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Comparative phytochemical profile and bioethanol production potential of plantain (*Musa paradisiaca*) and cucumber (*Cucumis sativus*) peels

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Abstract
Fruit and vegetable peels are frequently discarded despite containing carbohydrates and bioactive compounds that can support waste-to-value bioprocesses. This study compared the phytochemical composition and bioethanol production potential of plantain (Musa paradisiaca) and cucumber (Cucumis sativus) peels purchased from Towobowo market in Igboora and Eleyele market in Ibadan, Oyo State, Nigeria. Peels were air-dried, milled, subjected to acid and alkaline pretreatment, enzymatically hydrolyzed, fermented for 7 days using Saccharomyces cerevisiae and Aspergillus niger, and distilled. Both substrates contained alkaloids, flavonoids, tannins, saponins, phenols, terpenoids, steroids, cardiac glycosides and phlobatannins in the qualitative screening, whereas anthraquinones were reported as absent. Quantitatively, plantain peel contained higher phenols (52.02 ± 0.24 g/100 g), terpenoids (22.12 ± 0.14 g/100 g), alkaloids (3.53 ± 0.64 g/100 g), saponins (1.88 ± 0.24 g/100 g), steroids (7.25 ± 0.11 g/100 g) and cardiac glycosides (7.73 ± 0.02 g/100 g) than cucumber peel (47.00 ± 0.21, 10.00 ± 0.05, 2.60 ± 0.14, 1.28 ± 0.003, 5.02 ± 0.00 and 4.35 ± 0.23 g/100 g, respectively). Distillation recovered 300 ml ethanol from 1 kg plantain peel and 200 ml from 1 kg cucumber peel; the source dataset reports yield of 66% and 50.2%, respectively. The findings support plantain peel as the stronger substrate under the tested conditions, while also demonstrating the potential for integrated recovery of bioactive compounds and fermentation products.

Keywords: *Agricultural waste; bioethanol; cucumber peel; phytochemicals; plantain peel; Saccharomyces cerevisiae; waste valorization*

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I. Introduction

Fruit and vegetable processing generates substantial quantities of peels and other non-edible fractions. Rather than treating these materials solely as disposal streams, current biorefinery research increasingly considers them feedstocks for simultaneous recovery of bioactive compounds and production of fuels and other value-added products. Recent reviews identify fruit wastes as renewable and potentially low-cost substrates for bioethanol, while emphasizing that substrate composition, pretreatment severity, hydrolysis efficiency and fermentation conditions strongly influence process performance (Mgeni *et al.,* 2024; Kasaeian *et al.,* 2025). Fruit and vegetable by-products can also contain phenolic compounds, flavonoids and other phytochemicals of industrial interest, strengthening the rationale for integrated valorization rather than single-product conversion (Mateus *et al.,* 2024). Lignocellulosic and carbohydrate-rich residues generally require structural disruption before efficient enzymatic saccharification. Acid, alkaline, biological and combined pretreatments can improve accessibility of fermentable carbohydrates, but excessive chemical severity may increase degradation products that inhibit hydrolysis or fermentation. Recent work therefore stresses substrate-specific optimization and careful control of pretreatment conditions (Kululo *et al.,* 2025).

Plantain peels are particularly relevant in tropical food systems because they are generated in large quantities and have demonstrated potential as fermentation substrates. Recent Nigerian studies have evaluated *Saccharomyces cerevisiae* mediated bioethanol production from plantain peel and reported that fermentation performance depends strongly on substrate concentration, pH, temperature and fermentation time (Akinola *et al.,* 2025; Offor-Emenike *et al.,* 2025). Cucumber peel has received comparatively less attention as a bioethanol substrate, although its phytochemical richness makes it a relevant biological agent for integrated waste valorization. The present study therefore compared the phytochemical composition and bioethanol recovery from plantain and cucumber peels following chemical pretreatment, enzymatic hydrolysis and microbial fermentation. The objective was to identify the stronger substrate under the reported experimental conditions while framing the findings within a circular-bioeconomy perspective.

II. Materials and methods

2.1. Sample collection and preparation

cucumber and Plantain were purchased from two locations in Oyo State, Ibarapa central (Towobowo market) and Akinyele Local Government (Eleyele market), Nigeria. Samples were washed, weighed and peeled. The peels were air-dried at room temperature, weighed, milled and stored until processing.

2.2. Pre-treatment and hydrolysis

Grounded peels material was subjected to dilute-acid treatment using 20% (v/v) H_2SO_4 at 170 °C for 45 min and subsequently washed to approximately neutral conditions. Alkaline pretreatment was then performed using 3% (w/v) NaOH at 120 °C for 60 min. The pretreated material was enzymatically hydrolyzed at 50 °C for 48 h and filtered.

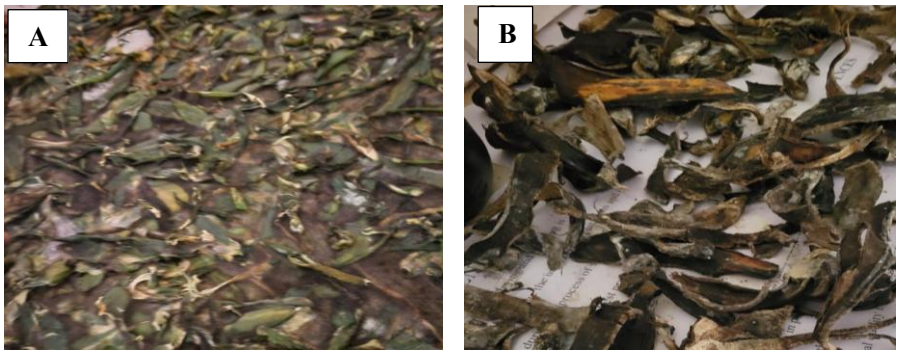


Figure 1: Pictorial evidence of (a) Cucumber peel (b) Plantain peel

2.3. Fermentation

Hydrolysates were transferred into labelled flasks and autoclaved at 121 °C for 15 min. After cooling, inoculation was performed using 12 mm discs of 50 grams of *Saccharomyces cerevisiae* as enzymes for each sample that is plantain peel and cucumber peel at ratio 1:1. Appropriate controls were included. Fermentation was conducted at room temperature for 7 days with periodic agitation.

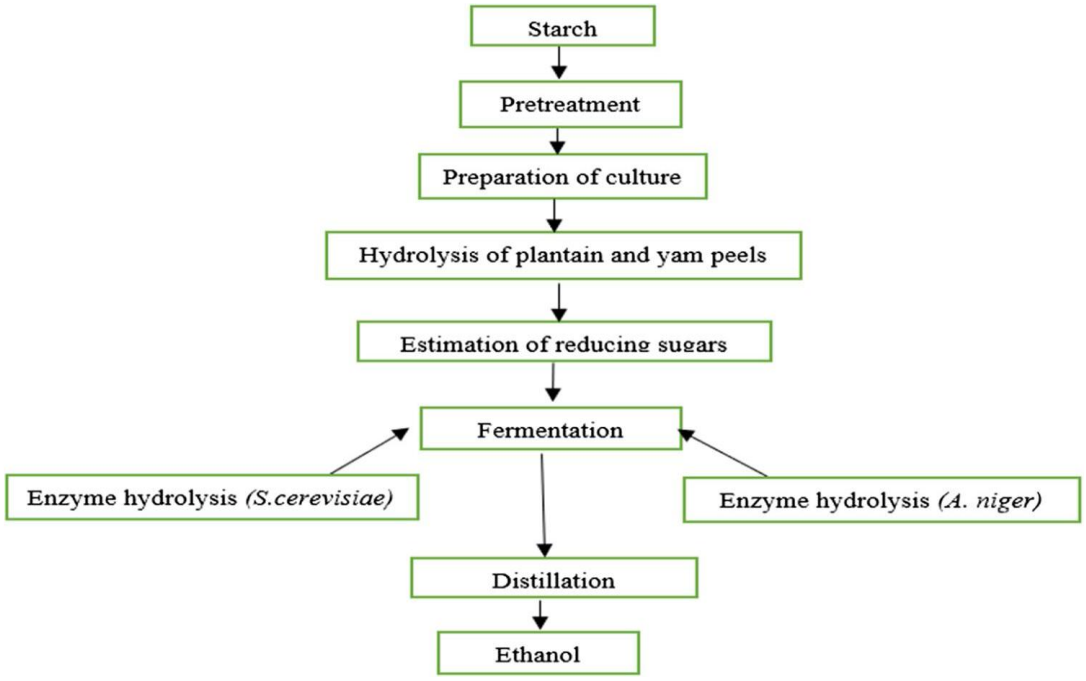


Figure 2: Schematic diagram of bioethanol production using plantain and cucumber peels with enzymes *S. cerevisiae* and *A. niger*

2.4. Ethanol recovery and physicochemical characterization

Fermented mash was distilled using a heating mantle and distillation column at approximately 78 °C. Recovered distillates were added with 1.5 g of Calcium Oxide (CaO) powder and were evaluated by colour, odour, volatility, boiling point, pH and density. Alcoholmeter measurements were also reported. The study records recovered volumes of 300 ml for plantain peel and 200 ml for cucumber peel from 1 kg starting substrate using measuring cylinder.

2.5. Phytochemical analysis

Qualitative and quantitative phytochemical analyses were performed using standard phytochemical procedures. The reported analytes included alkaloids, flavonoids, tannins, saponins, phenols/polyphenols, terpenoids, steroids/phytosterols, cardiac glycosides, phlobatannins and anthraquinones. Quantitative results are expressed as g/100 g in the supplied dataset.

2.6. Statistical considerations

Results were reported as mean ± SEM in the source dataset. However, replicate number, raw replicate observations and the statistical model used to derive the SEM values were not supplied. Consequently, formal ANOVA, Tukey HSD grouping, confidence intervals and p-values were not recalculated. Reporting such statistics from the summary values alone would not be statistically defensible. The present manuscript therefore distinguishes descriptive comparisons from inferential claims.

III. Results

3.1. Quantitative phytochemical composition

Plantain peel showed higher reported concentrations for all quantitatively listed phytochemical classes than cucumber peel except that the supplied qualitative/quantitative anthraquinone records require reconciliation. The largest numerical differences were observed for terpenoids and phenols/polyphenols. Plantain contained 22.12 ± 0.14 g/100 g terpenoids compared with 10.00 ± 0.05 g/100 g in cucumber, representing approximately a 121.2% higher value relative to cucumber. Phenols/polyphenols were 52.02 ± 0.24 and 47.00 ± 0.21 g/100 g, respectively, corresponding to an approximately 10.7% higher reported value in plantain peel, the values were expressed in mean ± SEM. The percentage yield and percentage differences were calculated using;

$$Percentage\ yield = \frac{Different\ in\ weight\ of\ the\ substrate\ after\ hydrolysis}{Original\ weight\ of\ the\ substrate} \times 100$$

$$Percentage\ difference = \frac{Plantain - Cucumber}{Cucumber} \times 100$$

Table 1. Quantitative phytochemical composition of plantain and cucumber peels.

Phytochemical	Plantain peel (g/100 g)	Cucumber peel (g/100 g)	Percentage difference (%)
Alkaloids	3.53 ± 0.64	2.60 ± 0.14	35.80
Flavonoids	0.16 ± 0.05	0.10 ± 0.02	60.00
Tannins	2.18 ± 0.63	2.11 ± 0.00	3.30
Saponins	1.88 ± 0.24	1.28 ± 0.003	46.90
Phenols/polyphenols	52.02 ± 0.24	47.00 ± 0.21	10.70
Terpenoids	22.12 ± 0.14	10.00 ± 0.05	121.20
Steroids/phytosterols	7.25 ± 0.11	5.02 ± 0.00	44.40
Cardiac glycosides	7.73 ± 0.02	4.35 ± 0.23	77.70
Phlobatannins	0.36 ± 0.00	0.16 ± 0.20	125.00

3.2. Biomass conversion and ethanol recovery

From an initial substrate mass of 1000 g, the reported post-hydrolysis masses were 650 g for plantain and 500 g for cucumber. Fermented mash masses were 125.7 g and 102.6 g, respectively. Distillation recovered 300 ml ethanol from plantain peel and 200 ml from cucumber peel. Thus, the recovered volume per kilogram starting substrate was 300 and 200 ml kg^{-1}, respectively. The source dataset reports corresponding ethanol yields of 66% and 50.2%; however, these percentages cannot be independently reproduced from the reported recovered volumes and 1 kg starting mass without the original yield equation and density/concentration basis.

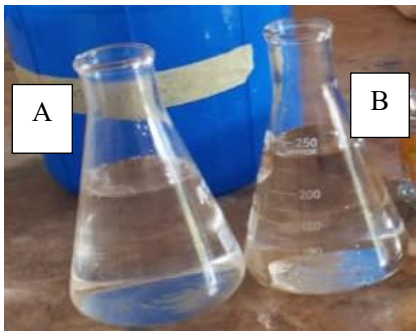


Figure 3: Ethanol recovery from (a) Cucumber peel (b) Plantain peel

Table 2. Substrate conversion and ethanol recovery from Plantain and Cucumber peel

Parameter	Plantain	Cucumber	Absolute difference	Relative difference
Initial substrate (g)	1000.00	1000.00	0.00	0%
Post-hydrolysis mass (g)	650.00	500.00	150.00	30.0%
Fermented mash (g)	125.70	102.60	23.10	22.5%
Recovered ethanol (ml)	300.00	200.00	100.00	50.0%
Recovered volume (ml/kg)	300.00	200.00	100.00	50.0%
Reported ethanol yield (%)	66.00	50.20	15.80	31.5%

Relative difference is calculated against the cucumber value for nonzero comparisons.

3.3. Physicochemical characteristics of recovered distillates of Plantain and Cucumber peel

Property	Plantain	Cucumber
Odour	Pungent	Pungent
Colour	Colourless	Colourless
Volatility	Highly volatile	Moderately volatile
Boiling point (°C)	77.8	77.6
Ph	6.9	6.8
Density	0.74	0.73

IV. Discussion

The comparative profile indicated that plantain peel had the greater quantitative abundance of the measured phytochemical classes under the analytical conditions used. The particularly large difference in terpenoids and the higher phenolic content were consistent with the broader literature showing that fruit and vegetable by-products can retain substantial concentrations of bioactive constituents and therefore represent useful secondary resources rather than simple waste streams (Mateus *et al.,* 2024). These compounds may provide additional valorization routes, although the present study did not chemically identify individual phenolics, terpenoids or other constituents. The ethanol recovery data was high in plantain peel. Recovery of 300 ml kg^{-1} starting substrate was 50 % greater than the 200 ml kg^{-1} obtained from cucumber peel. This difference may reflect variation in fermentable carbohydrate availability, structural composition, hydrolysis efficiency and microbial accessibility. Recent works on fruit-peel bioethanol production emphasize that pretreatment, hydrolysis and fermentation were interconnected process steps and that performance varies substantially among feedstocks (Mgeni *et al.,* 2024; Kasaeian *et al.,* 2025).

The use of both acid and alkaline pretreatment provides a plausible route for increasing substrate accessibility, but the severity reported here is relatively high. Recent pretreatment literature stresses that acid and alkaline conditions must be optimized for individual substrates because excessive severity can increase chemical consumption and generate compounds that inhibit subsequent enzymatic or microbial conversion (Kululo *et al.,* 2025). A stronger future design would therefore quantify reducing sugars before and after hydrolysis and monitor fermentation inhibitors such as furfural, hydroxymethylfurfural and phenolic degradation products.

Recent experimental studies further support the need for optimization rather than assuming a single set of fermentation conditions is universally optimal. Offor-Emenike *et al.* (2025) reported optimized plantain-peel fermentation with *S. cerevisiae* using response-surface methodology, while Akinola *et al.* (2025) similarly used response-surface optimization to examine substrate concentration, pH, temperature and fermentation time. These studies reinforce the interpretation that the present plantain result demonstrates substrate potential.

V. Conclusion

Plantain peel demonstrated a quantitatively richer phytochemical profile and greater ethanol recovery than cucumber peel under the reported processing conditions. Plantain peel contained 52.02 ± 0.24 g/100 g phenols/polyphenols and 22.12 ± 0.14 g/100 g terpenoids, compared with 47.00 ± 0.21 and 10.00 ± 0.05 g/100 g, respectively, for cucumber peel. Distillation recovered 300 ml and 200 ml ethanol from 1 kg plantain and

cucumber peel, respectively. These findings support both materials as potential feedstocks for waste valorization, with plantain showing stronger performance in the present dataset.

Recommendation

It could be recommended for this research work that further work should be carried out on the purity and Quantity of reducing sugar of ethanol production using GC-MS or HPLC.

Conflict of interest

The are no conflicts of interest that could have influence the research, its analysis or the preparation of the manuscript.

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