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RESEARCH ARTICLE

Evaluation of herbal blended roxburgh fig (*Ficus auriculata* Lour.) wine for quality and storage stability

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Abstract

Roxburgh fig (*Ficus auriculata* Lour.), an underutilised fruit species native to Asia, possesses high nutritional value and bioactive compounds, offering significant health benefits. Despite the recognised nutritional and medicinal value of *F. auriculata*, there is limited scientific evidence on its utilisation for standardised wine production, particularly in combination with functional herbal extracts. Hence, the study aims to utilise Roxburgh fig to produce wine enriched with leaf extracts of gotu kola (*Centella asiatica* (L.) Urb.) and vetiver (*Chrysopogon zizanioides* (L.) Roberty) root extracts and to optimise fermentation parameters, as well as to develop pilot-scale production technology. The study was conducted using eight different concentrations of herbal blends (2, 4, 6 and 8 % of gotu kola and vetiver) along with a control (fruit pulp). During the standardisation of herbal blended wine, T_2 and T_6 (2 % gotu kola and vetiver extract, respectively) resulted in significantly high alcohol (9.08–9.12 %) and lower reducing sugar content (6.91–6.93 mg/mL). It was comparable with the control (9.28 % alcohol and 6.40 mg mL^{-1} reducing sugar). However, the highest overall acceptability score (4.1) was obtained in T_2 (fruit pulp with 2 % gotu kola leaf extract). *Saccharomyces cerevisiae* (MTCC 178) culture at a 3 % concentration, with a pH level of 4.5 and a temperature of 30 °C, was found to be optimum for maximum alcohol production, resulting in higher sensory evaluation scores. This study demonstrates that roxburgh fig, combined with moderate concentrations of herbal extracts, can produce high-quality, sensory-appealing wine.

Keywords: fermentation; *Ficus auriculata*; gotu kola; herbal blended wine; optimisation; storage stability; vetiver

Introduction

Roxburgh fig (*Ficus auriculata* Lour.), native to the Asia/Indo-China region, including the Western Ghats, represents a valuable but often overlooked resource. Commonly known as elephant ear fig, it belongs to the family Moraceae and thrives in diverse habitats, particularly tropical and subtropical regions, at altitudes up to 1800 m above sea level. The fruit of *F. auriculata* is notable for its high nutritional value, rich in potassium (1505.16 mg 100 g^{-1} dry weight), sugar (9.98 %) and vitamin C (18.40 mg 100 g^{-1} dry weight) (1). In addition, fruits are reported to contain bioactive compounds, flavonoids, phenolics, carotenoids, tannins and dietary fibre, which contribute to a wide spectrum of health benefits, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective and anticancer activities (2, 3). Traditionally, *F. auriculata* has been valued in Ayurveda, Unani, Siddha and Homeopathy for its laxative effects, gastrointestinal support and bone-strengthening properties (3). Roxburgh figs bear a massive quantity of fruits seasonally and the fruits are highly perishable in nature and it is not exploited commercially. Hence, processing and addition technology may play a crucial role in the conservation and improved utilisation of fruits. Wine production, a globally practiced fermentation-based process, offers an innovative approach to valorise such underutilised fruits. Particularly, herbal-infused wine combines the nutritional richness of fruits with the therapeutic potential of botanicals. Beyond preserving seasonal surpluses, these products introduce unique flavours and functional properties, catering to the growing demand for health-oriented beverages (4).

Gotu kola, *Centella asiatica* (L.) Urban is an important medicinal herb that has neuroprotective properties, used to enhance memory, for the treatment of epilepsy, Alzheimer's disease and other cognitive disorders (5–7). Gotu kola herb, reported to be rich in nutrients, polyphenols and antioxidants, has been used traditionally for culinary purposes in South India over the years, basically due to its healing and cognitive properties (8, 9). Similarly, vetiver, *Chrysopogon zizanioides* (L.) Roberty is a medicinal and aromatic grass species that produces a huge biomass of roots used for conservation of soil (10, 11). Medicinally, roots possess cooling properties used in aromatherapy, which can relieve stress and treat conditions such as rheumatism, paralysis, arthritis and gouty joints (11, 12). Although fruit wine production is widely practiced and herbal wines are gaining interest as functional beverages, scientific standardisation of non-grape fruit wines enriched with medicinal plants such as *C. asiatica* and *C. zizanioides* is scarce. Furthermore, there is inadequate information on optimised fermentation parameters and storage stability for such herbal-blended fruit wines. Thus, the study was planned to address the research gap by developing and standardising a functional roxburgh fig herbal wine, optimising fermentation and conducting pilot-scale validation.

Materials and Methods

The experiment was conducted at the College of Forestry, Sirsi and at the Department of Food Safety and Quality Assurance Laboratory, College of Community Science, Dharwad, University of Agricultural Science, Dharwad, Karnataka, India, during the year 2023–2024.

Standardisation of herbal blending

Sample collection and extraction

Healthy and ripened roxburgh fig fruits and herbs (gotu kola leaves and vetiver roots) were collected from the farmer's fields of the Uttara Kannada district. Fruit pulp was extracted and blended with an equal weight of water (1:1 w/v ratio) and the resulting juice was then filtered through cheesecloth.

The known weight of freshly harvested gotu kola leaves was washed and ground with a 1:1 (leaves: water) ratio of distilled water and the juice was strained through cheesecloth. Similarly, the known weight of dried vetiver root was boiled in distilled water (1:2 ratio) for 20 min and strained through cheesecloth.

Preparation of inoculum

Saccharomyces cerevisiae, MTCC 178, a yeast strain, was obtained from the Microbial Type Culture Collection (MTCC), Dharwad. It was maintained on Malt Extract-Glucose-Yeast Extract-Peptone (MGYP) agar slants at refrigeration temperatures. A loopful of the yeast culture was transferred to 6 mL of MGYP broth and incubated at 37 °C for 24 hr to obtain a fresh culture. After incubation, 1 mL of this broth was added to 99 mL of a 1 % sterilised sucrose solution and incubated for 3 hr before inoculation.

Fermentation of samples

The experiment was laid out in a completely randomised design with 9 treatments and 3 replications as follows:

T1: Control- 100 % fruit juice

T2: Fruit pulp + 2 % gotu kola extract (aqueous extract of 2 g of fresh gotu kola leaves blended with 98 g of fruit pulp)

T3: Fruit pulp + 4 % gotu kola extract (aqueous extract of 4 g of fresh gotu kola leaves blended with 96 g of fruit pulp)

T4: Fruit pulp + 6 % gotu kola extract (aqueous extract of 6 g of fresh gotu kola leaves blended with 94 g of fruit pulp)

T5: Fruit pulp + 8 % gotu kola extract (aqueous extract of 8 g of fresh gotu kola leaves blended with 92 g of fruit pulp)

T6: Fruit pulp + 2 % vetiver extract (aqueous extract of 2 g of dry vetiver roots blended with 98 g of fruit pulp)

T7: Fruit pulp + 4 % vetiver extract (aqueous extract of 4 g of dry vetiver roots blended with 96 g of fruit pulp)

T8: Fruit pulp + 6 % vetiver extract (aqueous extract of 6 g of dry vetiver roots blended with 94 g of fruit pulp)

T9: Fruit pulp + 8 % vetiver extract (aqueous extract of 8 g of dry vetiver roots blended with 92 g of fruit pulp)

The herbal blended fruit juice was added uniformly with sugar up to 24 °B and 150 ppm potassium metabisulfite (KMS) to inhibit the growth of unwanted microorganisms.

Furthermore, the juice was supplemented with yeast inoculum at a concentration of 10^6 colony-forming units/mL (CFU/mL) and was set aside for fermentation. Initially, the culture was incubated under aerobic conditions for 24 hr and subsequently, anaerobic conditions were established by sealing the fermentation flasks with rubber stoppers, equipped with nylon tubes to capture carbon dioxide. The incubation continued until CO_2 production ceased.

Optimisation of fermentation parameters

The efficient herbal blend in roxburgh fig vermouth was selected for optimisation of fermentation parameters based on alcohol percentage, reducing sugar content and sensory evaluation results. A completely randomised design was planned with 4 treatments and 4 replications for each wine parameter optimisation. Three levels of inoculum size (1, 2 and 3 %), pH (3.5, 4.5 and 5.5) and incubation temperature (25, 30 and 35 °C) were imposed along with an untreated control to evaluate the best wine parameters for pilot-scale production of roxburgh fig vermouth. The pH of fruit juice was adjusted to various levels by the addition of saturated citric acid or calcium carbonate solutions.

Pilot-scale production of herbal blended roxburgh fig wine

The best herbal blend combination of roxburgh fig vermouth with optimised fermentation parameters was used for large-scale production and storability study of the vermouth. A pilot scale study was designed with 5 treatments and 4 replications to assess the storability of fig wine. The storage stability of the vermouth was studied at intervals of 30 (T_1), 45 (T_2), 60 (T_3), 75 (T_4) and 90 (T_5) days after fermentation.

Biochemical evaluation

Alcohol percent: The ethanol content in the wine sample was estimated using the colorimetric method as described in previous studies and expressed in percent (13, 14).

Reducing sugar content: The reducing sugar was estimated by the 3, 5-dinitro salicylic acid method and expressed in mg/mL (15).

pH: pH of the wine was determined with a digital pH meter.

Total soluble solids (TSS): The TSS of blended wine was determined using an ERMA hand refractometer having a range of 0–32 °B and the readings were expressed as °B.

Titratable acidity: It was estimated by using the titration method expressed in terms of citric acid (16).

$$\text{Acidity (\%)} = \frac{\text{Titre value x Normality of NaOH x 0.0064}}{\text{The volume of the aliquot taken}} \text{ x 100}$$

Total phenolic content (TPC): It was estimated using the Folin-Ciocalteau method, as described by Singleton and Rossi, using gallic acid standard and expressed as (mg mL^{-1}) (17).

Tannins (mg mL^{-1}): Tannin estimation will be made as per the procedure cited in the Handbook of Analysis and Quality Control by using Folin denins reagent and tannic acid standard (16).

Total sugars and reducing sugars (%): Lane and Eyon's titration method was followed as suggested by Ranganna (16). The titre value was used for calculations of total sugars and reducing sugars and expressed in percentage.

$$\text{Total reducing sugars (\%)} = \frac{\text{Factor (0.052) x Dilution x 100}}{\text{Titre value x Weight of Sample}}$$

Sensory evaluation

The prepared wine was subjected to sensory evaluation using a 9-point hedonic scale and grading based on the quality parameters, such as colour, appearance, taste, flavour, aroma and mouth feel, was analysed by a panel of 10 judges on a 9-point Hedonic scale (18).

Statistical analysis

The results obtained were analysed statistically using a completely randomised design as described in previous studies (19). The data were analysed statistically using single-factor ANOVA in Microsoft Excel software. Critical difference at 1 % level of significance ($p < 0.01$) was used to compare the significant difference between the treatments.

Results and Discussion

Effect of herbal blends on the quality of roxburgh fig wine

The effect of different concentrations of herbal blends on alcohol and reducing sugar content in roxburgh fig wine is presented in Fig. 1. Among the treatments, T_2 (fruit pulp with 2 % gotu kola leaf extract) recorded the highest alcohol content (9.12 %), closely followed by T_6 (2 % vetiver root extract) with 9.08 %. Both treatments were statistically on par with each other. Correspondingly, the lowest reducing sugar levels were observed in the same treatments (T_2: 6.91 mg/mL; T_6: 6.93 mg mL^{-1}). These values were comparable with the control (9.28 % alcohol and 6.40 mg mL^{-1} reducing sugar). Figure 1 clearly illustrates the inverse relationship between alcohol production and residual sugar: as the alcohol content increased, reducing sugar declined. Similar trends of enhanced sugar utilisation and higher alcohol yield under moderate herbal blending levels (0.5–2 %) during fruit juice fermentation have been reported by previous researchers (20). Conversely, higher concentrations of herbal extracts (>4 %) tend to lower fermentation efficiency, leading to increased residual sugar levels (21). In the present study, increasing concentrations of gotu kola and vetiver extracts resulted in a significant decline in alcohol production, accompanied by an increase in reducing sugar. This effect may be attributed to the antimicrobial properties of these herbs, which can inhibit yeast metabolism at higher concentrations (11, 22).

Sensory evaluation of herbal blended roxburgh fig wine

The sensory evaluation results of the herbal blended roxburgh fig wine are presented in Table 1. A 9-point hedonic scale was employed to assess appearance, colour, aroma, acidity, sweetness, body, astringency and overall acceptability. Among the treatments, T2 (fruit pulp with 2 % gotu kola leaf extract) achieved the highest scores for appearance (7.0), colour (7.2), acidity (7.2), sweetness (7.0), body (7.0), astringency (6.8) and overall acceptability (7.4). These scores were comparable to those obtained for commercial red wine, indicating consumer-level acceptance. Previous researchers found that 2 % spice blending in bael vermouth attributed optimum sensory attributes compared to higher spice levels (3.5–5.0 %) (23). Interestingly, the maximum aroma score (7.9) was recorded in the

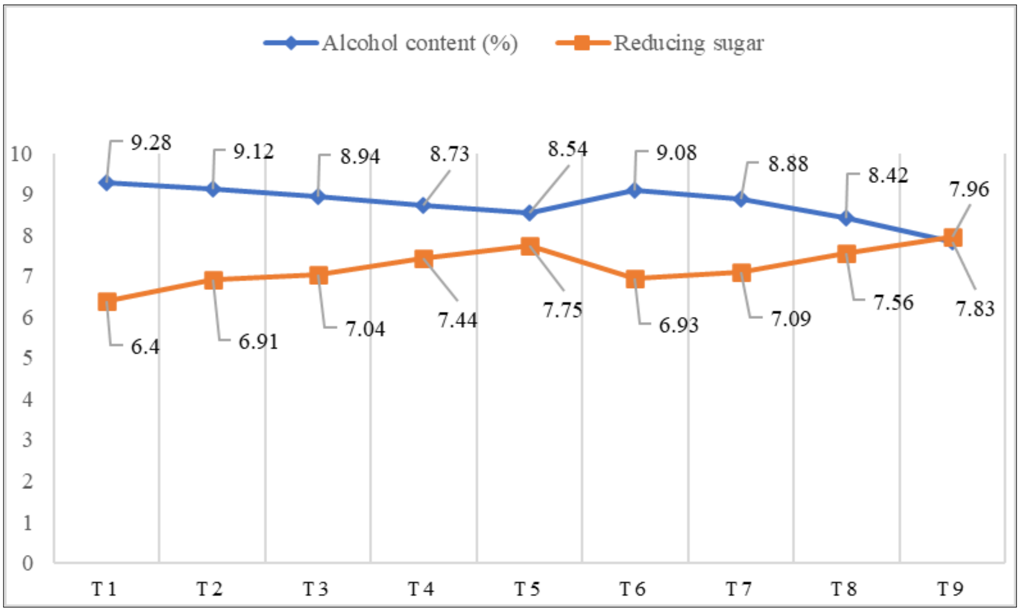

Fig. 1. Effect of different concentrations of herbal blends on the alcohol percentage and reducing sugar content in roxburgh fig wine.

Table 1. Sensory evaluation of herbal blended roxburgh fig wine

Treatments	Appearance	Colour	Aroma	Acidity	Sweetness	Body	Astringency	Overall acceptability
Hedonic scale	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
T_1: Control (Fruit pulp)	6.8	6.8	7.2	7.0	7.2	6.8	6.7	6.7
T_2: Fruit pulp + 2 % gotu kola leaf extract	7.0	7.2	7.6	7.2	7.0	7.0	6.8	7.4
T_3: Fruit pulp + 4 % gotu kola leaf extract	6.7	5.9	6.7	5.9	6.5	5.9	5.9	6.3
T_4: Fruit pulp + 6 % gotu kola leaf extract	6.5	6.1	6.1	6.1	6.3	5.9	5.9	6.1
T_5: Fruit pulp + 8 % gotu kola leaf extract	6.8	6.8	5.9	6.3	5.9	6.5	5.6	5.9
T_6: Fruit pulp + 2 % vetiver root extract	6.8	7.2	7.9	6.8	6.8	6.7	6.8	7.0
T_7: Fruit pulp + 4 % vetiver root extract	6.7	6.8	7.2	6.3	6.7	6.8	6.3	6.7
T_8: Fruit pulp + 6 % vetiver root extract	6.8	6.7	6.8	6.3	6.1	6.7	6.1	6.5
T_9: Fruit pulp + 8 % vetiver root extract	6.7	6.3	7.0	5.9	5.6	6.3	5.8	6.1
Commercial red wine (Control 2)	7.2	8.1	7.2	7.2	7.2	7.2	8.1	8.1

Scale: Like extremely: 9; Like very much: 8; Like moderately: 7; Like slightly: 6; Neither like nor dislike: 5; Dislike slightly: 4; Dislike moderately: 3; Dislike very much: 2; Dislike extremely: 1

2 % vetiver root blend (T_6). This can be explained by the fact that vetiver roots and their essential oils are traditionally infused into food and beverages to enhance aroma (11). However, wines prepared with higher concentrations of both gotu kola and vetiver extracts recorded lower sensory scores, which may be due to the overexpression of herbal flavours. A similar observation was reported earlier in pomegranate blended wines, where excessive herbal extract addition negatively affected taste and aroma (24).

Based on the combined evaluation of alcohol content, reducing sugar levels and sensory attributes, T_2 (fruit pulp with 2 % gotu kola leaf extract) emerged as the best blend. This treatment not only recorded the highest alcohol content with the lowest residual sugar but also achieved the greatest overall acceptability, making it suitable for parameter optimisation in roxburgh fig wine.

Optimisation of fermentation parameters

The effects of inoculum size, pH and temperature on the quality of roxburgh fig herbal blended wine are summarised in Table 2.

Inoculum concentration

Among the different inoculum levels, the highest alcohol content (9.73 %) and the lowest reducing sugar (6.0 mg mL^{-1}) were recorded at 3 % inoculation. This indicates that a moderate inoculum size provides a balance between yeast cell density and sugar availability, thereby enhancing fermentation efficiency. Earlier reports state that moderate inoculum levels of yeast cells can improve sugar utilisation and alcohol yield (20, 25). Conversely, excessively high inoculum concentrations can lead to substrate limitation, where increased yeast biomass fails to enhance alcohol production (26). The importance of optimising yeast inoculum size for efficient fermentation was also emphasised previously (27).

pH levels

The highest alcohol content (9.74 %) and the lowest reducing sugar (5.98 mg/mL) were observed at pH 4.5, confirming that a slightly acidic medium supports optimal yeast fermentation. In contrast, at higher acidity (pH 3.5) or lower acidity (pH 5.5), reduced alcohol yields were recorded, with the lowest alcohol content (8.31 %) at pH 5.5. These findings are consistent with earlier reports that a pH around 4.5 maximises alcohol production in fruit wines (25, 28, 29). Maintaining this pH range promotes efficient sugar conversion while minimising residual sugars.

Temperature levels

Among the different fermentation temperatures, the highest alcohol yield (9.80 %) with the lowest reducing sugar (6.0 mg mL^{-1}) was obtained at 30 °C. At lower (25 °C) or higher (35 °C) temperatures, alcohol production was significantly reduced. This aligns with the understanding that low temperatures slow down yeast metabolism, whereas higher temperatures cause enzyme denaturation, reducing fermentation efficiency (29–30). Supporting studies have also highlighted that 30 °C optimises yeast metabolism in fruit wine fermentation, with maximum alcohol yields observed in jackfruit wine and other fruit wines (31, 32).

Sensory evaluation as influenced by fermentation parameters

The sensory evaluation of herbal blended roxburgh fig wine, influenced by different inoculum sizes, pH levels and temperatures, was carried out using a 9-point hedonic scale and the results are presented in Table 3. The highest sensory scores across all attributes *viz.*, appearance (8.1), colour (7.9), aroma (8.1), acidity (7.6–7.7), sweetness (7.7–7.9), body (7.7), astringency (6.8–7.6) and overall acceptability (7.7–7.9) were observed in T_4 (3 % inoculum size) and T_3 (pH 4.5, 30 °C), reflecting the optimum fermentation conditions. These findings are consistent with studies on litchi, jackfruit and carambola wines, where the best sensory attributes were reported at 30 °C with 3 % inoculum levels (21, 25, 31). This emphasises the importance of maintaining a balance among inoculum size, pH and temperature to enhance sensory quality and ensure consumer acceptability.

Overall, the sensory evaluation confirmed that the combination of 3 % inoculum size, pH 4.5 and 30 °C was optimal for producing herbal blended roxburgh fig wine with superior appearance, colour, aroma, acidity, sweetness, body, astringency and overall acceptability. This optimised blend not only delivered the best sensory characteristics but also demonstrated strong potential for consumer preference and pilot-scale production.

Storage stability of herbal blended roxburgh fig wine

A pilot-scale production of herbal blended roxburgh fig wine (2 % gotu kola leaf extract) was carried out using optimised fermentation parameters and its quality traits were monitored over 90 days of storage. The influence of storage on pH, total soluble solids (TSS), titratable acidity, alcohol, tannins, total phenols, total sugars and

Table 2. Influence of different inoculum size, pH and temperature on alcohol and reducing sugar content of herbal blended roxburgh fig wine

Parameters	Treatments	Alcohol content (%)	Reducing sugar content (mg mL^{-1})
Inoculum size	T_1: Control	6.03	9.75
	T_2: 1 %	9.10	6.52
	T_3: 2 %	9.54	6.23
	T_4: 3 %	9.73	6.00
	SEm (±)	0.0139	0.0200
	C.D (1 %)	0.0600	0.0863
	F test	**	**
pH	T_1: Control	9.72	6.01
	T_2: 3.5	8.41	7.62
	T_3: 4.5	9.74	5.98
	T_4: 5.5	8.24	7.84
	SEm (±)	0.0108	0.0118
	C.D (1 %)	0.0467	0.0511
	F test	**	**
Temperature	T_1: Control	9.78	5.97
	T_2: 25 °C	8.20	7.91
	T_3: 30 °C	9.80	5.94
	T_4: 35 °C	8.45	7.81
	SEm (±)	0.0098	0.0072
	C.D (1 %)	0.0425	0.0312
	F test	**	**

** Significant at 1 % level

Table 3. Sensory evaluation of herbal blended roxburgh fig wine as influenced by various concentrations of inoculum size, pH level and temperatures

Parameters	Treatments	Appearance	Colour	Aroma	Acidity	Sweetness	Body	Astringency	Overall acceptability
Hedonic scale		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Inoculum size	T_1: Control	4.5	6.3	1.8	3.6	1.8	2.7	5.4	2.7
	T_2: 1 %	7.0	7.2	7.7	6.8	6.8	6.7	7.0	7.2
	T_3: 2 %	7.4	7.2	7.9	7.2	7.6	6.8	7.4	7.6
	T_4: 3 %	8.1	7.9	8.1	7.6	7.9	7.7	7.6	7.9
pH	T_1: Control	6.8	6.8	7.2	6.8	7.2	6.8	6.8	7.2
	T_2: 3.5	5.4	6.3	6.3	6.3	5.8	6.3	6.5	6.3
	T_3: 4.5	8.1	7.9	8.1	7.7	7.7	7.7	6.8	7.6
	T_4: 5.5	7.0	6.7	6.8	6.5	7.2	6.7	6.3	7.2
Temperature	T_1: Control	7.0	6.8	7.2	7.2	7.0	6.3	6.3	7.2
	T_2: 25 °C	6.3	6.3	5.9	5.4	5.6	5.8	5.8	5.4
	T_3: 30 °C	8.1	7.9	8.1	7.9	7.7	7.7	7.4	7.7
	T_4: 35 °C	6.3	6.3	5.6	6.1	5.6	5.9	5.6	5.8
Commercial red wine		8.1	8.1	7.2	7.6	8.1	8.1	8.1	8.1

Scale: Like extremely: 9; Like very much: 8; Like moderately: 7; Like slightly: 6; Neither like nor dislike: 5; Dislike slightly: 4; Dislike moderately: 3; Dislike very much: 2; Dislike extremely: 1

Table 4. Influence of storage period on quality of herbal blended roxburgh fig wine

Treatment	Storage period (Days)	pH	(TSS °B)	Titratable acidity (%)	Alcohol (%)	Tannins (mg mL^{-1})	Total phenols (mg mL^{-1})	Total sugars (%)	Reducing sugar (%)
T_1	15 days	4.16	9.30	0.91	9.87	0.18	0.45	6.20	4.20
T_2	30 days	4.09	8.90	0.95	9.97	0.17	0.44	6.13	3.90
T_3	45 days	3.97	8.50	1.03	10.02	0.17	0.43	6.09	3.60
T_4	60 days	3.88	8.10	1.09	10.09	0.16	0.42	6.01	3.20
T_5	90 days	3.84	7.97	1.13	10.11	0.16	0.41	5.95	3.12
SEm (±)		0.0075	0.0116	0.0089	0.0065	0.0008	0.0008	0.0071	0.0065
C.D(1 %)		0.0334	0.0522	0.0401	0.0291	0.0035	0.0035	0.0320	0.0291
F test		**	**	**	**	**	**	**	**

** Significant at 1 % level

reducing sugars is presented in Table 4. During aging, the pH of the wine gradually decreased from 4.16 (15 days) to 3.84 (90 days), indicating a corresponding increase in acidity. A similar decline in pH was reported in ginger–amla wine (3.79 to 3.56) during 24 days of storage (33).The TSS also showed a steady decline (9.30 to 7.97 °B), in line with observations by previous researchers, who reported a reduction in TSS (12–7.7 °B) after 180 days of wine storage (34).

The decrease in pH correlated with an increase in titratable acidity (0.91 % to 1.13 %), reflecting ongoing organic acid production by yeast cells during storage. These results are consistent with earlier studies, who reported an increase in titratable acidity (0.65–1.20 %) and a decrease in pH (3.8–3.0) in mango wine after 12 months of storage (35). The alcohol content showed a slight but steady increase from 9.87 % to 10.11 % during the 90-day maturation. Comparable increases in alcohol content during wine storage have been reported earlier (36, 37). In contrast, the tannin content decreased from 0.18 to 0.16 mg mL^{-1}, reflecting a softening of the wine due to tannin degradation. This trend is consistent withearlier reports, which observed a decline in tannins during red wine aging (38). Similarly, the total phenolic content declined slightly (0.45 to 0.41 mg mL^{-1}). A comparable reduction in phenolic compounds during storage has been reported in red wines (39) and sand pear vermouth (40). Total sugars (6.20 to 5.91 %) and reducing sugars (4.20 to 3.12 %) also decreased significantly during storage, indicating continuous utilisation of sugars as part of ongoing fermentation and maturation (28).

The pilot-scale storage study demonstrated that roxburgh fig herbal blended wine undergoes significant physicochemical changes over time, including decreased pH, TSS, tannins, phenols and sugars, alongside increased titratable acidity and alcohol content. These transformations reflect the natural fermentation and maturation processes that contribute to the development of desirable sensory qualities in wine. Long-term studies could further optimise storage conditions to achieve an ideal balance between acidity, sweetness and astringency, thereby improving consumer appeal and enhancing the functional value of wine.

Conclusion

The present study demonstrated that roxburgh fig (*F. auriculata*) fruit can be effectively utilised to produce herbal-infused wine. Among the different herbal blends tested, the incorporation of 2 % gotu kola leaf extract produced wines with superior quality and sensory attributes. Practically, the findings provide a scalable protocol for the commercial production of a value-added, health-oriented beverage from an underutilised fruit, supporting diversification and income generation in fig-growing regions. Future research should focus on detailed phytochemical profiling, antioxidant and functional property validation, shelf-life extension under different packaging systems and consumer market acceptability studies to strengthen commercialisation prospects.

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Authors' contributions

JTR conducted the research and performed the result analysis and interpretation. YS designed the study and carried out the analysis and compilation. AM provided technical and instrumental support for conducting the research. HM provided technical support and assisted in result interpretation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Shrestha S, Bohara M, Khadayat K, Limbu A, Basnyat RC, Poudel R. Nutritional analysis and phytochemical determination of fruits of *Ficus auriculata*. Food Humanity. 2023;1:370–7. https://doi.org/10.1016/j.foohum.2023.06.014
2. Bhatt SC, Kumar V, Naik B, Gupta AK, Saris PEJ, Kumar V, et al. *Ficus auriculata* Lour., an underutilized nonconventional alternative fruit to *Ficus carica* with nutraceutical potential. Discov Sustain. 2024;5(1):254. https://doi.org/10.1007/s43621-024-00480-3
3. Tamta G, Mehra N, Tandon S. Traditional uses, phytochemical and pharmacological properties of *Ficus auriculata*: A review. J Drug Deliv Ther. 2021;11(3):163–9. https://doi.org/10.22270/jddt.v11i3.4853
4. Rathi V. Herbal wine: A review. Adv Weight Loss Manag Med Dev. 2018;3(2). https://doi.org/10.35248/2593-9793.18.3.113
5. Kumar A, Dogra S, Prakash A. Neuroprotective effects of *Centella asiatica* against intracerebroventricular colchicine-induced cognitive impairment and oxidative stress. Int J Alzheimers Dis. 2009;2009:972178. https://doi.org/10.4061/2009/972178
6. Orhan IE. *Centella asiatica* (L.) Urban: From traditional medicine to modern medicine with neuroprotective potential. Evid Based Complement Alternat Med. 2012;2012:946259. https://doi.org/10.1155/2012/946259
7. Chandrika UG, Prasad Kumarab PAAS. Gotu kola (*Centella asiatica*): Nutritional properties and plausible health benefits. Adv Food Nutr Res. 2015;76:125–57. https://doi.org/10.1016/bs.afnr.2015.08.001
8. Sabaragamuwa R, Perera CO, Fedrizzi B. *Centella asiatica* (Gotu kola) as a neuroprotectant and its potential role in healthy ageing. Trends Food Sci Technol. 2018;79:88–97. https://doi.org/10.1016/j.tifs.2018.07.024
9. Pittella F, Dutra RC, Junior DD, Lopes MTP, Barbosa NR. Antioxidant and cytotoxic activities of *Centella asiatica* (L.) Urb. Int J Mol Sci. 2009;10(9):3713–21. https://doi.org/10.3390/ijms10093713
10. Lunz K, Stappen I. Back to the roots-an overview of the chemical composition and bioactivity of selected root-essential oils. Molecules. 2021;26(11):3155. https://doi.org/10.3390/molecules26113155
11. Sharma Y. Cultivation of vetiver (*Chrysopogon zizanioides* (L.) Roberty)-A versatile medicinal and aromatic plant. Eur J Med Plants. 2024;35(5):16–22. https://doi.org/10.9734/ejmp/2024/v35i51199
12. David A, Fărcaș A, Socaci SA. An overview of the chemical composition and bioactivities of *Vetiveria zizanioides* (L.) Nash essential oil. Trends Food Sci Technol. 2023;140:104153. https://doi.org/10.1016/j.tifs.2023.104153
13. Caputi A Jr, Ueda M, Brown T. Spectrophotometric determination of ethanol in wine. Am J Enol Vitic. 1968;19(3):160–5. https://doi.org/10.5344/ajev.1968.19.3.160
14. Lehninger AL, Nelson DL, Cox MM. Lehninger principles of biochemistry. New York: Macmillan; 2008.
15. Miller GL. Use of dinitrosalicylic acid reagent for determination of reducing sugar. Anal Chem. 1959;31(3):426–8. https://doi.org/10.1021/ac60147a030
16. Ranganna S. Handbook of analysis and quality control of fruit and vegetable products. New Delhi: Tata McGraw-Hill Publishing Company Limited; 1986.
17. Singleton VL, Rossi JA Jr. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am J Enol Vitic. 1965;16(3):144–58. https://doi.org/10.5344/ajev.1965.16.3.144
18. Wichchukit S, O'Mahony M. The 9-point hedonic scale and hedonic ranking in food science: Some reappraisals and alternatives. J Sci Food Agric. 2015;95(11):2167–78. https://doi.org/10.1002/jsfa.6993
19. Panse VS, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: ICAR; 1985.
20. Bely M, Stoeckle P, Masneuf-Pomarède I, Dubourdieu D. Impact of mixed *Torulaspora delbrueckii-Saccharomyces cerevisiae* culture on high-sugar fermentation. Int J Food Microbiol. 2008;122(3):312–20. https://doi.org/10.1016/j.ijfoodmicro.2007.12.023
21. Singh RS, Kaur P. Evaluation of litchi juice concentrate for the production of wine. Nat Prod Radiance. 2009;8(4):386–91.
22. Jagtap NS, Khadabadi SS, Ghorpade DS, Banarase NB, Naphade SS. Antimicrobial and antifungal activity of *Centella asiatica* (L.) Urban, Umbelliferae. Res J Pharm Technol. 2009;2(2):328–30.
23. Chauhan H, Kaul RK, Ahmed N, Gupta P, Anjum A. Preparation and evaluation of bael (*Aegle marmelos*) vermouth. Int J Food Ferment Technol. 2016;6(1):41. https://doi.org/10.5958/2277-9396.2016.00025.8
24. Paul SK, Sahu JK. Process optimization and quality analysis of carambola (*Averrhoa carambola* L.) wine. Int J Food Eng. 2014;10(3):457–65. https://doi.org/10.1515/ijfe-2012-0125
25. Panesar PS, Panesar R, Singh B. Application of response surface methodology in optimization of process parameters for production of kinnow wine. Nat Prod Radiance. 2009;8:366–73.
26. Togarepi E. Optimization of fermentation parameters for ethanol production from *Ziziphus mauritiana* fruit pulp using *Saccharomyces cerevisiae* (NA33). Int J Biochem Res Rev. 2012;2(2):60–9. https://doi.org/10.9734/IJBCRR/2012/1096
27. Fleet GH. Yeast interactions and wine flavour. Int J Food Microbiol. 2003;86(1–2):11–22. https://doi.org/10.1016/S0168-1605(03)00245-9
28. Mathewson WS. The manual for the home and farm production of alcohol fuel. Berkeley (CA): Ten Speed Press; 1980. p.1–228.
29. Singh M, Panesar P, Marwaha SS. Studies on the suitability of kinnow fruits for the production of wine. J Food Sci Technol. 1998;35:455–7.
30. Veloso IIK, Rodrigues KCS, Sonego JLS, Cruz AJG, Badino AC. Fed-batch ethanol fermentation at low temperature as a way to obtain highly concentrated alcoholic wines: Modeling and optimization. Biochem Eng J. 2019;141:60–70. https://doi.org/10.1016/j.bej.2018.10.005
31. Sharma N, Bhutia SP, Aradhya D. Process optimization for fermentation of wine from jackfruit (*Artocarpus heterophyllus* Lam.). J Food Process Technol. 2012;4(2):1–5. https://doi.org/10.4172/2157-7110.1000204
32. Wang NS. Biochemical engineering laboratory manual: Wine fermentation. United States: University of Maryland; 2009.
33. Nandagopal G, Nair PS. Production of wine from ginger and Indian gooseberry and a comparative study over commercial wine. Am J Eng Res. 2013;2(5):19–38.
34. Mendes-Ferreira A, Mendes-Faia A, Leão C. Growth and fermentation patterns of *Saccharomyces cerevisiae* under different ammonium concentrations and its implications in winemaking industry. J Appl Microbiol. 2004;97(3):540–5. https://doi.org/10.1111/j.1365-2672.2004.02331.x
35. Kulkarni JH, Singh H, Chadha KL. Preliminary screening of mango variety for wine making. J Food Sci Technol. 1980;17:218–20.
36. Romano P, Capece A, Jespersen L. Taxonomic and ecological diversity of food and beverage yeasts. In: Yeasts in food and beverages. Berlin, Heidelberg: Springer; 2006. p.13–53. https://

doi.org/10.1007/978-3-540-28398-0_2

37. Vignault A, Gombau J, Jourdes M, Moine V, Canals JM, Fermaud M, et al. Oenological tannins to prevent *Botrytis cinerea* damage in grapes and musts: Kinetics and electrophoresis characterization of laccase. Food Chem. 2020;316:126334. https://doi.org/10.1016/j.foodchem.2020.126334

38. Vignault A, Gombau J, Pascual O, Jourdes M, Moine V, Canals JM, et al. Copigmentation of malvidin-3-O-monoglucoside by oenological tannins: Incidence on wine model color in function of botanical origin, pH and ethanol content. Molecules. 2019;24(8):1448. https://doi.org/10.3390/molecules24081448

39. Katalinić V, Milos M, Modun D, Musić I, Boban M. Antioxidant effectiveness of selected wines in comparison with (+)-catechin. Food Chem. 2004;84(4):593–600. https://doi.org/10.1016/j.foodchem.2003.10.007

40. Attri BL, Lal BB, Joshi VK. Technology for the preparation of sand pear vermouth. Indian Food Packer. 1994;48:39–43.

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