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Valorization of Foxtail Palm (*Wodyetia bifurcata*) Fruit Waste: Phytochemical, Antioxidant, Antibacterial and Growth–Medium Potential of Peel, Seed and Fibrous Fractions

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ABSTRACT

This tree is a fleshy-fruited arecoid ornamental palm, with the ripe fruit which consists of a thick fibrous covering, a coarse fibre covering and a hard seed, commonly being discarded in the garden. The peel and seed fraction in this study was subjected to Soxhlet extraction using ethanol and hexane, while fibrous material was analyzed as a component of a soilless growth media. The ethanol and hexane peel extracts recovered more crude material from both tissues compared to the ethanol and hexane seed extracts, with the ethanol peel extract having the highest crude material yield (6.84%) followed by the ethanol seed extract (4.60%). Hexane peel extract (0.24%) and hexane seed extract (0.18%) were negligible. The seed fraction of hexane, however, was oil-like with FTIR spectra showing the presence of aliphatic C–H stretching (2956, 2922, 2851), an ester carbonyl band (1744) and C–O signals in the 1260–1000 cm^{-1} region, which is typical of a triglyceride oil. The qualitative screening of the ethanol peel extract yielded positive results for saponins, terpenoids, phenols, anthraquinones, reducing sugars and steroids, while the total phenolic content in the extract was calculated to be 81.11 µg/mL gallic acid equivalents (R^2 = 0.9972). With increasing concentration of the DPPH assay the peel extract scavenged radicals more consistently than the seed extract where scavenging dropped and then levelled off. The zones of ethanol peel extract were found to be dose-dependent against Escherichia coli (5 mm and 16 mm at 5 µg and 10 µg, respectively while it didn't show any effect against Staphylococcus aureus. The chana (Cicer arietinum) and mung (Vigna radiata) achieved 100% germination on cocopeat and also in a 1:1 foxtail-fibre–cocopeat mixture and the seedling vigour index was raised compared to cocopeat. The outcomes suggest two possible ways to utilize the same ornamental waste stream the phenolics and antimicrobial constituents as peel, and the covering fibres as part of an amendment of growing medium, which could be replicated at the compound level in subsequent studies.

Keywords: *Wodyetia bifurcata; Foxtail palm; Fruit-waste valorization; Soxhlet extraction; Total phenolic content; Antimicrobial; Growing medium; Cocopeat.*

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1. Introduction

Vegetative debris generated in landscaping/horticulture operations, and generally considered waste, amounts to large scale quantities. Peels, seeds, shells, fibre and leaves from foxtail palm, and in public gardens and campuses are deposited, put to costly disposal with no value whatsoever; these are rich in lipids, polysaccharides, phenolics and structural polymers. Circular-bioresources thinking is not based on thinking that the entire biomass is one single problem, but will ask what part of the residue is suited for what use [3,4].

Wodyetia bifurcata, the foxtail palm, is an ornamental plant, now widely planted throughout the tropics and subtropics, previously confined to north-eastern Queensland where it is native [1,2]. It can be seen lining streets and filling grounds of institutions in many Indian cities, with conspicuous and colourful orange-red fruits that mature seasonally and fall. These fruits are fibrous and hard-seeded and have received little attention in fruit chemistry studies compared to edible crop residues, and little assessment of value has been undertaken.

In the report here the fruit has been considered as three separate physically distinct materials, namely the flesh of the fruit or pericarp, the seed, and the hard outer material, because the different parts have different biological functions and are, therefore, chemically different. The peel will be exposed to the environment and may provide protective pigments and phenolics; the seed will have reserve lipids; and the covering, which is designed for mechanical protection of the seed should be high in lignocellulose and should resist tissue damage by size reduction. This separation will also prevent masking because a key but less abundant fraction will not be overpowered by dilution with a large, uninteresting fraction.

The first step was a solvent extraction of the sample. Ethanol is a polar organic solvent which extracts phenolic, flavonoid-like and moderately polar substances, while the non-polar extractives (lipids, waxes, etc.) are extracted using hexane. The Soxhlet extraction was selected because it repeatedly overflows the matrix with the freshly condensed solvent by reflux and siphon, which ensures high mass transfer [5]. A high crude yield is not evidence of activity but it is a useful screen – it indicates the amount of tissue which yields extractable mass under defined conditions and therefore a low yield fraction may or may not be scientifically informative, but may certainly contain a condensed concentration of a compound class that is specifically bioactive. That distinction is important here since the ethanol peel extract yielded more, and the hexane seed extract, although very thin, was obviously oily, and therefore called for spectroscopic attention.

Functional groups were profiled using Fourier-transform infrared spectroscopy (FTIR) without destroying the sample. It does not identify molecules, but bonds like O–H, C–H, C=O and C–O are identified directly; typical of the triglycerides and fatty acid esters are bands near 2950–2850 cm^{-1} from C–H bonds and 1740–1750 cm^{-1} from carbonyl groups in esters in lipid-rich materials [11,12]. The inclusion of antioxidant work was due to the fact that the fruit peels and seeds are generally known to donate electrons or hydrogens to the radicals. The first-line test used was the DPPH assay, which is based on the stable free radical DPPH being bleached at 517 nm [9,10]. Practical selection of representatives of Gram-negative and Gram-positive bacteria, Escherichia coli and Staphylococcus aureus respectively, made the use of well-diffusion testing with these microorganisms feasible and with use of chloramphenicol as the positive control, antimicrobial screening followed [13,14].

A second thread of the project was also horticultural. The fibrous covering was impractical to grind to a usable powder, but was thought to be a structural material. Peat is a popular plant medium for water retention and aeration and is also expensive to harvest for the environment, and growers are increasingly experimenting with coir, bark, compost and crop residues as partial alternatives [15–18]. The covering was already used for this purpose and was softened, broken and sun dried and mixed with equal amounts of cocopeat. The use of a pure-fibre medium was intentionally omitted because the unbroken material was deemed to be too free-draining.

The study constitutes a single practical question of a common ornamental waste: is it possible to sensibly take the waste for both bioactivity and use in growing media at the same time, as a small biorefinery? There is a wealth of published literature on fruit-waste valorization, but systematic data on the foxtail palm residues are limited, and the present report is meant as a preliminary but complete basis for more ambitious studies, from which it can be used as a basis.

1.1 Aim

To assess the sustainability of the fruit and hard covering of the foxtail palm and define the solvent extractability, phytochemical profile, antioxidant and antibacterial activities, and FTIR functional group profile of the fruit and hard covering and the scope of the processed hard covering for use as a cocopeat fraction in a germination medium.

1.2 Objectives

(i) compare the extraction efficiency of ethanol and hexane on peel and seed; (ii) screen selected extracts for phytochemical classes and estimate total phenolics; (iii) measure antioxidant activity of extracts measured by DPPH relative to ascorbic acid; (iv) test antibacterial activity of the extracts against *E. coli* and S. aureus; (v) characterise the oil-like hexane seed extract by FTIR; (vi) assess a 1:1 foxtail-fibre–cocopeat medium against cocopeat using the germination and growth of chana and mung.

2. Review of Literature

W. bifurcata is botanically very well described as an arecoid palm with an unusual crown and fruit which is orange red out of its native Australian range [1,2]. What is interesting is that very little of this documentation is focused on the fruit residue per se. In contrast, valorization of fruit by-products (peels, seeds and processing waste) is a dynamic area, with recent reviews highlighting the recovery of phenolics, flavonoids, fibres and antioxidants with applications in food [4,5] or nutraceutical applications [3,6], antimicrobial applications [5,6] or agricultural applications [5]. The foxtail palm does not meet this model, but it is an ideal representative of the other, which is the subject of the present work.

Methodologically, Soxhlet extraction is still a reliable means of gaining access to plant matrices, as the repeated contact of the solvent is well documented [5] and the polarity of the solvent to a large extent determines the constituents that are extracted, ethanol being rich in polar and mid-polar compounds and hexane in oils and waxes [6]. The qualitative phytochemical screening of the extract was carried out using the colour and precipitation tests for alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, phenols, steroids and reducing sugar as a standard early-stage triage procedure, which will guide the choice of extracts for quantitative work [7]. The total phenolics are typically measured calorimetrically using Folin–Ciocalteu reagent and a gallic acid standard at 765 nm [8].

The most commonly used first screen is the DPPH radical-scavenging assay introduced by Blois and formalized by Brand-Williams and co-workers [9,10] which is simple and rapid and should be considered as an in vitro antioxidant assay not as an in vivo efficacy test. FTIR showed a long history of spectral characterization of oils and fats based on the C–H and ester carbonyl absorptions and was therefore the obvious spectroscopic technique to use with the oily hexane seed fraction. Phenolics, terpenoids and saponins have potential antimicrobial activity against the membranes and enzymes, and they are often screened in plant extracts, but zone-diffusion results are influenced by the diffusion, solubility and concentration of the antimicrobial agents as well as by their intrinsic activity; therefore, proper controls are required [13,14].

Research on growing media is increasingly focused on finding alternatives to peat which are sustainable. Coir pith is a coir by-product which has been found to have advantageous physical properties and is currently being used widely, but the literature consistently tests candidate residues as mixtures of materials rather than as a full peat substitute because none of the materials so far tested performs on every axis as well as peat [15–18]. This is the reasoning behind the use of 1:1 blend of foxtail fibre and cocopeat, instead of a pure fibre medium. The literature thus supports an integrated approach, and the use of the fruit waste of *W. bifurcata* remains virtually unstudied. The rationale for the present project is to provide a first set of preliminary numbers in the fields of extraction, phytochemistry, bioactivity, spectroscopy and performance in growing media.

3. Materials and Methods

3.1 Study design

The investigation was laboratory-based and was constituted by six related modules: sample collection and processing, solvent extraction, FTIR characterization, qualitative and quantitative phytochemical analysis, antioxidant and antibacterial screening, and a germination trial, in which a fibrous covering was used as partial substitute for cocopeat.

3.2 The Collection and Processing of samples.

Reddish orange fruits of foxtail palm were picked in the first week of January, 2026 from Lalbagh Gardens, Bengaluru, Karnataka, India with the permission of the Joint Director of Horticulture (Parks, Gardens & Floriculture). Dust and attached debris were cleaned from the fruits by washing with distilled water. The flesh was removed from the seed and the hard seed coat, after hot-air drying, was reserved for extraction; the other material with seed (tough) was processed separately.

3.3 Soaking and Grinding inner and outer layer of the foxtail palm

As the outer covering is resistant to normal mechanical disruption, breaking and grinding of seeds was done at the National Institute of Unani Medicine, Bengaluru with the support of the laboratory of Dr. Hamid Uddin. The material was broken using a motorized pestle and mixer and sieved to get a fairly homogeneous fraction for extraction.

The foxtail fibre was prepared as follows. The foxtail fibre was prepared for the growth-medium trial as follows.

Hard covering was soaked in water for about 2 weeks, broken to smaller pieces by hammer, and sun-dried. The foxtail-fibre component was made up of this material. A 1:1 mixture of foxtail-fibre and cocopeat (v/v) was used as the test treatment instead of a pure-fibre medium because the undigested fibre was expected to hold water poorly.

3.4 Soxhlet extraction

The processed material used for each extraction was 50 g of the dried material. Seed was extracted with ethanol for 8 cycles and hexane for 10 cycles; peel with ethanol for 12 cycles and hexane for 6 cycles. It was taken off with a water bath, and crude residue was collected in a pre-weighed beaker. A small precipitate was observed in the ethanol peel extract and the supernatant liquid was taken further for centrifugation. Extraction yield was reported as a percentage of dry mass of the starting material.

3.5 FTIR analysis

The evaporated hexane seed extract was found to be oily and was subjected to analysis of the same in the Forensic Science Laboratory, Jain School of Sciences on a Nicolet Summit LITE (Thermo Scientific) instrument. Spectra were collected ranging from 4000–400 cm^{-1} with 16 sample scans and 16 background scans, and the main bands were identified by comparing with reported FTIR signatures of plant oils and lipid-rich samples.

3.6 Qualitative phytochemical screening

The selected extracts were subjected to analysis, using the following standard method for detection of the different classes of the secondary metabolites.

a. Mayer's reagent for alkaloid
b. Alkaline reagent for flavonoids
c. Ferric chloride reagents for tannins and phenolics
d. Foam test for saponins
e. Keller-Kiliani test for cardiac glycosides
f. Fehling's solution for reducing sugar
g. Acetic anhydride-sulfuric acid test for steroids.
h. acid reagent for anthraquinones.

Positive (+) or negative (-) results were noted.

3.7 Phenolic content

Phenolics were subjected to analysis by the method of Folin-Ciocalteu, considering gallic acid as the standard. A calibration graph was constructed using the solution containing different concentrations of gallic acid, which is 20, 40, 60, 80, 100 µg/mL with the wavelength set to 765 nm. The unknown concentration of the extract from the peel was estimated by inputting the absorbance into the regression equation to give results in gallic acid equivalents (GAE).

3.8 Antioxidant activity (DPPH)

Methanol was used to prepare radical DPPH. The extracts of the seeds, peels were subjected to experimentation of antioxidant activity and was measured at 200, 400, 600, 800, 1000 µg per assay respectively. In the dark conditions, the reaction mixtures were allowed to settle down for 30 mins and were subjected to measurement for absorbance at 517nm and inhibition percentage was calculated.

3.9 Antibacterial well-diffusion test

The strains of Escherichia coli or Staphylococcus aureus were cultured in Mueller-Hinton nutrient media. The relevant extract from the sample was tested for antibacterial activity, by placing in the well at 5 or 10 µg. The positive control was considered to be chloramphenicol.

3.10 Germination and seedling growth

After the antibacterial assay, the seeds 'germination and growth were assessed. Chickpea (*Cicer arietinum*) and mung bean (*Vigna radiata*) seeds (30 each) were used for sowing in two different media for 10 days; cocopeat as the control media and the 1:1 foxtail fibre–cocopeat media for the testing. Daily observations were made for germination while at the end, the seeds were classified as normal, abnormal or dead/rotted. For the normal seedlings, the length of shoot, root, total length of seedling and seedling vigor index I [(% germination × average total length)] was measured.

3.11 Statistical analysis

Calculations were done using standard formulas for yield and DPPH inhibition while that for total phenolics was based on the calibration curve with gallic acid. Germination and growth data were reported as percentages with mean ±standard deviation. Comparison of growth parameters (shoot length, root length and total plant length) was made using Welch's t-test for each crop separately.

4. Results

4.1 Crude extract recovery

Solvent and tissue both shaped the yields (Figure 1, Table 1). Ethanol recovered much more than hexane from either tissue. The observed order in more recovery was found to be ethanol peel (6.84%)> ethanol seed (4.60%) > hexane peel (0.24%) > hexane seed (0.18 %).

Table 1: Crude extract recovery and percentage yield from foxtail palm peel and seed fractions

Extract	Empty beaker (g)	Beaker + crude (g)	Crude mass (g)	Sample (g)	Yield (%)
Ethanol peel	144.68	148.10	3.42	50.0	6.84
Ethanol seed	140.19	142.49	2.30	50.0	4.60
Hexane peel	151.98	152.10	0.12	50.0	0.24
Hexane seed	143.46	143.55	0.09	50.0	0.18

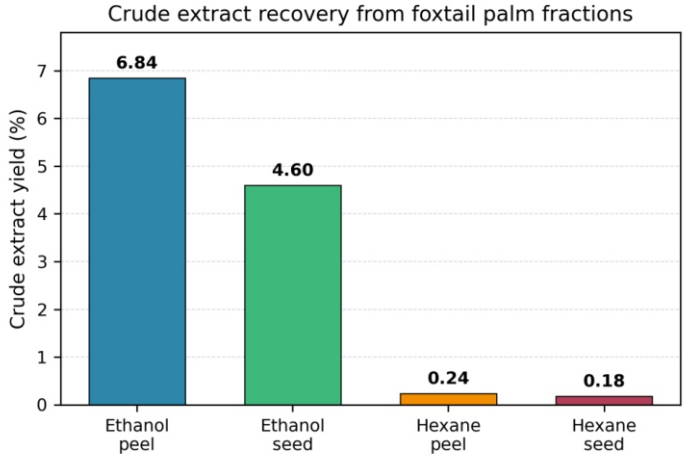

Figure 1. Crude extract yield of foxtail palm peel and seed fractions

4.2 FTIR profile of the hexane extract of the seeds

The hexane seed extract was more oily in nature and had a spectrum similar to a fixed oil fraction. The C–H stretching frequencies were observed at around 2956, 2922 and 2851 cm^{-1}, which are aliphatic C–H stretching frequencies. The frequency of 1744 cm^{-1} was attributed to a strong ester carbonyl band. The C–O frequencies in the 1260–1000 cm^{-1} region is assigned to aliphatic C–O stretching frequencies (Table 2). These features indicate triglycerides or fatty-acid esters, but cannot identify specific fatty acids by FTIR.

Table 2: Principal FTIR bands of the hexane seed extract and their tentative assignments

Peak (cm^{-1})	Tentative assignment	Interpretation
3409.67	O–H stretching	Trace moisture/hydroxyls (interpreted cautiously)
2956.19	CH_3 asymmetric C–H stretch	Aliphatic, lipid-associated hydrocarbon
2922.70	CH_2 asymmetric C–H stretch	Long-chain fatty acyl signal
2851.19	CH_2 symmetric C–H stretch	Long aliphatic chain
1744.25	Ester C=O stretch	Characteristic of triglycerides/fatty-acid esters
1460.74	CH_2 bending/scissoring	Aliphatic-chain vibration
1375.96	CH_3 bending	Aliphatic fingerprint
1260.38	C–O stretch	Ester-related fingerprint
1095.85	C–O stretch	Glyceride/ester region
1007.33	C–O/fingerprint	Ester/glyceride-associated

4.3 Qualitative phytochemical screening

The metabolite coverage of the three tested extracts varied (Table 3). It was observed that the ethanol peel extract were showing positive results for the saponins, terpenoids, phenols, anthraquinones, reducing sugar, and steroids. The hexane peel extracts showed the positive results for flavonoids, saponins, cardiac glycosides, anthraquinones, reducing sugar and steroids. The ethanol seed extracts showed the positive result for terpenoids, anthraquinones and steroids. It was observed that none of the samples had shown negative results for the alkaloids and tannins.

Table 3: Qualitative phytochemical profile of foxtail palm extracts (+ positive, – negative)

Phytochemical test	Hexane peel	Ethanol peel	Ethanol seed
Alkaloids	–	–	–
Flavonoids	+	–	–
Tannins	–	–	–
Saponins	+	+	–
Cardiac glycosides	+	–	–
Terpenoids	–	+	+
Phenols	–	+	–
Anthraquinones	+	+	+
Reducing sugars	+	+	–
Steroids	+	+	+

4.4 Total phenolic content

The gallic acid curve was observed to be linear ($y = 0.0072x$, $R^2 = 0.9972$). The ethanol peel extract were meassured at 765nm which gave reading of 0.584, equated to 81.11 µg/mL of GAE in the tested sample (figure 2). Form this, the ethanol peel extract was considered to be phenol- positive.

Table 4: Gallic acid standard readings and the unknown peel-sample absorbance.

Gallic acid concentration (µg/mL)	Absorbance at 765 nm
20	0.142
40	0.284
60	0.431
80	0.573
100	0.718
Unknown (peel)	0.584

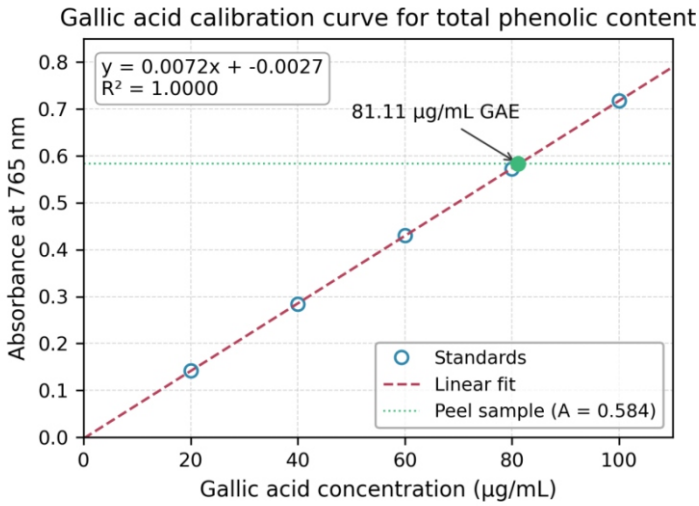

Figure 2. Gallic acid calibration curve for total phenolic content estimation.

4.5 DPPH antioxidant activity

The ability of ascorbic acid to inhibit the production of radicals was by far the highest with the strongest inhibition being observed at the lowest concentration tested with a value of approximately 93% at 0.004% (w/v) test concentration. The peel extract was also found to show a gradual increase in its inhibition performance as the concentration of the extract increased from no measurable inhibition at 200 µg to approximately 83% inhibition at 800–1000 µg. The seed extract was not as coherent, ranging from around 52% to 66% and tending to decrease with higher doses (Table 5, Figure 3). The peptide fraction also exhibited a more predictable antioxidant activity across all concentrations.

Table 5: DPPH radical-scavenging data for ascorbic acid, seed extract and peel extract (abs., absorbance at 517 nm; inh., inhibition)

Concentration (µg)	Ascorbic acid abs.	Ascorbic acid inh. (%)	Seed abs.	Seed inh. (%)	Peel abs.	Peel inh. (%)
Control	0.435	–	0.424	–	0.420	–
200	0.085	80.46	0.142	66.51	0.427	0.0
400	0.056	87.13	0.162	61.79	0.105	75.0
600	0.042	90.34	0.147	65.33	0.085	79.76
800	0.031	92.87	0.152	64.15	0.070	83.33
1000	–	–	0.202	52.36	0.070	83.41

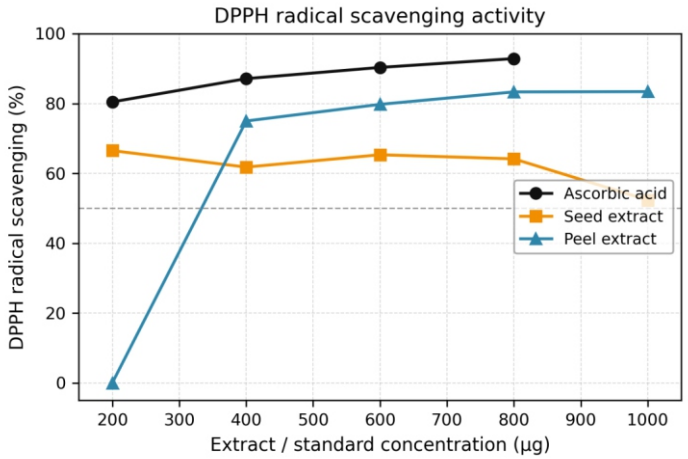

Figure 3. DPPH radical-scavenging activity of ascorbic acid, seed extract and peel extract across tested concentrations

4.6 Antibacterial activity

Only the ethanol peel extract inhibited growth and the only bacteria inhibited were *E. coli* with zones of 5 mm at 5 µg and 16 mm at 10 µg (Table 6, Figure 4). There was no zone of inhibition found against *S. aureus* and the ethanol seed and hexane peel extracts did not inhibit either organism. The zone size obtained with chloramphenicol was 9 mm (*E. coli*) and 8 mm (S. aureus) respectively, indicating good assay and culture conditions.

Table 6: Zones of inhibition in the agar well-diffusion assay.

Extract / control	Concentration	*E. coli* zone (mm)	S. aureus zone (mm)
Ethanol peel	5 µg	5	0
Ethanol peel	10 µg	16	0
Ethanol seed	5 µg	0	0
Ethanol seed	10 µg	0	0
Hexane peel	5 µg	0	0
Hexane peel	10 µg	0	0
Chloramphenicol (control)	10 µg	9	8

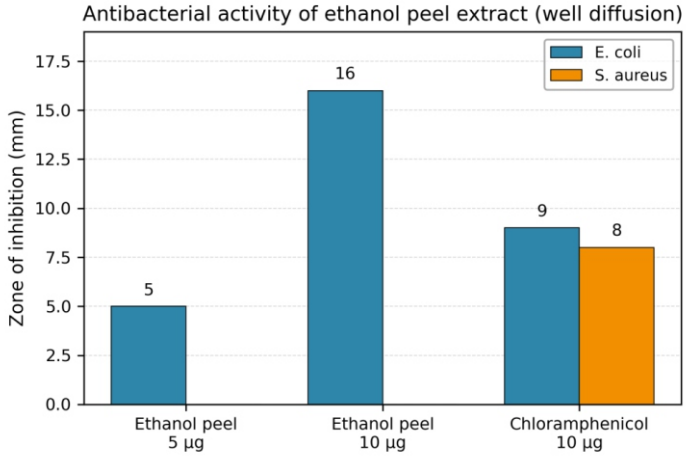

Figure 4. Antibacterial activity of the ethanol peel extract and the chloramphenicol control in the well-diffusion assay

4.7 Germination and growth-medium performance

Table 7 shows that both crops have 100% cumulative germination on cocopeat and on 1:1 foxtail-fibre–cocopeat blend. These differences were seen at the seedling stage. The blend increased shoot length and total seedling length of chana and increased root length in mung and total seedling length compared to control, and also improved seedling vigour index in both the crops (Table 8, Figures 5 and 6). More of the mung seedlings were dead/rotted (9 of 30) than the mung blend (3 of 30), suggesting that the blended medium may have improved drainage or aeration.

Table 7: Germination indices for chana and mung in cocopeat control and the foxtail-fibre–cocopeat 1:1 medium. MGT, mean germination time; GI, germination index; CVG, coefficient of velocity of germination

Group	Seed	Medium	n	Germination	Normal	Abnormal	Dead/rotted	MGT	GI	CVG
CHANA_CTRL	Chana	Cocopeat control	30	100%	30	0	0	4.77	6.59	20.98
CHANA_FOXT1:1	Chana	Foxtail fibre:cocopeat 1:1	30	100%	29	1	0	4.03	7.63	24.79
MUNG_CTRL	Mung	Cocopeat control	30	100%	21	0	9	4.43	7.07	22.56
MUNG_FOXT1:1	Mung	Foxtail fibre:cocopeat 1:1	30	100%	27	0	3	4.20	7.32	23.81

Table 8: Seedling growth parameters (mean ± SD) among normal seedlings after 10 days. SVI-I, seedling vigour index-I.

Group	Shoot length (cm)	Root length (cm)	Total length (cm)	SVI-I
Chana control	14.59 ± 2.93	5.22 ± 1.15	19.81 ± 3.45	1981.33
Chana foxtail 1:1	18.62 ± 3.87	5.75 ± 0.87	24.37 ± 4.34	2437.24
Mung control	15.71 ± 1.92	3.05 ± 1.32	18.76 ± 2.68	1875.71
Mung foxtail 1:1	16.22 ± 2.36	4.58 ± 1.30	20.80 ± 2.91	2080.37

4.8 Preliminary statistical comparison of seedling growth

Seedling growth was preliminarily compared using statistical analysis.

The shoot and total length of chana and root length of mung were significantly improved in the blended medium, while the root length of chana was on the borderline and shoot length of mung were not significantly different from each other (Table 9) when compared with the control medium by Welch t test. The p values presented should be interpreted with caution as each treatment had only one biological replicate.

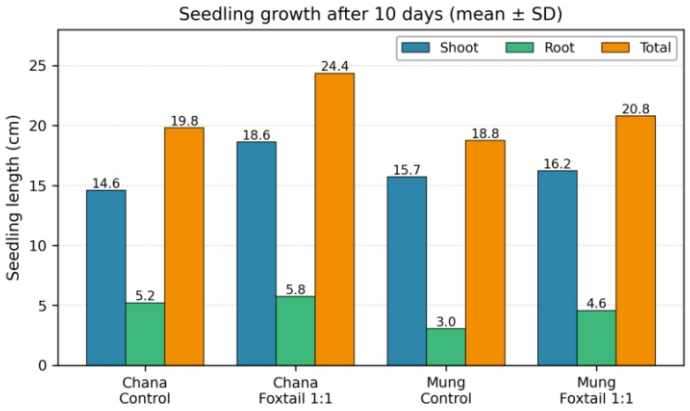

Figure 5. Shoot, root and total seedling length among normal seedlings after 10 days (mean ± SD)

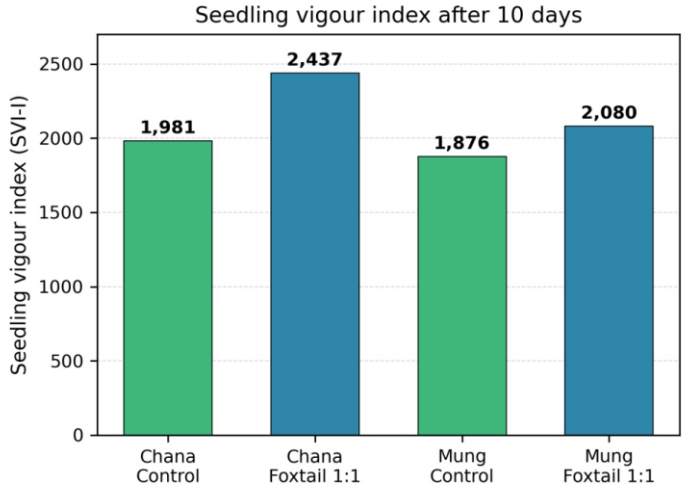

Figure 6. Seedling vigour index-I for control and foxtail-fibre–cocopeat 1:1 treatment

Table 9: Welch t-test results for seedling growth comparisons.

Comparison	Variable	Test	p-value	Interpretation
Chana ctrl vs foxtail 1:1	Shoot length	Welch t	0.000038	Higher in foxtail 1:1
Chana ctrl vs foxtail 1:1	Root length	Welch t	0.0508	Borderline; repeat needed
Chana ctrl vs foxtail 1:1	Total length	Welch t	0.000043	Higher in foxtail 1:1
Mung ctrl vs foxtail 1:1	Shoot length	Welch t	0.4106	No significant difference
Mung ctrl vs foxtail 1:1	Root length	Welch t	0.000233	Higher in foxtail 1:1
Mung ctrl vs foxtail 1:1	Total length	Welch t	0.0151	Higher in foxtail 1:1

5. Discussion

The main conclusion is that the ornamental fruit waste can be divided into useful streams. It was found that the ethanol peel extract yielded the highest amount and was also rich in phytochemical content with antimicrobial activity as the only fraction that demonstrated antimicrobial activity. This is consistent with the exposed nature of the peel and the fact that the phenolics and terpenoids are found there as a protective measure. The FTIR data (aliphatic C–H, ester carbonyl, C–O) confirms the presence of a reserve organ containing lipids rather than defensive metabolites, while the low level of ethanol production and the high production of oily hexane extract of the seed is consistent with a triglyceride-type fixed oil [11,12]. The extraction yields contain information.

The small absolute yields (less than 7%) for ethanol compared to the peel, confirm that the peel is a fibre-rich, lignified tissue type, not one devoid of tissue. The low hexane yields are not evidence of the lack of oil, but rather are a result of the small amount of crude mass which is obtained from 50 g of dry seed, and the oil-rich nature of this mass is why it was subjected to FTIR.

The phenol-positive screen is supported by the phenolic content of the peel (81.11 µg/mL GAE) and the concentration-dependent DPPH scavenging. It is important to note that the scavenging power of the seed extract decreased at higher concentrations; this is a desirable consideration because it indicates that the scavenging ability of the seed extract is either small or saturated at higher concentrations, and that high yield does not mean high scavenging power. The interpretation of the antibacterial picture was limited to *E. coli*. Well-diffusion results are indicative of both solubility and diffusion as well as potency [14] and the lack of activity against S. aureus may be due to either lack of relevant chemistry or to poor compound diffusion. The dose-response against *E. coli* (5 → 16 mm) is good and preliminary. In the horticultural sector, complete germination in the blended medium indicates the fibrous covering is not phytotoxic at the ratio being tested, and the increased vigour index for seedlings suggests a genuine though small improvement. The reduced number of dead/rotted mung seedlings in the blend suggests that there may have been greater aeration or lower waterlogging compared to cocopeat alone, which would be an interesting testable hypothesis. From these data, it is difficult to conclude whether the effect is due to physical properties or due to any mild bioactivity of the fibre constituents that can be leached out, or both are at work; both are possible and not mutually exclusive.

The results presented here should be interpreted as an indication, not as a proof. The study was a single batch screen; the extraction was not repeated, only two bacteria and two concentrations were tested, phytochemical identification did not go beyond the qualitative classes and the germination trial only had one biological replicate per treatment. Each of these options was very suitable for the first time around, but each one of them restricts the kind of claims that can be advanced. The p-values, in particular, are indicative. The merit of the work is to demonstrate that it's worthwhile to do at all for foxtail palm waste, and to outline a set of "rules" for converting fractions to applications that a larger-scale study could proceed.

6. Conclusion

The foxtail palm fruit waste was a true multifunctional biological resource, not a mere waste product. The ethanol peel extract gave the most yield and had the highest phytochemical content of measured phenolics and anti-*E. coli* activity with a dose-dependent relationship, whereas the hexane seed extract showed FTIR fixed-oil rich content of the extract with lipids making up the major component. The hard shell fibres, on the other hand, were able to germinate completely and to give better seedling vigour when mixed with cocopeat. Combined, the data indicate two alternative destinies for one waste stream: as a candidate bioactive extract and as a partial component of a growing-medium covering. Prior to any recommendation, the next steps are replication and compound identification, followed by longer growth trials.

7. Limitations and Future Work.

Structural constraints were the primary constraints.

Yield variability was not available because extraction was performed as a single batch; qualitative testing identified compound classes, not identification of individual molecules; FTIR provided information on functional groups, not identification; the DPPH assay was an in vitro screen; the two organisms tested for antibacterial activity were not chosen to reflect the diversity of the target group; medium physics (pH, EC, bulk density, porosity, water-holding capacity) were not measured and the germination trial only had 1 biological replicate per treatment. Further studies should include the extraction of flavonoids in addition to phenolics, identification of flavonoids by GC-MS, LC-MS or HPLC, MIC/MBC testing against additional bacterium strains, testing of other fibre:cocopeat ratios (25:75, 75:25, 100% fibre), and medium physicochemical properties measurements, and further extend plant tests beyond germination stage.

Declarations

Author contributions

Conceptualization, M.H.; methodology, M.H., R.K.S., S.S., H.P.H., H.P. and V.S.V.S.V.; investigation, R.K.S., S.S., H.P.H., H.P. and V.S.V.S.V.; data curation, R.K.S., S.S., H.P.H., H.P. and V.S.V.S.V.; writing—original draft preparation, all authors; writing—review and editing, M.H.; supervision, M.H.; project administration, M.H. All authors have read and agreed to the published version of the manuscript.

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Institutional review board statement

Not applicable. The study involved plant material only and no vertebrate or human subjects.

Informed consent statement

Not applicable.

Data availability statement

The data presented in this study are contained within the article. Raw spectral and measurement files are available from the corresponding author on reasonable request.

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Conflicts of interest

The authors declare no conflicts of interest.

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