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Original Research Article

Antimicrobial Efficiency and Chemical Composition of Jackfruit (*Artocarpus heterophyllus* Lam.) Extracts from Different Plant Parts

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ABSTRACT

Jackfruit (*Artocarpus heterophyllus* Lam.), a tropical plant widely cultivated for its edible fruit, has been traditionally used in folk medicine for its potential therapeutic properties. Despite its extensive use, limited studies have comprehensively evaluated the antimicrobial efficacy and chemical composition of its various plant parts. This study investigates the antimicrobial properties and chemical composition of 95% ethanol extracts from the bark, leaves, peel, and seeds of jackfruit, aiming to explore their potential as natural antimicrobial agents. The antimicrobial activity was assessed using the paper disc diffusion method at 250 mg/ml. The bark extract exhibited significant inhibition against *Salmonella Typhi* ATCC16122, *Staphylococcus aureus*, *S. aureus* DMST20645, *Candida albicans*, and *C. albicans* ATCC10231, with inhibition zones ranging from 6.89±0.70 to 9.67±0.58 mm. Leaf extracts were active against *S. Typhi*, *S. aureus*, and *C. albicans* (7.00±0.58 to 7.66±0.30 mm). Peel extracts inhibited *Serratia marcescens* and *C. albicans* (8.33±1.15 to 9.33±0.58 mm), while seed extracts inhibited *S. Typhi*, *S. marcescens*, and *C. albicans* (8.33±1.15 to 10.33±0.58 mm). Minimum inhibitory concentrations (MIC) ranged from 0.97 mg/ml to 125 mg/ml, with minimum bactericidal concentrations (MBC) between 62.5 and >500 mg/ml. Gas Chromatography-Mass Spectrometry (GC-MS) identified bioactive compounds such as linoleic acid, *β*-sitosterol, stigmasterol, tocopherols, and cycloartenol, known for antimicrobial and antioxidant properties. These findings underscore the potential of jackfruit extracts as natural agents in medicinal and industrial applications.

Keywords: *Artocarpus heterophyllus, Gas Chromatography-Mass Spectrometry, Minimum inhibitory concentration, pathogenic bacteria*

Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.), a member of the Moraceae family, is often referred to as the "queen of tropical fruits" due to its distinctive characteristics and prolific fruit production, surpassing many other fruit-bearing trees in yield and size.[1] Known for producing the world's heaviest fruit, ripe jackfruit is highly valued for its soft, juicy texture and sweet aroma. Nutritionally, jackfruit is a rich source of carbohydrates, proteins, vitamins, minerals, and various bioactive phytochemicals, making it a vital dietary component and an integral part of traditional medicine.[2] Both the seeds and pulp are widely consumed in various forms, such as curries and boiled dishes, while fully ripe jackfruit is often eaten raw. Additionally, its pulp is extensively used in the preparation of jams, jellies, and ice creams, demonstrating its versatility as a food ingredient.[3]

In traditional medicine, various parts of the jackfruit tree, including the fruit, leaves, and bark, have been employed for their reported anticancer, antimicrobial, antifungal, anti-inflammatory, wound-healing, and hypoglycemic properties.[4, 5] Phytochemical investigations have revealed the presence of flavonoids, tannins, polysaccharides, saponins, proteins, sterols, glycosides, anthocyanins, and lipids in jackfruit leaves, while its wood extracts yield compounds such as cudraflarone, albanin A, 6- prenylpigenin, kuwanon C, artocarpin, and norartocarpin.[6] The bark contains artocarpanone, whereas the pulp is abundant in flavonoids, carotenoids, and malic acid. These bioactive compounds found in the bark, leaves, peel, and seeds exhibit antimicrobial, antioxidant, and anti-inflammatory properties, highlighting jackfruit's potential as a functional and medicinal plant.[7, 8] Previous studies have demonstrated the antimicrobial potential of jackfruit latex against Gram-positive and Gram-negative bacteria, including *Staphylococcus aureus*, *Salmonella* spp., *Campylobacter*, and *Shigella*.[9] Similarly, research on the peels of other fruits, such as mangosteen and durian, has revealed a correlation between high phenolic content and antimicrobial activity. Acetone extracts generally exhibit the highest antibacterial efficacy, with mangosteen peel extract effectively inhibiting *Bacillus subtilis*, *S. aureus*, *Escherichia coli*, and *Salmonella typhimurium* at a minimum inhibitory concentration (MIC) below 195.7 mg/ml.[10] Jackfruit latex extracts in trifluoroethanol (TFE) solutions have also shown antibacterial activity against *Pseudomonas aeruginosa*, *S. aureus*, and *Bacillus* species, with aqueous extracts exhibiting higher antioxidant capacity.[11]

The growing concern over antibiotic-resistant pathogens underscores the need for alternative antimicrobials derived from plants. Bioactive plant compounds, such as fatty acids, sterols, tocopherols, and flavonoids, present in jackfruit's bark, leaves, peel, and seeds, have demonstrated significant antimicrobial potential in various studies.[12, 13] For example, jackfruit bark and seed extracts have been found to inhibit specific bacterial and fungal strains, making jackfruit a promising source of natural antimicrobial agents.[14, 15]

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This study investigates the antimicrobial efficacy of ethanol extracts (95%) derived from different parts of the jackfruit tree (bark, leaves, peel, and seeds) against pathogenic bacteria. By employing Gas Chromatography-Mass Spectrometry (GC-MS), this research aims to identify and characterize the bioactive compounds present in these extracts. The novelty of this research lies in its comprehensive approach to evaluating the antimicrobial properties and chemical composition of jackfruit tree extracts, which remains underexplored. Additionally, the study adopts GC-MS as a precise and reliable method for identifying bioactive compounds, ensuring the relevance and robustness of the methods used. The findings of this research have the potential to contribute to the development of plant-based antimicrobial agents for applications in medicine, cosmetics, and agriculture, addressing the urgent need for sustainable solutions to combat microbial resistance.

Materials and Methods

Microorganisms

The microorganisms used in this study included three isolates of Gram-positive bacteria (*Bacillus cereus*, *Staphylococcus aureus*, and *Staphylococcus aureus* DMST20645), six isolates of Gram-negative bacteria (*Enterobacter cloacae*, *Escherichia coli*, *Escherichia coli* ATCC25922, *Pseudomonas aeruginosa*, *Salmonella Typhi* ATCC16122, and *Serratia marcescens*), and two isolates of yeast (*Candida albicans* and *Candida albicans* ATCC10231). These microorganisms were provided by the Microbiology Laboratory, Department of Biology, Faculty of Science, Mahasarakham University, and were stored in 20% sterile glycerol at -20 ℃ until further testing.

Plant sample preparation

The fresh bark, leaves, peels, and seeds were collected in April 2023 from a 25-year-old jackfruit tree (Lamut variety, *Artocarpus heterophyllus*), located in Ban Kham Thao Phatthana, Kantharawichai District, Maha Sarakham Province, Thailand (16°15'47.7"N 103°18'40.6"E). The plant materials were authenticated at the BGO Plant Database, The Botanical Garden Organization, Thailand, with the accession number 00-3185 A1. After collection, the samples were washed thoroughly to remove any dirt. The seeds were cleaned, and the white seed coat was removed, following the method described by Eve et al.[16] All samples were then sun-dried and finely ground. The prepared samples were stored in tightly sealed containers at 4 ℃ to prevent moisture absorption and preserve quality until further extraction.

Preparation of extracts from Jackfruit

Dried and finely ground samples of jackfruit bark, leaves, peels, and seeds were soaked in 95% ethanol[17] at a ratio of 100 g of plant material to 600 ml of solvent (1:6) in a 1,000 ml Erlenmeyer flask. The flask was tightly sealed, placed on a shaker at room temperature, and shaken at 150 rpm for 48 h. The mixture was first filtered through a fine cloth to remove plant debris, and then through Whatman No. 1 filter paper. The resulting filtrate was transferred to a bottle and concentrated using a rotary vacuum evaporator **(**Buchi Vacuum Pump set of 215+V-700/V-855**,** Switzerland) at 45 ℃ to remove the ethanol. The percentage yield (% yield) of the extract was calculated using the following equation 1:

% yield = (Weight of extract (g) / Weight of dried plant material (g)) x 100. (Equation 1)

The extracts were stored in sterile amber bottles at -20 ℃ until further testing on pathogenic bacteria.[18]

Preparation of bacterial inoculum

Bacterial colonies used for testing, including Gram-positive bacteria (*B. cereus*, *S. aureus*, and *S. aureus* DMST 20645), Gram-negative bacteria (*E. cloacae*, *E. coli*, *E. coli* ATCC25922, *P. aeruginosa*, *S. Typhi* ATCC16122, and *S. marcescens*), and yeast (*C. albicans* and *C. albicans* ATCC10231), were cultured on nutrient agar (NA, Himedia™, India**)** and Sabouraud dextrose agar (SDA, Himedia™, India) for 18-24 h. The colonies were then suspended in normal saline solution, and the turbidity was adjusted to match of McFarland Standard No. 0.5. This resulted in a cell suspension with a bacterial density equivalent to 1.5×10^8 CFU/ml.

Study on the efficacy of jackfruit extracts in controlling pathogenic bacteria by paper disc diffusion

The test bacteria, prepared to the desired concentration, were inoculated by swabbing the surface of the Muller Hinton agar (MHA, Himedia™, India) for bacteria and SDA for yeast using a sterile cotton swab dipped in the cell suspension. After swabbing, the plates were left for 3-5 min to allow the surface to dry. Sterile paper discs (6 mm diameter) were then placed onto the surface of the MHA and SDA media. The jackfruit extracts, at a concentration of 250 mg/ml,[16] were applied by dropping 20 µl of the extract onto the discs. For the positive control, Streptomycin (3 mg/ml) was used for bacterial testing and Fluconazole (0.2 mg/ml) for yeast testing. A 10% dimethyl sulfoxide (DMSO, 99% AR grade, Loba, India) solution was used as the negative control. The plates were incubated at the appropriate temperatures for each microorganism for 24 h, with three replicates conducted for each experimental condition. After incubation, the diameter of the inhibition zones was measured by assessing the clear zones formed around the discs, and the results were recorded in millimeters. Data were analyzed using IBM SPSS Statistics (Version 29, IBM Corp., Armonk, NY, USA). A one-way analysis of variance (ANOVA) was performed to determine significant differences among the treatments, followed by Least Significant Difference (LSD) tests for pairwise mean comparisons.

Determination of minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), and minimum fungicidal concentration (MFC) by broth microdilution assay

Bacteria preparation: The test bacteria were cultured in 10 ml of MHB for bacterial strains and Sabouraud dextrose broth (SDB, Himedia™, India) for yeast for 24 h at 37 ℃. After adjusting the turbidity to match the 0.5 McFarland standard (1.5×10^8 CFU/ml).

Extract preparation: From the extracts that showed effective antimicrobial activity, the test was conducted to determine the MIC, MBC, and MFC values. The extracts were weighed to achieve an initial concentration of 500 mg/ml, dissolve in 10% DMSO, and filter sterilize using a 0.45-µm filter. A 2-fold serial dilution was performed to prepare concentrations ranging from 500 mg/ml to 0.4 mg/ml.

Microtiter plate setup: For each extract concentration (500 mg/ml to 0.4 mg/ml), 100 µl was added to wells 1-11 of a 96-well microtiter plate. 100 µl of the bacterial suspension was added into each well, including positive controls, Streptomycin (for bacteria) and Fluconazole (for fungi), at 500 mg/ml. Wells 12 contained 100 µl sterile distilled water and 100 µl of the bacterial or yeast suspension as the negative control.

The plate was incubated at 37 ℃ for 24 h with three replicates conducted for each experimental condition. The MIC was recorded by using a Multimode Microplate Reader (Varioskan LUX, Thermo Scientific, USA). For MBC/MFC determination, the contents of the well with the MIC and the two adjacent wells with higher and lower concentrations were streaked onto MHA for bacteria and SDA for yeast. The plates were incubated at 37 ℃ for 24 h. If no growth occurs on the agar, the concentration is lethal and is recorded as the MBC/MFC.[19, 20]

Determination of chemical composition of jackfruit extract by Gas Chromatography-Mass Spectrometry (GC-MS)

The chemical composition of jackfruit bark, leaf, fruit peel, and seed extracts were analyzed using GC-MS (GC: Agilent 7890A, MS: Agilent 7000B). A 30-m HP-5 GC column with a 0.25 µm diameter was used, with helium (He) as the carrier gas at a flow rate of 1 ml/min. A sample volume of 2 µl was injected in split mode at a 5:1 ratio. The temperature program was as follows: the column temperature was initially set to 40 ℃ for 5 min, then increased to 200 ℃ at a rate of 8 ℃/min and held for 25 min. Following this, the temperature was further increased to 280 ℃ at a rate of 5 ℃/min and maintained for 61 min. The resulting chromatogram was analyzed by comparing the retention times and mass

spectra of the chemical constituents in the extracts to standard reference values in the NIST MS Search 2.0 library.

Results and Discussion

Preparation of Extracts from Jackfruit

The extraction of jackfruit components (bark, leaves, peels, and seeds) using 95% ethanol yielded extracts with distinct physical properties, aroma profiles, and varying yields, reflecting the phytochemical composition of each part. The bark extract (14.51%) exhibited a brown, opaque appearance and herbal aroma, consistent with the presence of tannins, flavonoids, and lignans, while the leaf extract (32.36%) displayed a green, opaque appearance with a banana-like aroma, reflecting its higher flavonoid and phenolic content. The peel extract (22.44%) had a transparent brown appearance and a ripe jackfruit fragrance, indicating the presence of carotenoids and terpenoids. The seed extract (4.84%), with a sweet, chocolate-like aroma, contained sugars, proteins, and flavonoids. These findings are consistent with previous studies, highlighting the antimicrobial and antioxidant potential of jackfruit components.[21, 22] The higher yield from the leaves and peels suggests higher solubility of their bioactive compounds, while the lower yield from the seeds suggests they may contain more complex or less soluble phytochemicals.[23, 24]

Antimicrobial activity of jackfruit extracts

The antimicrobial activity of jackfruit extracts (bark, leaves, peels, and seeds) at a concentration of 250 mg/ml was measured by the inhibition zones against various microbial species, including bacteria and yeast. The results show that the bark extract demonstrated activity against *S. Typhi* ATCC16122 (8.44 ± 0.51 mm), *S. aureus* (7.66 ± 0.35 mm), *S. aureus* DMST20645 (6.89 ± 0.70 mm), and both strains of *C. albicans*. The highest inhibition was observed against *C. albicans* ATCC10231 (9.67 ± 0.58 mm), suggesting some antifungal potential.

The leaf extract showed moderate inhibition against *S. Typhi* ATCC16122 (7.33 ± 0.34 mm) and *S. aureus* (7.66 ± 0.35 mm), and displayed some antifungal activity against *C. albicans* (7.00 ± 6.08 mm), but no activity against *C. albicans* ATCC10231. The peel extract exhibited antimicrobial activity mainly against *S. marcescens* (9.00 ± 1.00 mm), *C. albicans* (9.33 ± 0.58 mm), and *C. albicans* ATCC10231 (8.33 ± 1.15 mm), indicating a slightly stronger antifungal effect than antibacterial. The seed extract showed considerable inhibition against *S. Typhi* ATCC16122 (8.56 ± 0.51 mm), *S. marcescens* (8.33 ± 1.15 mm), *C. albicans* (10.33 ± 0.58 mm), and *C. albicans* ATCC10231 (10.00 ± 0.00 mm). The strongest antifungal activity was observed with the seed extract, especially against *C. albicans*. Streptomycin (3 mg/ml) showed strong antimicrobial activity across bacterial strains, with inhibition zones ranging from 23.67 mm to 35.00 mm. Fluconazole (0.2 mg/ml) showed no inhibition for *C. albicans* but had activity (8.33 ± 0.58 mm) against *C. albicans* ATCC10231. The jackfruit extracts, particularly from bark and seeds, exhibited antimicrobial properties, whereas the seed extract showed the most potent antifungal effects, especially against *C. albicans*. While none of the extracts were as effective as the positive control (streptomycin/fluconazole), they do show some promise as natural antimicrobials, particularly against specific bacterial and yeast strains (Table 1).

When Samrot and Sean[9] investigated the antimicrobial activity of *A. heterophyllus* Lam. (jackfruit) latex, they found that the TFE extract of jackfruit latex exhibited antimicrobial activity against *P. aeruginosa*, *S. aureus*, and *Bacillus* species.

The antimicrobial activity of jackfruit extracts (bark, leaves, peels, and seeds) demonstrated promising potential against various microbial strains, with differences in efficacy attributed to their phytochemical compositions. The bark extract's activity against *S. Typhi*, *S. aureus*, and *C. albicans* aligns with previous findings that tannins, flavonoids, and lignans present in bark exhibit antimicrobial properties, with its highest inhibition against *C. albicans* supporting its antifungal potential.[22.] The leaf extract exhibited moderate antimicrobial effects, likely due to flavonoids and other phenolics known for their broad-spectrum antimicrobial activities. [25] However, its limited efficacy against *C. albicans* suggests variability in antifungal compounds compared to the bark and seed extracts. The peel extract displayed stronger antifungal than antibacterial activity, consistent with studies highlighting the richness of terpenoids, carotenoids, and phenolic acids in fruit peels, which are effective against bacteria and fungi.[24] The seed extract showed the most potent antifungal activity, particularly against *C. albicans*, attributed to tocopherols, flavonoids, and low-molecular-weight phenolics that disrupt fungal cell membranes and inhibit cell wall synthesis.[26] While jackfruit extracts were less potent than standard antibiotics such as Streptomycin and Fluconazole, their bioactive compounds provide valuable potential as natural antimicrobials, particularly in complementary treatments. Chavez-Santiago et al.[27] observed that phenolic extracts from jackfruit significantly inhibited the growth of phytopathogenic fungi such as *Penicillium digitatum* and *Botrytis cinerea*, supporting their application in natural product-based preservatives. This study reinforces the potential of jackfruit extracts, especially from seeds and bark, as supplementary antimicrobial agents with prospective uses in pharmaceuticals and food preservation.

Table 1: Antimicrobial activity of extracts from jackfruit extracted with 95% ethanol

Pathogens	Inhibition zone (mm)						
	Bark extracts	Leaves extracts	Peels extracts	Seeds extracts	Streptomycin	Fluconazole	10% DMSO
E. coli	0.00 ± 0.00^{bE}	0.00 ± 0.00^{bD}	0.00 ± 0.00^{bC}	0.00 ± 0.00^{bC}	30.00 ± 0.00^{aD}	nd	0.00 ± 0.00^{b}
E. coli ATCC25922	0.00 ± 0.00^{bE}	0.00 ± 0.00^{bD}	0.00 ± 0.00^{bC}	0.00 ± 0.00^{bC}	30.00 ± 0.00^{aD}	nd	0.00 ± 0.00^{b}
E. cloacae	0.00 ± 0.00^{bE}	0.00 ± 0.00^{bD}	0.00 ± 0.00^{bC}	0.00 ± 0.00^{bC}	31.33 ± 3.06^{aC}	nd	0.00 ± 0.00^{b}
P. aeruginosa	0.00 ± 0.00^{bE}	0.00 ± 0.00^{bD}	0.00 ± 0.00^{bC}	0.00 ± 0.00^{bC}	33.00 ± 0.00^{aB}	nd	0.00 ± 0.00^{b}
S. Typhi ATCC16122	8.44 ± 0.51^{bB}	7.33 ± 0.34^{cC}	0.00 ± 0.00^{dC}	8.56 ± 0.51^{bB}	23.67 ± 1.15^{aF}	nd	0.00 ± 0.00^{d}
S. aureus	7.66 ± 0.35^{bC}	7.66 ± 0.35^{bB}	0.00 ± 0.00^{cC}	0.00 ± 0.00^{cC}	29.33 ± 0.58^{aD}	nd	0.00 ± 0.00^{c}
S. marcescens	0.00 ± 0.00^{cE}	0.00 ± 0.00^{cD}	9.00 ± 1.00^{bA}	8.33 ± 1.15^{bB}	29.00 ± 1.00^{aD}	nd	0.00 ± 0.00^{c}
S. aureus DMST 20645	6.89 ± 0.70^{bD}	0.00 ± 0.00^{cD}	0.00 ± 0.00^{cC}	0.00 ± 0.00^{cC}	26.33 ± 0.58^{aE}	nd	0.00 ± 0.00^{c}
B. cereus	0.00 ± 0.00^{bE}	0.00 ± 0.00^{bD}	0.00 ± 0.00^{bC}	0.00 ± 0.00^{bC}	35.00 ± 1.00^{aA}	nd	0.00 ± 0.00^{b}
C. albicans	8.50 ± 0.50^{aB}	7.00 ± 6.08^{aA}	9.33 ± 0.58^{aA}	10.33 ± 0.58^{aA}	nd	0.00 ± 0.00^{bH}	0.00 ± 0.00^{b}
C. albicans ATCC 10231	9.67 ± 0.58^{aA}	0.00 ± 0.00^{cD}	8.33 ± 1.15^{bB}	10.00 ± 0.00^{aA}	nd	8.33 ± 0.58^{bG}	0.00 ± 0.00^{c}

Values are expressed as mean ± SD of triplicate measurement, (n=3), Lowercase letters (a, b, c) indicate means followed by the same letter within rows are not significantly different by the least significant difference (LSD) method ($P < 0.05$), Uppercase letters (A, B, C) indicate means followed by the same letter within columns are not significantly different ($P < 0.05$), nd**,** not determined

Minimum Inhibitory Concentration (MIC), Minimum bactericidal concentration (MBC) and minimum fungicidal concentration (MFC)

The determination of minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), and minimum fungicidal concentration (MFC) of jackfruit extracts from bark, leaves, peels, and seeds underscores their antimicrobial potential, particularly against pathogenic bacteria and yeast. The bark extract demonstrated the lowest MIC (3.90 mg/ml) against *S. Typhi* ATCC16122 and *S. aureus*, indicating the presence of potent bioactive compounds, likely tannins and polyphenols, which inhibit bacterial growth at lower concentrations. Similarly, the MIC for *S. Typhi* ATCC16122 was lower for bark extracts compared to leaf and seed extracts (125.00 mg/ml), reinforcing the superior antimicrobial potency of bark due to its higher concentrations of phenolics and polyphenols, which disrupt bacterial cell walls. For *S. marcescens*, bark extract again showed the lowest MIC (3.90 mg/ml), while peel and seed extracts required higher concentrations (125.00 mg/ml), reflecting variations in phytochemical content and potency across jackfruit parts.[25] Regarding antifungal activity, the bark and seed extracts exhibited activity against *C. albicans* with MICs of 250.00 mg/ml and 125.00 mg/ml, respectively (Tables 2 and 3).

Table 2: Minimum inhibitory concentration (MIC) of ethanol extracts of different parts of jackfruit

Pathogens	Bark extracts (mg/ml)	Leaves extracts (mg/ml)	Peels extracts (mg/ml)	Seeds extracts (mg/ml)
S. Typhi ATCC16122	3.90	125.00	nd	125.00
S. aureus	3.90	125.00	nd	nd
S. marcescens	nd	nd	3.90	125.00
S. aureus DMST20645	125.00	nd	nd	nd
C. albicans	250.00	125.00	250.00	250.00
C. albicans ATCC10231	62.50	nd	0.97	15.62

Values are expressed as MIC of triplicate measurement (n=3), nd**,** not determined

Notably, the peel extract showed exceptional efficacy against *C. albicans* ATCC10231 with an MIC of 0.97 mg/ml, potentially due to terpenoids and low-molecular-weight phenolics in the peel, which disrupt fungal cell membranes.[22] The MBC values correlated with the MIC findings, with the bark extract showing bactericidal activity at an MBC of 500.00 mg/ml against *S. Typhi* ATCC16122. For *S. aureus* DMST20645 and *S. marcescens*, the MBC was significantly lower at 125.00 mg/ml for bark extract, demonstrating its bactericidal effectiveness. These findings align with previous studies on natural plant extracts, where higher concentrations are often required for complete microbial eradication due to the complex mixtures of bioactive compounds present.[25] The seed extract exhibited the most potent fungicidal activity, with the lowest MFC (62.50 mg/ml) against *C. albicans* ATCC10231, likely attributed to tocopherols, flavonoids, and saponins, which interfere with fungal enzyme systems and cell wall integrity. This supports earlier findings on the antifungal potential of fruit seeds, where active components like tocopherols and flavonoids exhibit membrane-disruptive effects. The peel extract also displayed notable antifungal properties, consistent with its rich composition of terpenoids and phenolic acids.[26]

Table 3: Minimum bactericidal concentration (MBC) and minimal fungicidal concentration (MFC) of ethanolic extracts of jackfruit bark, leaves, peels and seeds

Pathogens	Bark extracts (mg/ml)	Leaves extracts (mg/ml)	Peels extracts (mg/ml)	Seeds extracts (mg/ml)
S. Typhi ATCC16122	500.00	500.00	nd	500.00
S. aureus	>500.0	>500.00	nd	nd
S. marcescens	nd	nd	500.00	500.00
S. aureus DMST20645	125.00	nd	nd	nd
C. albicans	62.50	250.00	125.00	125.00
C. albicans ATCC10231	125.00	nd	62.50	62.50

Values are expressed as MBC or MFC of triplicate measurement (n=3), nd**,** not determined

Overall, jackfruit bark and seed extracts demonstrated significant antibacterial and antifungal activity, particularly against *S. Typhi*, *S. aureus*, and *C. albicans*, with the peel extract being particularly effective against *C. albicans* ATCC10231. Although higher concentrations of these natural extracts are required compared to standard antibiotics, the diverse MIC, MBC, and MFC values highlight their potential as supplementary antimicrobial agents. These findings reinforce the potential of jackfruit extracts, especially from bark, seeds, and peels, as sources of natural antimicrobial compounds with applications in medicinal and preservative formulations.

Chemical composition of jackfruit extracts by Gas Chromatography-Mass Spectrometry (GC-MS)

The analysis of ethanol extracts from jackfruit (seeds, leaves, bark, and peels) via GC-MS highlights a range of bioactive compounds known for their health benefits and potential applications in antimicrobial, anti-inflammatory, antioxidant, and anticancer treatments. The presence of fatty acids, sterols, tocopherols, and other bioactive compounds aligns with previous research indicating the medicinal potential of jackfruit components (Table 4, Figure 1).

Fatty Acids: The identification of linoleic acid in seeds (9.14%) and leaves (8.22%) highlights its potential for cardiovascular support, immune modulation, and antimicrobial activity, particularly against Gram-positive bacteria and fungi. This is consistent with earlier reports indicating linoleic acid's ability to disrupt bacterial membranes and inhibit fungal growth.[28] Oleic acid, a methyl ester detected in bark (3.32%), also contributes antimicrobial properties, especially against bacterial pathogens.

Sterols and Triterpenoids**:** The high concentrations of β-sitosterol, stigmasterol, and lanosterol across jackfruit parts, particularly in the bark (stigmasterol 13.39%; lanosterol 13.31%), underscore their immune-modulating, cholesterol-lowering, and antimicrobial effects. Previous studies corroborate these findings, with β-sitosterol and stigmasterol demonstrating inhibition of Gram-positive bacteria, while lanosterol has fungicidal activity. Cycloartenol, found abundantly in bark (25.33%) and peel (24.53%), further supports anti-inflammatory and anticancer potential, consistent with its reported efficacy in inhibiting fungal infections and cancer cell proliferation.[29, 30]

Tocopherols (Vitamin E): Tocopherols were particularly abundant in leaves (δ-tocopherol 6.25%; β-tocopherol 3.76%), providing antioxidant activity. This aligns with findings that tocopherols protect against oxidative stress and exhibit antibacterial properties, particularly against gram-positive bacteria. These compounds' ability to neutralize free radicals enhances their suitability for applications in skin care and health supplements.[1]

Table 4: Chemical composition of jackfruit extracts by gas chromatography-mass spectrometry (GC-MS)

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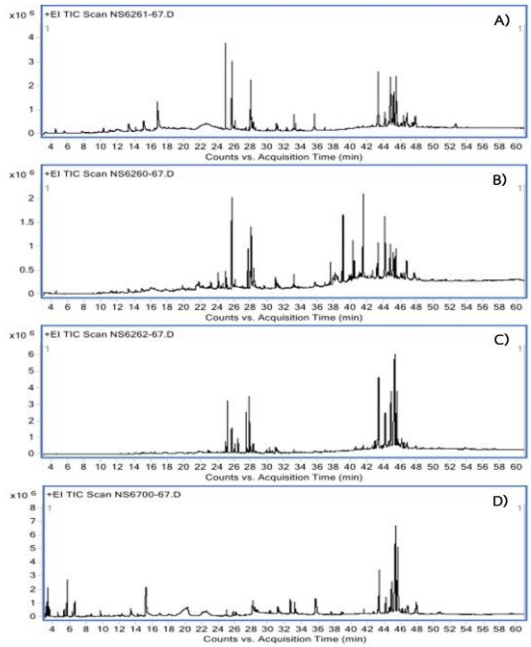
No.	RT	Name	% Relative peak areas			
			Seeds	Leaves	Bark	Peel
1	3.107	1-Propanol	-	-	-	0.28
2	3.323	Acetic acid	-	-	-	2.66
3	3.529	2-Propanone, 1-hydroxy-	-	-	-	0.48
4	4.539	2,2'-Bioxirane	-	-	-	0.52
5	4.508	Formamide, N-methoxy-	0.49	0.30	0.09	3.65
6	5.301	Propanoic acid, 2-oxo-, methyl ester	-	-	-	0.78
7	5.553	Urethane	0.36	-	-	-
8	5.678	2,2-Dimethoxy-ethanol	-	-	-	3.71
9	6.253	Furfural	-	-	-	0.59
10	6.949	2-Furanmethanol	-	-	-	0.15
11	7.684	Butanoic acid, 4-hydroxy-	0.22	-	-	-
12	8.560	1,2-Cyclopentanedione	-	-	-	0.26
13	9.721	2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3-one	-	-	-	0.48
14	10.269	Benzyl chloride	0.46	-	-	-
15	10.756	Diethoxymethyl acetate	-	-	-	0.15
16	12.275	4,5-Diamino-2-hydroxypyrimidine	-	-	-	0.62
17	13.257	Pyranone	2.76	0.98	0.24	2.03
18	14.157	Methyl salicylate	0.29	0.15	0.10	0.25
19	15.076	5-Hydroxymethylfurfural	3.10	-	-	9.40
20	16.715	Cyclohexanol, 2-(dimethylamino)-, cis-	3.20	-	-	-
21	23.088	Tetradecanoic acid	-	0.50	-	-
22	24.063	Phytol, acetate	-	0.89	-	-
23	24.927	Lidocaine	6.56	1.71	1.26	0.51
24	25.154	Hexadecanoic acid, methyl ester	-	-	3.57	-
25	25.660	n-Hexadecanoic acid	10.31	10.93	2.76	0.51
26	26.008	Hexadecanoic acid, ethyl ester	0.58	0.46	0.56	0.19
27	26.429	Heptadecanoic acid, methyl ester	-	-	1.13	-
28	27.411	Oleic acid, methyl ester	0.24	-	3.32	-
29	27.543	10-Octadecenoic acid, methyl ester	-	-	0.67	-
30	27.583	Phytol	-	2.93	-	-
31	27.766	Octadecanoic acid, methyl ester	0.26	-	4.53	-
32	27.829	Linoleic acid	9.14	1.99	0.68	3.23
33	28.001	Linolenic acid	-	8.22	-	-
34	28.240	Linoleic acid ethyl ester	0.60	-	0.96	0.29
35	28.287	Octadecanoic acid	0.27	1.47	-	-
36	28.326	Linolenic acid, ethyl ester	-	0.95	-	0.38
37	28.326	Ethyl 9,12,15-octadecatrienoate	-	-	0.29	-
38	28.602	Hexadecanamide	-	-	-	0.16
39	30.128	Glycerol α-palmitate	-	-	-	0.20
40	30.233	Octadecanoic acid, 10-oxo-, methyl ester	-	-	0.53	-
41	30.912	4,8,12,16-Tetramethylheptadecan-4-olide	-	0.95	-	-
42	30.943	12-Methyl-E,E-2,13-octadecadien-1-ol	-	-	0.74	-
43	31.029	9-Octadecenamide, (Z)-	1.99	2.10	1.30	1.63
44	32.207	Benzylephedrine	0.39	-	-	
45	32.582	*α*-Glyceryl linoleate	-	-	-	1.37
46	33.101	Glycerol β-palmitate	1.73	1.27	0.32	1.29
47	33.339	Lidocaine benzyl benzoate	0.69	-	-	-
48	33.832	cis-13-Eicosenoic acid	0.15	-	-	-
49	35.585	*β*-Monolinolein	1.88	-	-	3.07

50	36.820	13-Docosenamide, (Z)-	0.35	0.40	0.23	-
51	37.494	Squalene	-	2.14	-	0.25
52	39.028	*δ*-Tocopherol	-	6.25	-	-
53	40.196	*β*-Tocopherol	-	3.76	-	-
54	40.377	*γ*-Tocopherol	-	1.60	-	-
55	41.408	dl-*α*-Tocopherol	0.17	9.69	0.44	0.54
56	42.579	Campesterol	0.29	1.03	0.48	0.42
57	42.861	Olean-13(18)-ene	-	-	1.13	-
58	43.080	Stigmasterol	-	1.47	-	0.71
59	43.224	Lanosterol	9.23	4.99	13.31	7.48
60	44.050	*β*-Sitosterol	2.84	9.50	8.64	3.38
61	44.467	Betulin	-	-	0.92	-
62	44.514	*β*-Amyrin	0.44	-	-	0.85
63	44.688	Stigmasterol	11.22	5.57	13.39	7.64
64	44.866	Lupeol	1.03	-	-	-
65	45.057	Cycloartenol acetate	8.02	4.73	25.33	24.53
66	45.353	Cycloartenol	9.92	4.84	10.09	14.02
67	46.003	24-Methylenecycloartan-3-one	2.14	1.14	2.17	-
68	46.604	Olean-12-en-3-yl acetate	1.86	-	-	-
69	46.660	Vitamin E	-	5.50	-	-
70	46.715	Lanosterol acetate	2.60	-	-	1.33
71	47.558	Friedelanol	-	1.62	-	-
72	47.711	Cycloeucalenol acetate	2.98	-	0.79	-
73	52.563	Olean-12-en-3-one	1.22	-	-	-
		Total	100	100	100	100

Figure 1: GC-MS chromatogram of jackfruit extracts prepared with 95% ethanol A(Seed extract B) Leaves extract C) Bark extract D) Peel extract



Other Bioactive Compounds: Lidocaine, predominantly found in seeds (6.56%), is notable for its dual role as a local anesthetic and antimicrobial agent. The presence of furfural (0.59%) and 5-hydroxymethylfurfural (9.40%) in peels aligns with reports highlighting their antibacterial activity, particularly against Gram-positive bacteria and fungi. Phytol, detected in leaves (2.93%) and peels (0.25%), has shown antimicrobial properties by disrupting bacterial membranes, further supporting its use in antimicrobial formulations.[31]

Statistically Significant Findings: The bark and peel extracts exhibited the highest concentrations of cycloartenol (25.33% and 24.53%, respectively), aligning with their superior antifungal activity against *C. albicans* (MIC 250.00 mg/ml and 0.97 mg/ml, respectively). This supports the hypothesis that cycloartenol disrupts fungal cell structures, as observed in previous studies.[32] The presence of stigmasterol in bark (13.39%) and peels (7.64%) is noteworthy, as its known effects on Gram-positive bacteria are consistent with the significant inhibition zones recorded against S. aureus. The seeds' high linoleic acid content (9.14%) contributes to their observed antibacterial and antifungal activities, particularly against Gram-positive bacteria and *C. albicans*. Similarly, the tocopherol-rich leaves demonstrated antioxidant potential, supporting findings that tocopherols enhance oxidative protection in biological systems.[33]

Comparative analysis: Jackfruit bark, seeds, and peels demonstrated superior antimicrobial and antioxidant properties compared to leaves, likely due to higher concentrations of sterols, tocopherols, and cycloartenol. The peel extract's efficacy against *C. albicans* ATCC10231 (MIC 0.97 mg/ml) is particularly significant, outperforming bark and seed extracts. This highlights the potential of peel extracts in antifungal applications, consistent with studies demonstrating the antimicrobial efficacy of terpenoids and phenolics in fruit peels.

The distinct bioactive profiles of jackfruit parts highlight their potential as valuable sources of natural antimicrobial, anti-inflammatory, antioxidant, and anticancer agents. The bark and peel extracts, rich in cycloartenol, stigmasterol, and lanosterol, demonstrated significant antimicrobial and antifungal activities, particularly against *C. albicans* and Gram-positive bacteria. Seeds, abundant in linoleic acid and lidocaine, exhibited promising antibacterial and antioxidant properties, making them suitable for medicinal and skincare applications. Leaves, with high tocopherol content, showcased strong antioxidant potential. These findings underscore the therapeutic and

industrial value of jackfruit components, supporting their potential use in medicinal, preservative, and cosmetic formulations.

Conclusion

In conclusion, the study demonstrates that extracts from the bark, leaves, peels, and seeds of jackfruit (*A. heterophyllus* Lam.) possess notable antimicrobial and bioactive properties, supported by their chemical composition as revealed through GC-MS analysis. The extracts showed varied antimicrobial activity, with bark and seed extracts exhibiting the most potent effects against pathogenic bacteria and fungi, especially *C. albicans*, suggesting their potential as natural antimicrobial agents. The MIC and MBC results indicated that the bark extract was the most effective against *S. Typhi*, *S. aureus*, and *S. marcescens*, with low MIC values. Seed extracts demonstrated the strongest antifungal activity, especially against *C. albicans*. The chemical composition analysis identified key bioactive compounds, including fatty acids like linoleic acid and oleic acid, sterols such as *β*-sitosterol and stigmasterol, and tocopherols, which are known for their anti-inflammatory, antioxidant, and antimicrobial effects. These bioactive compounds are distributed differently across the parts of jackfruit, with the seeds showing high concentrations of linoleic acid and lidocaine, the leaves being rich in tocopherols, the bark containing high levels of lanosterol and stigmasterol, and peels exhibiting a balance of tocopherols and cycloartenol. The results highlight jackfruit as a promising source of natural bioactive compounds with antimicrobial, anti-inflammatory, antioxidant, and anticancer properties, positioning it as a valuable resource for medicinal, cosmetic, and industrial applications. Further studies on the extraction techniques and clinical applications of these extracts could enhance their use in developing alternative natural remedies.

Conflict of interest

The author reports no conflicts of interest in this work.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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