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AR Kakade
Ph.D. Research Scholar, Department of Fruit Science, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

SR Dalal
Professor of Horticulture, College of Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

AS Thutte
Ph.D. Research Scholar, Department of Fruit Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

SR Kakade
Assistant Professor, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Malegaon, Maharashtra, India

Corresponding Author:
AR Kakade
Ph.D. Research Scholar, Department of Fruit Science, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Sensory evaluation of BAEL wine influenced by PH and TSS levels of must during maturation

AR Kakade, SR Dalal, AS Thutte and SR Kakade

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Abstract

Wine from bael (*Aegle marmelos*) fruit, widely known for their immense medicinal properties was prepared by standardizing pH and TSS of must through fermentation by the use of wine yeast (*Saccharomyces cerevisiae*) as a starter culture, with the objectives to study the effect of different levels of pH and TSS on sensory quality of bael wine and to find out the suitable combination of pH and TSS for obtaining superior quality of bael wine. Experiment was conducted during the year 2018-19 in Factorial Completely Randomized Design (FCRD) with two factors as factor A, levels of pH viz., 3.0, 3.5, and 4.0 and factor B, levels of TSS viz., 20, 22, 24, 26 °B) and replicated thrice. The observations in respect of sensory evaluation during maturation were recorded of fresh wine and 7 months maturated wine. From the findings, it was observed that when the pH levels of must was maintained at 0.4 was recorded significantly superior result for taste score, flavour score, colour score and overall acceptability score in 7 months maturated wine. Regarding the different sugar concentration, 24 °B of must was found suitable for preparation of wine with respect to taste score, flavour score, colour score and overall acceptability score of wine. The treatment combination P_3T_3 (pH-4.0 with 24 °B TSS) was found superior for preparation of wine from bael. There is a good prospect for commercialization of this wine as a medicinal wine.

Keywords: Bael wine, *Aegle marmelos*, fermentation, pH levels, total soluble solids

Introduction

Bael fruit (*Aegle marmelos*), also known by various names such as Bengal quince, Indian quince, Golden apple, Holy fruit, Bel, Belwa, Sriphal, Stone apple, and Maredo in India, belongs to the Rutaceae family and is cultivated primarily for its fruit. Native to India and Bangladesh, this sub-tropical, medium-sized deciduous tree with slender aromatic branches has spread throughout much of Southeast Asia. Historically, bael has been known in India since ancient times, dating back to the era of Lord Shiva (Deshpande, 2011) [5].

Currently, many tropical fruits remain underutilized despite their significant role in fulfilling the demand for nutritious, flavorful, and visually appealing natural foods with therapeutic benefits. Generally rich in vitamins, minerals, and dietary fiber, these fruits are essential components of a healthy diet. Beyond their nutritional and medicinal values, many tropical fruits possess excellent flavor and attractive colors. Bael fruit, although not easily consumed fresh due to its hard shell, mucilaginous texture, and numerous seeds, offers great potential for processing into various products, with bael pulp being the key raw material (Kahar *et al.*, 2024b) [6, 14].

Since the whole fruit's storage quality deteriorates quickly, improving post-harvest processing techniques is crucial to enhancing its utilization (Manaswini *et al.*, 2025). Bael's distinctive aroma remains intact even after processing, which further enhances its potential for use in various processed forms such as preserves, refreshing drinks, fruit wine, powder, leather, squash, and jam (Khatal *et al.*, 2025) [7].

Wine gains added value through the release of amino acids and nutrients by yeast during fermentation. Studies have also indicated health benefits from wine consumption attributed to phenolic compounds and alcohol, which help protect the body from free radicals and increase High Density Lipoprotein (HDL) levels. Fruit wines, being undistilled alcoholic beverages, are nutritious, flavorful, and mild stimulants. They provide essential minerals, vitamins, and energy, formed through yeast fermentation of sugars and possess a long shelf life (Kahar *et al.*, 2024c) [6, 14].

The integration of modern process engineering tools, including IoT and AI, has recently enabled improved control over fermentation, ensuring consistent quality in wine production (Kahar *et al.*, 2024 n.d.) [6, 14]. Historically, wine has been used as both food and medicine due to its healthful properties (Chaudhary *et al.*, 2014) [4]. Wine is chemically complex, consisting mostly of water (85-90%), alcohol (10-14%), and phenolic compounds (1-5%).

Red wine, in particular, has been associated with reduced risk of heart disease (Boucheron, 1995) [2]. Its phenolic content contributes positively to cardiovascular health, cancer prevention, and slowing brain degeneration because of antioxidant effects (Budak and Guzel-Seydim, 2010) [3].

Bael fruit is well-known for its medicinal qualities and shows promise for value-added products like wine. However, the quality of bael wine is highly influenced by fermentation parameters, especially the pH and total soluble solids (TSS) of the must, which affect sensory characteristics such as taste, flavor, color, and overall acceptability. This study focuses on evaluating how varying pH levels (3.0, 3.5, 4.0) and TSS concentrations (20, 22, 24, 26 °B) impact the sensory attributes of bael wine during maturation. The goals are to determine the ideal combination of pH and TSS for optimal sensory quality and to assess the potential for commercial production of bael wine under these optimized conditions.

Materials and Methods

1. Location

An experiment entitled "Sensory evaluation of bael wine influenced by pH and TSS levels of must during maturation" was carried out during the year 2017-18 at Post Harvest Technology Laboratory, Section of Horticulture, College of Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola with the objectives to study the effect of different levels of pH and TSS on sensory quality of bael wine and to find out the suitable combination of pH level and TSS to obtain superior quality of bael wine .

2. Process Description

Fully ripened bael fruits were weighed and split into two halves, followed by the separation of seeds and fibrous material. The fruit pulp was crushed with water in a 1:1 ratio, and the resulting pulp (must) was extracted by sieving through a mesh. Sodium benzoate at 150 ppm was added for preservation. The must was then ameliorated by adjusting pH using citric acid and maintaining TSS at required levels by adding cane sugar as per treatments. The prepared must was inoculated with a 24-hour-old starter culture of Saccharomyces cerevisiae, along with 0.1% diammonium hydrogen phosphate (DAHP) as a nitrogen source. Fermentation was carried out at ambient temperature for 15 days. The first racking was performed at 6-7 °Brix, followed by two more rackings at 20-day intervals. Before final racking, clarification was achieved using 0.04% bentonite. The clarified wine was bottled with 150 ppm sodium benzoate, corked, and sealed with wax to ensure stability during storage.

3. Experimental Treatments

The experiment investigated the effects of two key factors: pH level (Factor A) and sugar concentration (Factor B). Three specific pH levels were tested: 3.0 (designated P_1), 3.5 (P_2), and 4.0 (P_3). Simultaneously, four sugar concentrations, measured in degrees Brix (°B), were examined: 20°B (T_1), 22°B (T_2), 24°B (T_3), and 26°B (T_4). To study the combined effects of these factors, all possible treatment combinations were created. This resulted in a total of twelve distinct experimental treatments, systematically labeled as follows: P_1T_1, P_1T_2, P_1T_3, P_1T_4, P_2T_1, P_2T_2, P_2T_3, P_2T_4, P_3T_1, P_3T_2, P_3T_3, and P_3T_4.

4. Sensory evaluation

Sensory evaluation of the developed samples was performed by 30 semi-trained panelists using a 9-point hedonic scale, following standard procedures (Meilgaard *et al.*, 2006) [11]. Samples were coded and presented randomly, and attributes such as colour and appearance, texture, flavour, taste, and overall acceptability were assessed.

5. Statistical Analysis

The recorded data were statistically analyzed using Analysis of Variance (ANOVA) as per FCRD, and treatment means were compared using the Least Significant Difference (LSD) test at a 5% significance level. (AOAC, 2019).

Ripened Bael fruits
↓
Weighing and splitting into two halves
↓
Separating the seed and fibre from the fruits
↓
Crushing the fruit pulp with water (1:1 ratio)
↓
Pulp extracted by sieving through mesh (must) and addition of sodium benzoate (150 ppm)
↓
Amelioration of must
↓
Adjustment of pH by addition of citric acid, similarly TSS maintained by adding cane sugar as per treatments
↓
Inoculation with 24 hours starter culture along with 0.1% DAHP as nitrogen source
↓
Fermentation at ambient temperature for 15 days
↓
Racking
First racking carried out at 6-7 °Brix
Racking was repeated for three times in 20 days interval
Clarification with 0.04% bentonite before final racking
↓
Bottling and Corking
150 ppm sodium benzoate was added.
Bottle was filled full, corking was done and the bottle was sealed with wax
↓
Bael Wine

Fig 1: Process flow Chart for the Preparation of Bael Fruit Wines

The experiment was conducted using a Factorial Completely Randomized Design (FCRD) involving two factors: factor A being the pH levels set at 3.0, 3.5, and 4.0, and factor B consisting of sugar concentrations at 20, 22, 24, and 26 °Brix, with a total of twelve treatment combinations, each replicated three times.

Fully matured and well-ripened bael fruits were freshly collected from the main garden field during the 2017-18 season and immediately brought to the laboratory. The pulp was extracted by breaking the fruits with a hammer and then homogenizing with water in a 1:1 ratio. This pulp served as the fermentation substrate. The pH was adjusted to the required levels (3.0, 3.5, and 4.0) by adding citric acid, and the total soluble solids (TSS) were regulated by incorporating cane sugar to achieve concentrations of 20, 22, 24, and 26 °B, respectively. Sodium benzoate was added at 150 ppm per liter to inhibit wild yeast and microbial spoilage as well as to prevent oxidative browning. This treated juice was designated as 'must.' Sensory evaluation parameters including taste, flavor, color, and overall acceptability were recorded for both freshly prepared wine and after seven months of maturation.

Results and Discussion

1) Individual Effects of pH and TSS

The sensory data (Table 1; Fig. 2) reveal that both pH and TSS significantly influenced taste, flavor, color, and overall acceptability of bael wine at the fresh stage and after seven months of maturation.

A) Taste Scor

In freshly prepared bael wine, the highest taste score (16.31) was recorded for treatment P_3 (pH 4.0), significantly outperforming all other treatments. The lowest taste score (12.56) was seen in P_1 (pH 3.0). Among the sugar levels, T_3 (24 °B) achieved the maximum taste score of 16.67, significantly better than other treatments, while the lowest (13.55) was recorded for T_4 (26 °B). After seven months, the highest taste score (17.18) again corresponded to P_3, followed by P_2 (15.75). Among TSS treatments, T_3 maintained the highest taste score (19.04), while T_2 (22 °B) showed the lowest (14.72).

B) Flavor Score

For freshly prepared wine, treatment P_3 (pH 4.0) attained the maximum flavor score (15.95), significantly higher than others, while P_2 (pH 3.5) scored the lowest (13.28). Within sugar treatments, T_3 recorded the highest flavor score (15.95), and T_4 the lowest (13.58). At seven months maturation, P_3 continued to have the highest flavor score (17.78), and P_1 the lowest (13.81). T_3 again led the sugar treatments (16.82), followed by T_4 (15.40), and T_1 (20 °B) scored the least (14.26). These results suggest that an optimal balance of pH and TSS favors flavor development in matured bael wine, aligning with recent studies linking sugar-acid balance to improved aromatic complexity in fruit wines during storage (Zhang *et al.*, 2023) [13].

C) Color Score

Fresh bael wine from P_3 (pH 4.0) received the highest color score (15.31), significantly superior to other pH levels, while P_2 scored the lowest (12.39). Color scores generally increased as maturation progressed. For fresh wines, T_3 yielded the highest color score (14.64), with T_2 lowest (12.98). After seven months, P_3 again led with 17.12, and P_2 was lowest (13.59). Among sugar levels, T_3 had the highest color score (16.04) and T_2 the lowest (14.34). These findings indicate that higher pH combined with moderate TSS improves visual appeal in matured bael wine, consistent with literature highlighting that optimal sugar-acid balance enhances wine color stability during storage (Zou *et al.*, 2022) [15].

D) Overall Acceptability

The highest overall acceptability for fresh bael wine was recorded in P_3 (17.22), significantly better than all other treatments, with P_1 having the lowest score (13.73). Generally, acceptability improved with maturation. Among sugar treatments, T_3 showed the highest acceptability (16.53) fresh, while T_1 scored the lowest (14.04). After seven months, P_3 continued to be the most preferred (17.99), with P_1 at the lowest (14.38). Similarly, T_3 maintained the highest acceptability (17.19), and T_1 the lowest (14.70). These results align with recent findings that higher pH within acceptable limits and optimal TSS enhance sensory quality of matured fruit wines (Patel *et al.*, 2023) [12].

2) Interaction Effects of pH and TSS

A) Taste Score

Taste scores generally increased with maturation. The highest taste score for fresh bael wine (18.37) was observed in P_2T_3, while the lowest (11.10) was in P_1T_1. After seven months, the top score (19.13) was recorded for P_3T_3, followed closely by P_1T_3 (19.08). The lowest score after maturation was again in P_1T_1 (12.38).

B) Flavor Score

Fresh wine flavor peaked at 16.95 in treatment P_3T_3 and was lowest at 11.53 in P_1T_1. After maturation, P_3T_3 scored highest (18.55), and P_1T_1 the lowest (12.15).

C) Color Score

Significant combined effects of pH and sugar levels were observed for color at all maturation stages. The highest fresh wine color score (16.55) was recorded in P_3T_3, while P_1T_4 had the lowest (11.22). After seven months, P_3T_3 remained superior (18.58), with P_1T_1 the lowest (12.82).

D) Overall Acceptability

Overall acceptability increased with maturation. Fresh wine acceptability was highest in P_3T_3 (17.98) and lowest in P_1T_1 (11.57). After seven months, P_3T_3 again led (18.65), followed by P_3T_2 (18.20), whereas P_1T_1 recorded the lowest score (12.15). Sensory evaluation revealed significant differences among treatments.

Lakshmana *et al.* (2006) [8] reported similar findings in carambola wine, where must with 24 °Brix yielded the highest sensory score (18.64/20) at 360 days, with excellent qualities in appearance, aroma, acidity, and flavor. This supports the conclusion that wines prepared from 24 °B must demonstrate acceptable sensory attributes supported by their physical and chemical characteristics.

The experiment was laid out in Factorial Completely Randomized Design (FCRD) with two factors as factor A, levels of pH viz., 3.0, 3.5, and 4.0 and factor B, sugar concentrations viz., 20, 22, 24, 26 °B) with twelve treatment combinations replicated thrice

Fully matured and well ripened bael fruits were procured from field of main garden during the year 2017-18 were brought fresh to the Laboratory. The pulp was obtained by breaking fruits by hammer and then homogenize with water (1:1 rati) and pulp was used for fermentation. Adjustment of pH was done as per the treatment *i.e.* 3.0, 3.5 and pH-4.0 by adding citric acid. Similarly total soluble solids was also maintained as per treatment i.e 20, 22, 24 and 26 °B by adding cane sugar. Addition of sodium benzoate to the juice @ 150 ppm per litre was done to inhibit the wild yeast and spoilage through microorganisms and also to prevent browning due to oxidation. This was treated as 'Must' The observations in respect of sensory evaluation viztaste score, flavour score, colour score and overall acceptability score were recorded for fresh wine and seven months maturated wine.

Table 1: Effect of different levels of pH and sugar concentrations on Taste score, Flavour score, Colour score and Overall acceptability score of fresh and 7 months maturated bael wine

Treatment	Taste score		Flavour score		Colour score		Overall acceptability score	
	Fresh	**At 7 months of maturation**	**Fresh**	**At 7 months of maturation**	**Fresh**	**At 7 months of maturation**	**Fresh**	**At 7 months of maturation**
pH levels								
P_1	12.56	15.57	14.15	13.81	12.62	13.91	13.73	14.38
P_2	14.90	15.75	13.28	14.13	12.39	13.59	14.60	15.23
P_3	16.31	17.18	15.95	17.78	15.31	17.12	17.22	17.99
F Test	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
SE(m)±	0.032	0.005	0.004	0.004	0.004	0.006	0.003	0.003
CD at 5%	0.092	0.015	0.012	0.011	0.012	0.019	0.010	0.010
sugar source								
T_1	14.59	15.77	13.89	14.26	13.30	14.58	14.04	14.70
T_2	13.56	14.72	14.41	14.48	12.98	14.34	15.47	16.14
T_3	16.67	19.04	15.95	16.82	14.64	16.04	16.53	17.19
T_4	13.55	15.14	13.58	15.40	12.84	14.54	14.70	15.43
F Test	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
SE(m)±	0.036	0.006	0.005	0.004	0.005	0.007	0.004	0.004
CD at 5%	0.106	0.017	0.014	0.013	0.014	0.022	0.012	0.012
Interaction (PxT)								
P_1T_1	11.10	12.38	11.58	12.15	11.80	12.82	11.57	12.15
P_1T_2	13.14	15.46	15.33	13.44	13.20	14.22	13.40	14.07
P_1T_3	13.49	19.08	15.40	15.45	14.25	15.32	15.40	16.11
P_1T_4	12.51	15.37	14.33	14.20	11.22	13.26	14.55	15.17
P_2T_1	17.29	17.86	14.41	13.56	14.05	15.07	13.65	14.24
P_2T_2	11.40	12.63	11.60	12.15	10.62	11.73	15.50	16.15
P_2T_3	18.37	18.90	15.50	16.45	13.10	14.21	16.21	16.82
P_2T_4	12.54	13.58	11.60	14.35	11.78	13.35	13.05	13.71
P_3T_1	15.37	17.07	15.73	17.05	14.05	15.86	16.90	17.70
P_3T_2	16.13	16.05	16.30	17.85	15.13	17.05	17.50	18.20
P_3T_3	18.13	19.13	16.95	18.55	16.55	18.58	17.98	18.65
P_3T_4	15.58	16.46	14.80	17.65	15.50	17.00	16.50	17.42
F Test	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
SE(m)±	0.063	0.010	0.008	0.007	0.008	0.013	0.007	0.007
CD at 5%	0.184	0.030	0.024	0.022	0.024	0.037	0.020	0.020

Lakshamana *et al.* (2006) [8] observed from the sensory evaluation at the end of storage (360th day) that, the carambola wine prepared from 24 °B must has scored the highest (18.64) sensory points out of 20.00 score in terms of appearance, colour, aroma, acidity and flavour. It can be concluded from the study that, wine prepared from the must of 24 °B of carambola fruit has acceptable sensory qualities supported by different physical and chemical characters.

Effect of different levels of pH and sugar concentrations on Taste score, Flavour score, Colour score and Overall acceptability score of fresh and 7 months maturated bael wine as shown in Table 1 and Fig 2.

Fig 2: Seven months Maturated bael wine of different Treatment Combination

Conclusion

The present investigation demonstrated that both pH and TSS levels significantly influenced the sensory quality of bael wine, with marked improvements observed after 7 months of maturation. Among the individual factors, a pH of 4.0 (P_3) consistently yielded superior scores for taste, flavour, colour, and overall acceptability, while a TSS of 24 °B (T_3) emerged as the most favourable sugar concentration. The interaction effect further highlighted that the combination P_3T_3 (pH 4.0 with 24 °B TSS) produced wines with the highest sensory ratings across all parameters, maintaining superiority from the fresh stage through maturation. The results indicate that careful standardization of must composition prior to fermentation is critical for developing high-quality bael wine. Given its desirable sensory attributes, coupled with the known medicinal properties of bael fruit, this optimized formulation offers strong potential for commercial production and market positioning as a functional, fruit-based alcoholic beverage.

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