Journal of Plant Development Sciences
Meerut, India

RESEARCH

UTILISATION OF MARKET REJECTED OVERRIPE FRUITS OF PINEAPPLE (*ANANAS COMOSUS* (L.) MERR.) VARIETY MAURITIUS

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Received-17.09.2024, Revised-10.10.2024, Accepted-24.10.2024

Abstract: Disposal of overripe and market-rejected pineapple (*Ananas comosus* (L.) Merr) fruits poses a serious economic and sustainability challenge. This study focuses on physico-chemical characterisation of pineapple wastes and the valorisation of peel waste as substrate for *nata* production with *Acetobacter xylinum*. The juice, peel, and pomace of market-rejected fruits recorded total sugar content of 11.10±0.08 %, 7.33±0.02%, and 5.68± 0.01% respectively, making them ideal substrates for fermentation. *Nata de pina*, with a thickness of 8 mm and an average yield of 34.62 %, could be obtained from pineapple peel waste, highlighting its' potential as a valuable substrate for *nata* production. The rich amount of fiber, cellulose, and carbohydrates observed with the peel and pomace makes them highly suitable for biorefinery processes, supporting a circular bioeconomy model.

Keywords: *Nata de pina***,** Pineapple waste, Physico-chemical properties, Valorization

INTRODUCTION

Pineapple (*Ananas comosus* (L.) Merr), with exceptional nutritional quality and delightful flavour profile, represents a significant horticultural crop within the family Bromeliaceae. It is a widely cultivated fruit crop in tropical and subtropical regions worldwide. India has the 6th position globally in pineapple production (1.706mT) with a cultivation area of 105.58 million hectares. Pineapple is a highly relished fruit for fresh consumption, juice extraction, canned products, and dried snacks. Inadequate handling and disposal of pineapple wastes can lead to environmental degradation, primarily caused by the breakdown of the sugar-rich contents, impacting the overall quality of the environment (Rabiu *et al*., 2018). Market rejected pineapple fruits and processing waste can be used as raw material for fermentation and extraction technologies for unique and valuable products.

While extensive literature (Tran *et al*., 2008, Kodagoda *et al*., 2017) exists for the physico-chemical properties of superior quality fruits of pineapples at various maturity stages, research pertaining to the quality parameters or utilisation of market rejected overripe pineapple fruit is scanty. Pineapple juice and its by-products are rich in sugars, vitamins, and minerals, which serve as nutrients for microbial growth. Physico-chemical characterisation of these fruits can illuminate possible ways of utilisation in the biorefinery processes. The bioprocessing of pineapple waste into healthy food products represents an effective strategy for advancing circular economy practices and waste valorisation.

The carbon and nitrogen sources available in pineapple substrates can be utilised to produce *Nata de pina*. *Nata de pina*, also referred to as pineapple gel or pineapple gelatin, is a chewy, transparent, jelly-like product formed through the bacterial fermentation of pineapple juice by *Acetobacter xylinum* (Almeida *et al*., 2013). This fibre rich functional food can be incorporated in fruit salads, preserves, and frozen desserts for health benefits. This research focuses on physico-chemical characterisation of juice, pomace and peel of market rejected overripe pineapple fruits and preliminary studies on utilisation of pineapple peel for *nata de pina* production.

MATERIALS AND METHODS

Overripe, discarded fruits of pineapple variety Mauritius were obtained from the largest Asian pineapple market located at Vazhakulam, Kerala, India. Fruits were decrowned, cleaned and washed thoroughly with potable water after sanitizing with 120 ppm sodium hypochlorite solution for 5 minutes. The fruits were peeled, fruit along with core were cut into pieces and processed in an

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electric blender and juice, peel and pomace were collected separately for subsequent analyses.

Physico-chemical characterisation

The pH of pineapple juice was measured directly with ECPHTUTOR-S Cyber Scanp H Tutor (U.S), whereas pH of pineapple peel and pomace was observed after blending with distilled water in 1:1 and 1:2.5 ratio respectively. The juice, peel and pomace were analysed for TSS(°B), moisture content (%), titrable acidity (%), ascorbic acid (mg/100g), dietary fiber (%) reducing sugars and total sugars (Ranganna, 1997), lignin (%), hemicellulose (%), cellulose (%), crude fibre (%), total carbohydrates (g/100g), and starch (g/100g) (Sadasivam and Manickam,1996).

***Nata de pina* production**

Microorganism for *Nata de pina* production

Acetobacter xylinum (NCIM 2526) was sourced from NCIM, Pune. The organism was grown and maintained in Hestrin and Shramm (HS) media and stored at 4°C. The starter culture was prepared by inoculating *Acetobacter xylinum* in HS broth for 7 days at 30°C. The formulation of HS broth comprised of glucose (20g), yeast extract (5g), peptone (5g), and dipotassium hydrogen phosphate (2.7g) and the pH was adjusted to 4.2 using acetic acid.

Substrate preparation

The peel of over riped, market rejected pineapple fruits was blended with distilled water in 1:3 ratio, filtered and the extract was mixed with ammonium sulphate (0.5%) and sugar (10%). The pH of the substrate was adjusted to 3.5 and sterilized. The sterilized substrate was inoculated with starter culture (40% concentration) under aseptic conditions, covered with muslin cloth and incubated at ambient conditions for 14 days.

Harvesting and characterisation of *Nata de pina*

The nata formed was strained out from the media and washed thoroughly with water, the excess water was dripped off completely and weight (g) was recorded. Thickness (mm) of nata sheet was measured at four different positions using a vernier caliper. Crude fibre content of nata was estimated as per standard procedures (Sadasivam and Manickam ,1996). Yield of nata was estimated as:

$$\text{Yield (\%)} = \frac{\text{Weight of Nata (g)} \times 100}{\text{Weight of substrate (g)}}$$

RESULTS AND DISCUSSION

The effectiveness of various pineapple waste/by-products in industrial applications can be attributed to their unique physico-chemical properties. Significant differences existed between the pH of different parts of the market rejected fruits with the lowest pH value in pineapple peels (4.17±0.01) and the highest in juice (5.43±0.01). Pineapple juice exhibited robust buffering capacity against pH fluctuations, while its organic nitrogen compounds and other nutrients contribute to enhanced productivity and increased yield when subjected to fermentation for bioethanol (Tanaka *et al*.,1999) A lower pH effectively inhibits the growth of undesirable microorganisms, thereby enhancing the quality of the vinegar production (Chalchisa and Dereje, 2021).

The moisture content of all the three parts were within a range of 85-87% with significant differences. These results aligned with the findings of Kodagoda *et al*., (2017) who reported that pineapple peels had moisture content ranging from 82-88%. In another study, on the drying characteristics of pomace, it was found that pomace exhibited moisture content of 84.48 % which is also in line with present findings.

The titrable acidity of pineapple parts showed a significant difference at $P<0.05$, with the highest acidity in pineapple peels (2.43±0.12) %. A titrable acidity value of 2.03% for Indian pineapple juice and 1.86% for waste was reported while ascorbic acid content was 21.5 % for pineapple pulp and 26.5 % for pineapple waste (Hemalatha and Anbuselvi ,2013). There was significant difference between ascorbic acid content of juice (24.86±2.96) mg/100g, pomace (18.37±2.96) mg/100g and peel (12.97±2.96) mg/100g of market rejected fruits The concentration of vitamin C present in freshly extracted pineapple juice has been documented to fluctuate between 9.2 and 93.8 mg/100 mL (Miller and Schaal, 1951). This indicates a significant degree of variability in the vitamin C levels found within pineapple fruit. Previous research done by Badjona *et al*., (2019) has demonstrated that Pineapple pomace from sugarloaf variety have higher concentration of vitamin C (15.41 ± 0.62) mg/100g and can be used as an ingredient in the manufacture of bread with enhanced nutritional properties, illuminating the multi directional valorisation strategies where market rejected pineapple fruits can be used

The peels of market rejected fruits exhibited total soluble solids (TSS) content of 6.36±0.05 °Band significant differences existed between different parts. Total sugar content was the highest for juice (11.10±0.08) °B followed by peels (7.33±0.02) °B, whereas pomace (5.68±0.01) °B demonstrated minimal levels and all treatments showed statistically significant differences. Reducing sugars of juice (7.89±0.07) % documented the most elevated levels, in contrast to pomace (3.02±0.03) %which displayed the lowest concentrations with significant differences between all of them. These results are comparable to the findings in the study conducted by Samreen *et al*., (2020) where juice extracted from a fully ripened and high-quality pineapple exhibits a concentration of reducing sugars measuring 9.48±0.8 %, total sugars quantifying at 13.13±1.25 %, and non-reducing sugars at a level of 3.65±1.10%. A study conducted by Bakri *et al.*, (2020) revealed that peels of pineapples exhibit a fructose concentration of 10.310 g/100 g (the predominant sugar), alongside a glucose content of 9.12 g/100 g and a sucrose concentration of 5.52 g/100 g. Favourable levels of sugar content in the discarded pineapple fruit parts observed in the current study indicates their feasibility in biorefinery processes.

More cellulose (60.23±1.92) % and hemicellulose (27.24±1.63) % content was obtained in pomace than peels (43.6±1.62, 19.91±1.7) %. Traces of cellulose (2.01±0.31) % and hemicellulose (0.344±0.04) %were also seen in juice which was extracted from pulp with core. The pomace exhibited the most substantial concentration of lignin, quantified at 13.38±1.41%, whereas the peels contained a lesser proportion of 8.18±1.17%. Low levels of starch (6.5±0.25) %were noticed in the pineapple pomace (Figure 1). Priera *et al*., 2022 reported 6.35±0.28 % of lignin content in fresh pineapple peels. Dahunsi *et al*., (2019) have reported that elevated concentrations of lignin, cellulose, and hemicellulose in the pineapple waste makes them suitable substrate for the synthesis of fermentable sugars for energy generation. The total carbohydrate concentration of juice (14.5 ± 0.41 g/100g), peels (12.2±0.2 g/100g) and pomace (35.25 ± 0.11) showed significant differences. Mala *et al.*, (2024) reported 73.03% of total carbohydrate content in dried pineapple peels. The high carbohydrate levels in pineapple waste make it a viable feedstock for biogas production. After six months of ensiling, pineapple peel waste produced a biogas yield of 0.67 m³ per kilogram of volatile solids added, with a methane concentration of 65% (Rani and Nand, 2004).

Pineapple peels have total fibre content of 34.6±2.08 % and a dietary fibre content of 13.97±0.66 % and pomace contained a high dietary fiber content of 48.34 ± 1.33%, consistent with the 45.22% TDFs reported by Selani *et al*., (2014). The insoluble dietary fibre is utilised as an ingredient to increase the indigestible and insoluble compounds in food products. In addition, a high insoluble dietary fibre content could have beneficial health effects related to increases in satiety and in the volume and weight of fecal mass, thus promoting improved functioning of the digestive system (Martinez *et al*., 2012)

Nata-de-pina is a gelatinous food product derived from the fermentation of pineapple juice. In the current study, pineapple peels were employed as a substrate for the production of nata. Physico-chemical characterisation has indicated that the essential components necessary for the provision of nutrients conducive to the growth of *A. xylinum* are present in pineapple peels. Khanagoudar *et al*., (2016) conducted a study on the production of *Nata de pina* utilizing over-ripened pineapple pulp waste as a substrate where optimal production conditions included a pineapple broth ratio of 1:2, a glucose concentration of 7.5%, a tryptone concentration of 1%, a pH level of 4.5, and a temperature of 30°C. Study conducted by Sutanto (2012) showed that incorporating nutrients into pineapple liquid waste during the production of *Nata de pina* led to the highest weight and thickness outcomes. Previous studies have shown that the bacterial cellulose yield from pineapple peel juice (2.8 g/L) exceeded that of Hestrin-Schramm's medium (2.1 g/L), indicating the sufficiency of carbon and nitrogen in the peel juice for microbial growth (Castro *et al*., 2011). Although in the current study ammonium sulphate and sucrose were added into pineapple peel medium to supplement necessary carbon and nitrogen for fermentation in addition to the existing ones to enhance yield. These findings highlight the potential of agro-industrial residues as a low-cost alternative for large-scale bacterial cellulose production. Studies have also shown that despite variations in carbon source cellulose produced was consistently pure and crystalline and also highlighted that *G. xylinus* can metabolize different carbon sources for BNC production, with variations in yield attributed to substrate limitations rather than changes in cellulose polymerization or structure (Mikkelsen *et al*., 2009) Market rejected and overripened pineapple peels when used as a substrate for *nata de pina* production gave a mean yield of 34.62 % with a thickness of 8mm and a crude fibre content of 4.05%, thus confirming the potential of peels to be used for nata production (Figure 2). Studies conducted by Yovita *et al*., 2020 have shown that a yield of 12.02% *nata de pina* with thickness 0.39 cm was obtained from pineapple fruit peel which was higher than yield from flesh and core. Physico-chemical characterisation of discarded pineapples confirms their potential as substrate for biorefinery processes and *nata de pina* production.

Table 1. Physico-chemical properties of market rejected pineapple fruits

Sl. No	Parameter	Juice	Peel	Pomace
1	pH	5.43±0.01	4.17±0.01	4.53±0.03
2	Total soluble solids	15.32±0.10	6.36±0.05	8.24±0.05
3	Titrable acidity (%)	2.23±0.19	2.43±0.12	1.63±0.10
4	Moisture content (%)	85.87±0.88	87.21±0.34	86.95±0.75
5	Ascorbic acid (mg/ 100g)	24.86±2.96	12.97±2.96	18.37±2.96

6	Reducing sugars (%)	7.89±0.07	4.75±0.05	3.02±0.03
7	Non-reducing sugars (%)	3.20±0.02	2.67±0.02	2.58±0.04
8	Total sugars (%)	11.10±0.08	7.33±0.02	5.68±0.01
9	Total fibre (%)	1.97±0.05	34.6±2.08	24.67±1.30
10	Dietary fibre (%)	1.46±0.21	13.97±0.66	48.34± 1.33

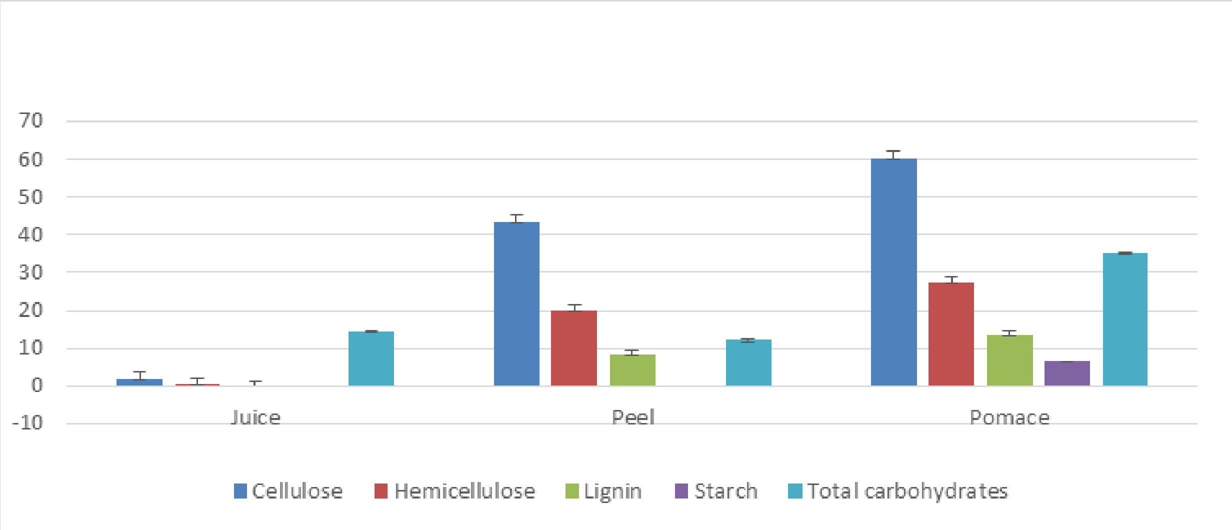

Figure 1: Carbohydrate composition of juice, peel and pomace of market rejected pineapple fruits

Figure 2: *Nata de pina* formation in pineapple peel extract, *Nata de pina* sheet

ACKNOWLEDGEMENT

We thank Kerala Agricultural University for giving the facility and financial support for conducting this research work.

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