Physicochemical and Sensory properties of vinegar produced from pineapple waste

**ABSTRACT**

Food processing waste is not only considered as a sustainability issue related to [food security](https://www.sciencedirect.com/topics/food-science/food-security) but also an economic challenge, impacting the profitability of the whole food supply chain. Pineapple processing generates a huge amount of by-products like peels, core and pomace which are often discarded, resulting in major disposal and environmental issue. These residues are rich in sugars making them an ideal substrate for fermentation to produce value-added product like vinegar. With fruit vinegar gaining recognition in recent years as a fermented beverage rich in functional components, utilizing pineapple waste for its production offers a sustainable approach to waste management. In this context, this study aimed to evaluate the physico-chemical and sensory properties of vinegar produced from pineapple processing waste. For must preparation, all the treatments were adjusted to 15° Brix with sugar and inoculated with wine yeast (2.5 g/L). The resulting wines were acetified with 10% (v/v) Acetobacter aceti (MTCC-3246) under aerobic conditions. The results indicated that vinegar derived from pineapple peel exhibited the highest acetic acid content (4.75%), the lowest pH (2.60), and superior colour intensity (4.05) and density (2.99). Sensory evaluation further revealed that peel vinegar was the most preferred in terms of colour (7.65), flavour (6.96), sourness (8.02), and overall acceptability (7.76). These findings highlight the significant impact of different pineapple waste components on vinegar quality and a sustainable approach to fruit waste utilization.

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

**1. Introduction**

Pineapple (*Ananas comosus* L.) is an important horticultural crop belonging to bromeliaceae family, valued for its nutritional content, pleasant flavour and taste (Samreen *et al*., 2020). It 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). In comparison with temperate fruits, tropical and sub-tropical fruits are reported to have considerably higher ratio of by-products (Schieber *et al*., 2001). Pineapple processing alone generates substantial waste, 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 mostly 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). Wastes generated during pineapple processing are valuable raw materials composed of dietary fibre, protein, pectin, phenolic compounds, vitamins and minerals (Diaz-Vela *et al*., 2013).

With the growing demand for processed pineapple products, pineapple production are increasing annually, leading to massive waste been generated ( Aili Hamzah *et al*., 2021). These wastes contain high moisture, sugars, albumins and vitamins that are highly prone to microbial spoilage contributing to environmental issues (Rico *et al*., 2020). Consequently, much of this waste are discarded in landfills, leading to ecosystem contamination, accelerated biological and chemical oxygen demand and disease risk (Zaki *et al*., 2017). Large capital costs are required to dispose of this waste through land filling, incineration, pyrolysis etc in turn contributing to greenhouse gas emissions (Roda and Lambri, 2019). Despite these challenges, pineapple processing wastes are rich source of sugars serving as an ideal substrate for fermentation of vinegar and other fermented beverages (Tropea *et al*., 2014). Vinegar production provides a sustainable waste management strategy, allowing for full utilization of by-products without compromising the quality of the product. Historically, Vinegar has been used as a preservative, condiment and therapeutic agent, often valued for its functional properties (Solieri *et al*., 2009) and can be produced from any non-toxic material with sugar juice or directly from sugar juice itself (Omojasola *et al*., 2008). Vinegar production 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 study has highlighted the antimicrobial, anti-inflammatory, antidiabetic, antioxidant, and antihyperlipidemic properties of fruit-based vinegar, facilitating growing interest in their production (Yagnik *et al*., 2021).

To enhance the sustainability of pineapple waste utilization, biotechnological approaches and the circular bioeconomy model are increasingly been explored (Polania *et al*., 2022).These strategies integrate various process technologies to valorize pineapple waste into a diverse range of industrially significant products, in 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). Utilization of pineapple residues has a promising prospect not only in terms of minimizing environmental impact but also for generating an added income. Keeping this in view and considering the potential of pineapple waste. 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 knife. The pulp was manually pressed by hand to obtain the pomace. In first stage fermentation (alcoholic fermentation) 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 yielded an alcohol content of 7.68%, 6.7%, and 7.24% in peel, core and pomace wines respectively. Total Soluble Solids (TSS) was 5.1 brix0 for peel, 5.5 brix0 in core, and 5.3 brix0 in pomace wine after fermentation.

In the second stage of fermentation (acetic fermentation), prepared wines from different pineapple wastes was transferred into sterilized glass bottles with wide mouths and inoculated with 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. Samples were analyzed at 3 day interval until acidity stabilized for a period of 25 days. 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 for a period of 25 days

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**

The experiment was laid out in completely randomized design with five replications. Means and standard deviations were calculated using Microsoft Excel (Microsoft Corporation, USA) and 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 prepared from pineapple peel showed a higher acetic acid content, likely due to the higher alcohol content in peel wine (7.68% v/v) as compared to pomace (7.24% v/v) and core wine (6.7% v/v).This 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). These interactions illustrate the complex relationship between alcohol, yeast, and acetic acid production during fermentation. 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 this 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 obtained 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 indicated that the type of substrate used for vinegar production significantly affects the pH content.

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

Regarding TSS, no significant difference was observed among the treatments (Table 1). However, highest value for TSS (3.36 °Brix) was observed in vinegar prepared from core and 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. These findings are in partial conformity 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. Specific gravity of vinegar prepared from different pineapple waste ranged from 1.012 to 1.014 corroborating with the previous research findings. Raichurkar and Dadagkhair (2017) reported specific gravity of 1.019 in custard apple vinegar, while Constance *et al.* (2021) observed a broad range (1.001-1.083) of specific gravity in Garcinia and Jackfruit vinegar. Also, Sahin *et al.* (1977) documented specific gravity of grape vinegars in the range of 1.010 to 1.0119, further supporting the findings of this study.

**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.

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 may be 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**

From the present study, it was observed that vinegar obtained from peel exhibited the highest acidity, colour intensity, density, lowest pH and had the highest overall acceptability from the judges, while vinegar prepared from pomace scored the lowest across these parameters. Overall, vinegar derived from pineapple waste (core, peel & pomace) ranged from 4-4.75%, which aligns with the standard requirements of brewed vinegar. These findings highlight the potential of utilizing pineapple waste for vinegar, adding value to by-products that are often discarded. Future research should investigate on product diversification and market expansion strategies to enhance consumer acceptance and commercial viability, further strengthening the role of pineapple waste utilization in sustainable food production. One of the key challenges in vinegar production is the long maturation period required to develop a desirable flavour profile, which significantly impacts production cost. Therefore, work on infusion of aromatic herbs or oils to enhance aromatic and sensory profile, as well as nutraceutical value could be taken up. This approach may help reduce aging time, improve the overall product quality, thereby making pineapple waste derived vinegar both economically viable and appealing to consumers.

**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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