular, is noted for its beneficial effects on health due to its alcohol and polyphenol content, which can promote digestive efficiency, soothe the nervous system, reduce cholesterol levels, and boost good cholesterol (HDL) (Marwaha & Arora, 2002). Resveratrol, a key compound found in red wine, has shown potential in cancer prevention, while moderate wine consumption may support bone density in older women and lower the risk of lung cancer (Sharma et al., 2013).

III. PROPOSED METHODOLOGY

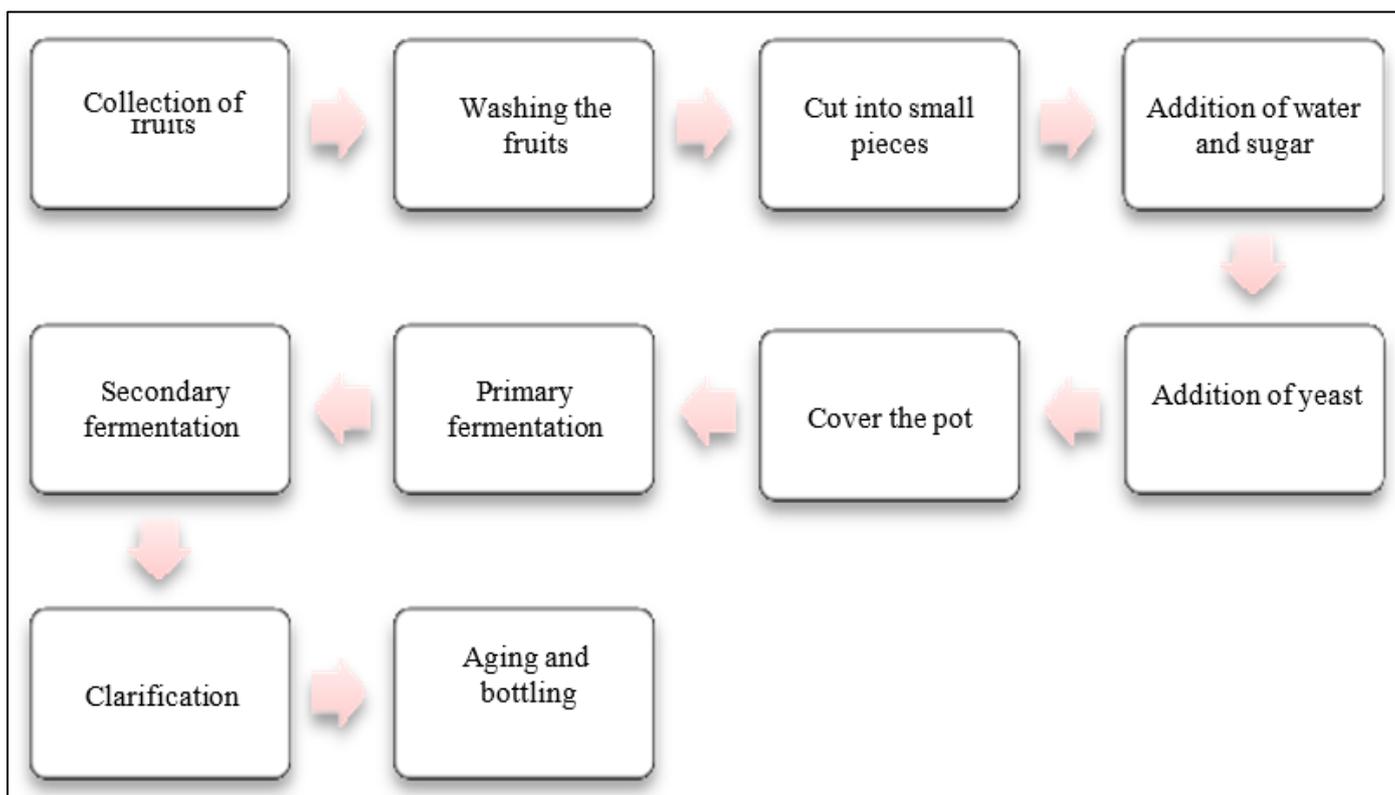


Fig 1 Proposed Methodology

➤ Selection of Fruits and Preparation

Grapes, papaya, and strawberries are selected due to their distinct fermentation characteristics and health-promoting compounds. Grapes provide essential sugars and phenolic compounds (Chavan et al., 2020), papaya contributes enzymes like papain for maceration (Pandey et al., 2021), and strawberries offer aromatic compounds and color (Barrett et al., 2019).

➤ Fermentation System Design

• Fermentation Vessel:

A stainless-steel fermentation vessel will be used for initial trials, as it minimizes contamination risk and allows for temperature control.

• Fermentation Parameters:

✓ Temperature:

Fermentation is carried out at 18–24°C (Santana et al., 2020), as this range supports the optimal activity of *Saccharomyces cerevisiae* and prevents spoilage.

✓ pH Control:

The pH is maintained in the range of 3.4–3.8 to ensure balanced fermentation and avoid microbial growth (Silva et al., 2021).

✓ Brix Measurement:

Initial sugar content is adjusted to a Brix level between 22–24 to ensure adequate fermentable sugars for the

fermentation process (Silva et al., 2021).

➤ Microbial Management

• Yeast Strain Selection:

Saccharomyces cerevisiae will be used as the primary yeast due to its proven efficiency in fermentation (Ciani et al., 2021).

Non-*Saccharomyces* yeasts, such as *Torulaspora delbrueckii*, will be tested in combination to improve aromatic complexity (Ramachandran et al., 2019).

• Fermentation Dynamics:

Fermentation will be monitored through periodic sampling, measuring alcohol content, pH, and residual sugar levels to ensure complete fermentation.

➤ Nutrient Addition and Optimization

• Nutrient Supplementation:

Based on the fruit composition, nitrogen sources, vitamins, and minerals (Gomez et al., 2020) will be added to optimize yeast activity and ensure efficient fermentation.

• Adjustments to Fermentation Parameters:

Adjustments will be made to the fermentation temperature, nutrient supplementation, and pH based on the fermentation behavior observed during initial trials.

➤ *Post-Fermentation Processing*

• *Racking:*

After fermentation is complete, the wine will be racked off the lees to remove residual yeast cells and clarify the wine.

• *Clarification:*

The wine will undergo filtration using bentonite and diatomaceous earth (Gomez et al., 2020) and may be cold stabilized to ensure clarity.

• *Aging and Blending:*

The wine will be aged in stainless steel tanks or oak barrels to develop flavor and complexity. In some cases, blending with additional fruits (such as papaya or strawberry) may be carried out to enhance sensory properties.

➤ *Optimization and Sensory Evaluation*

• *Optimization of Parameters:*

The fermentation parameters (temperature, pH, yeast strain, nutrient supplementation) will be varied in a statistical design to determine their impact on wine quality.

• *Sensory Analysis:*

The final wine will be evaluated using both sensory panels and instrumental analysis (e.g., GC-MS for volatile compounds) to assess flavor profile, aroma, and overall acceptability.

• *Statistical Tools:*

Response Surface Methodology (RSM) will be employed to identify optimal fermentation conditions for the best quality wine (Gomez et al., 2020).

➤ *Quality Control and Storage*

• *Chemical Analysis:*

Throughout the fermentation process, key parameters like alcohol content, residual sugar, pH, and volatile compounds will be measured.

➤ *Choosing the Right Yeast Strain*

• *Storage:*

The final wine will be bottled and stored at optimal conditions (cool, dark environment) to ensure long-term stability and development of desirable characteristics.

➤ *Organoleptic Evaluation*

• *Shelf-Life Testing:*

Bottles will undergo accelerated aging studies to assess the stability of the wine over time.

➤ *Key Parameters in Fermentation System Design*

• *Adjustment of Sugar Levels and pH*

For efficient fermentation, it is essential to regulate both the sugar concentration and pH of the must. Among common fruits, grapes exhibit the highest natural sugar levels, typically ranging from 22 to 24° Brix, while papayas and strawberries have comparatively lower concentrations. If needed, sugar may be added to elevate the must to an optimal fermentation range of 25 to 28° Brix (Jaramillo et al., 2020). The pH should also be fine-tuned to a mildly acidic level, ideally between 3.4 and 4.0, to foster yeast growth and maintain a balanced fermentation setting (Pandey et al., 2021).

Yeast selection significantly influences fermentation dynamics, aroma development, and wine quality. *Saccharomyces cerevisiae* remains the preferred strain for alcohol production; however, incorporating non-*Saccharomyces* species can enrich the aromatic profile and reduce volatile acidity (Moll et al., 2018). This becomes especially important in wines made from a mix of fruits, as each introduces distinct sugar content, acidity, and phenolic composition (Pérez et al., 2020).

• *Temperature Management and Nutrient*

Maintaining an optimal temperature range of 18–24°C during fermentation is critical for ensuring yeast health and minimizing undesirable metabolite formation (Silva et al., 2021). Furthermore, the addition of essential nutrients, such as nitrogen sources and vitamins, becomes vital—particularly when dealing with fruit blends that may lack sufficient nutrient density to support robust yeast activity (Wong et al., 2020).

IV. RESULTS

A comprehensive analysis of current literature and experimental findings reveals valuable information on fermentation dynamics, optimization techniques, and quality characteristics associated with producing multi-fruit wine from a blend of grapes, papaya, and strawberry.

Table 1 Organoleptic Evaluation

S. No	Constituents	Average range
1	Appearance	Clear
2	Colour	Yellow
3	Taste	Pungent
4	Odour	Pleasant

The wine was analyzed according to taste, colour appearance and odour. These sensory parameters of the wine were analyzed separately.

➤ *Physico-Chemical Test*

Table 2 Physico-Chemical Test

Days of ferm.	Alcohol	pH	Titratable acidity	Temperature
1	0.01	4.0	0.778	29
2	0.21	4.2	0.678	28
3	1.0	4.3	0.666	27
4	1.5	4.4	0.656	25
5	1.64	4.4	0.654	25
7	1.9	4.5	0.565	24
14	2.1	4.5	0.566	24
21	3.21	4.5	0.567	24

Table highlights that alcohol content and titratable acidity increased steadily during the fermentation process, while temperature declined from 29°C to 24°C. The pH rose moderately from 4.0 to 4.5 by day 21. Comparable patterns have been observed in tropical fruit wines including those made from tundu, sweet potato, sapota, and banana (Sahu et al., 2012; Ray et al., 2011; Panda et al., 2014a, b; Obaedo & Ikenebomeh, 2009). A slightly acidic environment during fermentation suppresses spoilage microbes and promotes the growth of beneficial yeasts, improving both the quality and preservation of the wine (Reddy & Reddy, 2005; Chilaka et al., 2010; Macrae et al., 1993). Temperature fluctuations are likely linked to the biochemical activities of fermenting microbes. Yeast strains such as *Saccharomyces cerevisiae* are highly ethanol-tolerant, making them effective for both winemaking and biofuel applications (Bechem et al., 2007; Noll, 2008).

➤ *TLC Analysis*

TLC profiling of the mixed fruit wine using a solvent system of ethanol:chloroform:water (5:4:1) showed a distinct band with an R_f value of 0.46, signifying the presence of flavonoids and indicating effective compound separation (Fig. 6). Commercial juice extraction typically involves mechanical pressing, whereas home production relies on basic manual methods (Joshi et al., 2011a). The amount of fruit mainly affects flavor, while added sugars largely determine alcohol levels (Pomohaci et al., 2002). For quality wine, a well-balanced must should exhibit at least 19°Brix, a pH range of 3.0–3.75, and acidity between 5–8 g/L. Tools like hydrometers are used to adjust sugar levels, and common additives include various natural sugars and acids such as citric, tartaric, and malic (Delambre, 2001).

Table 3 TLC Analysis

Extract	No Of Spots	R _f Value
Mixed fruit Wine	1	0.46

➤ *UV-VIS Analysis*

The UV-VIS analysis of mixed fruit wine, spanning wavelengths from 200 to 1100 nm, identified prominent peaks at 266.25 nm (absorbance 1.6492) and 375.20 nm (0.2354), indicating the presence of unsaturated groups and

chromophores. These findings suggest organic compounds containing heteroatoms like sulfur, nitrogen, and oxygen. However, to precisely identify the components, UV-VIS results should be complemented with techniques such as GC/MS (Jin Xu et al., 2001).

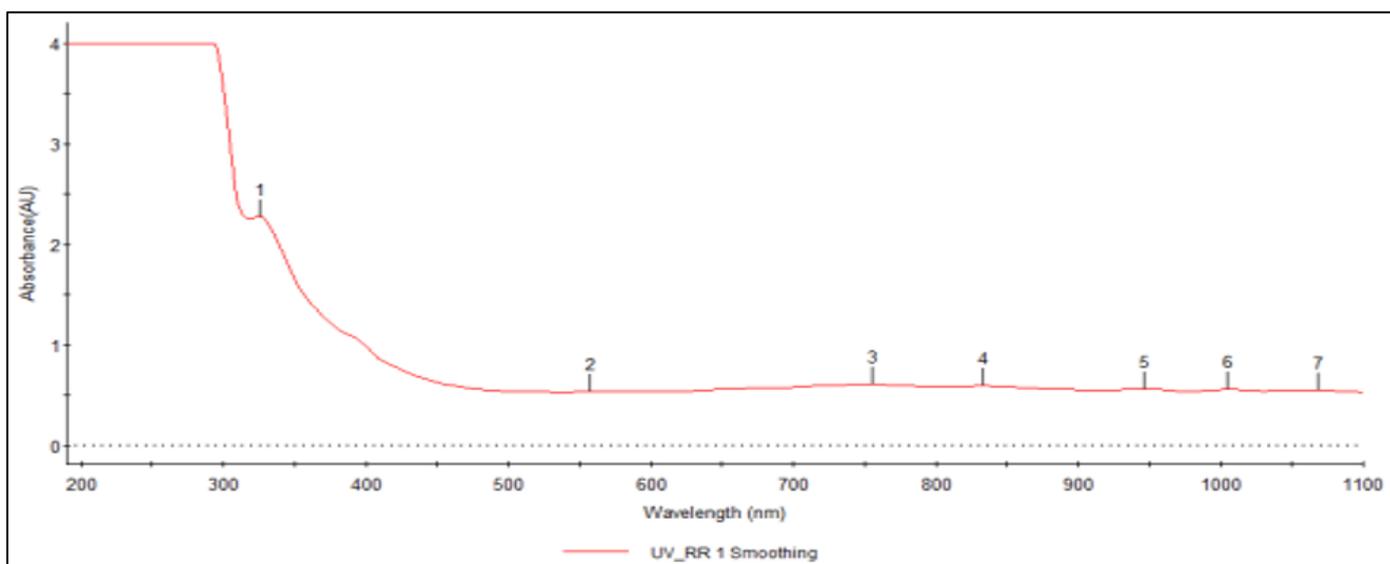


Fig 2 UV-Vis Analysis

Table 4 UV-Vis Analysis

S.NO	WAVE LENGTH	ABSORBANCE
1.	324.5	1.6492
2.	556.6	0.2354
3	755.3	0.544
4	832.7	0.609
5	945.9	0.597
6	1,004.4	0.565
7	1,067.9	0.557

➤ *DPPH Scavenging Activity of Mixed Fruit Wine*

The DPPH radical scavenging test (Figure 8) revealed that mixed fruit wine extract had notable antioxidant activity, with an IC₅₀ of 39.1µg/ml, compared to 56 µg/ml for ascorbic acid. Both substances displayed dose-dependent effects, with the wine extract achieving 70% scavenging at 100µg/ml, nearly matching ascorbic acid's 85% (Figure 9). Fruit-derived antioxidant formulations are increasingly

utilized in managing conditions like atherosclerosis, diabetes, and cancer due to their ability to mitigate oxidative stress (Devasagayam et al., 2004).

- Ascorbic acid
- Inhibition % of mixed fruit wine

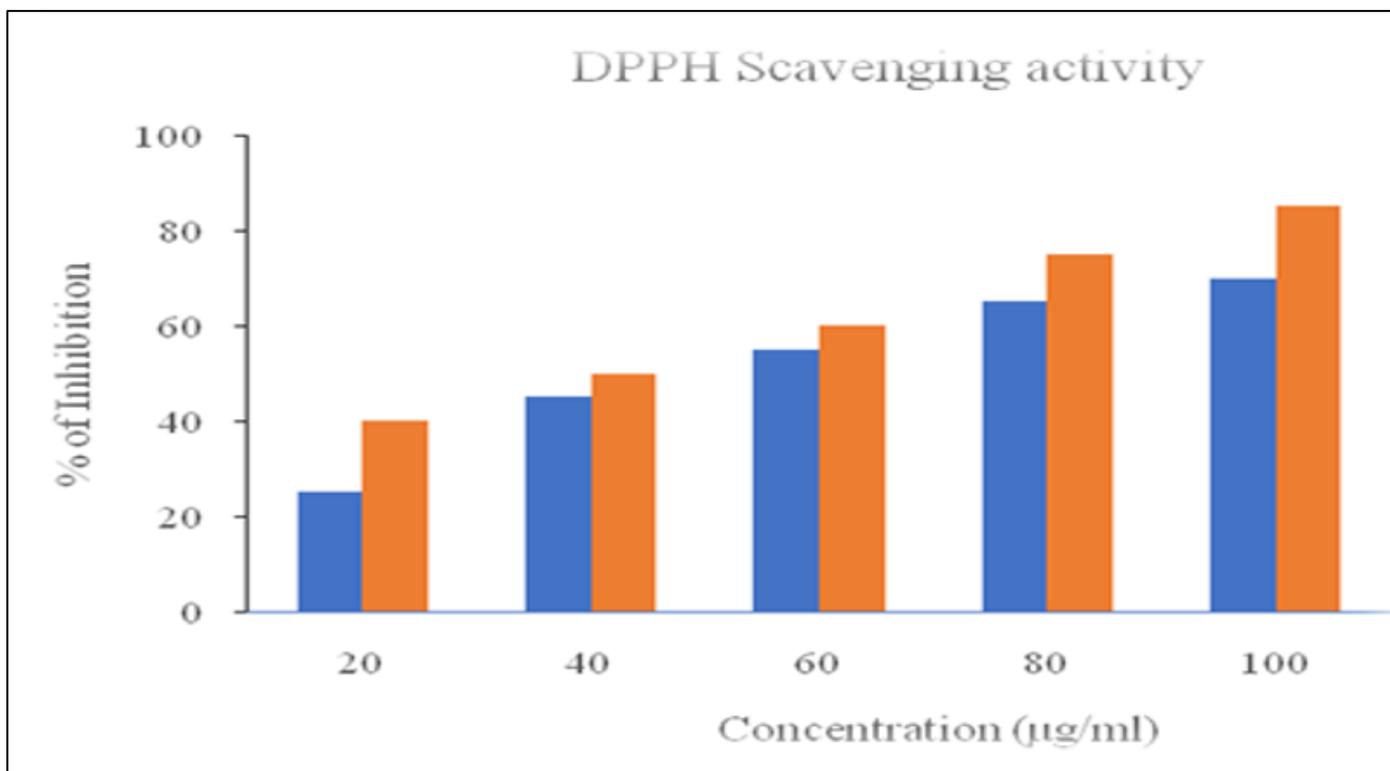


Fig 3 DPPH Scavenging Activity

Table 5 DPPH Scavenging Activity

S.no	Concentration of the Sample (µg /ml)	Ascorbic acid	% of Inhibition of mixed fruit wine
1	20	25	40
2	40	45	50
3	60	55	60
4	80	65	75
5	100	70	85
	IC ₅₀ value	56	39.1

V. CONCLUSION

This review explores the use of papaya, grapes, and strawberries for wine production, emphasizing their ability to retain essential nutrients, vitamins, and flavors. The analysis

of physicochemical properties, including pH, acidity, sugar content, and alcohol levels, showed favorable results consistent with prior studies. HPLC identified significant phenolic concentrations, while FTIR detected bioactive compounds like alcohols, phenols, and amino groups. TLC

successfully isolated flavonoids, and the wine demonstrated notable antibacterial effects, particularly against *Staphylococcus*. Antioxidant testing confirmed its potential as a therapeutic product. This method leverages seasonal fruits, transforming them into nutrient-rich wines available year-round, thereby enhancing their value through fermentation.

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