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Phytochemical profiling and antioxidant activities of different parts of *Artocarpus heterophyllus* Lam. (Moraceae): A review on current status of knowledge

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Abstract

Background: *Artocarpus heterophyllus* Lam. (Jackfruit tree) is one of the most ancient fruits indigenous to Western Ghats of India. They are large edible summer fruits and are good source of nutritional and antioxidant components which hold their potential for nutraceutical development.

Main body: The present review attempts to document reports on the chemical and pharmacological investigations carried out with jackfruit. Research shows that the fruit contains a huge amount of phytochemicals such as phenolics, flavonoids, terpenoids, steroids, glycosides, saponins, alkaloids, and tannins which exhibit antioxidant properties.

Conclusions: Diversity of secondary metabolites present in the jackfruit shows that it is a functionally, nutritionally, and medicinally important fruit. Detailed studies are essential for awareness among people for the proper use of jackfruit as a functional food and utilize the medicinal uses of jackfruit.

Keywords: Jackfruit, Antioxidant property, Phenolics, DPPH

Background

Jackfruit is one among the most ancient fruits indigenous to Western Ghats of India. It is large edible summer fruit and is known to be the "Poor man's food" [1, 2]. Locally, jackfruit is known to be "Chakka" while Sanskrit refers it to be Panasa (synonym: Atibruhatphala which means big fruit) [2–4]. Jackfruit is a good source of nutritional and antioxidant compounds which hold their potential for nutraceutical development. These phytonutrients promote opportunities for manufacturing value-added products [5, 6]. Research shows that compounds such as flavonoids and phenolics exhibit antioxidant properties [7, 8].

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Main text

Distribution

The jackfruit tree is widely distributed in tropical countries such as Brazil, Thailand, Indonesia, India, Philippines, and Malaysia [9]. Jackfruit is a common tree in every house of tropical and sub-tropical countries mainly Sri Lanka, Bangladesh, Burma, Philippines, Indonesia, Thailand, Malaysia, and Brazil [4, 10–16]. In India, it is widely seen in several parts of the country [17].

Morphology

The fruit weighs up to 50 kg in which only 30–35% of the bulb is edible [1, 4, 12, 18–20]. Jackfruit is a multiple (compound) fruit. It consists of a lower fleshy edible (bulb), middle fused (syncarp), and an outer spiny region (spike) [2]. When ripe, flakes get fleshy, outer spines widen, and flesh becomes soft and yellow in color [21]. The thorny outer bark and axis are not edible [4].

Jackfruit is about 2- to 4-cm long consisting of about 100 to 500 seeds per fruit.

Variety of jackfruit

In jackfruit, the flake characteristics belong to two categories namely Varikka which consists of somewhat hard flakes and Koozha, consisting of soft and fibrous flakes [4, 22–25]. Further, jackfruits are classified based on their phenotypic and organoleptic characters with variation in their flakes and seed color, shape, size, odor, and period of maturity [1–3, 11].

Phytochemical compositions

The composition of jackfruit seeds has already been reported [18, 26] to possess similar compositions to that of grains. Phytochemical components in jackfruits may vary and depend upon the cultivar type as well as the habitat [3, 4, 27–29]. The fruit is rich in phytocompounds such as flavonoids, stillbenoids, morin, artocarpin, dihydromorin cynomacurin, isoartocarpin, cyloartocarpin, artocarpesin, artocarpetin, artocarpanone, oxydihydroartocarpesin, norartocarpetin, and cycloartinone [30], thus making it a potent antioxidant, anti-inflammatory, antibacterial, antifungal, anticariogenic, antineoplastic, cicatrizent, and hypoglycemic fruit.

Nutritional aspects

Jackfruit pulp is eaten afresh and is used in fruit salads and ice creams due to its high nutritional value [31]. The fat content of the seeds is negligible making it a good constituent of fat free diet. It is a source of vitamins and minerals [3, 20, 27–29]. The seeds may vary in their protein and carbohydrate contents, with certain varieties consisting of about 6.8% of proteins [4, 32, 33], which is almost similar to that of rice, where it is about 7–8%. The maximum sugar (21%), carbohydrate (31%), and protein (2.3%) contents were reported to be in the flakes of Valayan, Mondan, and Nettadivarika varieties, respectively. Moreover, the seeds of these varieties were reported to have maximum carbohydrate (42%) and protein (6.8%) contents [33] (Table 1).

Major sugars, fatty acids, and carotenes are also present in jackfruit [9, 34–37]. Jacalin is the major protein reported in the seed of jackfruit [37–40]. It is a lectin compound that can easily react with varieties of monosaccharides and can bind with human IgA [38, 41, 42] and T-antigen [43]. Besides, it has several health benefits such as anticancer, antioxidant, anti-ageing properties to mention a few [3, 20, 44–46].

Useful products

The seeds are consumed either boiled or roasted and also used as a snack. However, fresh seeds have short shelf-life and so the seeds are dried or powdered to store for a long time. Jackfruit is widely used for preparing baby foods, jams, jellies, juice, biscuits, bread, chips, nectar, deserts, beverages like squash, wine, and so on [3, 18, 20, 28, 47, 48] (Table 2).

Medicinal properties

Jackfruit is both gluten-free and casein-free and hence has anti-inflammatory benefits to the skin. It has plenty of antioxidants, vitamin C, various bioflavonoids, and fibers. It also has anti-cancerous property due to the presence of the protein jacalin and active bioflavonoids. Raw jackfruit is good to consume for diabetic patients, due to its anti-diabetic property. Being fibrous and low in glycemic load (glucose level) jackfruit is widely accepted by the diabetologists as a perfect food source for diabetic patients. The glycemic index research conducted on jackfruit by the Sydney University had stated that one cup of jackfruit in which the glycemic value is 17 is almost half the glycemic value of other foods like chappathi (glycemic value—27) and rice (glycemic value—29).

Phytochemical analysis

Studies reveal that phytochemical screening tests have a significant role in the detection of bioactive principles and is mostly due to the presence of flavonoids, tannins, carbohydrates, saponins, alkaloids, tannins, triterpenoids, and proteins in the jackfruit peel extracts [49]. The phytochemical screening of aqueous, hydroalcoholic, and methanolic extracts of *A. heterophyllus* seeds indicate the presence of phytochemicals in the order of methanolic>hydroalcoholic>aqueous extracts which is an indication of its possible medicinal value [50]. The fruit peels

Table 1 Biochemical difference in different jackfruit varieties from Southern India [33]

Sl. No.	Name of Variety	Total soluble sugar in flake (%)	Total carbohydrate in flake (%)	Total protein in flake (%)	Total carbohydrate in seed (%)	Total protein in seed (%)
1	Valayan	21.3 ± 1.02	23.8 ± 2.6	1.4 ± 2.2	42.5 ± 0.6	5.9 ± 0.7
2	Nettadivarikka	17.5 ± 0.9	28.4 ± 1.7	2.3 ± 1.5	40.3 ± 2.3	6.8 ± 2.3
3	Chemparathy	20.7 ± 0.4	26.1 ± 0.8	1.9 ± 2.7	37.4 ± 1.1	5.3 ± 1.4
4	Mondan	18.6 ± 1.9	31.2 ± 2.0	2.0 ± 1.4	42.8 ± 0.9	6.5 ± 1.8
5	Venkanni	15.3 ± 1.15	28.4 ± 1.3	1.7 ± 2.3	40.2 ± 1.5	6.0 ± 1.5

Numbers indicate means ± standard deviation of mean

Table 2 Uses of different jackfruit parts [20, 37]

Plant part	Use
Fruit	Food: Vegetable, pickle, chutney, jam, jelly, paste, candies, juice, powder, confectionery
Seed	Eaten boiled, roasted and salted as table nuts, flour for baking, substrate for solid state fermentation, animal feed
Jackfruit peel	Adsorbent for the removal of cadmium

were extracted using 95% ethanol in the soxhlet apparatus. The semi-solid extract so obtained was aromatic and pale brownish in color. The extractive value was found to be 15 g [51]. Quantitative phytochemicals estimated in seed powder in 100 g – 1 DW concerning tannins, saponins, and alkaloids were 1.45 ± 0.29, 2.67 ± 0.17, and 3.05 ± 0.19, respectively. Three different extracts aqueous acetone, aqueous methanol, and mix solvent were used to evaluate the phenolic and flavonoid contents and the quantitative analysis of polyphenols [52]. Dichloromethane:Methanol::1:1 solvent system was able to extract more phytochemicals in comparison to acetone in the seeds of jackfruit [53]. The highest extraction efficiency (22.88%) was obtained in ethanolic leaf extract of *A. heterophyllus* [54]. High tannin content was estimated in the root (3.88–2.69 mg/g) and lowest in bark (0.93–0.52 mg/g). Overall, the average tannin composition in all the parts reported so far is 2.14 ± 0.45 mg/g [55].

Total flavonoid content

Total flavonoid content (μg RE/mg extract) estimated from acetone extract of jackfruit seed was 290.6 ± 3.41 μg/mg and that from dichloromethane:methanol::1:1 extract was 457.1 ± 5.82 μg/mg [56]. Flavonoid contents were assessed using aluminium chloride methods which revealed 96.7, 131.6, and 164.6 mg quercetin equivalent/g of flavonoid in spine, skin, and rind, respectively [57]. In fresh tissues, the total flavonoid content was found out to be 10.1 QE/g of fresh tissue, respectively. Total flavonoid content was calculated for the standard curve of quercetin ($y = 0.00148x$; $R^2 = 0.9988$) and was estimated to be 10 mg QE/g dry weight [50]. When compared to standard (1.20 mg of RE/g), high-flavonoid content present in the edible part was estimated to be 10.5 ± 0.21 mg/100 mg [5]. The total flavonoid content of the four different extracts of *A. heterophyllus* was found to be 4.05 ± 0.01 mg/g for ethanolic fraction, 2.21 ± 0.02 mg/g for acetone fraction, 2.67 ± 0.01 mg/g for ethyl acetate fraction, and 0.86 ± 0.01 mg/g for an aqueous fraction of quercetin equivalent per 100 mg seed extract [58]. High-flavonoid content was also present in roots (10.74–7.31 mg/g) and lowest in bark (3.09–1.49 mg/g). Flavonoid contents (mg/g) obtained were 5.74, 8.73, and 2.24 for leaves, roots, and bark, respectively. Overall, the average flavonoid composition in all parts of the entire jackfruit was estimated to be 5.57 mg/g [55] (Table 3).

Table 3 Phenolic, flavonoid content, and antioxidant activity of Jackfruit in undigested and digested extracts [59, 60]

Parameters	Jackfruit undigested	Jackfruit digested
Total phenolic content	23.3 ± 3.5	33.9 ± 0.8
Total flavonoid content	33 ± 9.5	28.4 ± 1.2
TEAC	56 ± 2.0	218 ± 12.0
ORAC	2117 ± 388	3047 ± 455

Numbers indicate means ± standard deviation of mean
TEAC trolox equivalent antioxidant capacity, *ORAC* oxygen radical absorbance capacity

Total phenolic compounds

The highest total phenolic content was reported from 125 μg/ml of ethyl acetate fraction [61]. Total phenolic content (μg gallic acid equivalents (GAE)/mg extract) determined from acetone extract of Jackfruit seed was estimated to be 1.45 ± 0.007 μg/mg and 2.12 ± 0.009 μg/mg from dichloromethane:methanol (1:1) extract [56]. Polyphenol contents were assessed using Folin's Ciocalteu reagent which revealed 316, 355, and 382 mg tannic acid equivalent/g of polyphenol in spine, skin, and rind, respectively [57]. Total phenolic content in fresh tissues obtained was 0.4 GAE/g. Total phenolic content in the methanolic extracts of *A. heterophyllus* seeds was calculated using the standard curve of gallic acid ($y = 1.4882x–0.0067$; $R^2 = 0.950$) was found to be 0.4 mg GAE/g dry weight [50]. Phenolic content in the shell powder is higher than that reported earlier [5, 62]. Total phenolic contents obtained in four different solvents were 4.16 ± 0.01 mg/g (ethanolic), 2.30 ± 0.02 mg/g (acetone), 2.77 ± 0.02 mg/g (ethyl acetate), and 1.18 ± 0.01 mg/g (aqueous) of GAE at 100 mg/g of jackfruit seed extracts [58].The phenolic content of methanol extract of jackfruit seeds was 437 ± 0.006 mg of GAE/gm of the dried extract [63]. The highest phenolic content was observed in roots (67.37–59.00 mg/g) and lowest in barks (38.14–28.34 mg/g). Average phenolic contents (mg/g) reported were 35.18, 65.56, and 23.59 for the leaves, roots, and bark, respectively. Overall, the average phenolic composition of all the parts so far reported was 41.44 mg/g [55] (Table 3).

Antioxidant activity

Polyphenolic content and antioxidant properties in seed using dichloromethane:methanol::1:1 extract of jackfruit was found to be higher [56]. Maximum antioxidant activity has seen in leaf extract of methanol, water, ethanol, and ethyl acetate using ABTS, DPPH, and FRAP assays but not on petroleum ether extract [64]. Phenolic and flavonoid contents, antioxidant activity, and quantitative analysis of polyphenols were evaluated from three different extracts such as aqueous acetone, aqueous methanol, and mix of these solvents, of which the methanol the extract showed the highest antioxidant activity which is

largely correlated with phenolic and flavonoid contents. The highest antioxidant activity is scavenging hydroxyl radical activity and followed by scavenging hydrogen peroxide and chelating of ferrous iron [65]. The antioxidant activity can be well preserved through storage at a lower temperature, perhaps due to the stability of protocatechuic acid (PCA). Findings indicate that jackfruit rind extract could be a potential source of antioxidants which could be utilized for developing value added products [66].

Total antioxidant capacity of the extracts was calculated by using percentage of inhibition against concentration of ascorbic acid ($y = 0.1065x + 7.717$; $R^2 = 0.794$). At 500 μg/ml concentration, methanolic extracts of seeds exhibited 31.06% inhibition. Studies on various parts of the jackfruit have shown the occurrence of higher antioxidant activity in seeds with IC50–410 μg/ml [50]. The highest antioxidant activity shown is the scavenging hydroxyl radical activity followed by scavenging hydrogen peroxide and chelating of ferrous iron [65]. Total antioxidant capacity of jackfruit seeds was found to be 170.75 ± 0.001 mg/gm equivalent of ascorbic acid (Table 3).

DPPH radical scavenging activity

The dichloromethane:methanol::1:1 extract had shown higher radical scavenging activity (IC_{50} = 0.6433 ± 0.0029 mg/ml) than acetone extract (IC_{50} = 0.7867 ± 0.0104 mg/ml) by DPPH. Both the extracts were significantly different ($p < 0.05$) in their IC_{50} values [56] by DPPH assay. The values obtained by DPPH radical scavenging activity by the aqueous the extract was found to be more related to standard ascorbic acid than the ethanolic acid [67] (Table 4). The IC_{50} value for DPPH radical scavenging was found to be 398.8 μg/ml [50]. The antioxidant activity of the seed extracts in various solvents using DPPH assay had shown varying percentages of free radical scavenging activity. Methanol and ethyl acetate extracts showed IC_{50} values of 636.5 μg/ml and 715.86 μg/ml, respectively [68]. There is a decrease in the absorbance of DPPH with the addition of jackfruit leaf and bark extract in DPPH solution. The greater the decrease in absorbance, the greater the antioxidant activity. This positive result is indicated with the colour change of the solution from dark purple to bright yellow. The decrease in absorbance value occurs due to the electron transfer of the antioxidant hydrogen atom to DPPH. IC_{50} of each extract can be calculated by plotting the concentration of the test solution and the percentage of inhibition of DPPH as a parameter of antioxidant activity. The IC_{50} for jackfruit leaf extract obtained was 52.08 mg/ml, and for the bark extract, it was 33.93 mg/ml [69]. In DPPH method, jackfruit seeds had shown moderate antioxidant potentiality in a dose-dependent manner with the IC_{50} value of 116.04 μg/ml. The percentage scavenging of DPPH radical was found to be concentration-dependent with the IC_{50} value of 116.04 μg/ml, while the IC_{50} value of standard ascorbic acid was found to be 9.02 μg/ml. The DPPH scavenging activity was also highest in the roots (66–72%), while that of the bark was (24–40%) [66]. A study conducted in Egypt found that jackfruit leaf extracts at concentrations 0.2, 0.4, and 0.6 mg/ml scavenge by 70% ethanol to DPPH were 21, 32, and 51%, respectively [59] (Table 4).

Table 4 Results of DPPH assay showing % inhibition with respect to ascorbic acid, ethanolic, and aqueous stem extracts of jackfruit [67]

Conc. (μg/ml)	Ascorbic acid	Ethanol extract	Aqueous extract
25	66.20 ± 0.22	61.25 ± 0.29	66.24 ± 0.90
50	70.44 ± 0.57	62.54 ± 0.62	68.52 ± 0.13
75	76.22 ± 0.67	64.22 ± 0.56	72.44 ± 2.76
100	78.44 ± 0.29	67.77 ± 0.56	77.34 ± 1.56
150	87.47 ± 1.05	74.24 ± 2.33	85.59 ± 1.99
200	92.02 ± 0.02	76.23 ± 0.24	88.33 ± 1.97

Numbers indicate means ± standard deviation of mean

ABTS scavenging activity

Acetone extract (IC_{50} = 0.0491 ± 0.0005 mg/ml) and dichloromethane:methanol (1:1) (IC_{50} = 0.0556 ± 0.0002 mg/ml) had shown less scavenging activity than that of standard ascorbic acid (IC_{50} = 0.0027 ± 0.0003 mg/ml) by ABTS scavenging assay [56]. Higher inhibition was measured by NSP35 water extract but in the case of petroleum ether extract, ABTS reagent was immiscible and hence antioxidant assay on petroleum ether leaf extract by using ABTS assay cannot be carried out [64]. A moderate correlation was found between total flavonoid and ABTS assays ($r = 0.62$) [52].

Reducing power assay

The results had shown that the reducing power of jackfruit seed extracts ranged from 13.12–9.56 μg/ml for various solvent extracts [58]. The reducing power of the roots, leaves, and bark ranged from 114.38 to 93.62 μg/ml, 71.63 to 67.04 μg/ml, and 54.16 to 33.15 μg/ml, respectively [55]. Reducing power of dichloromethane:methanol::1:1 extract was found to be 16.678 μg GAE/mg, which was higher than that of acetone (14.029 μg GAE/mg) extract [56]. FRAP was reported as 5 mg/ml for pulp methanolic extract [5]. The percentages of Fe^{++} chelating activity of 70% ethanol were 62, 75, and 78% at concentrations of 0.2, 0.4, and 0.6 mg/ml, respectively [70].

Hydrogen peroxide scavenging activity

It was observed that the chloroform and hexane extracts showed scavenging activity above 50%. The EC_{50} (free radical scavenger) values of ethanolic, hexane, chloroform, and ethyl acetate extracts were 76.71, 399.64, 534.83, and 65.51 μg/ml,

respectively [61]. Other studies using ethanolic and methanolic extracts of the jackfruit seeds showed comparable values with that of the ascorbic acid standard [50, 67].

Lipid peroxidase, superoxide radical rcavenging, and nitric oxide scavenging assays

Removal of H_2O_2 is essential for maintaining redox balance within a cell. It was found that scavenging of H_2O_2, and its percentage inhibition in methanolic extracts of jackfruit seeds exhibited an IC_{50} value of 32.51 μg/ml while that of the ascorbic acid standard was found to be 31.99 μg/ml [50]. Lipid peroxidase, superoxide radical scavenging, and nitric oxide scavenging assays showed that there have been significant inhibitions of free radicals with ethanolic and aqueous extracts of jackfruit seeds as compared with the standard ascorbic acid [67].

Future directions

Jackfruit is declared as the State fruit of Kerala state by the Government of India in March 2018. Jackfruit tree is eco-friendly and produces pesticide-free fruit as the tree has no serious pests and diseases. Usually, jackfruit tree produces plenty of fruits during the fruiting season and people use jackfruit in different forms even though many fruits and seeds are wasted on large scale due to its high availability during every season. Hence, it becomes essential to create awareness among people for the functional and medicinal uses of jackfruit besides converting fruits and seeds to value-added products. Further, awareness creation is essential for indiscriminate cutting of the trees in large numbers for timber which in turn will reduce its genetic diversity remaining in the species. There is no scientific study carried out so far on the local jackfruit varieties in Kerala. It is very important to conserve the locally available jack trees for the maintenance of biodiversity and future use. Management system should take appropriate action for its proper conservation and utilization of these important genetic resources. In ancient times, people in Kerala used jackfruit when food was scarce and used as a common food item like rice. But today, unfortunately, nobody is aware of the priceless medicinal as well as nutritional properties which this fruit has to offer when it is included in our daily diet. Further studies would help to promote the consumption of jackfruit regularly by the general public and offers the opportunity to develop value-added products.

Conclusion

The present review reveals that *Artocarpus heterophyllus* Lam. is a chemically and pharmacologically studied tree having diverse secondary metabolites present in its fruits and seeds such as phenolics, flavonoids, terpenoids, steroids, glycosides, saponins, alkaloids, and tannins. Thus, jackfruit is considered to be a functionally, nutritionally, and medicinally important fruit in all respects.

Abbreviations

DPPH: 2,2-Diphenyl-1-picryl hydrazyl; QE/g: Quercetin equivalent per gram; RE/g: Rutin equivalent per gram; GAE: Gallic acid equivalents; ABTS: 2,2′-Azino-Bis(3-ethyl benzothiazoline-6-sulfonic acid); FRAP: Fluorescence recovery after photobleaching; TE: Trolox equivalents; IC_{50}: Half maximal inhibitory concentration; JFBE: Jackfruit n-butanol extract; EC_{50}: Half maximal effective concentration

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Authors' contributions

PSSD collected the data and drafted the manuscript. NSK and KKS analysed the collected literature and finalized the manuscript. The authors read and approved the final manuscript.

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Availability of data and materials

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Competing interests

The authors declare no conflict of interest.

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