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Quantitative estimation and phytochemical profiling of different extracts of Jackfruit (*Artocarpus heterophyllus* Lam.) peel waste by GC-MS technique

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Abstract

The plant species *Artocarpus heterophyllus* Lam., commonly called Jackfruit, belongs to the Moraceae family. It is typically abundant in tropical and subtropical regions of Asia. Extensive research has revealed the presence of numerous beneficial compounds within jackfruit, which have demonstrated its potential in the treatment of various diseases. One environmental issue associated with the disposal of unused components of fruits, such as peels, perianths, rinds and outer cores, is the increasing accumulation of biowaste. Using bioactive constituents found in fruit peels, typically regarded as waste material, offers numerous advantages for human consumption and exhibits potential as effective antimicrobial agents in agriculture. The present study is an attempt to gain complete knowledge of the phytochemical constituents such as flavonoids, polyphenolics, tannins, saponins, carbohydrates, reducing sugars and antioxidants found in the peels of jackfruit.

Keywords

aqueous extract; *Artocarpus heterophyllus* Lam. (jackfruit); dimethyl phthalate; ethanol extract; GC-MS; phytochemicals

Introduction

The plant species known as *Artocarpus heterophyllus*, commonly called jackfruit, belongs to the *Moraceae* family. Jackfruit is widely recognized as the most significant fruit cultivated in tropical and subtropical areas worldwide (1). Its origin can be traced back to the rainforests of the Western Ghats in India, where it is believed to have originated as an evergreen tree (2). The nutritional composition and volatile biochemical profile of jackfruit have been of significant concern because of their potential therapeutic benefits in various health conditions. Studies conducted by some researchers have highlighted the medicinal properties of jackfruit, especially for the cure of cardiovascular disease, cancer and ageing-related diseases (1, 3). Because of these properties, jackfruit has been considered to be a valuable fruit with global significance in the field of medicine. One of the primary attributes of jackfruit is the presence of high nutritional content. The nutritional composition of jackfruit is further enhanced by the presence of bioactive compounds that exhibit beneficial properties for preventing various persistent diseases like cancer, cardiac diseases and age-related ailments (4).

Besides its high nutritional value, a more significant portion of it, in the form of peel, is not used and is discarded as waste, accumulating as bio-

waste. The environmental issue of disposing of unused portions of fruits is essential due to the increased accumulation of bio-waste. According to research, waste is regarded as a potential environment conducive to the proliferation of pathogens that can be transmitted through food and water (5). It was reported that the global volume of waste is projected to reach 1.3 billion tons per year, with a potential increase to 2.2 billion tons by 2025 (6). The primary origins of bio-waste can be attributed to industrial facilities, such as fruit juice processing plants within the food industry, which generate substantial quantities of unused fruit components (7). Hence, it is imperative to recycle underutilized components of fruits to mitigate the potential bioaccumulation of these substances. Analyzing the phytoconstituents, essential elements and antioxidant and antimicrobial properties of underutilized fruit components renders them significant to the food, agriculture and pharmaceutical sectors (8, 9). Studies have substantiated the presence of substantial quantities of bioactive compounds in discarded fruit components, such as peels. These compounds exhibit potential advantages for human well-being as fungicides and bactericides and aid in ailment management within the agricultural sector (8). Another study reported that jackfruit leaves possess properties that can potentially alleviate symptoms associated with fever, boils, wounds and various skin conditions (10). Additionally, the study suggests that the new fruits of the jackfruit plant have acrid and astringent characteristics, which may contribute to their ability to alleviate flatulence.

The protein content of jackfruit seeds ranges from 5 -6 % (11). It is stated that this large, evergreen tree yields an annual production of approximately 100 to 200 jackfruit fruits (12). There is limited research on the jackfruit's underutilized components. Due to its high perishability, jackfruits are usually exported as whole fruits, and more than half of the fruit consists of inedible waste materials. Perianth meal, rind and core meal constitute a non-edible portion of the fruit, representing 59.2 % of whole fruit with a total dry meal recovery of 11.6 % (63). In addition to being a rich source of nutrients, jackfruit pulp and seeds are known to contain many bioactive compounds (13). Fig. 1. Jackfruit parts showing the rags, core, peel and seed (a, b, c, d) (49).

Extensive research has revealed that jackfruit possesses diverse beneficial compounds that exhibit therapeutic properties for treating various diseases. However, the environmental issue associated with the disposal of unused components, such as peels, perianths, rinds and outer cores, is the escalation of bio-waste accumulation.

Metabolomics has emerged as a significant omics technology following the advancements in genomics and proteomics (14). The utilization of qualitative and quantitative analysis in investigating metabolomes has witnessed an increasing prevalence. Metabolomics studies have been shown to yield significant insights into various areas of research, including systems biology, biochemistry and cellular function. Gas chromatography-mass spectrometry (GC-MS) is a widely used analytical technique in metabolomics (15). In the present investigation, the utilization of GC-MS analysis proved advantageous in identifying compounds that hold significance in industrial applications and raise concerns in the environmental context.

Therefore, the present investigation aimed to identify and characterize various phytochemicals and bioactive components using jackfruit peel solvents. The spectrophotometric methods were employed to determine the total phenolic, flavonoids, saponins, alkaloids, tannins content, total antioxidants, etc.

Materials and Methods

Fruit peel collection and processing

Jackfruit peels (fresh, healthy, contamination-free) were collected from the nearby area/markets of Jaitpur (New Delhi, India) and the kitchen garden. The material was washed initially with tap water, followed by rectified alcohol to remove contamination and then shade-dried (64).

Preparation of fruit peel extract

The dried fruit peels were ground into a coarse powder and phytochemicals were extracted by soxhlet process using petroleum ether, ethanol and distilled water as solvent (500 g powder in 2 L solvent sequentially). Afterwards, the solvent was evaporated using a water bath to remove the solvent from the crude extract. The dried crude extract was stored under refrigeration till further analysis. Later, these dried crude extracts were subjected to GC-MS and phytochemical analysis (64).

Quantitative Estimation of Phytochemicals

The selected sample extracts were processed for the quantitative estimation of the following phytochemicals.

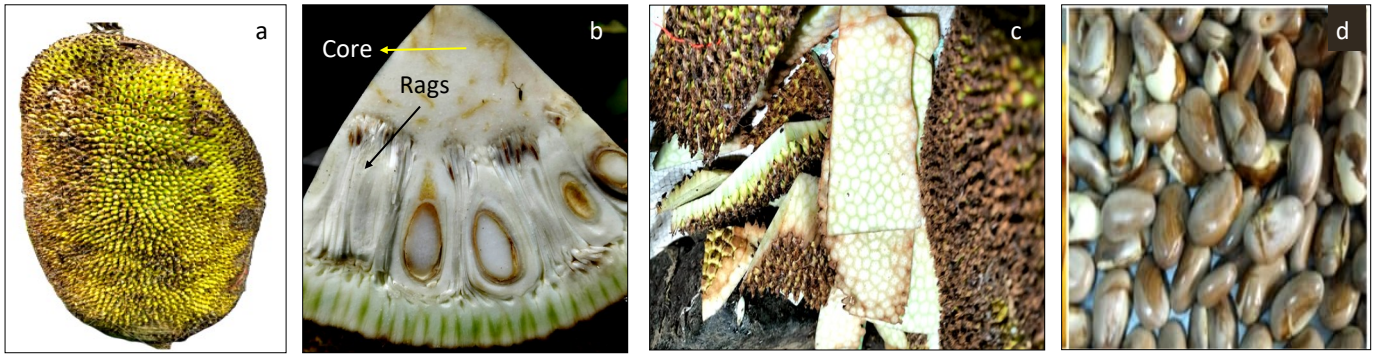


Fig. 1. Jackfruit parts showing the Rags, core, peel and seed (**a**) Jackfruit; (**b**) Rags and core; (**c**) Peel; (**d**) Seed (49).

Estimation of TPC (Total Phenolic Content)

The Folin-Ciocalteu method was used to estimate TPC. Taking 50 mg of Gallic acid in 50 mL of distilled water and 1000 µg/mL was prepared and used as stock solution. 1 N Folin-Ciocalteau reagent and 2 mL Na_2CO_3 solution were mixed with the dilutions prepared from stock (Fig. 2) and a standard calibration curve was prepared (absorbance at 765 nm). It was noted as mg of gallic acid equivalent GAE/g of peel extract (16).

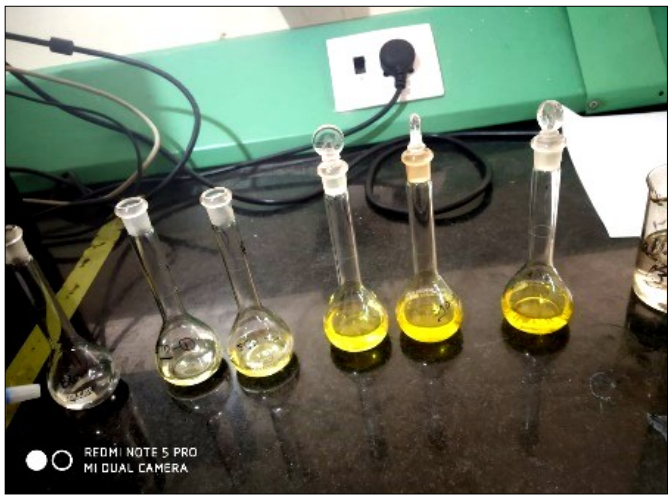


Fig. 2. Preparation of sample and standard solution.

Estimation of Flavonoids

The aluminium chloride colourimetric method was utilized to ascertain the flavonoid content (17). Developing an acid -stable flavonoid–aluminium complex is the method's foundation. After adding 0.5 mL test sample extract in ethanol (10 mg/mL) and 1.5 mL methanol, 0.1 mL 10 % aluminium chloride, 0.1 mL potassium acetate solution and 2.8 mL distilled water were added in that order and thoroughly mixed (Fig. 3). A blank sample was similarly produced by substituting distilled water for $AlCl_3$. The solution for the test was agitated vigorously. Absorbance at 415 nm was measured following a 40 min incubation period. At 415 nm, a standard calibration plot was produced by employing quercetin at known concentrations. Using the calibration plot, the flavonoid concentrations in the test samples were determined and noted as mg quercetin equivalent/g of the sample. Each of the analyses were performed in triplicate.

Fig. 3. Preparation of standard and extract stock solution.

Estimation of Total Bitter

After adding 50 mL methanol and 1g test sample extract in a flask, the mixture was metabolized in a water bath for half an hour. Following filtration, the extracted substance was collected in a beaker. The residue underwent 2 additional cycles of extraction, which resulted in the development of a 5 mL viscous substance. Following three cycles of shaking with 25 mL of boiling water, the concentrated extract was rinsed, pooled and shifted to a separating funnel. After four extractions with 25 mL of petroleum ether at 60-80 °C, this aqueous extract was aggregated and shifted to a pre-weighed evaporating dish and 3 washes with ethyl acetate were employed. The percentage of bitter residue was calculated by weighing the residue and was expressed in weight % (w/w) in relation to the air-dried sample (18).

$$\% \text{ bitters (w/w)} = \frac{(A - B)}{W} \times 100$$

Where, A = Total (Weight of dish + Residue), B = Total Weight of empty dish and W = Total Weight of material taken

Estimation of Tannin

Following a precise weighing of 0.05 g of the sample, 250 mL DW was transferred to the flask, thoroughly mixed and then subjected to sonication for 10 min. Following this, 25 mL sulphonic acid (indigo) solution was introduced, thoroughly mixed and titrated against a 0.02 M $KMnO_4$ solution until a stable yellow tinge was produced (Fig. 4). Then, burette reading was noted. By applying the subsequent factor, the overall tannin content was determined. The weight of 1 mL of 0.02 M $KMnO_4$ represented 0.00415 g of tannin (16).

Estimation of Total Alkaloids

The spectrophotometric method utilizing Dragendorff's reagent was used to quantify alkaloids (19). For Ten minutes at 3000 revolutions per min, 10 mg of the crude extract were centrifuged to remove suspended particles, if any. Approximately 1 mL of 0.1 N HCl was added to 0.5 mL of extract and 0.25 mL of Dragendroff's reagent; the precipitate was then centrifuged. Following a 0.25 mL ethanol wash with the precipitate, the filtrate was thrown and the residual precipitate was treated with 0.25 mL of 1 % disodium solution (Fig. 5). Following a 5 min centrifugation at 3000 rpm of the brownish-black precipitate produced, the residue was dissolved in 0.2 mL of concentrated nitric acid. Then, 0.1 mL was combined with 0.5 mL of 3 % thiourea solution. Absorbance was noted at 435 nm against a blank. A calibration curve encompassing 20-100 µg of caffeine was constructed. The alkaloids were measured in mg of caffeine equivalent per g of leaf extract.

Fig. 4. Shaking and titration against N/10 $KMnO_4$ up to golden yellow colour.

Fig. 5. Separating chloroform layer (lower layer).

Estimation of saponin

The sample weighing 5 g was taken in a flask with 50 mL of (90 %v/v) methanol, mixed the contents, refluxed for 30 min and then filtered on cooling. Further, the residue was washed with methanol (90 %) until it turned colourless. This extract was evaporated in a water bath to get a thick paste. The residue was treated with 25 mL petroleum ether (60-80 °C). The petroleum ether layer was discarded and the process was repeated with chloroform. The solvent layer was discarded and the residue was treated with ethyl acetate (25). Again, the solvent layer was discarded and 5 mL of 90 % methanol was mixed and agitated to dissolve. The mixture, thus obtained, was added gradually to a glass beaker containing 25 mL acetone with shaking to get precipitation. The flask was rinsed with 2 mL of methanol (90 %). The organic layer was transferred and the residue was dried until it reached a constant weight. The saponin percentage was calculated and noted as % w/w concerning the air-dried sample (16).

Estimation of protein

After weighing 1 g of material in a 500 mL Kjeldahl flask, 10 g of powdered K_2SO_4 or anhydrous sodium sulphate (Na_2SO_4) and 0.5 g of copper sulphate were added to a flask containing 20 mL of concentrated sulphuric acid. The mixture was slowly heated below the boiling point until foaming stopped and gave a bright green colour. After cooling, 150 mL water was added to the flask and swirled for proper mixing, followed by 100 mL of a 30 % sodium hydroxide solution. In a separate flask containing 50 mL of 0.5 N sulphuric acid, a few pieces of granulated zinc were added and the flask was connected to a condenser via a Kjeldahl connecting bulb so the delivery tube dipped below the mixture during distillation. Titration with 0.5 N NaOH neutralized the acid excess after adding 3 drops of methyl red solution to the receiving flask (Fig. 6). Ammonia was neutralized with an acid concentration (16).

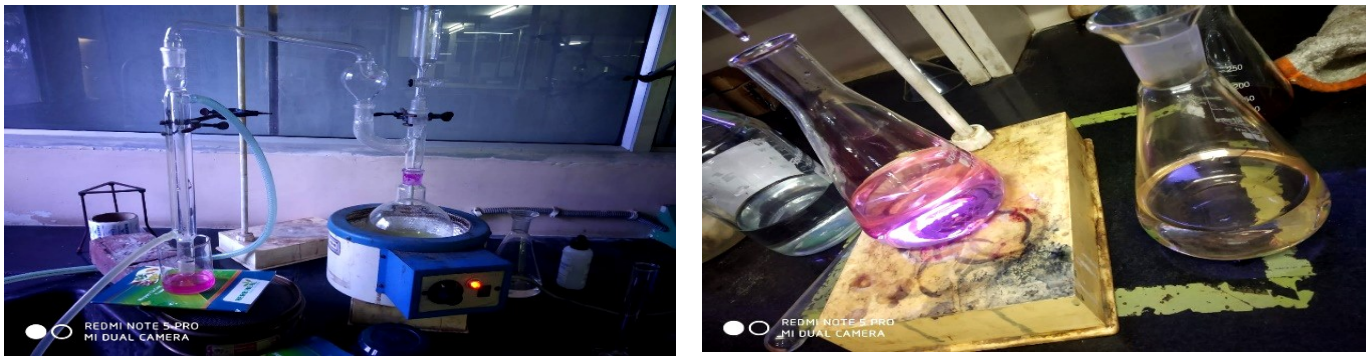


Fig. 6. Distillation of Ammonia and titration.

Estimation of Carbohydrate

The anthrone method calculated the total carbohydrate content (20). Anthrone has a maximum absorption at 630 nm and the technique relies on its synthesis from hydroxyl methyl furfural in an acidic solution to give a green colour. For this purpose, after 3 h in a boiling water bath, 10 mg of the sample was cooled to room temperature and hydrolyzed with 0.5 mL of 2.5 N HCl. Some sodium carbonate was added to neutralize it until the fizzing stopped. The 10 mL of the solution was taken and centrifuged; from it, 1 mL of the supernatant was taken and standards were prepared between 0.2 and 1.0 mL of glucose and 1 mL of water was used as control. The absorbance at 630 nm was measured after adding 4.0 mL of anthrone reagent, heating it for eight minutes in a boiling water bath, and then quickly cooling it. After preparing the standard curve, the concentration of an unknown amount in the sample was measured.

Estimation of Reducing Sugar

125 mL of extract was measured and topped up in a 250 mL standard flask; 10 mL of Fehling's solution I and solution II were pipetted and 30 ccs of water was added and brought to a boil. Drop by drop, this extract from the burette was added until the solution no longer appeared blue. After 2 min of boiling, 3-5 drops of methylene blue indicator were added without turning off the heat. Further, the extract was gradually added drop by drop until the blue colour disappeared within 1 min (Fig. 7). Titration was repeated until concurrent results were obtained (21).

Fig. 7. Titration.

Estimation of Antioxidants

The DPPH assay was used to estimate the ability of the ethanol and aqueous extracts to quench free radicals. DPPH solution was prepared in methanol (0.004 % w/v). The peel extract stock solution (1mg/mL) and the ascorbic acid standard solution (0.5 mg/mL) were made up of methanol, too. Aluminium foil was used to shield test tubes from light while extract and ascorbic acid were added at 10-50 g/mL and 1 mL of newly produced DPPH solution. Each test tube had its final volume brought up to 2 mL with methanol before being incubated in the dark for 30 min at room temperature. The spectrophotometer (UV-2700) was used to take the absorbance at 517 nm following incubation. As a control sample, a matching volume of methanol and DPPH without any extract or reference ascorbic acid was made. As a control, methanol was used (22).

GC-MS analysis

GC-MS analysis of selected samples was attained using GC-2010 gas chromatography combined with a TQ8030 mass spectrometer to identify further and characterise phyto components. The sample was injected into a 30 m glass capillary column of 0.25 µm film thickness. The sample volume was 1.0 µL. The ion source temperature is 250 °C and the interface temperature is 300 °C. The acquisition mode is Q3 Scan. The carrier gas (Helium) was used at 1 mL/min constant flow mode, pressure 57.5 kPa. The spectra obtained for individual unknown compounds were matched with the database stored in the software database libraries.

Statistical analysis

Every phytochemical analysis was carried out in triplicate and MS-Excel 2007 was utilized to compute the mean and standard deviation (SD). It is a measurement of the data's dispersion concerning the mean. Data with a low standard deviation or small standard deviation are closely grouped around the mean, whereas data with a significant or large standard deviation are widely dispersed. When the standard deviation is around zero, it signifies that the data points are close to the mean; when it is more, it implies that the data points are dispersed further from the mean.

Results

Quantitative Estimation of Phytochemical Constituents

After preliminary screening and quantitative estimation, the different extracts of jackfruit peel wastes have shown the presence of a variable amount of phytocomponents for each solvent. In petroleum ether extract -polyphenol (9.80 GAE/g in PE), bitter (1.92 % in PE), alkaloid (0.60 mg of caffeine equivalent/g in PE), protein (1.82 % in PE); in ethanolic extract- flavonoid (0.59 mg quercetin equivalent/g in EE), saponins (34.39 % in EE), antioxidants (0.25 ± 0.04 mg/mL; IC_{50} in EE) and in aqueous extract - tannin (3.68 % in AE), carbohydrate (17.17 % in AE) and reducing sugar (4.73 % in AE) were found to be present in more quantity as compared to other extracts. Table 1 show the quantitative estimation results of various phytocomponents present in different extracts of jackfruit peel.

GC-MS analysis

Through the GC spectra analysis, many biologically active chemical compounds have been successfully detected. Fig. 8, 9 and 10 shows the GC-MS chromatogram of jackfruit peel extracts, confirming various phytocomponents presence. However, none of the significant peaks were observed in the GC–MS chromatogram of the petroleum ether extract. The maximum number of peaks were observed for ethanolic extract, i.e. 27, whereas only 6 were obtained in aqueous extract. After comparing the 6 peaks with already known compounds available in the software database libraries, it was revealed that Dimethyl phthalate was the most abundant compound in ethanolic extract. In contrast, in aqueous extract, it was Diethyl phthalate. Besides this, Hexadecanoic acid (methyl ester) was also identified in ethanolic extract as another abundant component (Table 2 and 3).

Table 1. Showing results of quantitative estimation of phytochemical constituents in various extracts of jackfruit peel

Sample Name	Polyphenol (GAE)/g	Flavonoid mg quercetin equivalent/g	Bitter (%)	Tannin (%)	Alkaloid mg of caffeine equivalent/g	Saponins (%)	Protein (%)	Carbohydrate (%)	Reducing Sugar (%)	Antioxidants (mg/mL) (IC_{50})
Petroleum ether extract	9.8 ± 0.50	0.24 ± 0.02	1.92 ± 0.13	1.29 ± 0.08	0.6 ± 0.16	1.16 ± 0.08	1.82 ± 0.08	0.055 ± 0.00	0.06 ± 0.00	0.85 ± 0.09
Ethanol extract	3.5 ± 0.26	0.59 ± 0.07	0.26 ± 0.02	2.85 ± 0.10	0.18 ± 0.02	34.49 ± 0.86	1.77 ± 0.09	9.84 ± 0.88	3.71 ± 0.17	0.25 ± 0.04
Aqueous extract	3.19 ± 0.16	0.34 ± 0.03	0.43 ± 0.03	3.68 ± 0.04	0.1 ± 0.01	6.74 ± 1.13	0.64 ± 0.07	17.17 ± 0.35	4.73 ± 0.32	0.28 ± 0.06

Values in parenthesis are the standard deviation of the mean.

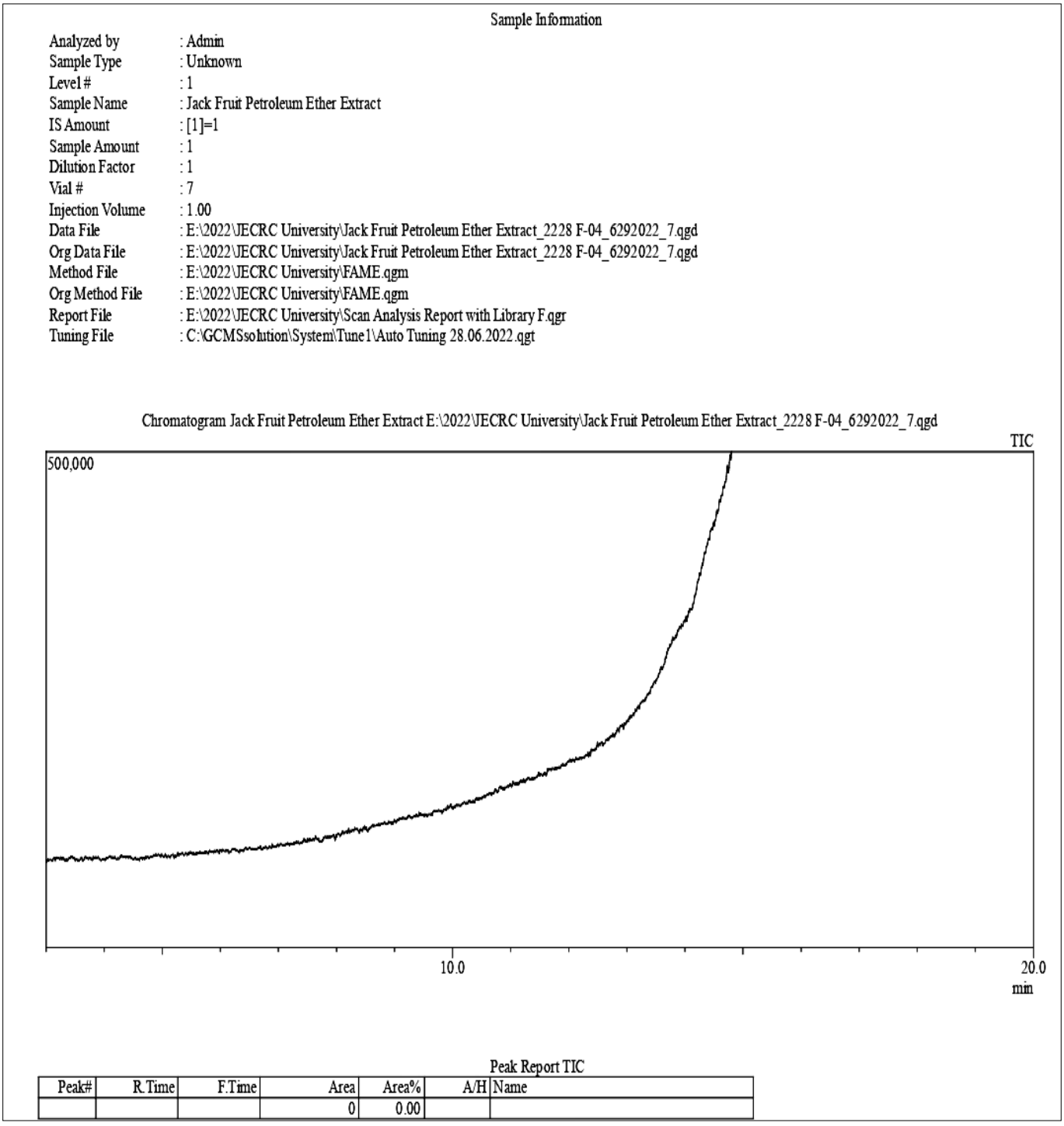
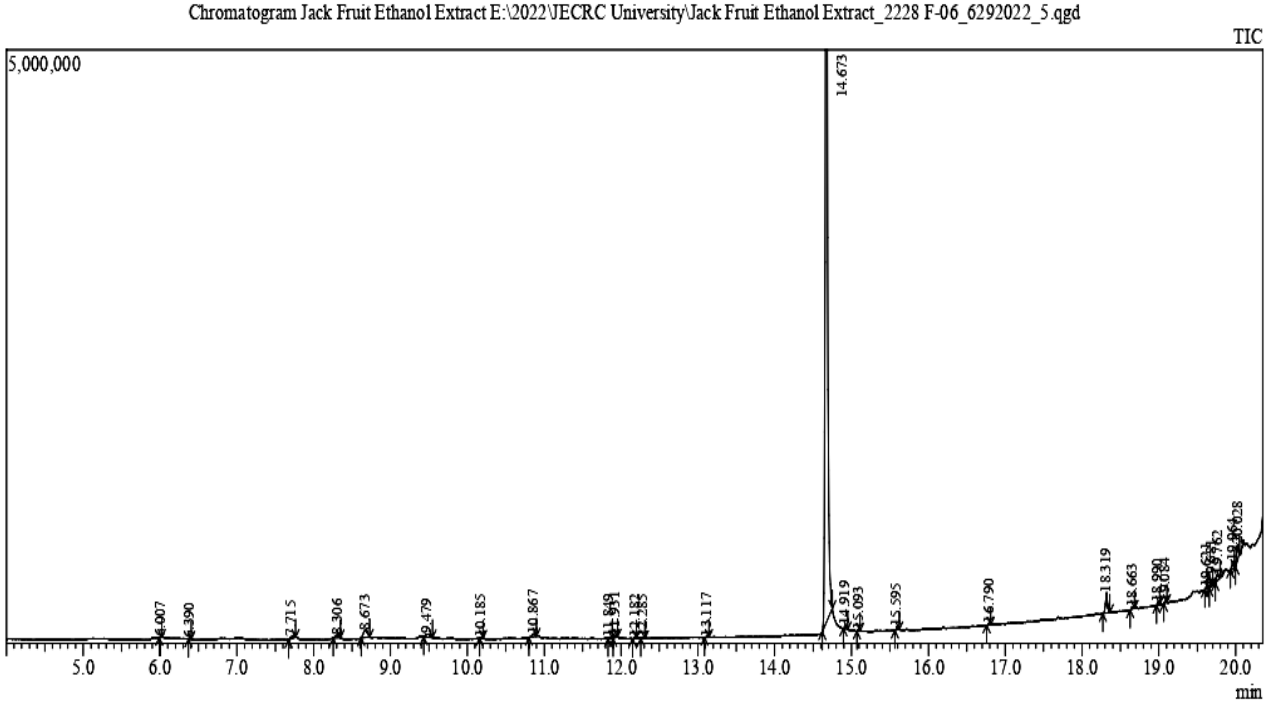


Fig. 8. GC-MS chromatogram of petroleum ether extract of jackfruit peel.

Sample Information

Analyzed by	: Admin
Sample Type	: Unknown
Level #	: 1
Sample Name	: Jack Fruit Ethanol Extract
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 5
Injection Volume	: 1.00
Data File	: E:\2022\JECRC University\Jack Fruit Ethanol Extract_2228 F-06_6292022_5.qgd
Org Data File	: E:\2022\JECRC University\Jack Fruit Ethanol Extract_2228 F-06_6292022_5.qgd
Method File	: E:\2022\JECRC University\Q3 Scan Plant Extract.qgm
Org Method File	: E:\2022\JECRC University\Q3 Scan Plant Extract.qgm
Report File	: E:\2022\JECRC University\Scan Analysis Report with Library F.qgr
Tuning File	: C:\GCMSsolution\System\Tune1\Auto Tuning 28.06.2022.qgt

Chromatogram Jack Fruit Ethanol Extract E:\2022\JECRC University\Jack Fruit Ethanol Extract_2228 F-06_6292022_5.qgd



Peak Report TIC

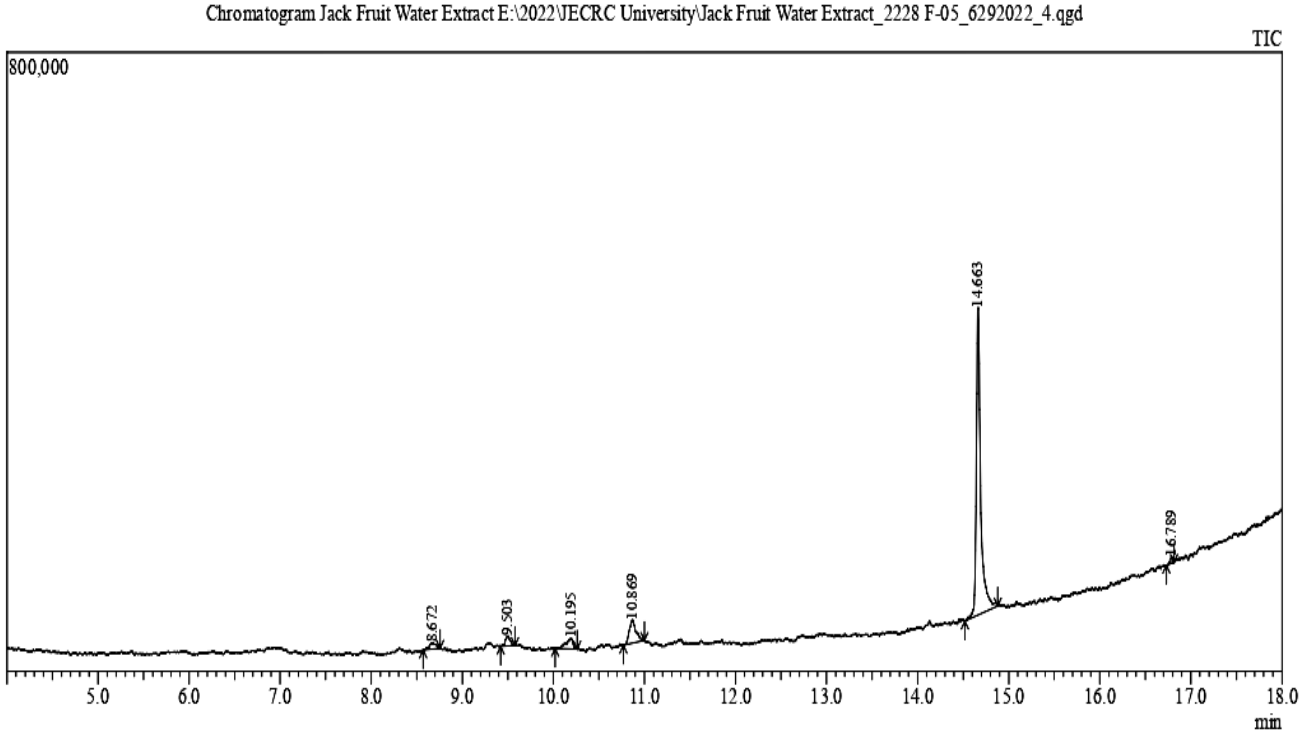
Peak#	R.Time	F.Time	Area	Area%	A/H	Name
1	6.007	6.020	4880	0.03	1.06	D-Fucose
2	6.390	6.405	3058	0.02	1.03	Methyl 3-acetamido-4:6-phenylisopropylidene
3	7.715	7.765	47643	0.26	2.92	Pimelic acid, 5-methoxy-3-methylpent-2-yl pe
4	8.306	8.350	74633	0.41	3.39	5-(1-Acetoxy-1,2-dihydroxypropyl)[1,3]dioxo
5	8.673	8.730	226677	1.24	3.74	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6
6	9.479	9.545	100220	0.55	3.92	1,3:2,4-Dimethylene-d-epirhamnitol
7	10.185	10.205	6285	0.03	1.46	Propanal, 2-methyl-3-phenyl-
8	10.867	10.900	74848	0.41	3.22	p-Cymen-7-ol
9	11.849	11.885	13470	0.07	1.50	Glutaric acid, octyl 2,3,4,5-tetrafluorobenzyl e
10	11.931	11.955	28243	0.16	1.57	1-Undecanol
11	12.182	12.200	9219	0.05	1.56	E-14-Hexadecenal
12	12.285	12.310	13753	0.08	1.76	Tetradecane
13	13.117	13.145	13718	0.08	1.56	Cycloheptasiloxane, tetradecamethyl-
14	14.673	14.750	16569004	90.98	2.03	Diethyl Phthalate
15	14.919	14.950	48984	0.27	1.55	Asarone
16	15.093	15.110	14418	0.08	1.32	Cyclooctasiloxane, hexadecamethyl-
17	15.595	15.620	42605	0.23	1.68	aR-Turmerone
18	16.790	16.810	25808	0.14	1.40	Cyclononasiloxane, octadecamethyl-
19	18.319	18.360	304333	1.67	1.79	Hexadecanoic acid, methyl ester
20	18.663	18.685	34677	0.19	2.29	Phthalic acid, butyl undecyl ester
21	18.990	19.010	21297	0.12	1.29	Hexadecanoic acid, ethyl ester

Fig. 9. GC-MS chromatogram of ethanolic extract of jackfruit peel.

Sample Information

Analyzed by	: Admin
Sample Type	: Unknown
Level #	: 1
Sample Name	: Jack Fruit Water Extract
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 4
Injection Volume	: 1.00
Data File	: E:\2022\JECRC University\Jack Fruit Water Extract_2228 F-05_6292022_4.qgd
Org Data File	: E:\2022\JECRC University\Jack Fruit Water Extract_2228 F-05_6292022_4.qgd
Method File	: E:\2022\JECRC University\Q3 Scan Plant Extract.qgm
Org Method File	: E:\2022\JECRC University\Q3 Scan Plant Extract.qgm
Report File	: E:\2022\JECRC University\Scan Analysis Report with Library F.qgr
Tuning File	: C:\GCMSsolution\System\Tune1\Auto Tuning 28.06.2022.qgt

Chromatogram Jack Fruit Water Extract E:\2022\JECRC University\Jack Fruit Water Extract_2228 F-05_6292022_4.qgd



Peak Report TIC

Peak#	R.Time	F.Time	Area	Area%	A/H	Name
1	8.672	8.755	39910	2.42	5.10	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6
2	9.503	9.580	47733	2.90	3.71	Methyl 4,7,10,13-hexadecatetraenoate
3	10.195	10.260	71547	4.34	5.01	Propanal, 2-methyl-3-phenyl-
4	10.869	11.000	151268	9.18	5.05	p-Cymen-7-ol
5	14.663	14.880	1324428	80.39	3.33	Diethyl Phthalate
6	16.789	16.815	12636	0.77	1.44	Cyclononasiloxane, octadecamethyl-
			1647522	100.00		

Fig. 10. GC-MS chromatogram of aqueous extract of jackfruit peel.

Table 2. Retention time and phytochemical compounds identified in ethanolic extract of Jackfruit peel through GC-MS technique

Peak	R. Time	Area	Area %	Name of the identified compound	Molecular formula	Molecular weight
1	6.007	4880	0.03	D-Fucose	$C_6H_{12}O_5$	164
2	6.390	3058	0.02	Methyl 3-acetamido-4:6-phenyl isopropylidene	$C_{18}H_{25}NO_6$	351
3	7.715	47643	0.26	Pimelic acid, 5-methoxy-3-methylpent-2-yl pe	$C_{29}H_{56}O_5$	484
4	8.306	74633	0.41	5-(1-Acetoxy-1,2-dihydroxypropyl) [1,3]dioxo	$C_{10}H_{16}O_8$	264
5	8.673	226677	1.24	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6	$C_6H_8O_4$	144

6	9.479	100220	0.55	1,3:2,4-Dimethylene-d-epirhamnitol	$C_8H_{14}O_5$	190
7	10.185	6285	0.03	Propanal, 2-methyl-3-phenyl-	$C_{10}H_{12}O$	148
8	10.867	74848	0.41	p-Cymen-7-ol	$C_{10}H_{14}O$	150
9	11.849	13470	0.07	Glutaric acid, octyl 2,3,4,5-tetrafluorobenzyle	$C_{20}H_{26}F_4O_4$	406
10	11.931	28243	0.16	1-Undecanol	$C_{11}H_{24}O$	172
11	12.182	9219	0.05	E-14-Hexadecenal	$C_{16}H_{30}O$	238
12	12.285	13753	0.08	Tetradecane	$C_{14}H_{30}$	198
13	13.117	13718	0.08	Cycloheptasiloxane, tetradecamethyl-	$C_{14}H_{42}O_7Si_7$	518
14	14.673	16569004	90.98	Diethyl Phthalate	$C_{12}H_{14}O_4$	222
15	14.919	48984	0.27	Asarone	$C_{12}H_{16}O_3$	208
16	15.093	14418	0.08	Cyclooctasiloxane, hexadecamethyl-	$C_{16}H_{48}O_8Si_8$	592
17	15.595	42605	0.23	aR-Turmerone	$C_{15}H_{20}O$	216
18	16.790	25808	0.14	Cyclononasiloxane, octadecamethyl-	$C_{18}H_{54}O_9Si_9$	666
19	18.319	304333	1.67	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	270
20	18.663	34677	0.19	Phthalic acid, butyl undecyl ester	$C_{23}H_{36}O_4$	376
21	18.990	21297	0.12	Hexadecanoic acid, ethyl ester	$C_{18}H_{36}O_2$	284
22	19.084	18091	0.10	Carbonic acid, eicosyl vinyl ester	$C_{23}H_{44}O_3$	368
23	19.621	27959	0.15	Methoxyacetic acid, 4-hexadecyl ester	$C_{19}H_{38}O_3$	314
24	19.680	53057	0.29	Triacontane, 1-iodo-	$C_{30}H_{61}I$	548
25	19.762	108744	0.60	Hexatriacontane	$C_{36}H_{74}$	506
26	19.964	98744	0.54	2-Methylhexacosane	$C_{27}H_{56}$	380
27	20.028	227242	1.25	Eicosane	$C_{20}H_{42}$	282
	Total	18211610	100.00			

Table 3. Retention time and phytochemical compounds identified in aqueous extract of Jackfruit peel through GC-MS technique

Peak#	R.Time	Area	Area %	Name of the identified compound	Molecular formula	Molecular weight
1	8.672	39910	2.42	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6	$C_6H_8O_4$	144
2	9.503	47733	2.90	Methyl 4,7,10,13-hexadecatetraenoate	$C_{17}H_{26}O_2$	262
3	10.195	71547	4.34	Propanal, 2-methyl-3-phenyl-	$C_{10}H_{12}O$	148
4	10.869	151268	9.18	p-Cymen-7-ol	$C_{10}H_{14}O$	150
5	14.663	1324428	80.39	Diethyl Phthalate	$C_{12}H_{14}O_4$	222
6	16.789	12636	0.77	Cyclononasiloxane, octadecamethyl-	$C_{18}H_{54}O_9Si_9$	666
	Total	1647522	100.00			

Discussion

According to earlier studies conducted by various researchers, the phenolic constituents found in jackfruit include phenols like ferulic acid, tannic acid and gallic acid and flavonoids - rutin, myricetin and catechin (23, 24).

As a combined analytical technique, gas chromatography-mass spectroscopy (GC-MS) provides a better analytical tool for investigating phytochemicals and chemotaxonomic research on medicinal plants with physiologically active constituents compared to HPLC and LCMS (60), the extracts of jackfruit peel were investigated through it. Also, GC–MS analysis offers better reproducibility measurements, dynamic range and universal mass spectral library for compounds with small molecular weight, as found in the present study (61, 62). In the present study, many of the bioactive compounds identified by GC-MS technique in ethanolic and aqueous extracts of jackfruit peels have been considered to possess various biological properties. Based on abundance, the 2 main constituents in the ethanolic extract were dimethyl phthalate and hexadecanoic acid-methyl ester, whereas diethyl phthalate was majorly present in the aqueous extract. The methyl ester dimethyl phthalate is a common additive to many products, including insecticides, pesticides, rubber coating agents, moulding powders and safety eyewear (25, 26). Hexadecanoic acid, a fatty acid ester, was found to be the second most significant chemical and it has been linked to a variety of health benefits, viz. antioxidant, anti-inflammatory, hypocholesterolemic and cancer-preventative roles (27) and antagonist to certain pathogenic bacteria (28, 29). Diethyl phthalate (DEP) is a diester and an ethyl ester and synthetic compound with widespread application in various industries, particularly in the production of plasticizers, toothbrushes, automobile parts, tools, toys, insecticides and pharmaceuticals such as aspirin and food packaging, cosmetics, etc. Also, it possesses various roles, including that of a teratogenic agent, a neurotoxin and a plasticizer (30).

Additionally phytochemicals, including polyphenol (9.80 GAE/g in PE), flavonoid (0.59 mg quercetin equivalent/g in EE), bitter (1.92 % in PE), tannin (3.68 % in AE), alkaloid (0.60 mg of caffeine equivalent/g in PE), saponins (34.39 % in EE), proteins (1.82 % in PE), carbohydrates (17.17 % in AE), reducing sugars (4.73 % in AE) and antioxidants (0.25 ± 0.04 mg/mL; IC_{50} in EE) were also investigated in the peel extracts. Jackfruit has several beneficial components, but phenolic compounds and carotenoids have received the greatest attention. In earlier studies, researchers discovered various functional ingredients with potential health benefits, including polysaccharides and oligosaccharides (31). Furthermore, pectin, commonly found in fruits, has also been recognized for its potential health-promoting properties (32). It was found that extracts derived from jackfruit peels exhibited a significantly higher concentration of total phenols and flavonoids than extracts obtained from the fruit's seeds, pulp and flakes (1, 33). The existence of tannins support the application of jackfruit peel in wound healing, frostbite, varicose ulcers, haemorrhoids and burns (34). Additionally, saponins are considered anti-nutritional elements and lessen the uptake of some nutrients with cholesterol and glucose (35).

Some other fruit peels have also been studied for their phytochemical richness. In an examination of watermelon (*Citrullus lanatus*) peels, significant levels of saponin (25.0 %) and flavonoids (1.2 mg quercetin equivalent/g) were obtained (50). Another similar study showed a flavonoid content of 0.65 mg quercetin equivalent/g and a total phenolic content of 7.2 GAE/g in the peels of *Artocarpus altilis* (51). Similarly, in banana (*Musa acuminata)* peels, high tannin content at 6.5 % was observed, which correlates with its notable antioxidant activity (52). Similarly, studies on *Artocarpus heterophyllus* showed polyphenols at 8.5 GAE/g (53) and studies on *Artocarpus champeden* demonstrated phenolics at 6.8 GAE/g and saponins at 28.0 % and emphasized promising antioxidant and anti-inflammatory properties of these peels (54). In peels of some of the other plants such as lemon (55), mango (56) and pomegranate (59) a significantly high level of antioxidant compounds have been reported. Additionally, a significant level of flavonoid concentrations of 0.75 mg quercetin equivalent/g and polyphenols at 9.0 GAE/g in *Artocarpus nobilis* and saponin (32.0 %) and tannin (4.5 %) levels in the peels of *Artocarpus Odoratissimus* was observed (57, 58). In many other studies also, it was discovered that jackfruit peel contains significant amounts of ascorbic acid, flavonoids and polyphenols, viz. catechin and chlorogenic acid, which can be attributed to the content of antioxidants found in the present study (36). The functional ingredients found in jackfruit have shown significant attention due to their potential uses in the foodstuff and pharmacological sectors, particularly for health-related advantages. In a study, the research was conducted on the extraction of jacalin from jackfruit peel (37). Other researchers (38) also investigated the polyphenol content derived from various solvent extraction systems from jackfruit peel, seeds and rags in Pressurized Hot Water Extraction (PHWE).

Numerous studies have examined the influence of different extraction methods on acquiring functional components from jackfruit. A study (1) found that the use of 90 % methanol for a duration of 6 h resulted in significantly higher yields of phenolics from jackfruit peel compared to other parts of the fruit, including seeds, pulp and flakes. Previous studies have revealed a significant impact of temperature and extraction time on the type and quantity of compounds extracted from jackfruit peel (31, 39). The current study also detected the variation in the phytochemicals extracted from different solvents. Our results are aligned with earlier reports stating the influence of different solvents on the levels of total phenolic content in methanol extract, the total flavonoid content in ethyl acetate and the total alkaloid content in methanol extract (40). In previous investigations, the leaves of *A. heterophyllus,* after preliminary phytochemical screening, revealed the presence of flavonoids and steroids (41). According to a study (42), the methanol extract of the leaf petiole of jackfruit exhibited the highest amount of phenols, flavonoids and alkaloids. This finding also suggests that the presence of these phytochemicals is influenced by the type of solvents used. The ethyl acetate and hexane extract also showed significant levels of these compounds, albeit lower than the methanol extract. In another study (43), the GC-MS analysis of acetone extracts from pomegranate and jackfruit peels revealed comparable findings. The analysis indicated the presence of furanone, furfural and phenolic compounds, with benezenetriol being the primary retention peak. These components are recognized for their aromatic properties and heterocyclic aldehyde nature.

The nutritional composition of jackfruit reveals a significant presence of carbohydrates, encompassing various types such as monosaccharides, disaccharides and polysaccharides. According to a study conducted, the carbohydrate content in seeds of various jackfruit cultivars was found to range from 37.4 % to 42.5 % (44). The study also reported the total carbohydrate content in the methanol extract to be 85.15 %. The present study's findings also suggested that jackfruit peel could be used in the food industries as a source of carbohydrates (17.17 % in AE). According to a study (45), only 10 % of jackfruit peel is currently utilized in the food industry. However, the remaining 90 % of the peel is repurposed to make biofilm, biosorbent and activated carbon. This indicates a substantial potential for further exploration and utilization of jackfruit peel in various industries beyond just food. According to a study (46), the utilization of it has been explored for different applications. One such application involves the production of biohydrogen, a renewable energy source.

Additionally, peel waste has shown potential as an absorbent material for removing hazardous chemicals from wastewater, particularly in the textile and pharmaceutical industries. In a study (39), the researchers explored the potential utilization of jackfruit peel waste to extract pectin. An earlier study (47) reported that the components extracted from jackfruit peel have been found to have potential applications in the production of bionanocomposite materials. These materials exhibit desirable properties, including anti-inflammatory, anticoagu-

lant, antimicrobial, cytocompatibility and biodegradability (48). The present study has also established that ethanol and water can be a good choice for extracting the compounds of industrial and pharmaceutical significance from the peel of jackfruit.

This is a comprehensive study on jackfruit peel wastes, confirming the abundance of Dimethyl and Diethyl phthalate in the jackfruit peel extracts, which are usually discarded as waste.

Currently, most of the peel is used to obtain pectin and bioremediation. Our study on Jackfruit peel revealed a polyphenol content of 9.80 GAE/g, comparable to the values reported for other *Artocarpus* species and the notably high concentration of saponins (34.39 %) in our study also surpasses the 32.0 % reported in *Artocarpus odoratissimus* peels. Our study has revealed that polyphenols and saponins in jackfruit peels are comparatively and significantly higher than some other peels of jackfruit species. The compounds identified in GC-MS are prominently found in ethanol and aqueous extracts of jackfruit peel. They can be utilized as an asset to obtain Dimethyl and Diethyl phthalate for food and pharmaceutical sectors, thus contributing towards environmental remediation. Also, we established the presence of enormous bioactive compounds like polyphenols, alkaloids, tannins, flavonoids, sugars and antioxidants.

Conclusion

The present study revealed the presence of major bioactive constituents in different Jackfruit peel extracts. Identifying these phytoconstituents in the peel extracts is the basis for determining the possible biological and pharmacological importance. Compounds like Diethyl phthalate have shown antibacterial activity against common pathogens. Also, the antioxidant compounds present a better alternative to replace conventionally used chemical counterparts. Thus, it suggests the possibility of jackfruit peel wastes as a source of valuable goods and can unlock new avenues for novel therapeutics. However, additional research is requisite to understand the full potential of jackfruit peels, variation in the extract component on the varietal basis, consideration for the exploration and effective utilization of various levels of functional and bioactive constituents for the designing and improving food, pharmaceutical and cosmetic products.

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Authors' contributions

Both the authors, RY and AK, contributed equally to drafting, analyzing and finalizing this manuscript. AK carried out GC-MS analysis and in vitro experiments. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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