Quality assessment and sensory evaluation of vinegar produced from pineapple Waste

 **ABSTRACT**

The study investigated on the physico-chemical properties and sensory attributes of vinegar prepared from pineapple by-products (peel, core and pomace). Pineapple peel, pomace and core wines were produced using commercial wine yeast and acetified with 10% (v/v) bacterial culture Acetobacter aceti (MTCC-3246). The results indicated that vinegar prepared from pineapple peel showed the highest acetic acid content (4.75%), lowest pH (2.60), good colour intensity (4.05) and density (2.99). Sensory evaluation further indicated that vinegar derived from peel waste was the most preferred in terms of colour (7.65), flavour (6.96), sourness (8.02) and overall acceptability (7.76). Pineapple peel vinegar was adjudged the most acceptable product, highlighting the significant impact of different pineapple waste components on vinegar quality.

Key words: Pineapple; processing waste; fermentation; acetic acid; vinegar.

**1. Introduction**

Pineapple (*Ananas comosus* L.) is the third most important tropical fruit after banana and citrus. India is the seventh largest producer of pineapple with an average yield of 17.06 MT/ha in 2021 (Anonymous). Compared to temperate fruits, processing of tropical and subtropical fruits processing have considerably higher ratios of by-products than the temperate fruits (Schieber *et al*., 2001). During processing of pineapple, huge amount of fruit waste are generated comprising of peel (30%), pomace (50%), core (7%) and crown (13%), which accounts to about 25–35% of the fruit weight (Banerjee *et al*., 2018). These losses are mainly due to selection and elimination of components unsuitable for human consumption. Additionally, rough handling of fruits and exposure to adverse environmental conditions can lead to further losses of up to 55%, thereby generating significant waste (Salve and Ray, 2020).With increase in pineapple production annually and the growing demand for processed pineapple products, massive wastes are inevitably generated. As such effective management of this waste is a major concern, as improper disposal contributes to environmental pollution. Thus, biotechnological and robust approaches can be employed for sustainable use of pineapple by-products, given their rich source of antioxidants, phytochemicals, phenolic compounds and biofuels (Polania *et al*., 2022). The adoption of a circular bioeconomy approach, involving the integration of various process technologies for the valorization of pineapple waste into a diverse range of industrially significant products, is crucial for enhancing economic sustainability and achieving towards a zero-waste paradigm (Nath *et al.*, 2023). Food valorization is an emerging trend and an innovative strategy to preserve the economic and beneficial properties of food waste and by-products (Garcia *et al*., 2022). Since pineapple processing waste is a rich source of sugars, it serves as an ideal substrate for fermentation for production of vinegar and other fermented beverages (Tropea *et al*., 2014). Thus, vinegar production can be effective approach to utilize the processing by-products without compromising the quality of the final product. Vinegar has historically been used as a preservative, condiment, and therapeutic agent, often valued for its functional properties (Solieri *et al*., 2009). Vinegar can be produced from any non-toxic material with sugar juice or directly from sugar juice itself (Omojasola *et al*., 2008). The vinegar production process undergoes two-stage fermentations, where alcoholic fermentation first takes place converting sugars to ethanol by *Saccharomyces* yeasts, followed by oxidation of ethanol to acetic acid by acetic acid bacteria (Raspor and Goranovic, 2008). Recent interest in fruit vinegars has been driven by their antimicrobial, anti-inflammatory, antidiabetic, antioxidant, and antihyperlipidemic effects (Yagnik *et al*., 2021). Therefore, the present experiment was undertaken to evaluate the feasibility of production of vinegar from different pineapple processing wastes and to assess their qualitative and sensory characteristics of the developed vinegars.

**2. Material and methods**

Ripened pineapple fruits were procured directly from farmers’ field at Molvom village, Nagaland and brought immediately to the laboratory for processing. Commercial wine yeast *Saccharomyces cerevisiae* Lalvin (EC-1118) used in this study was procured from brewmart, India. The pure bacterial culture *Acetobacter aceti* (MTCC3246) was obtained from CSIR-Institute of Microbial Technology, Chandigarh for acetic acid fermentation. The lyophilized bacterial culture was revived right after arrival on Yeast extract peptone mannitol (YPM) medium, sub-culturing at bimonthly intervals as and when required.

**2.1. Inoculum preparation for alcoholic and acetic fermentation**

For alcoholic fermentation, commercial wine yeast *Saccharomyces cerevisiae* Lalvin (EC-1118) was rehydrated in lukewarm water. For acetous fermentation, a loopful of *A. aceti* was transferred into conical flask containing sterile glucose yeast extract broth with 7% (v/v) ethanol and incubated in a rotary incubator at 300 C until an optical cell mass density of 0.5 was obtained as per the procedure described by Molelekoa *et al*. (2018). The *A. aceti* (±0.5 g) was prepared in glucose yeast extract broth (250 mL) consisting of 1% (w/v) glucose, 1% (w/v) yeast extract powder, 6% (v/v) ethanol, 0.05% MgSO4 and 0.05% KH2 PO4, and incubated in a rotary incubator at 30 °C until an optical cell mass density of 0.5 (equivalent to 1 x 106 cfu/mL) was obtained.

**2.2. Preparation of vinegar**

Pineapple fruits were sorted, graded and washed in clean tap water to remove any dirt particles. The flow chart on preparation of vinegar is given in Fig.1. Pineapple core was extracted with the help of a core remover and the peels were carefully sliced with the help of a knife. The pulp was manually pressed by hand to obtain the pomace. For must preparation, pineapple waste viz., peel, core and pomace were ameliorated by adding sugar to obtain a 15 0brix. The must of different waste materials was then inoculated with wine yeast (2.5g/ litre) and allowed to ferment in glass containers in anaerobic condition. Fermentation was carried out for a period of 7 days at 28°C and stopped once it reached stable total soluble solids (TSS). After completion of fermentation, wine was clarified two-three times by siphoning and stored in sterilized glass jars for further processing of vinegar. The alcoholic fermentation process required 14 days which yielded alcohol content of 7.68%, 6.7%, and 7.24% in peel, core and pomace wines, respectively. In the second stage of fermentation, prepared wines from different pineapple wastes was transferred into sterilized glass bottles with wide mouths and inoculated with a 10% (v/v) bacterial culture (Sossou *et al*., 2009). The bottles were covered with a muslin cloth and loosely tied, a proper headspace was also given to undergo aerobic fermentation and incubated at 30°C. For the first 3-4 days, the jars were occasionally stirred to accelerate the fermentation process. Fig. 2 shows the process of acetous fermentation.

**2.3. Sensory evaluation**

The sensory evaluation for the developed vinegars was evaluated on the basis of colour, odour, sourness and overall acceptability by a panel of 10 semi-trained judges using a 9-point hedonic scale (1 = least like and 9 = strongly like) as described by Amerine *et al*. (1965). Samples were coded and placed in a random manner prior to testing. The coded samples were put in a transparent disposable cup and a glass of water was kept for rinsing the mouth after testing the given sample. A standard commercial apple cider vinegar sample was also included for standard comparison.

Sorting and washing of pineapple fruit

 Removal of peel, core and pomace

 Addition of sugar and yeast

Incubated at 28 °C for 7 days for alcoholic fermentation

Clarification and storage

Clarified wine were poured in sterile glass bottles

**Aerobic fermentation**

Addition of 10 % inoculum of broth containing *Acetobacter aceti*

Covering the bottles with sterile muslin cloth and incubated at 28 °C

Bottles were periodically stirred for first 4-5 days

Acidity of vinegar was taken till a constant value was obtained

 **Fig.1. Flow chart on preparation of pineapple waste vinegar**

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 **Fig.2. Acetous fermentation of pineapple derived waste**

**2.4. Analytical determinations**

pH was measured directly using a pH meter calibrated with standard buffer solutions. Total soluble solids were determined using an ERMA Hand Refractrometer (0 to 32° B) calibrated at 20°C and corrected using the international correction table, with the results expressed as °Brix (A.O.A.C., 1984). Specific Gravity (SG) was determined using a Pycnometer bottle, which was washed, oven-dried, cooled, and weighed before filling with the sample and weighing again (AOAC, 1984). Alcohol content was determined by the gravimetric method as described by Berry (2000). Acetic acid was estimated by titrating samples against 0.1 N NaOH using phenolphthalein as an indicator, with results expressed as percent acetic acid (A.O.A.C., 1984). Colour analysis was performed using a UV-VIS spectrometer at wavelengths of 420 nm, 520 nm, and 620 nm to determine colour intensity, density, and tone, following the method of Yildirim (2006). Colour parameters like colour intensity (A420 + A520 + A620), colour density (A420 + A520), and shade (A420/A520) were calculated. The proportions of yellow (%Y), red (%R), and blue (%B) were determined as A420 × 100/colour intensity, A520 × 100/colour intensity, and A620 × 100/colour intensity, respectively. Samples for analysis were carefully drawn with a Sorting and washing of pineapple fruit sterilized pipette to avoid disturbing the bacterial film (mother vinegar). The samples were analyzed every 3 days over a 25-day period.

**2.5. Statistical analysis**

Each treatment was conducted in five replicates, means and standard deviations were calculated using Microsoft Excel (Microsoft Corporation, USA). Statistical significance (p ≤ 0.05) of the data was assessed using analysis of variance (ANOVA).

**3. Results and discussion**

**3.1. Physico-chemical characteristics of prepared vinegar**

**3.1.1. Acetic acid**

Acetic acid content is a crucial parameter influencing the quality and acceptability of vinegar, given its prominence as the most abundant acid in vinegar. In the present study, acetic acid content varied significantly among the different pineapple waste residues used in vinegar production (Table 1). Highest acetic acid content was exhibited in peel (4.75%), followed by pomace (4.50%) and the lowest content was recorded in core (4.22%). Vinegar made from pineapple peel showed higher acetic acid content, likely due to the higher alcohol content in peel wine (7.68% v/v) compared to pomace (7.24% v/v) and core wine (6.7% v/v). This is in agreement with Beegum *et al.* (2018), who reported that higher alcohol content related to an increase in acetic acid content. As alcohol concentration decreases acetic acid concentration increases, a process influenced by yeast stress and acetaldehyde oxidation to acetic acid by acetic-acid producing bacteria (Jimoh *et al*., 2013; Claro *et al*., 2007). Furthermore, in accordance with FDA (Food and Drug Administration, USA) standards, vinegar produced through alcoholic and acetous fermentation of sugary or starchy substances is required to contain at least 4% acetic acid. The vinegar obtained in the present study from different pineapple waste all fell within the specified range. Similar results on acetic acid content have been reported by Raji *et al*. (2012) with acetic acid of 4.77% in pineapple peel vinegar and 4.91-5.01% of total acidity in mangosteen vinegar (Suksamran *et al*., 2022).

**3.1.2. pH**

The data pertaining to pH of vinegar prepared from different pineapple waste, as shown in Table 1, revealed a significant effect. Maximum pH was found in vinegar prepared from core (2.81) followed by pomace (3.02) and the minimum in peel (2.6). As acetic acid content increases, the pH value decreases indicating a higher acidity, corroborating with the findings reported by Jamaludin *et al.* (2017). In this study, pH values ranged from 2.69 to 3.02. These findings are in line with Roda *et al.* (2017) who reported a pH of 3 in pineapple vinegar and Chalchisa and Dereje (2021) for pineapple peel vinegar with pH range of 3-3.5. The results indicate that the type of substrate used significantly affects the pH content in vinegar.

**3.1.3. Total soluble solids (TSS)**

TSS content of vinegar prepared from pineapple waste showed no significant difference (Table 1). However, the highest TSS was recorded in vinegar made from core (3.36 °Brix) whereas the lowest was found in peel (3.25 °Brix). The decrease in TSS after acetic fermentation may be due to the hydrolysis of sucrose into glucose and fructose, which are more soluble and can lead to a reduction in TSS. This finding is consistent with Shi *et al.* (2019), who reported a reduction in total soluble solids after fermentation in kiwifruit vinegar.

**3.1.4. Specific gravity**

From Table 1, non-significant effect (P>0.05) was observed in respect to specific gravity. pH of vinegar prepared from different pineapple waste ranged from 1.012 to 1.014. Similar observations have previously been reported by Raichurkar and Dadagkhair (2017) in custard apple vinegar (1.019); Constance *et al.* (2021) in Garcinia and Jackfruit vinegar (1.001 to 1.083); Sahin *et al.* (1977) in grape vinegar (1.010 and 1.0119).

**3.2. Colour properties**

Significant differences were observed in colour intensity, density, tone and the percentages of yellow, red, and blue among the vinegars, prepared from pineapple waste (Table 2). It is evident that peel vinegar recorded the highest colour intensity (4.05), colour density (2.99), percentage of blue (26.09%) and red (33.59%). In regard to colour tone and percentage of yellow, highest value was obtained in core vinegar with 1.39 and 43.92%, respectively. Whereas, core vinegar recorded the lowest colour intensity (3.27), colour density (2.46) and percentage of blue (%B) (24.57%). In all the prepared vinegars, colour intensity was relatively higher than colour density and colour tone in contrary to wine samples, where colour tone exhibited a higher value. This variation in colour properties could be attributed to acetous fermentation, along with factors such as change in pH, temperature fluctuations, and different processing methods (Vagiri and Jensen, 2017). The colour properties of vinegar also depends on the raw material and production technology used (Kilic and sengun, 2021). The prepared vinegars exhibited more towards yellow hues, with percentages (%Y) ranging from 40.31% to 43.92%.

**3.3. Sensory evaluation**

The data pertaining to effect of different pineapple waste on sensory evaluation of vinegar is given in Table 3. The results showed significant difference for various sensory quality attributes. Highest score for colour and appearance was recorded in peel (7.65) followed by pomace (6.32) and the lowest in core (6.17). From the data, the most preferred vinegar in terms of colour and appearance was adjudged in treatment T1 (peel). Individual preferences play a crucial role but the inclination among the judges towards peel vinegar may be due to its more prominent yellowish hue as compared to both pomace and core which exhibited a light pale yellow colour. The colour and appearance of vinegar prepared from different pineapple waste are shown in Fig. 3.

Flavour of vinegar prepared from pineapple waste recorded a significant effect (Table 3). The highest flavour score of 6.96 was obtained in T1 (Peel) followed by 6.62 in T3 (Pomace) while lowest was recorded in 6.50 in T2 (Core). The preference towards peel vinegar (T1) may be attributed to peel waste having a more pronounced aromatic flavour compared to the other waste residues used for vinegar production. According to Chen, H. *et al*. 2016 , aroma in fruit vinegars is related to the presence of organic acids which are either present naturally in the raw materials or which occur during the process of fermentation.

Highest rating in sourness was also recorded in vinegar prepared from peel (8.02) and the lowest in core (7.66). This variation can be attributed to the higher **acetic acid content** in peel-derived vinegar, which contributed to higher score in sourness.

Vinegar derived from peel waste (T1) exhibited the highest level of preference from the judges, attaining an overall acceptability score of 8.31, followed by pomace vinegar with 7.76 and the lowest score of 7.50 recorded in core vinegar (Table 3). In general, all the prepared vinegars had a good acceptability rating among the judges as a product. However, considerable preference towards peel vinegar was observed in the sensory evaluation which is probably attributed to influence of colour/appearance and flavour of the peel vinegar. As colour and appearance usually attract consumers to a product while the quality of its aroma and flavour play a crucial role in determining impulse purchasing decisions (Barett *et al*., 2010).

 

**Fig.3. Colour and appearance of vinegar derived from different pineapple waste**

**4. Conclusion**

The present study revealed that vinegar derived from pineapple waste (core, peel & pomace) recorded an acidity content ranging from 4-4.75%, which aligns with the standard requirements of brewed vinegar. Among the different by-products, vinegar obtained from peel recorded the maximum acidity, colour intensity, density, lowest pH and had the highest overall acceptability score from the judges, while vinegar prepared from pomace scored the lowest across these parameters. Utilizing pineapple processing waste for vinegar production can be a strategic method for full utilization of the fruit within a circular economy framework. This method not only adds to the economic value of discarded pineapple by-products but also provides a sustainable solution for waste management. Therefore, transforming pineapple waste into value-added product can be an effective and sustainable method to enhance resource efficiency whilst minimizing environmental impact.

**Table 1**: Effect of different pineapple waste on pH, TSS, specific gravity and acetic acid content of vinegar

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **pH** | **TSS (brix0)** | **Specific gravity** | **Acetic acid (%)** |
| T1 (Peel) | 2.69 | 3.25 | 1.014 | 4.75 |
| T2(Core) | 3.02 | 3.36 | 1.012 | 4.22 |
| T3 (Pomace) | 2.81 | 3.28 | 1.012 | 4.50 |
| **SEm (±)** | **0.02** | **0.02** | **0.00** | **0.04** |
| **CD(P=0.05)** | **0.07** | **NS** | **NS** | **0.14** |

**Table 2:** Effect of different pineapple waste on colour properties of vinegar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Colour intensity** | **Colour density** | **Colour tone** | **%Y** | **%R** | **%B** |
| T1 (Peel) | 4.05 | 2.99 | 1.20 | 40.32 | 33.59 | 26.09 |
| T2 (Core) | 3.27 | 2.46 | 1.39 | 43.92 | 31.47 | 24.57 |
| T3 Pomace) | 3.52 | 2.63 | 1.38 | 43.30 | 31.45 | 25.25 |
| **SEm (±)** | **0.07** | **0.05** | **0.02** | **0.29** | **0.21** | **0.16** |
| **CD(P=0.05)** | **0.21** | **0.15** | **0.06** | **0.90** | **0.65** | **0.48** |

 **Table 3:** Effect of different pineapple waste on sensory evaluation of vinegar

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Colour/appearance** | **Flavour** | **Sourness** | **Overall acceptability** |
| T1 (Peel) | 7.65 | 6.96 | 8.02 | 8.31 |
| T2 (Core) | 6.17 | 6.50 | 7.66 | 7.50 |
| T3 (Pomace) | 6.32 | 6.62 | 7.82 | 7.76 |
| **SEm(±)** | **0.03** | **0.03** | **0.03** | **0.04** |
| **CD (P=0.05)** | **0.08** | **0.09** | **0.11** | **0.13** |

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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