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# Antioxidant and antimicrobial activities of mango peel and radish peel—a comparative investigation

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The present study investigated the antioxidant and antimicrobial activities of Bao mango and daikon radish peel (Thai variety) ethanolic extracts. The percentage extraction yield of radish peel was higher compared to the mango peel ( $p < 0.05$ ). However, Mango peel extract (MPE) contained higher total phenolic content (TPC) than radish peel extract (RPE) ( $p < 0.05$ ). Similar to the TPC value, antioxidant activities including DPPH radical scavenging activity, reducing power, and peroxidation inhibition were higher in the MPE, compared to the RPE, except for metal chelating activity. The antimicrobial analyses suggested that the MPE showed lower minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values compared to the RPE ( $p < 0.05$ ) against Gram-positive and Gram-negative bacteria. High-performance liquid chromatography (HPLC) revealed that mangiferin was the major phenolic compound present in MPE, followed by 3, 4 dihydroxybenzoic acid. Therefore, MP could be used as a promising natural antioxidant and antimicrobial agent for food applications.

## KEYWORDS

recycling, sustainability, waste utilization, antioxidant, antimicrobial

## 1 Introduction

Fruits and vegetables are the most commonly consumed commodities among all horticultural crops. Hence, the production and processing of these horticulture products have increased exponentially to fulfill their increasing demands. In Thailand, an increase in agricultural production has been reported by the Office of Agricultural Economics (OAE), and it was reported that the agricultural gross domestic product (GDP) of 2021 expanded by 1.7 to 2.7%, compared to the year 2020 (OAE, 2019; Nation, 2021). Similarly, these industries generated 10–60% of waste in the form of peels, seeds, pomace, etc. (Kaur et al., 2019). The Food and Agriculture Organization of the United Nations (FAO) reported that annual global food waste is at least one-third (1.3 billion tons) of the food produced, and most of the food loss occurs in the horticulture sector. An increase in agricultural production will bring about increased waste. Most of these wastes are simply dumped in municipal landfills, causing health hazards due to environmental pollution.

The utilization of this waste for the recovery of added-value compounds offers a new avenue for waste management, industrial growth, and the country's economy. Generally, these wastes contain large amounts of polysaccharides, fibers, pigments, minerals, and phytochemicals (Kumar et al., 2017). The extraction of phytochemical compounds can be a sustainable and lucrative alternative due to their broad spectrum of bioactivities (Nirmal et al., 2015). The phytochemicals mostly present in fruit and vegetable waste (FVW) are polyphenols, flavonoids, carotenoids, isoflavones, phenolic acid, tannins, isothiocyanates, lignans, saponins, etc. (Nirmal et al., 2023b). Many *in-vitro* and *in-vivo* studies provide evidence that various phytochemicals extracted from plant waste material showed prevention or control of various diseases, including diabetes, cancer, cardiovascular disorders, hypertension, etc. (Nirmal et al., 2015; Rajput et al., 2022). In addition, these plant waste extracts or phytochemicals act as natural preservatives and increase the shelf life of various food systems, including shrimp, mincemeat, fish fillets, etc. (Rathod et al., 2023; Nirmal et al., 2023b). Thus, for value addition to waste, the extraction of bioactive and functional compounds is the best approach (Leong and Chang, 2022).

Globally, a large amount of mango (*Mangifera indica*) peel waste is generated during mango juice processing. As per the 2020 report of the FAO, the total quantity of mangoes exported from Thailand was nearly 339,917 tonnes in 2022 (FAO, 2023), and during the processing of mangoes, fruit culls, peels, and seeds make 35–60% of the total weight that is discarded as waste (Manhongo et al., 2021). At the same time, mango peel has been frequently reported to have a high bioactive compound content, including flavonoids, phenolic acids, fiber, vitamins, carotenoids, etc. (Okino-Delgado et al., 2020). Mangiferin (a xanthone), one of the most abundant and potent antioxidants, has been identified in *Mangifera indica* L. var. (Zafra Ciprián et al., 2023). On the other hand, radish extract is reported to have strong antimicrobial activity (Maqbool et al., 2020). Primarily, radish contains flavonoids and isothiocyanate (4-(methylthio)-3-butenyl isothiocyanate, benzyl isothiocyanate, allyl isothiocyanate, and phenethyl isothiocyanate). Lugasi et al. (2005) investigated the *in vitro* antioxidant activities of radish peel, and L-tryptophan was identified to possess antioxidant activity. Moreover, radish root extract prevents membrane alterations induced by a high-fat diet and stimulates scavenging activity in rats, thus safeguarding cell membranes from lipid peroxidation (Sipos et al., 2002). However, a few or no reports on the antioxidant and antimicrobial activities of the ethanolic extracts from Bao mango (*Mangifera indica* L. var.) from the south of Thailand and from Daikon radish (*Raphanus sativus* var. Longipinnatus) grown in Thailand exist. Therefore, the present study investigated total phenolic content, antioxidant and antimicrobial potential of Bao mango peel and Daikon radish peel ethanolic extracts. Furthermore, the major phytochemicals present in Bao mango peel extract were also determined.

## 2 Materials and methods

### 2.1 Raw material

Radish peel (Daikon/White Radish, *Raphanus sativus* var. Longipinnatus) waste was collected from MK restaurant in Nakhon Pathom province, Thailand, whereas Thai indigenous mango peel

(Bao mango, *Mangifera indica* L. var.) waste was received from Promsap (Thailand) Company Limited, Hat Yai, Songkla, Thailand. Only peels from either mango and radish were collected and washed to remove any dust or foreign particles.

### 2.2 Preparation and extraction of mango and radish peel

The peel was dried overnight in a hot air oven at 50°C until the moisture content was reduced to less than 10%. Afterward, each dried sample was ground to powder with the blender and sieved with a stainless-steel sieve of mesh size 35. Each sample was extracted with 80% ethanol solvent (5 g/250 mL) at 40°C for 2 h using a temperature-controlled hot plate magnetic stirrer (IKA C-MAG HS7, Don Mueng, Bangkok, Thailand). Then, the mixture was filtered using Whatman filter paper no. 1, and the filtrate was concentrated using an Eyela rotary evaporator (Eyela USA, NY, United States) at 40°C. The concentrated extract was collected and lyophilized.

The extraction yield was calculated by dividing the weight of the extract powder by the weight of the initial sample and multiplying by 100.

### 2.3 Total phenolic content

Initially, properly diluted extract (200 µL) was added with 10% Folin–Ciocalteu reagent (1 mL) and stood for 3 min at room temperature. Thereafter, 1 mL of a 2% sodium carbonate solution was added to the mixture and left to stand for 30 min under dark conditions. The absorbance of the reaction mixture was read at 760 nm using a spectrophotometer (Perkin Elmer LS 55, United States). For the blank, deionized water was used instead of the Folin–Ciocalteu reagent in the sample blank, and the extract was excluded and ethanol was used instead in the control. The concentration of total phenolic compound in the extracts was calculated from the standard curve of quercetin with a range of 1–10 µg/mL and expressed as µg QE/ g of extract powder.

### 2.4 DPPH radical scavenging assay

Briefly, diluted extract (1 mL) was added to 1 mL of DPPH (0.15 mM) prepared in 95% ethanol and incubated for 30 min at room temperature in dark conditions (Nirmal and Benjakul, 2011). The absorbance of the mixture was read at 517 nm using the UV spectrophotometer. The sample blank was prepared using ethanol instead of a DPPH solution, while the control consisted of a DPPH solution and ethanol. The percentage inhibition of DPPH radical was calculated using the following equation and results were expressed as the IC<sub>50</sub> value (µg/ mL):

Percentage inhibition of DPPH radical

$$= \left( 1 - \left( \frac{A_{\text{sample}}}{A_{\text{control}}} \right) \right) \times 100$$

where  $A_{\text{sample}}$  and  $A_{\text{control}}$  are the absorbance of sample and control, respectively.

## 2.5 Reducing power assay

A diluted extract in phosphate buffer (500  $\mu$ L, 0.2 M, pH 6.6) was mixed with 1% potassium ferric cyanide (500  $\mu$ L), and the mixtures were incubated at 50°C for 20 min (Nirmal and Panichayupakaranant, 2015). Thereafter, 500  $\mu$ L of 10% trichloroacetic acid was added and cooled at room temperature. The mixtures were centrifuged at 1000  $\times$  g for 10 min and the supernatant (500  $\mu$ L) was added to the deionized water (500  $\mu$ L) and 0.1% ferric chloride (100  $\mu$ L) mixture. The preparation of each sample blank and the control were managed similarly. The phosphate buffer was used instead of potassium ferric cyanide in the sample blank and instead of extract in the control. The absorbance of the reaction was read at 700 nm. A higher absorbance of the sample indicated a higher reducing capacity.

## 2.6 Metal chelating assay

The assay was conducted as mentioned by Nguyen et al. (2023). Briefly, 1 mL of each sample (0.25–4 mg/mL) was added to the 25  $\mu$ L of 2 mM FeCl<sub>2</sub> · 4H<sub>2</sub>O. Afterward, 5 mM ferrozine (100  $\mu$ L) was mixed with the mixture and vortexed. After incubation at room temperature for 10 min, the absorbance of the sample was recorded at 562 nm. EDTA was used as the positive control in this assay. The percentage of the chelating ability of the sample was determined using the following equation and the results were expressed as the IC<sub>50</sub> value (mg/mL).

$$\text{Chelating ability (\%)} = \frac{(A_0 - A_s)}{A_0} \times 100$$

where A<sub>0</sub> = Abs of control sample (95% Ethanol + FeCl<sub>2</sub> · 4H<sub>2</sub>O + Ferrozine)

A<sub>s</sub> = Abs of a sample

## 2.7 Linoleic acid peroxidation method

The fatty acid emulsion was prepared using linoleic acid (0.28 g), Tween-40 (0.28 g), and 50 mL of phosphate buffer (0.2 M, pH 7.0) as mentioned by Jayaprakasha et al. (2001). Each diluted sample in 75% ethanol (0.5 mL) was mixed with emulsion (2.5 mL) and phosphate buffer (2.5 mL) and incubated at 37°C for 120 h. The peroxidation of fatty acid emulsion was examined using the thiocyanate method. Briefly, 0.1 mL of the emulsion mixture was taken every 24 h to mix with 5.0 mL of ethanol (75%), 0.1 mL of ammonium thiocyanate (30%), and 0.1 mL of FeCl<sub>2</sub> (20 mM in 3.5% HCl). The absorbance of the reaction mixture was read at 500 nm after standing at room temperature for 3 min. The control was prepared using 75% ethanol instead of the sample in the same manner.

## 2.8 Gram-positive and gram-negative bacteria inhibition assay

Minimal inhibitory concentration (MIC) was determined using the broth microdilution assay as described by Htoo et al. (2019). Bacterial cultures Gram-positive (*Staphylococcus aureus*-ATCC 29213 and *Bacillus subtilis*-PY 79), and Gram-negative (*Escherichia coli*-ATCC 25922, and *Salmonella typhimurium*-DMST 562) were grown

on trypticase soy agar (TSA) plates. The freshly grown colonies were transferred to tryptic soy broth (TSB) until the absorbance of 0.2 was achieved at 600 nm. A 96-well plate was prepared with mango peel extract (MPE) or radish peel extract (RPE) with serial dilution. Subsequently, bacterial culture was diluted to 1:100 into each 96-well plate to obtain the final bacterial concentration of 10<sup>5</sup> CFU/mL. The plates were incubated at 30°C for 24 h and were visually observed for bacterial growth. The MIC of the sample was noted where there was no bacterial growth.

The medium from each MIC well that showed no apparent growth was removed and subculture onto Mueller-Hinton agar (MHA) plates. To determine the minimal bactericidal concentration (MBC), the MHA plates were incubated at 30°C for 24 h to observe the growth of bacteria.

## 2.9 Determination of phenolic profile

The sample with higher antioxidant and antimicrobial activities was subjected to high-performance liquid chromatography-electrospray ionization tandem mass spectrometry (HPLC-ESI-MS/MS) to examine the phytochemicals in the selected extract. The procedures mentioned by Sirichai et al. (2022) and Chupeerach et al. (2022) were followed. The standard phenolic compounds include 3,4-dihydroxybenzoic acid, genistein, caffeic acid, hesperidin, (–)-epigallocatechin gallate, 4-hydroxybenzoic acid, apigenin, kaempferol, cinnamic acid, chlorogenic acid, naringenin, *p*-coumaric acid, ferulic acid, mangiferin, sinapic acid, syringic acid, quercetin, myricetin, vanillic acid, gallic acid, rutin, and galangin and rosmarinic acid (Sigma-Aldrich, St. Louis, MO, United States) were used as the standards.

## 2.10 Statistical analysis

All experiments were performed in triplicates and the results are expressed as mean  $\pm$  standard deviation. One-way analysis of variance (ANOVA) followed by Duncan's tests was used to evaluate significant differences. All the statistical analysis was conducted using SPSS, and significant differences between treatments were considered significant at  $p < 0.05$ .

## 3 Results and discussion

### 3.1 Extraction yield and total phenolic content (TPC)

The percentage extraction yield of radish peel (39.12%) was higher compared to the mango peel extract powder (18.41%) ( $p < 0.05$ ). Safdar et al. (2017) reported that mango peel extracted using 80% methanol achieved higher extraction yield, but higher TPC was noted in 80% ethanol solvent. On the other hand, Janjua and Shahid (2013) reported that radish peel (*R. sativus*) extracted using 80% ethanol achieved a higher extraction yield (5.6%) compared to the petroleum ether (5%), and methanol (4.2%) extract. The extraction yield of radish peel in this study was higher compared to the report of Janjua and Shahid (2013). It was noted that Janjua and Shahid (2013)

extracted radish peel samples at room temperature, whereas this study used 40°C temperature for the extraction. Hence, the extraction yield of any plant material is affected by the type of solvent, temperature, time of incubation, and most importantly plant material structural integrity and presence of phytochemicals (Nirmal et al., 2023b).

TPC in the mango peel powder was significantly ( $p < 0.05$ ) higher than that of the radish peel powder. The TPC in the MPE sample was  $280.5 \pm 7.95$   $\mu\text{g}$  quercetin/ g of extract powder, whereas  $25.92 \pm 0.32$   $\mu\text{g}$  quercetin/ g of extract powder was found in the RPE sample (Table 1). Earlier, Noor et al. (2015) reported that the *Mangifera indica* L. var. Perlis Sunshine mango peel contained a TPC value of 21.7 mg/g of peels. The mango peel is known to have a higher TPC and free radical scavenging activity compared to the mango pulp (Abbasi et al., 2015; Agatonovic-Kustrin et al., 2018). On the other hand, Noman et al. (2021) reported that the TPC content in white radish leaves (125.3 GAE/g) was higher than the root (95.8 GAE/g). Also, extraction methods have a significant effect on the TPC of fruits and vegetable wastes, as Martínez-Ramos et al. (2020) documented that the optimal extraction is dependent on the solvent employed. Ethanol-acetone blend yielded the extract exhibiting the highest activity compared to the extract obtained from conventional extraction of mango (*Mangifera indica* L.) peel. Therefore, MPE had higher TPC content than RPE.

## 3.2 Antioxidant activities

### 3.2.1 DPPH radical scavenging activity

The  $\text{IC}_{50}$  values of MPE and RPE for DPPH free radical scavenging capacity are presented in Table 1. The lower the  $\text{IC}_{50}$  value, the higher the inhibitory activity of the compound was. For DPPH radical scavenging activity, the  $\text{IC}_{50}$  value of MPE was  $35.09 \pm 0.00$   $\mu\text{g}/\text{mL}$ , exhibiting higher scavenging activity, compared to the RPE ( $2,552.1 \pm 17.9$   $\mu\text{g}/\text{mL}$ ) ( $p < 0.05$ ). This result was in agreement with the TPC value of respective samples where higher TPC content was noted in MPE compared to the RPE. Ajila et al. (2007) reported that  $\text{IC}_{50}$  values of different varieties of Indian mango peel vary from 1.83 to 4.54  $\mu\text{g}/\text{mL}$  of GAE, where the concentration-dependent scavenging of DPPH radical was noted. Contrary to the present study, Noman et al. (2021) reported higher scavenging activity of *Raphanus sativus* L. roots extract, which possesses DPPH scavenging activity with an  $\text{IC}_{50}$  value of 359.7  $\mu\text{g}/\text{mL}$ . Thakare et al. (2023) reported that mango peel extract exhibited DPPH activity of 76.58 and 72.37% by sodium cumene sulfonate and methanolic (50%, v/v) extraction, respectively. Nevertheless, Dorta et al. (2012) reported that the antioxidant activities (DPPH, ABTS radical scavenging, and lipid peroxidation inhibition) of mango peel and seed extract were affected by different drying treatments. However, higher antioxidant activities were reported in mango peel extract compared to the mango seed extract.

Furthermore, the antioxidant activities of both samples were related to the phenols and anthocyanin content. Antioxidant activity evaluation by scavenging the DPPH free radical is attributed to the sample's ability to donate hydrogen atoms (Nirmal et al., 2021). When phenolic compounds interact with DPPH, it produces 2,2-diphenyl-1-picrylhydrazine, whose color shift reveals the scavenging ability of the antioxidants present in the extract (Dahal and Koirala, 2020). The reactive potentiality of the phenol moiety, i.e., the hydroxyl group on their aromatic ring, gives phenolics their antioxidant properties. Phenols can neutralize free radicals by either electron or hydrogen donation (Nirmal et al., 2022).

### 3.2.2 Metal chelating assay

As metals are involved in reactive oxygen species (ROS) generation, metal chelation is one of the routes to inhibit ROS production. Iron is one of the major transition metals involved in ROS formation; thus, iron chelators can inhibit metal-dependent oxidation and have the possibility of mitigating disorders caused by ROS (Finefrock et al., 2003). The metal chelating capacities of both extracts (mango peel and radish peel) are presented in Table 1. The result indicated that RPE had a significantly higher metal chelating capacity compared to MP ( $p < 0.05$ ). The MPE metal chelating  $\text{IC}_{50}$  value was calculated to be  $3.86 \pm 0.035$  mg/ mL, while the RPE sample showed  $2.39 \pm 0.016$  mg/mL. The results of the metal chelating abilities of MPE and RPE were contradictory to the TPC and DPPH radical scavenging activities of the respective samples. The difference in metal chelating activity could be related to the presence of different phenolic compounds having varying metal chelating capacities. Wang et al. (2010) mentioned that acylated pelargonidin derivatives, a major compound in the extract from red radish, showed metal chelation potential. Mango peel extract is rich in *mangiferin*, possesses potent metal-chelating properties (Safdar et al., 2017), and possibly acts as an antioxidant. This could prevent oxidative damage caused by metal-catalyzed decomposition processes (Joel et al., 2017). Besides their major active compound, crude extract samples plausibly consisted of various phenolic compounds, which might react toward metals differently, thereby influencing the particular bioactivities or mechanism of action. Stoilova et al. (2008) reported that mangiferin could chelate the Fe ions thereby inhibiting the degradation of deoxyribose and the production of hydroxyl radicals.

### 3.2.3 Reducing power assay

The potential antioxidant activity of a compound can also be strongly predicted by the reducing capacity of its component (Nirmal et al., 2022). The reducing abilities of the compounds are due to the presence of reductants, like ascorbic acid, which can break the chain of free radicals by donating a hydrogen atom. Some peroxide precursors react with reductants, blocking the formation of peroxide

TABLE 1 Total phenolic contents and antioxidant potential of mango peel and radish peel extract powder.

Sample	Extraction yield (%)	Total phenolic compound ( $\mu\text{g}$ quercetin/g)	DPPH radical inhibition ( $\text{IC}_{50}$ ) ( $\mu\text{g}/\text{mL}$ )	Metal chelating activity ( $\text{IC}_{50}$ ) (mg/ mL)
Radish peel	$39.12 \pm 0.60^a$	$25.92 \pm 0.32^b$	$2552.1 \pm 17.90^a$	$2.39 \pm 0.02^b$
Mango peel	$18.41 \pm 0.34^b$	$280.5 \pm 7.95^a$	$35.09 \pm 0.00^b$	$3.86 \pm 0.04^a$
Quercetin	NA	NA	$4.54 \pm 0.00^c$	NA

The values are mean  $\pm$  standard deviation ( $n = 3$ ). Different small letters within a column indicate significant differences ( $p < 0.05$ ). NA: not applicable.



(Nirmal and Panichayupakaranant, 2015). Ferric ion-reducing capacities of MPE and RPE are presented in Table 2. The results indicated that the MPE had significantly higher reducing power than the RPE ( $p < 0.05$ ). In general, increasing the concentration of phenolic compounds showed increasing reducing properties of the compounds ( $p < 0.05$ ). This result agreed with the report of Ajila et al. (2007) who indicated increasing reducing power while increasing mango peel extract concentration. It was noted that RPE required a higher concentration of the sample to exhibit the reducing ability compared to the MPE ( $p < 0.05$ ). The reducing powers of RPE and MPE could be co-related to the TPC of the extracts of the different varieties of mango and radish, which also serves as a significant indicator of antioxidant activity (Wang et al., 2010; Safdar et al., 2017). With regards to the solvent concentration, Safdar et al. (2017) documented that mango peel extracts obtained from 80% ethanol had the highest reducing ability ( $31.51 \pm 0.79$  mmol/100 g of extract). While recently, García-Villegas et al. (2023) reported that mango peel showed a FRAP value of 0.66 mmol FeSO<sub>4</sub>/g dry extract which was higher than the Safdar et al. (2017) report. On the other hand, Liu et al. (2017) showed that the FRAP value of eight different mango cultivars varied from 0.02–0.12 mmol FeSO<sub>4</sub>/g dry extract. The FRAP of mango peel extract was correlated with the presence of various phenolic compounds in mango peel extract. Also, Enkhtuya and Tsend (2020) reported that Fe<sup>3+</sup> ion reduction was significantly ( $p < 0.05$ ) higher in the dried unpeeled radish root compared to the dried peeled root.

### 3.2.4 Linoleic acid peroxidation

A linoleic acid peroxidation inhibition assay is usually conducted to understand the potentiality of extracts to inhibit peroxidation in lipids. Linoleic acid, a polyunsaturated fatty acid, undergoes auto-oxidation, which results in the production of peroxy radicals. These radicals are subsequently used to oxidize ferrous ions into ferric ions,

which combine with thiocyanate (SCN) ions and form a colored complex (Nguyen et al., 2023). A lower absorbance value indicates the high peroxide inhibition properties of the sample. Herein, it was noted that for a certain time exposure, MPE possesses strong lipid peroxide inhibition compared to RPE. Subsequently, the potentiality of both extracts to inhibit peroxidation in lipids declined. Lizárraga-Velázquez et al. (2018) reported that the hydrophilic extract from mango peel significantly inhibited the peroxidation of fish oil over time ( $p < 0.05$ ). The capacity of mango peel extract to inhibit lipid peroxidation was examined by Dorta et al. (2013) and there were several factors affecting the aforementioned capacity. Regarding the lipid peroxidation inhibitory activity of RPE, Enkhtuya and Tsend (2020) found that black radish peel reduced the formation of oxidized intermediates in the lipid peroxidation process. The MPE at 0.1 mg/mL efficiently lowered the lipid peroxidation compared to the RPE at 2 mg/mL. Stoilova et al. (2008) indicated that mangiferin at all concentrations (0.01–0.1%) inhibited the formation of hydroperoxides at the early stage of linoleic acid oxidation, while a higher concentration (0.1%) was needed to inhibit the secondary oxidation product. Furthermore, Ajila et al. (2007) indicated that ripe mango peel extract possesses higher inhibitory action against lipid peroxidation compared to the raw peel extract which was related to the higher TPC value, carotenoid, and anthocyanin content.

## 3.3 Antibacterial activities

Table 3 displays the antibacterial activities of MPE and RPE against Gram-positive and Gram-negative bacteria. The MIC and MBC values of MPE showed a stronger inhibitory capacity than those of RPE toward all tested bacteria ( $p < 0.05$ ). In general, Gram-positive bacteria showed higher sensitivity to natural compounds than Gram-negative bacteria due to their different cell wall compositions (Nirmal et al., 2023a). Loan et al. (2021) examined that a crude extract of mango peel waste inhibited *E. coli* growth with a zone of inhibition ranging from  $7.7 \pm 0.3$  to  $15.6 \pm 0.5$  (mm), and a dose-dependent inhibition manner was observed. Previous studies stated that mangiferin possesses excellent antibacterial activity against a wide range of Gram-positive and Gram-negative bacteria (Thambi et al., 2016; Kanatt and Chawla, 2018; Loan et al., 2021). Stoilova et al. (2005) also documented that mangiferin demonstrated antibacterial activity against *Staphylococcus*, *Bacillus*, *Escherichia coli*, and certain *Salmonella* spp. Also, Kanatt and Chawla (2018) found that mango peel extracted with 70% ethanol showed the maximum zone of inhibition against Gram-positive and Gram-negative bacteria. Radish peel, on the other hand, had a lower potential to inhibit bacterial growth. As illustrated in Table 3, the MBC of RPE to inhibit different

TABLE 2 Reducing power of the different concentrations of radish peel and mango peel extract powder.

Sample	Concentration	Absorbance (760 nm)
Radish peel (mg/mL)	2	0.002 ± 0.00 <sup>a</sup>
	10	0.246 ± 0.02 <sup>b</sup>
	20	0.722 ± 0.04 <sup>c</sup>
Mango peel (mg/mL)	0.5	0.016 ± 0.00 <sup>a</sup>
	0.7	0.133 ± 0.01 <sup>b</sup>
	0.9	0.289 ± 0.05 <sup>c</sup>

The values are mean ± standard deviation ( $n = 3$ ). Different small letters within a column indicate significant differences ( $p < 0.05$ ).

TABLE 3 Minimal inhibitory and minimal bactericidal concentration of mango peel and radish peel extract powder.

Microorganisms		Mango peel powder (mg/mL)		Radish peel powder (mg/mL)	
		MIC	MBC	MIC	MBC
Gram-positive	<i>Bacillus subtilis</i> (PY 79)	> 0.125 <sup>c</sup>	0.25 <sup>c</sup>	>2.5 <sup>b</sup>	5.0 <sup>a</sup>
	<i>Staphylococcus aureus</i> (ATCC 29213)	> 0.125 <sup>b</sup>	0.25 <sup>b</sup>	>5.0 <sup>a</sup>	>5.0 <sup>a</sup>
Gram-negative	<i>Escherichia coli</i> (ATCC 25922)	> 0.125 <sup>c</sup>	0.25 <sup>c</sup>	>2.5 <sup>b</sup>	5.0 <sup>a</sup>
	<i>Salmonella typhimurium</i> (DMST 562)	> 0.125 <sup>d</sup>	0.50 <sup>c</sup>	>2.5 <sup>b</sup>	5.0 <sup>a</sup>

The values are mean ± standard deviation ( $n = 3$ ). Different small letters within row indicate significant differences ( $p < 0.05$ ).

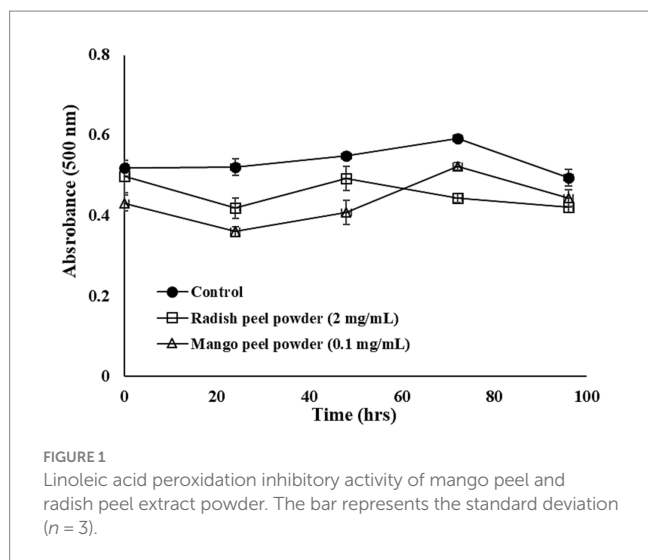


FIGURE 1  
Linoleic acid peroxidation inhibitory activity of mango peel and radish peel extract powder. The bar represents the standard deviation ( $n = 3$ ).

TABLE 4 Identification and quantification of major phenolic compounds in mango peel extract powder.

Phenolic compounds	$\mu\text{g/g}$ of extract powder
Mangiferin	$82806.97 \pm 8.34^a$
3,4-Dihydroxybenzoic acid	$1939.63 \pm 0.33^b$
Gallic acid	$1432.13 \pm 0.45^c$
Naringenin	$51.43 \pm 0.02^d$
Catechin	$11.77 \pm 0.03^e$
Epicatechin gallate (ECG)	$3.18 \pm 0.00^f$

The values are mean  $\pm$  standard deviation ( $n = 3$ ). Different small letters within a column indicate significant differences ( $p < 0.05$ ).

bacteria was 5 mg/mL or higher, which was 20-fold higher than mango peel (0.25 mg/mL). It was reported that the ethanolic extracts of *R. raphanistrum* subsp. *sativus* powder possesses antimicrobial activity against specific foodborne pathogens, such as *Bacillus cereus* ATCC 10876, *Salmonella enteritidis* 110, and *Staphylococcus aureus* ATCC 6538. However, no inhibitory activity was observed against *Escherichia coli* 23,716 (Lim et al., 2019) (see Figure 1).

### 3.4 Phenolic profile of mango peel extract

The polyphenolic compounds in MPE, which showed higher antioxidant and antimicrobial potentials, were determined using LC-ESI-MS/MS. Three major and three minor compounds were identified in the mango peel extract as shown in Table 4. The major phenolic groups were xanthonoids, gallotannins, and flavonoids. Mangiferin, a xanthonoids, was the main phenolic, which was  $82,806.97 \mu\text{g/g}$  of mango peel extract powder, followed by 3,4-Dihydroxybenzoic acid, and gallic acid. Figure 2 represents the LC-ESI-MS/MS chromatogram of mango peel extract indicating three major peaks. Also, trace amounts of naringenin, catechin, and epicatechin gallate were identified. The identification and quantification of the phenolic profile of different Brazilian mango cultivars byproducts (barks, kernels, peel, and old and young leaves) was conducted by Barreto et al. (2008). The authors indicated that mangiferin, penta-O-galloyl-glucoside, gallic acid, and methyl gallate were the four major compounds identified in all samples. Among them, mangiferin was reported in higher concentration in all byproducts and showed higher antioxidant activities (DPPH radical scavenging, FRAP, and ORAC). Marcillo-Parra et al. (2021) investigated the

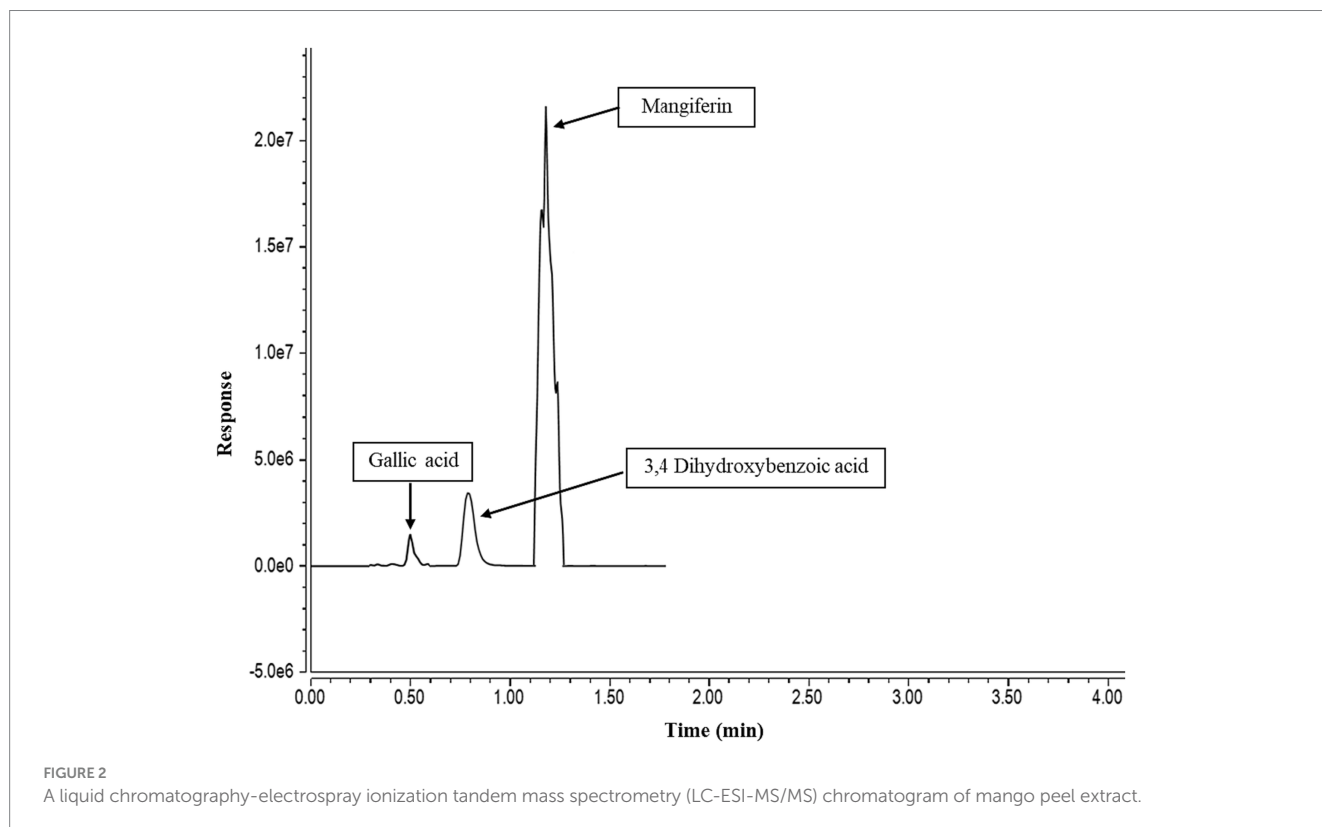


FIGURE 2  
A liquid chromatography-electrospray ionization tandem mass spectrometry (LC-ESI-MS/MS) chromatogram of mango peel extract.

TABLE 5 Correlation coefficient matrix between total phenolic content and antioxidant properties in mango peel extract powder.

Attributes	Mangiferin	3,4-Dihydroxybenzoic acid	Gallic acid	TPC	DPPH radical scavenging activity	Metal chelating ability	Reducing power	Lipid peroxidation inhibition
Mangiferin	1							
3,4-Dihydroxybenzoic acid	-0.975	1						
Gallic acid	0.986	-0.926	1					
TPC	0.998*	-0.984	0.978	1				
DPPH radical scavenging activity	0.997*	-0.989	0.971	0.961*	1			
Metal chelating ability	-0.901	0.783	-0.960	-0.881	-0.866	1		
Reducing power	-0.802	0.651	-0.890	-0.775	-0.756	0.982	1	
Lipid peroxidation inhibition	0.998*	-0.988	0.973	0.982*	1.00**	-0.869	-0.76	1

(\*) indicates  $r < 0.05$  and (\*\*) indicates  $r < 0.01$ .

presence of a phytochemical profile in MPE and reported that mangiferin ranged from 5.72 mg to 314 mg/100 g, gallic acid from 28.6 to 43.1 mg/100 g, and epicatechin from 9.01 to 9.24 mg/100 g of the dry weight of MPE. The variety, the region where the mango is grown, and the methods of extraction significantly affect the phenolic content of mango and its peel extracts (Coelho et al., 2019; Marcillo-Parra et al., 2021). The compounds identified in the present study have been recognized for their vital biological and health-beneficial properties, such as antioxidant, anti-inflammatory, anticancer capacity, antidiabetic, and antimicrobial properties (Ordoñez-Torres et al., 2021; Tacias-Pascacio et al., 2022). Therefore, the byproduct of mango, i.e., peel, has a wide range of applications in the food, pharmaceutical, and nutraceutical industries.

### 3.5 Correlations

Considering that several antioxidant mechanisms contribute to the total antioxidant activity, it is unclear whether the TPC results are responsible for the actual antioxidant capacity. Previous studies revealed a significant relationship between the total phenolic components of peel extracts and their antioxidant activities. Table 5 displayed correlation coefficient matrices between TPC in the mango peel extract and their antioxidant activities. In the mango peel samples, significant coefficients of determination were calculated between mangiferin-TPC, mangiferin-DPPH, and mangiferin-lipid peroxidation. These findings supported earlier research by Abbasi et al. (2015) which showed that phenolic compounds from mango peel play a key role in antioxidant capacity. According to our research, mango peel is one of the promising sources of phenolic compounds, which are a key source of naturally occurring antioxidants.

### 4 Conclusion

Mango peel and radish peel waste were extracted to obtain phenolic-rich extract. The extraction yield of radish peel was higher than that of mango peel. However, mango peel showed higher total phenolic content and antioxidant activities than radish peel ( $p < 0.05$ ). Similarly, mango peel showed higher inhibitory activity against Gram-positive and Gram-negative bacteria compared to the radish peel ( $p < 0.05$ ). The variation in antioxidant and antimicrobial activities of both samples could be related to the presence of active phytochemicals. Mangiferin was the major bioactive compound detected in the mango peel extract powder. TPC and phenolic profile of mango peel were very well correlated with the antioxidant activities of the extract. These results offer valuable insights into the potential use of native Thai mango peel waste as a source of phenolic compounds with stronger antioxidant and antibacterial properties.

### Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

PK: Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. PC: Data curation, Formal analysis, Investigation, Software, Writing – original draft. US: Formal analysis, Investigation, Methodology, Writing – original draft. SB: Validation, Writing – review & editing. KK: Investigation, Methodology, Writing – original draft. FA-A: Validation, Visualization, Writing – review & editing. NN: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

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## Conflict of interest

Radish peel waste was donated by MK restaurant in Nakhon Pathom province, Thailand. Whereas Thai indigenous mango peel (Bao, *Mangifera indica* L. var.) waste was received from Promsap (Thailand) Company Limited, Hat Yai, Songkla, Thailand.

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