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Diversity of fructo-oligosaccharides, antioxidants, and bioactive components in plantain peel as a function of genotype

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ABSTRACT

Plantains, a widely cultivated fruit crop, generate substantial peel waste, comprising approximately one-third of their total weight. Despite their potential, these peels are often discarded as waste. This study investigated the valorization of plantain peels as a source of functional carbohydrates, particularly fructooligosaccharides (FOS), and explored their phytochemical composition, focusing on phenolic compounds and antioxidant properties. FOS content was evaluated across 40 plantain varieties, ranging from 2.8 to 11.5%, with Lacatum-1, Manoranji Tham, and Nendran (unripe) exhibiting the highest levels. UPLC-QToF-ESI-MS/MS analysis identified 36 phenolic compounds in the peel extract, including chicoric acid, chlorogenic acid, ferulic acid, and p-coumaroyl tyrosine. Major flavonoids included rutin, catechin, myricetin and quercetin derivatives. Significant variations were observed in total phenolic content (TPC) and total flavonoid content (TFC). The highest TFC was recorded in Aayirakai Rasthali and Udayam, while Naadu and Virupakshi exhibited the highest TPC. Antioxidant activity, assessed using DPPH, ABTS, and FRAP assays, revealed IC_{50} values ranging from 49.3 to 125.7 µg/mL in DPPH, 54.1 to 127.8 µg/mL in ABTS, and 52.5 to 128.3 µg/mL in FRAP. This comprehensive study highlights the potential of plantain peel as a valuable source of functional carbohydrates and bioactive compounds, emphasizing its application in health-promoting and antioxidant-rich products.

Key words: Fructo-oligosaccharide, antioxidant activity, phenolics contents, UPLC, carbohydrate.

INTRODUCTION

Banana/plantain (*Musa paradisiaca*) is a major crop in India, contributing 37.2% to global banana production. Plantains, which are starchier and larger than bananas, are usually consumed unripe and cooked. The peel, comprising 30–40% of the fruit, is often discarded despite being rich in antioxidants and oligosaccharides. FOS-enriched plantains offer prebiotic, anti-inflammatory, and anti-cancer properties, with potential applications in food, animal feed, and traditional medicine (Sabater-Molina *et al.,* 9). Fructooligosaccharides (FOS), non-digestible carbohydrates with a degree of polymerization (DOP) ranging from 3–12, are composed of β (2→1) fructosyl-fructose bonds. Found in various plant parts, they serve as carbohydrate reserves and are recognized as GRAS (Generally Recognized As Safe) for their prebiotic and nutritional benefits (Belmonte-Izquierdo *et al.,* 4). Plantain peels rank among the highest in phenolic content compared to other fruit peels and are rich in bioactive compounds like phenolics, flavonoids, carotenoids, and tannins, exhibiting antioxidant, antidiabetic, and anti-inflammatory properties. Flavonoids such as kaempferol, quercetin, and myricetin effectively scavenge reactive oxygen species (ROS), reducing oxidative stress and chronic diseases. Also, the peels have higher protein, fat, and carbohydrate content than banana peels but lower fiber and ash. They are a rich source of nutrients, including minerals like potassium, calcium, and iron, and vitamins A, C, and B complex. Despite their nutritional value, plantain peels are often discarded, causing environmental issues such as waste accumulation and pollution. (Galankis *et al.,* 2021). Their phytochemical richness, including β-carotene, tocopherol, and gallocatechin, makes them valuable for sustainable applications, such as animal feed and waste management.

The phenolic content in plantain peels ranges from 11.8 to 90.4 mg/100g, significantly contributing to their antioxidant potential (Zamudio-Flores *et al.,* 18). Secondary metabolites include tannins, gallic acid, catechin, anthocyanin, and epicatechin, with gallocatechin levels in the peel nearly five times higher than in the pulp (Sidhu and Zafar, 10). Over 40 phenolic compounds, with a total phenolic content of 47 mg GAE/g dry matter, have been identified (Vu *et al.,* 16). Key flavonoids like kaempferol, quercetin, and myricetin act as potent ROS scavengers, reducing oxidative stress (Singh *et al.*, 12; Galanakis, 5). Variability in phenolic content and antioxidant activity among plantain/banana varieties is influenced by genetic, environmental, and ripening factors,

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as well as extraction methods. Nagarajaiah and Prakash (7) found water extracts exhibited the highest antioxidant activity compared to methanol and ethanol extracts. This study was done to address the gap of utilizing plantain peels as a sustainable source of functional carbohydrates, particularly FOS, while exploring their rich phytochemical composition and antioxidant potential for value-added applications in food and nutraceutical industries.

MATERIALS AND METHODS

For the variability assessment of phenolic compounds and antioxidant activity, analyses were conducted across forty plantain varieties. The selected varieties included Nendran, Kovvur Bontha, Nendran (ripe), Lacatum 1, Karthopium Tham, Ripe Seed Bhim Kol, Saba (ripe), Rasthali, Lataan-33, 969, Manoranji Tham, H-1, Ashy Bathesh, Vennudu Mannan, Kaveri Haritha, 31-Pisang Lin, Red Banana, Poovan Peel (ripe), Naadu, Sirumalai, Karpuravalli, Ney Poovan (ripe), NCR-17, Monthan Hybrid, Nakur-1, Grand Naine, Diploid Baralan, Matti Peel, Poovan, Aayirakai Rasthali, Virupakshi, Atti Kol, Udayam, Saba, Monthan (ripe), IITA-10, Neypoovan (unripe), Grand Naine (ripe), Popoulm, and Commercial Monthan Peel. The powdered samples of these varieties were supplied by ICAR-National Research Centre for Banana, Tiruchirapalli, Tamil Nadu, India.

Peels were washed, air-dried, chopped, and homogenized with acetone to remove chlorophyll. After grinding into fine powder (<1 mm), the FOS extraction was performed using ultrasound-assisted extraction (UAE) with parameters set at, amplitudes of 60, 80 & 100%, solvent-to-solute ratios of 10:1, 12:1 &14:1, and extraction times of 3,6, 9 minutes. The extract was treated with $Ca(OH)_2$ to remove proteins, neutralized with $H_3(PO_4)_2$, centrifuged, and precipitated with methanol to obtain the powdered extract. FOS content was determined using the equation:

FOS (%) = (Mass of extracted FOS/Mass of initial dried powder) × 100

The total phenolic content (TPC) of reagent extract was determined using the Folin-Ciocalteu method, with absorbance measured at 750 nm and expressed as gallic acid equivalents (GAE). The total flavonoid content (TFC) was quantified by reacting the extract with sodium nitrite, aluminum chloride, and sodium hydroxide, with absorbance also measured at 750 nm and expressed as quercetin equivalents (QE) using a calibration curve (62.5–1000 µg/mL). Phenolic variations across varieties were analyzed using UPLC-QToF-ESI-MS/MS, where extracts dissolved in methanol were filtered and injected into a gradient UPLC system with a mobile phase of water (A) and methanol (B) with 0.1% formic acid in both phases. A gradient program consisted of a constant flow rate of 0.2 mL/min of the solvent mixture, with the following time intervals: 0-5 min with 90% A, 5-10 min with 80%, 10-15 min with 60% A, 15-25 min with 50% A, 25-30 min 40% A, 30-34 min 30% A, 34-36 min 10 % A, 36-38 min 0% A and 38-40 min 90% A. The injection volume of the sample was 10 µL.

The antioxidant activity of the samples was evaluated using DPPH, ABTS, and FRAP assays. In the DPPH assay, 3.9 mL of the DPPH solution was added to 0.1 mL of the sample. The mixture was vortexed, and absorbance at 515 nm was measured after 30 minutes. Percent inhibition was calculated using equation 3.2, with IC_{50} values determined by plotting % inhibition against concentration, where lower IC_{50} values indicated higher antioxidant capacity.

% inhibition = 100 × (A_o - A)/A_o

where, A_o= net absorbance of DPPH (control) and A = net absorbance of sample.

In the ABTS assay, 0.3 mL sample was mixed with 2.7 mL of the ABTS solution, and absorbance was measured at 734 nm. % inhibition was calculated using equation 3.2. In FRAP assay, 3 mL of the FRAP reagent was added to 0.1 mL of the sample, vortexed, and incubated at 37 °C for 30 minutes. Absorbance was measured at 593 nm, and % inhibition was calculated using equation 3.2.

RESULTS AND DISCUSSION

The data presented in Table 1 showed the FOS (%) yield, TPC, TFC, and antioxidant activity (IC_{50} values) for various plantain varieties**.** The dietary fiber content in forty plantain varieties ranged from 2.80% to 11.45%, with high-yielding varieties like Lacatum-1, Saba unripe, Nendran unripe, and Manoranji Tham being ideal for dietary applications requiring high fiber (Slavin, 13). Moderate-yielding varieties like Matti peel and Grand Naine unripe offered a balanced fiber content, making them versatile for various dietary needs. Varieties with lower fiber yields, such as NCR-17 and Karthopium Tham, highlight the influence of genetic and cultivation factors on fiber content (Wang *et al.*, 17; Maria Perez *et al.,* 6). Udo *et al.* (15) reported fiber content ranging from 4.96% to 8.10%, with genetic factors and ripening stages contributing to this variability. Environmental factors, like soil type and climate, also significantly impact plantain nutrient composition, including fiber content. Figure 1 represents the variability of FOS content across varieties.

The variability in TFC and TPC among plantain varieties is influenced by genetic factors, environmental

Table 1: FOS (%) yield, Total Phenolic Content (TPC), Total Flavonoid Content (TFC), and Antioxidant Activity (IC_{50} values) for various plantain varieties.

S. No.	Variety	FOS (%) Yield	TFC (mg QE/100g)	TPC (mg GAE/100g)	IC_{50} DPPH (µg/mL)	IC_{50} FRAP (µg/mL)	IC_{50} ABTS (µg/mL)
1	NCR-17	4.14	392.67	998.91	76.96405	128.3039	84.1183
2	Ashy Bathesh	4.71	275.47	1002.47	63.61818	72.03353	69.09037
3	Nakur -1	4.61	454.37	945.21	65.89725	62.8977	99.16495
4	IITA-10	3.92	326.65	1511.35	52.75108	56.47184	105.4403
5	Grand naine	7.66	348.84	1013.24	70.7024	74.87859	68.23481
6	Sirumalai	2.99	345.13	986.59	93.41569	69.94338	92.95096
7	Virupakshi	5.02	559.42	1506.44	55.92357	94.9256	100.9296
8	Grand naine(Ripe)	3.29	377.46	1108.82	50.44177	74.37581	61.59159
9	Neypoovan	8.22	400.87	1461.42	72.74563	65.08467	56.80415
10	Manoranji Tham	10.98	291.99	1208.95	57.0794	91.81863	91.50325
11	31-Pisang Lin	4.92	273.44	1191.7	71.70792	122.9128	70.14258
12	Karpuravalli	3.43	471.92	978.14	61.27394	82.83063	98.76515
13	Poovan peel (ripe)	4.94	459.68	1141.88	118.5403	90.68566	54.07026
14	Lacatum 1	11.45	421.92	1034.51	64.78836	87.77719	90.85978
15	H 1	7.94	399.39	1099.22	125.6786	84.20328	106.2415
16	Monthan hybrid	3.31	419.52	1478.44	68.95095	116.1584	92.29172
17	Kaveri Haritha	5.90	223.06	1478.38	81.09418	52.51433	85.99578
18	Udayam	5.98	535.03	1169.95	59.26952	93.14738	68.25731
19	Vennudu Mannan	3.17	466.15	1399.97	76.02643	58.63131	87.74257
20	Popoulm	3.07	460.83	1225.9	103.0018	76.01467	84.16862
21	Nendran	8.53	273.95	1327.63	93.73682	90.97702	80.55617
22	Naadu	3.28	487.28	1512.48	72.47476	82.60532	72.78724
23	Atti kol	5.81	387.28	1419.54	68.67726	121.4047	69.011
24	Karthopium tham	2.80	247.92	1047.3	87.56677	59.56754	83.39288
25	Red banana	7.67	274.73	906.24	116.299	75.14848	89.77988
26	Ripe seed bheem kol	5.02	233.96	1167.05	82.01063	107.0596	67.76862
27	969	3.35	486.53	1069.39	103.7499	89.50365	115.8562
28	Monthan	4.84	232.64	959.46	119.7631	59.04827	79.59521
29	Rasthali	6.71	235.22	1340.99	99.58619	74.90218	77.00921
30	Saba (ripe)	6.85	461.29	1475.24	105.1599	110.8628	59.58923
31	Poovan	3.08	489.33	970.3	98.32057	119.7168	69.36442
32	Nendran (unripe)	9.54	354.47	1131.06	74.93689	108.3685	115.4412
33	Commercial monthan peel	4.20	300.57	1491.6	121.7796	73.18012	102.6613
34	Saba	11.04	360.3	1248.94	89.61415	79.86385	91.6873
35	Kovvur Bontha	8.82	348.21	1000.23	91.60544	81.0046	118.8584
36	Ney poovan (ripe)	4.30	517.03	910.69	94.17576	110.4441	120.2143
37	Diploid baralan	2.96	233.93	1453.06	85.23691	124.6496	89.15622
38	Aayirakaai Rasthali	6.03	571.75	1243.73	114.7016	74.29377	103.7708
39	Laatan 33	11.08	352.38	1248.17	100.832	111.6774	75.43278
40	Matti peel	6.25	207.98	1067.29	106.5486	70.6723	128.852

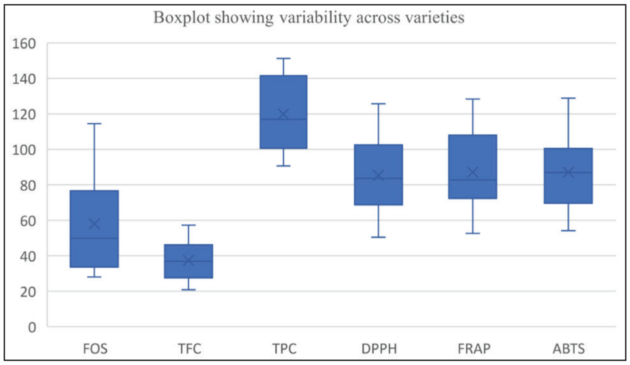

Fig. 1. Distribution of attributes across 40 varieties: Boxplot visualization.

conditions, and harvest maturity. Aayirakai Rasthali (571.75 mg QE/100 g), Virupakshi (559.42 mg QE/100 g), and Udayam (535.03 mg QE/100 g) showed the highest TFC, indicating strong antioxidant potential. Naadu (1512.48 mg GAE/100 g), IITA-10 (1511.35 mg GAE/100 g), and Virupakshi (1506.44 mg GAE/100 g) had the highest TPC, suggesting their value in functional food and nutraceutical development. Lower values in Matti Peel and Kaveri Haritha may be due to genetic or biosynthetic factors. Studies have shown that phenolic compounds and flavonoids contribute significantly to antioxidant activity by scavenging free radicals and preventing oxidative stress in biological systems, this aligns with findings by Pérez *et al.,* 2023, who reported that environmental factors and genotype strongly influence phenolic and flavonoid content in plant materials. The findings emphasize selecting high TFC and TPC plantain varieties like Virupakshi and Naadu for antioxidant-rich functional foods with health benefits.

Antioxidant activity of plantain varieties was assessed using three assays: DPPH, ABTS, and FRAP. The IC_{50} values obtained from the ABTS assay revealed significant variability, with Poovan Peel Ripe (54.04 µg/mL), Neypoovan (56.86 µg/mL), and Saba (59.58 µg/mL) demonstrating the strong antioxidant activity and free radical scavenging potential. Similarly, the FRAP assay highlighted substantial differences in reducing capacity among the varieties. IITA-10 (56.47 µg/mL), Kaveri Haritha (52.51 µg/mL), Vennudu Manan (58.63 µg/mL), and Karthopium Tham (59.56 µg/mL) exhibited the lowest IC_{50} values, reflecting strong antioxidant potential and reducing ability. In the DPPH assay, unripe Grand naine (49.34 µg/mL), followed by IITA-10 (57.89 µg/mL), Virupakshi (55.92 µg/mL), Manoranji tham (57.07 µg/mL) and Udayam (59.26 µg/mL) exhibited the strongest antioxidant potential. Overall, the variability in IC_{50} values across all assays underscores the influence of genetic and environmental factors on the antioxidant potential of plantain varieties, highlighting specific varieties as optimal candidates for antioxidant-enriched functional foods and dietary supplements. Parvez *et al.* (8) compared three unripe banana varieties Dimkumari, Sagor, and Madna, using methanol and ethyl acetate extracts. Dimkumari peel's methanolic extract had the highest phenolic content (10.2 ± 0.9 mg/g GAE) and flavonoid content (9.3 ± 0.4 mg/g CAE) whereas Madna peel exhibited the highest antioxidant activity with 39.0 ± 0.7 mg/g AAE and 69.44% DPPH scavenging. Siji *et al.* (11) also analyzed eight banana varieties in Kerala, finding significant variability. Kadali had the highest phenolic content (11.6 mg GAE/100g) and flavonoid content (9.5 mg QE/100g), while Red Banana had the lowest phenolic (3.5 mg GAE/100g) and flavonoid (3.6 mg QE/100g) content.

UPLC-QToF-ESI-MS/MS analysis further facilitated a comprehensive characterization of phenolic compounds in plantain. A total of 36 compounds were identified based on their accurate molecular masses. These compounds included a range of phenolic acids and flavonoids, as confirmed by their retention times and specific molecular ion peaks as shown in Table 2 and Fig 2. The identification of these bioactive compounds aligns with prior studies demonstrating the abundance of phenolic acids and flavonoids in plant-based extracts, for instance, Tsamo *et al.* (14) analyzed nine plantain cultivars, identifying hydroxycinnamic acids as dominant phenolics, with ferulic acid-hexoside levels ranging from 4.4 to 85.1 µg/g DW, the highest in Mbeta 1 (85.1 ± 13.5 µg/g DW). Peels were rich in flavonols, especially rutin (242.2–618.7 µg/g DW), with Gros Michel peels having the highest rutin content (494.4 ± 153.7 µg/g DW). HPLC confirmed the presence of phenolics like myricetin-deoxyhexose-hexoside and sinapic acid-hexoside. Similarly, Babu *et al.* (2) studied four banana varieties, showing the green variety had the highest phenolic content (180 µg GAE/mg) and the

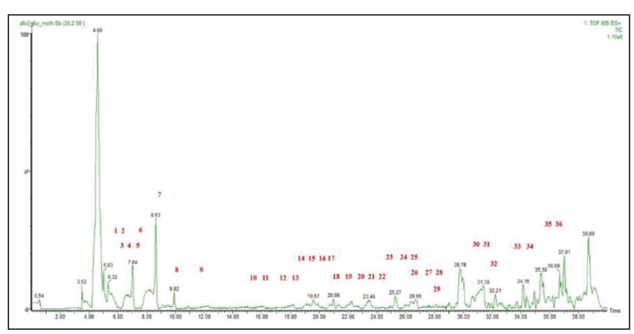

Fig. 2. Total ion chromatogram (TIC) of phenolic compounds analyzed in UPLC-QToF-ESI-MS.

Table 2: Identification of phenolic compounds present in FOS by UPLC-QToF-ESI-MS.

Peak	RT (min.)	Proposed compound	Formula	Neutral mass (Da)	Obs $[M+H]^+$	MS/MS fragments	Mass error (ppm)
		PHENOLIC ACIDS					
(i) Hydroxy-cinnamic acid							
3	6.96	Chicoric acid	$C_{22}H_{18}O_{12}$	474.0798	475.0868	271, 311, 162, 135	-1.68
10	16.05	Chlorogenic acid	$C_{16}H_{18}O_9$	354.0950	355.1028	193, 171, 163	2.53
15	19.72	Cinnamic acid	$C_9H_8O_2$	148.0524	149.0621	119, 103, 91, 77	-5.36
16	20.22	Caffeoyl glucose	$C_{15}H_{18}O_9$	342.2750	343.2845	323, 175, 161	3.95
20	23.58	Ferulic acid	$C_{10}H_{10}O_4$	194.0859	195.0928	175, 149, 134	-4.61
35	36.18	p-coumaroyl tyrosine	$C_{18}H_{17}NO_5$	327.1106	328.1190	310, 181, 148	1.82
11	16.24	Caffeic acid	$C_9H_8O_4$	180.0422	181.0539	163, 135, 119	-3.86
1	5.47	Sinapic acid	$C_{11}H_{12}O_5$	224.0684	225.0745	207, 181, 163, 150, 137	2.22
14	19.20	5,5-dihydro-diferulic acid	$C_{20}H_{18}O_8$	386.1002	387.1077	339, 194, 149	-0.77
21	24.89	Ferulic acid hexoside	$C_{16}H_{20}O_9$	356.3092	357.3153	339, 149	-4.75
23	25.26	p-coumaroyl glycolic acid	$C_{11}H_{10}O_5$	222.1838	223.1922	205, 171	-4.12
(ii) Hydroxyphenylpropanoic acid							
31	31.02	3-hydroxyphenyl propanoic acid	$C_9H_{10}O_3$	166.0529	167.0615	149, 138, 121	3.78
24	26.55	3-hydroxy-3-(3-hydroxy phenyl) propanoic acid)	$C_9H_{10}O_4$	182.0579	183.0649	152, 135	-3.37
		FLAVANOIDS					
Flavanols							
2	5.87	Myricetin	$C_{15}H_{10}O_8$	318.0375	319.0474	301, 267, 155, 181, 125	-5.01
25	26.70	Catechin	$C_{15}H_{14}O_6$	290.1790	291.1856	245, 203, 178, 149, 125	-4.19
27	29.79	Procyanidin dimer B 1	$C_{30}H_{26}O_{12}$	578.2654	579.2744	446, 302, 279	2.55
36	37.29	Procyanidin trimer C 1	$C_{45}H_{38}O_{18}$	866.2058	867.2099	453, 721, 301, 452	-3.26
34	35.79	Cinnamtannin A 2	$C_{60}H_{50}O_{24}$	1154.2690	1155.2788	577, 452, 289, 425	1.73
(i) Flavanones							
12	18.32	Hesperetin-3'-sulfate	$C_{16}H_{14}O_9S$	382.0359	383.0447	301, 284	2.61
(ii) Flavones							
9	12.66	Chrysin	$C_{15}H_{10}O_4$	254.0579	255.0668	235, 209, 147	4.31
(iii) Flavonols							
18	21.34	Quercetin 7-O- hexoside	$C_{21}H_{20}O_{12}$	464.0954	465.1050	446, 301, 271	-1.61
17	20.80	Rutin	$C_{27}H_{30}O_{16}$	610.1533	611.1699	301, 150	1.30
28	28.13	Kaempferol	$C_{15}H_{10}O_6$	286.1067	287.1142	257, 139, 148	-1.04
13	18.67	Quercetin deoxy hexose-hexoside	$C_{33}H_{40}O_{21}$	772.3632	773.3694	619, 301, 175	-1.55
19	22.78	Isorhamnetin-3-O-Rutinoside	$C_{28}H_{32}O_{16}$	624.5560	625.5616	627, 315	-3.51
26	26.80	Kaempferol-3-O-Rutinoside	$C_{27}H_{30}O_{15}$	594.3532	595.3604	573, 291	-1.00
30	31.74	Methyl myricetin deoxyhexose-hexoside	$C_{28}H_{32}O_{17}$	640.4431	641.4503	327, 620	-0.93
(iv) Isoflavanoids							
4	6.69	3-hydroxyphloretin 2'-O-glucoside	$C_{21}H_{24}O_{11}$	452.3162	453.3224	389	-3.52
8	9.59	5,6,7,3',4'-pentahydroxyisoflavone	$C_{15}H_{10}O_7$	302.0427	303.0450	273, 149	2.63

Contd...

Table 2 contd...

Peak	RT (min.)	Proposed compound	Formula	Neutral mass (Da)	Obs $[M+H]^+$	MS/MS fragments	Mass error (ppm)
Dihydrochalcones							
29	29.81	Phloridzin	$C_{21}H_{24}O_{10}$	436.1779	437.1870	279, 302, 149	2.97
Other polyphenols							
(i) Stilbene							
6	8.15	3-hydroxy 3,4,5,4'-tetramethoxy stilbene	$C_{17}H_{18}O_5$	302.1154	303.1220	273, 149	-3.97
(ii) Hydroxycoumarin							
32	32.64	Esculin	$C_{15}H_{16}O_9$	340.2434	341.2503	167, 151	-2.63
33	34.67	Esculetin	$C_9H_6O_4$	177.1441	178.1509	158, 139	-5.61
Others							
22	23.44	Unknown	$C_{10}H_{23}O_6$	239	240.2224	-	-
5	7.06	Unknown	$C_{20}H_{24}O_4$	328	329.1545	-	-
7	8.58	Unknown	$C_{12}H_{22}O_8$	294	295.1810	-	-

yellow variety had the lowest flavonoid content (3.06 µg QE/mg). Arun *et al.* (1) also reported the Nendran variety's peel extract had the highest phenolic (15.21 mg GAE/g) and flavonoid (9.39 mg QE/g) content, with strong antioxidant activity (DPPH IC_{50} 55.23 µg/mL). Major phenolics included gallic acid, quercetin, & chlorogenic acid. Additionally, Bashmil *et al.* (3) found Australian plantain peels had higher phenolic (0.87 mg GAE/g) and flavonoid (0.03 mg QE/g) content than the pulp, with strong antioxidant activity in DPPH, FRAP, and ABTS assays, revealing 24 phenolic compounds including caffeic and ferulic acids via LC-ESI-QTOF-MS/MS.

This biplot shows the relationship between 40 different varieties, represented by points, and their corresponding attributes, including FOS content, TPC, TFC, and antioxidant activity (Fig. 3). The axes represent the first two principal components (PC1 and PC2), which capture the maximum variance in the data. The vectors (arrows) represent the contribution of each attribute to the principal components, with the length and direction of the arrows indicating the strength and influence of each attribute on the variability observed across the varieties.

In conclusion, the study revealed significant variability in dietary fiber, TPC, and TFC across 40 plantain varieties, emphasizing their diverse bioactive potential. High-yielding varieties like Lacatum-1, Saba (unripe), and Nendran (unripe) showed the highest fiber content, while NCR-17 and Karthopium Tham had the lowest. TPC ranged from 906.56–1512.44 mg GAE/100 g, with Naadu, IITA-10, and Virupakshi showing the highest values, whereas Aayirakai Rasthali, Virupakshi, and Udayam

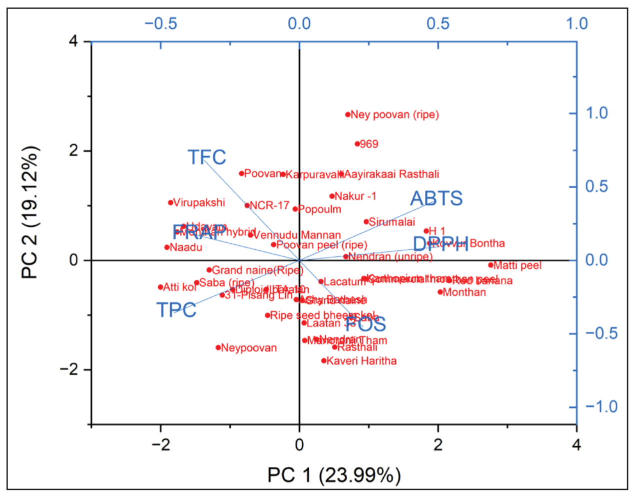

Fig. 3. PCA biplot showing variability across samples and key variables.

demonstrated the highest TFC (223.45–571.89 mg QE/100 g). Antioxidant activity evaluation using DPPH, ABTS, and FRAP assays identified varieties like Poovan Peel Ripe, Neypoovan, and Saba as optimal for ABTS; IITA-10, Kaveri Haritha, and Vennudu Manan for FRAP; and unripe Grand Naine for DPPH, indicating their potential as antioxidant-rich candidates for functional food products. Moreover, UPLC-QTOF-ESI-MS analysis identified 36 phenolic compounds, including phenolic acids (chicoric acid, chlorogenic acid, ferulic acid) and flavonoids (rutin, quercetin derivatives, kaempferol, catechin, and procyanidins), underscoring the rich diversity of bioactive compounds in plantain peels. These findings highlight the immense potential of plantain peel for applications in food and nutraceutical industries.

AUTHORS' CONTRIBUTION

Conceptualization of research (SS, PS); Designing of the experiments (SS, AK); Contribution of experimental materials (PSK, PS, SS); Execution of lab experiments and data collection (PS); Analysis of data and interpretation (PS, SS); Preparation of the manuscript (PS).

DECLARATION

The authors declare no conflict of interest

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