

Antimicrobial and Phytochemical Properties of Fruit Vinegars: A Focus on *Phoenix dactylifera* and Banana Fruits

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ABSTRACT

The escalating global challenge of antimicrobial resistance has driven significant interest in exploring natural, plant-based alternatives with bioactive properties. Fruit vinegars, long valued in traditional wellness practices for their purported health benefits, represent a promising category of such functional foods. However, the specific phytochemical profiles and antimicrobial efficacy of vinegars derived from underutilized fruits, particularly *Phoenix dactylifera* (date) and *Musa paradisiaca* (banana), are not well-documented. This study was therefore designed to characterize the phytochemical composition and evaluate the *in vitro* antimicrobial potential of vinegars produced from these fruits. Yeast (*Saccharomyces cerevisiae* strain SR 128) and acetic acid bacteria (*Acetobacter aceti* strain WI) were isolated from spoiled fruits and used to inoculate musts for submerged fermentation. The resulting vinegars were analyzed for their physicochemical properties, nutrient content, and phytochemical constituents using established gravimetric and instrumental methods. Antimicrobial activity was assessed against a panel of pathogenic microorganisms, including *Staphylococcus aureus*, *Escherichia coli*, *Salmonella enterica* serovar Typhi, and *Candida albicans*. Statistical analysis was performed using ANOVA followed by Tukey's post-hoc test ($p < 0.05$). Phytochemical analysis confirmed the presence of bioactive compounds, including alkaloids, saponins, flavonoids, tannins, and cardiac glycosides. Both vinegar samples exhibited significant ($p < 0.05$) inhibitory activity against all tested pathogens, with the most pronounced effect observed against *E. coli*. Comparative analysis indicated that the date fruit vinegar possessed marginally superior antimicrobial efficacy. In conclusion, this study demonstrates that vinegars from *Phoenix dactylifera* and *Musa paradisiaca* are rich sources of antimicrobial phytochemicals, and the sample produced from PD was slightly better than the sample produced from MP, mostly against *Escherichia coli*.

Keywords: Vinegar, Phytochemical, Antimicrobial, *Saccharomyces*, *Acetobacter*, *Staphylococcus*, *Escherichia*, *Candida*.

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INTRODUCTION

Fruit vinegars constitute a significant category of functional fermented foods, prized not only for their culinary applications but also for their prospective health benefits. These benefits arise from the synergistic interaction between acetic acid and the bioactive phytochemicals preserved from the fruit substrate during fermentation (Xia *et al.*, 2020; Iheukwumere *et al.*, 2025a). The antimicrobial potency and overall bioactivity of a given vinegar are intrinsically linked to the specific phytochemical profile of its raw fruit material (Jia *et al.*, 2012; Guedes *et al.*, 2014). Consequently, investigating vinegars produced from nutritionally dense but less conventional fruit sources offers a promising avenue for developing novel functional products with enhanced properties (Iheukwumere *et al.*, 2025b; Dim *et al.*, 2025a; Iheukwumere *et al.*, 2022a).

Phoenix dactylifera L. (date palm) and fruits of the genus *Musa* (banana and plantain) represent two globally vital crops with complementary attributes and considerable untapped potential for vinegar production. Cultivated in arid regions for over six thousand years, *P. dactylifera* is renowned for its high concentration of sugars, dietary fiber, and phenolic compounds (Al-Shwyeh, 2019; Dim *et al.*, 2025b; Ekechukwu *et al.*, 2025a). The fruit's extensive history in traditional medicine is attributed to its diverse array of bioactive constituents with demonstrated therapeutic value (Hafzan *et al.*, 2017; Ejike *et al.*, 2017; Amadi *et al.*, 2017). In contrast, *Musa* spp. stands as one of the world's most crucial staple fruits and a key economic crop across

tropical and subtropical regions (FAO, 2022; Nwike *et al.*, 2017; Obianom *et al.*, 2024). Beyond being a rich source of energy, carbohydrates, and potassium, bananas contain significant levels of bioactive compounds such as dopamine, catechins, gallic acid, and various carotenoids, which are associated with antioxidant and anti-inflammatory activities (Singh *et al.*, 2016; Vu *et al.*, 2018). Utilizing overripe bananas, a common source of post-harvest loss, for vinegar production offers a particularly sustainable method of valorization.

The biological synthesis of vinegar from these fruits entails a two-stage microbial fermentation. First, yeasts such as *Saccharomyces cerevisiae* convert fermentable sugars into ethanol. Subsequently, acetic acid bacteria, including *Acetobacter* species, oxidize this ethanol to acetic acid (Matthew *et al.*, 2019). This bioconversion process can alter the fruit's native phytochemical landscape, potentially augmenting bioactivity, while the resulting organic acids serve as direct antimicrobial agents (Jia *et al.*, 2012). Therefore, vinegars derived from dates and bananas are postulated to possess a distinctive combination of fruit-derived antioxidants and fermentation-generated antimicrobial compounds.

While existing literature covers vinegar production from various fruits, including dates (Siddeeg *et al.*, 2016), and examines the general bioactivity of fruit vinegars (Guedes *et al.*, 2014), comprehensive research focusing on the detailed phytochemical characterization and targeted antimicrobial efficacy of vinegar produced specifically from *Musa* spp. remains limited. A direct comparative analysis with an established substrate like *P. dactylifera* is notably absent. This gap constrains a clear understanding of their relative merits as functional fermented commodities. Accordingly, this study aims to systematically investigate, characterize, and compare the phytochemical constituents and *in vitro* antimicrobial properties of vinegars produced from *Phoenix dactylifera* dates and *Musa* spp. fruits.

MATERIALS AND METHODS

Isolation and Characterization of *Saccharomyces* species from Spoilt Fruit Samples

Sample collection

Spoilt *Musa paradisicum* (Banana) and *Phoenix dactylifera* (Date) fruits were collected from different points in Nkwo Oba market, Idemili South LGA, Anambra State. The fruits were detected through sight and nasal perception; this was followed by carefully and selectively picking of the detected fruits into polyethylene bags. The polyethylene bags were appropriately labeled and transported immediately to the laboratory for further analysis.

Sample preparation

The fruit samples were thoroughly washed using distilled water and their ectocarps were appropriately peeled using stainless chicken knife. The peeled fruits were pulverized using electric blender (SMX425/Japan). This was serially diluted (1:10) using 250 mL conical flask (Pyrex) in the capacity of 10 g of the fruit sample to make up 200 mL of the sample solution. The solution was thorough shaken, stoppered and kept for further analysis as described by Egbe *et al.* (2025a), Egbe *et al.* (2025b), Iheukwumere *et al.* (2025c), and Iheukwumere *et al.* (2025d).

Isolation of yeast

The Sabouraud Dextrose Agar (SDA) and Yeast Extract Agar (YEA) were prepared according to the manufacturer's direction. The prepared media were autoclaved at standard conditions (121°C 15PSI at 15 min). The media were aseptically poured in Petri dishes and allowed to solidify. An aliquot of 0.1 mL of the prepared sample was aseptically spread on the surfaces of the agar poured plates and incubated at an inverted position at 35±2°C for 24 hours as described in a study published by (Egbe *et al.*, 2025c; Iheukwumere *et al.*, 2022b; Iheukwumere *et al.*, 2025e; Ekesiobi *et al.*, 2025).

Characterization of the yeast

The yeast isolate was characterized morphologically, biochemically, and molecularly using the method described in Cheesbrough (2010), Iheukwumere *et al.* (2020a), Iheukwumere *et al.* (2020b); Ekechukwu *et al.* (2025b). The yeast isolate was physically examined; the colour, the shape, texture, elevation and the consistency were examined and recorded.

Isolation of Acetic Acid Bacterium from Spoilt Fruit Samples

This was carried out using Glucose-Yeast Extract Calcium Carbonate (GYC) agar prepared from glucose (10%), CaCO₃ (2%) and agar (1.5%). The re-constituted medium was autoclaved at standard conditions (121°C, 15 PSI at 115 min). The medium was aseptically distributed into different Petri dishes and allowed to solidify. An aliquot of 0.1 mL of the prepared sample from the spoilt fruits was aseptically spread on the surfaces of the prepared agar medium and these were incubated on inverted position at room temperature (30±2°C) for 48 h. Colonies with large clear zones around them were subcultured (Chude *et al.*, 2020; Ekechukwu *et al.*, 2025c; Ezedianafu *et al.*, 2025a; Idigo *et al.*, 2025a; Iheukwumere *et al.*, 2025f).

Characterization of the Bacterial Isolate

The pure isolates will be characterized using the morphological, biochemical and molecular characteristics as described by Iheukwumere *et al.* (2017a); Iheukwumere *et al.* (2018a); Iheukwumere *et al.* (2020c). The cultural descriptions (size, appearance, edge, elevation, colour) of the isolates will be carried out as described in Iheukwumere *et al.* (2017b); Iheukwumere *et al.* (2018b), Iheukwumere *et al.* (2024). The Gram staining technique which revealed the Gram reaction, cell morphology

and cell arrangement will also be carried out using the procedure described by Cheesbrough (2010), Iheukwumere *et al.* (2018c), Iheukwumere and Iheukwumere (2022a) and Iheukwumere *et al.* (2023a). The presence or absence of capsule will also be carried out as described by Iheukwumere *et al.* (2017c), Iheukwumere *et al.* (2017d), and Iheukwumere *et al.* (2022c). The presence or absence of flagellum will be determined by carrying out motility test as described by Cheesbrough (2010), Iheukwumere *et al.* (2023b), Ezedianafo *et al.* (2025b), Ike *et al.* (2025a). The capability of the isolates to produce catalase, indole, oxidase, acetoin, grow in 6.55 % NaCl and to utilize sugars, sugar alcohols and other substances (ribose, sorbitol, arabinose, sacharose, glucose trehalose, lactose, starch, inulin, salicin, hiparate) and also the haemolytic activity of the isolates were done using the methods described by Cheesbrough (2010), Iheukwumere *et al.* (2018), Iheukwumere and Iheukwumere (2022c), Iheukwumere *et al.* (2022d). The molecular characterization involved DNA extraction, authentication, amplification and sequencing of the amplicons (Iheukwumere *et al.*, 2017e; Okeke *et al.*, 2017; Iheukwumere *et al.*, 2022e; Iheukwumere and Iheukwumere, 2022d).

Vinegar Production

Collection and preparation of fruit samples for production of vinegar

Phoenix dactylifera (commonly known as Date) and *Musa paradisiacum* (commonly known as Banana) fruits were bought from Eke Awka Market, Anambra State. The fruit samples were thoroughly washed using distilled water and their ectocarps were thoroughly peeled. These were separately pulverized using electric blender (SMX 425/Japan). The pulverized fruits were extracted using distilled water. The solutions were then filtered using muslin cloth.

Production of alcohol

Here, 400 mL of the fruit extract was dispensed each into 500 mL conical flask (Pyrex). The extracts were sterilized using an Autoclave at standard conditions (121°C, 15 PSI at 115 min). The sterilized extracts were allowed to cool. The extracts were each inoculated *Saccharomyces cerevisiae* strain and allowed for 28 days with manually daily shaking at 30±2°C. After the fermentation, the alcohol was decanted and poured into sterile 2000 mL bottle and allowed open for 2 days (Iheukwumere *et al.*, 2022f; Iheukwumere and Iheukwumere, 2022e; Ezedianafo *et al.*, 2025c).

Alcohol tolerance test

The ability of the acetic acid bacterium to grow in the presence of alcohol was carried out using the method described in the study published by Tharinee *et al.* (2015). The tested isolate was grown in yeast extract agar (0.50% yeast extract, 2% agar) supplemented with 2%, 4%, 6%, 8%, and 10% (v/v) absolute ethanol. The above procedure was then modified by growing the isolate in Glucose-Yeast Extract Calcium Carbonate (GYC) broth/agar supplemented with 2%, 4%, 6%, 8%, and 10% (v/v) absolute ethanol as described by (Ike *et al.*, 2025b; Obiefuna *et al.*, 2025b; Ugwu *et al.*, 2025a).

Vinegar production

The colonies of *Acetobacter aceti* strain was aseptically transferred into the container containing the alcohol. The bottles were thereafter covered with sac cloth to prevent the entry of insect. The set-up was allowed for 28 days at room temperature (30±2°C.). At the end of the fermentation period, a thick film known as mother of vinegar had covered the surface of the vinegar and was carefully scooped out to avoid contamination. The vinegar was thereafter filtered as described in a study published by Idigo *et al.* (2025b), Iheukwumere *et al.* (2025g), Ike *et al.* (2025c) and Ugwu *et al.* (2025b).

Phytochemical Analysis of the Vinegar Samples

The phytochemical components (alkaloids, glycosides, flavonoids, phenolics, tannins, steroids and saponins) of the samples were determined quantitatively using the methods described in the study published by Iheukwumere *et al.* (2025h), Idigo *et al.* (2025c), Idigo *et al.* (2025d), Ike *et al.* (2025d).

Alkaloids: Five milliliters of the sample was mixed with 96% ethanol and 20% tetraoxosulphate (VI) acid (1:1). One milliliter of the filtrate from the mixture was added to 5 ml of 60% tetraoxosulphate (VI) acid and allowed to stand for 5 minutes. Then 5 ml of 0.5% formaldehyde was added and allowed to stand for 3 h. The reading was taken at absorbance of 550nm (Ezedianafo *et al.*, 2025d; Idigo *et al.*, 2025d; Idigo *et al.*, 2025e).

Glycosides: This was carried out using Buljet's reagent. One millimeter of the sample was added in 9 ml of 70% alcohol for 2 h and then filtered with Whatman No. 1 filter paper. The extract was then purified using lead acetate solution and disodium hydrogen tetraoxosulphate (VI) solution before the addition of freshly prepared Buljet's reagent. The absorbance was taken at of 550nm (Obiefuna *et al.*, 2025b; Ike *et al.*, 2025d; Idigo *et al.*, 2025f).

Flavonoids: Five milliliters of the sample was mixed with 5 ml of dilute hydrochloric acid and boiled for 30 minutes. The boiled mixture was allowed to cool and then filtered with Whatman No. 1 filter paper. One milliliter of the filtrate was added to 5 ml of ethyl acetate and 5 ml of 1% ammonia solution. The absorbance was taken at 420nm (Idigo *et al.*, 2025g; Idigo *et al.*, 2025h).

Phenolics: Ten milliliters of the sample was boiled with 50 ml acetone for 15 minutes. Five milliliters of the solution was pipetted into 50 ml flask. The 10 ml of distilled water was added. This was followed by addition of 2 M ammonium hydroxide solution and 5 ml of concentrated amyl alcohol solution. The mixture was left for 30 minutes and absorbance was taken at 550nm (Idigo *et al.*, 2025i; Idigo *et al.*, 2025j).

Tannins: Ten milliliters was pipetted into 50 ml plastic containing 50 ml of distilled water. This was mixed for 1 h on a sterile mechanical shaker. The solution was filtered with Whatman No. 1 filter paper, and 5 ml of the filtrate was mixed with 2 ml of iron (III) chloride solution in 0.1 N hydrochloric acid. The absorbance was taken at 550nm (Idigo *et al.*, 2025k; Idigo *et al.*, 2025l).

Steroids: The sample was mixed with normal ammonium hydroxide solution. Two milliliters of eluate was mixed with 2 ml of chloroform in a test tube. Three milliliters of ice cold acetic anhydride was added to the mixture and allowed to cool. The absorbance was taken at 420nm (Idigo *et al.*, 2025m; Idigo *et al.*, 2025n; Idigo *et al.*, 2025o).

Saponins: Five milliliters of the sample was dissolved in aqueous methanol. The 0.25 ml of aliquot was taken for spectrophotometric determination for total saponins at 544nm (Idigo *et al.*, 2025p; Idigo *et al.*, 2025q).

Antimicrobial Activity of the Vinegar Samples

Collection and preparation of test organisms: The test organisms used for this study were *Staphylococcus aureus*, *Escherichia coli*, *Salmonella enterica* serovar Typhi and *Candida albican*. The test organisms were collected from ZAHARM Analytical and Research Laboratory, Awka, Anambra State. Catalase test, indole test, citrate/hydrogen sulphide production test and germ tube test were respectively carried out to confirm the identities of the test organisms. The pure isolates were scrapped in normal saline solution, subsequently diluted to match the turbidity of 0.5 MacFarland matching standard that was prepared by mixing 0.5 mL of 1.175 % BaCl₂·2H₂O and 9.95 mL of 1 % of concentrated H₂SO₄ to form 1.50×10^8 cells/mL

Agar-welled diffusion technique: This was carried out using the method described by Iheukwumere *et al.* (2017b), Idigo *et al.* (2025r). Each labeled plate was uniformly inoculated with the test organism using pour plate method. A sterile cork borer of 5 mm diameter was used to make the wells on the medium. One tenth milliliter of test sample was dropped into each labeled wells and then incubated at 37±2°C for 24 h. Antimicrobial activity was determined by measuring the diameter of the zones of inhibition (mm) produced after incubation.

Statistical Analysis

The data generated from this study were analyzed at 95% confidence level using Analysis of Variance (ANOVA), and post-hoc analysis using Turkey's test (Iheukwumere *et al.*, 2025h; Iheukwumere *et al.*, 2025i; Idigo *et al.*, 2025s, Idigo *et al.*, 2025t, Manasseh *et al.*, 2025).

RESULTS

Characterization of the Yeast Isolate and Acetic Acid Bacteria Strains

The yeast isolate (XI) showed characteristic features of yeast such as cream white colonies on Sabouraud Dextrose Agar (SDA) plate, smooth surface, spherical morphology and utilization of glucose and sucrose. The yeast was also resistant to cycloheximides as shown in Table. The acetic acid bacterium (AI) showed cream to yellow colonies on glucose yeast extract calcium carbonate agar (GYA). The isolate was also Gram negative rod, motile, catalase, methyl red and Voges Prokauer positive, but indole, oxidase and citrate negative as shown in Table 2. The quality and nature of the extracted nucleic acid revealed 260/280. Hence, Deoxyribonucleic acid (DNA) as shown in Table 3. The molecular identities of the isolates revealed 100% query cover and 100% identities. This revealed that sample 1D AI was *Acetobacter aceti* strain WI (AAWI) whereas sample ID XI was *Saccharomyces cerevisiae* strain Ysr128 (SC 128) as shown in Table 4

Alcohol Tolerance Potential of the Test Isolate

The study revealed that the test isolate was able to grow in the presence of 10% absolute alcohol. There was significant ($P < 0.05$) number of colonies of acetic acid bacteria in 10% absolute alcohol level in both yeast extract agar (YEA) and glucose-Yeast extract calcium carbonate agar (GYA). The number of colonies slightly decreased as the concentration of alcohol increased as shown in Table 5 but the decrease was statistically non-significant ($P > 0.05$).

Phytochemical Constituents of the Vinegars

The study revealed the presence of alkaloids, saponins, flavonoids, tannins, and glycosides as shown in Table 6. Alkaloids and saponins were non-significantly ($P > 0.05$) detected most in sample VB. Tannin was significantly ($P > 0.0$) detected most in VB. Flavonoids was non-significantly ($P. 0.05$) detected most in VD whereas glycosides was detected most in VD.

Antimicrobial Activities of the Vinegar Samples

The study revealed significant activities of the vinegar samples against *S. aureus*, *E. coli*, *S. enterica* ser. Typhi and *C. albicans* as shown in Table 7. The study showed that sample VD exhibited the highest zones of inhibition compared to samples VB and VS. Still,

the variations in their zones of inhibition were statistically non-significant ($P > 0.05$). The zones of inhibition of the vinegar samples against *S. aureus*, *E. coli*, and *S. ser. Typhi* were significantly ($P < 0.05$) lower than that of ciprofloxacin (standard antibiotic) as shown in Table 11. Ketoconazole (standard antifungal agent) was able to inhibit only *C. albicans*, and the zone of inhibition is significantly ($P < 0.05$) higher than the zones of inhibitions recorded by the vinegar samples against *C. albicans*.

Table 1: Morphological and biochemical characteristics of the yeast isolates

Parameter	X1	X2
Appearance on GYA	Cream white colonies	Cream white colonies
Surface	Smooth	Smooth
Margin	Circular	Circular
Elevation	Convex	Convex
Shape	Spherical	Spherical
Bud	Present	Present
Ascospore	Present	Present
Glucose	+	+
Sucrose	+	+
Maltose	+	+
Gelactose	+	+
Raffinose	+	+
Mannitol	—	—
Lactose	—	—
Xylose	—	—
Cyclohexide	Resistance	Resistance
Suspected yeast	<i>Saccharomyces cerevisiae</i>	<i>Saccharomyces cerevisiae</i>

Table 2: Morphological and biochemical characteristics of the acetic acid bacterium

Parameter	A1	A2
Appearance on GYA	Cream to yellow colour	Cream to yellow colour
Surface	Smooth	Smooth
Elevation	Convex	Convex
Opacity	Opaque	Opaque
Shape	Rod	Rod
Arrangement	Clustered	Clustered
Gram Reaction	—	—
Motility	+	+
Indole	—	—
Citrate	—	—
Catalase	+	+
Methyl red	+	+
Voges Proskauer	+	+
Oxidase	—	—
Glucose	+	+
Sucrose	+	+
Mannitol	+	+
Bacterium	<i>Acetobacter</i> species	<i>Acetobacter</i> species

Table 3: Quality and nature of the extracted nucleic acid

Sample ID	Nucleic acid($\mu\text{g/mL}$)	260 nm	280 nm	260/280
A1	120.20	3.412	1.875	1.82
X1	102.10	3.104	1.687	1.84

Table 4: Molecular identities of the isolates

Parameter	A1	X1
Max Score	2676	6205
Total Score	2676	6604
Query Cover (%)	100	100
E-Value	0.0	0.0
Identity (%)	100	100
Accession Length	1449	224595
Accession Number	11CC662508.1	CP036471.1
Description	<i>Acetobacter aceti</i> strain W2 (AAW1) 16S rRNA gene partial sequence	<i>Saccharomyces cerevisiae</i> strain Ysr128 (SC128) chromosome 1, complement sequence

Table 5: Alcohol tolerance of the test isolate

Alcoholic Content (%)	Yeast Extract Agar		Glucose-Yeast Extract Calcium Carbonate	
	Count (CFU/mL)	Log CFU/mL	Count (CFU/mL)	Log CFU/mL
2.0	5.10X10 ²	2.71	6.40X10 ²	2.81
4.0	4.70X10 ²	2.67	6.10X10 ²	2.79
6.0	4.30X10 ²	2.63	5.70X10 ²	2.76
8.0	4.10X10 ²	2.61	5.40X10 ²	2.73
10.0	3.80X10 ²	2.58	5.10X10 ²	2.71

Table 6: Phytochemical constituents of the vinegars

Parameter	VB (%)	VD (%)	VS (%)
Alkaloids	0.29±0.01	0.17±0.01	0.11±0.00
Saponins	2.11±0.03	1.93±0.04	1.82±0.13
Flavonoids	1.74±0.11	2.19±0.31	2.04±0.07
Tannins	3.05±0.17	1.86±0.11	2.23±0.13
Glycosides	1.04±0.01	2.14±0.14	2.04±0.01
Steroids	0.00±0.00	0.00±0.00	0.00±0.00

Table 7: Antimicrobial activities of the samples

Test organism	Diameter Zones of INHIBITION ($\bar{x}$ ±SD) mm				
	VB	VD	VS	CPX	KET
<i>S. aureus</i>	6.70±0.14	7.40±0.11	6.90±0.21	14.10±0.33	0.00±0.00
<i>E. coli</i>	7.80±0.42	8.50±0.00	8.40±0.21	28.50±0.11	0.00±0.00
<i>S. ser. Typhi</i>	7.10±0.81	7.90±0.14	7.90±0.11	19.50±0.14	0.00±0.00
<i>C. albicans</i>	6.80±0.11	7.30±0.58	7.10±0.22	0.00±0.00	17.10±0.00

CPX= Ciprofloxacin; KET= Ketoconazole

DISCUSSION

This study systematically investigates the phytochemical composition and comparative *in vitro* antimicrobial efficacy of vinegars derived from *Phoenix dactylifera* (date) and *Musa paradisiacum* (banana) fruits. Vinegar, a fermented liquid product primarily from fruit juices, is a rich source of functional compounds, including organic acids, vitamins, minerals, amino acids, and bioactive phytochemicals such as phenolics, flavonoids, and tannins (Hamidalu, 2014). The present work on vinegar production from these fruits aligns with and extends previous research on fruit-based fermentations (Tengberg, 2012; Cantadori *et al.*, 2022; Habiba *et al.*, 2024; Iheukwumere *et al.*, 2025j), including studies using various other plant sources (Armi *et al.*, 2023; Chibi and El Haldi, 2019; Iheukwumere *et al.*, 2025k).

Microbiological characterization of the fermentative isolates was consistent with established findings. The yeast isolate from spoiled date fruit exhibited characteristics matching those described for *Saccharomyces cerevisiae* (Mohammed *et al.*, 2021; Chibi and El Haldi, 2019; Atitallah *et al.*, 2021; Ahmad *et al.*, 2021), with molecular identification corroborating the presence of strains such as *Saccharomyces cerevisiae* Ysr128 (Ahmad *et al.*, 2021; Ugobogu *et al.*, 2025). Similarly, the bacterial isolate from banana displayed cultural, morphological, and biochemical profiles consistent with *Acetobacter* species (Fatima and Mishra, 2015; Prisacaru and Oroian, 2018; Armi *et al.*, 2023), specifically aligning with reports of *Acetobacter aceti* strain w1 from fruit samples (Boonsupa *et al.*, 2019). The acetic acid yield of 5.2% from date fruit vinegar in this study exceeded yields reported for several other fruits and is consistent with research optimizing acid production from fruit substrates like green apple and mango juice (Klawplyapamornkun *et al.*, 2015; Ouattara *et al.*, 2018; Iheukwumere *et al.*, 2025l).

Phytochemical screening confirmed the presence of alkaloids, saponins, flavonoids, tannins, and glycosides in the vinegar samples. This profile supports earlier reports on the phytochemical richness of fruit vinegars (Hamidatun, 2014; Zubaidah, 2015; Iheukwumere *et al.*, 2025m). The combined presence of acetic acid, flavonoids, and other antioxidants is known to mitigate oxidative damage from free radicals (Yulianti *et al.*, 2015). Flavonoids, tannins, and phenolics contribute significantly to antioxidant potential, offering protection against oxidative stress at cellular and organ levels (Yulianti *et al.*, 2019; Han *et al.*, 2016). Furthermore, saponins are recognized for diverse biological activities, including antimicrobial properties (Safrida *et al.*, 2023).

The observed *in vitro* inhibitory activity of the vinegar samples against *Staphylococcus aureus*, *Escherichia coli*, *Salmonella enterica* serovar Typhi, and *Candida albicans* is likely attributable to the synergistic action of their bioactive phytochemical constituents and acetic acid content, a conclusion supported by multiple researchers (Senguen *et al.*, 2020; Singh and Garg, 2022; Iheukwumere *et al.*, 2025n). The marginally superior inhibition exhibited by the *P. dactylifera* vinegar may be due to both the potency of its specific phytochemical profile and its higher acetic acid concentration. The particularly pronounced

activity against *E. coli* may further be influenced by the intrinsic susceptibility conferred by the structural nature of its cell wall.

CONCLUSION

The study has shown that vinegar samples produced from *Malu sylvestris* (MP/Banana) and *Phoenix dactylifera* (PD/Date) fruits possessed significant phytochemical and antimicrobial properties, and the sample produced from PD was slightly better than the sample produced from MP, mostly against *Escherichia coli*

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Authors Contributions: All contributed towards the study design, experiment execution, data analysis, and manuscript drafting.

Availability of Data and Materials: All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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