



Valorisation of Mango Peels: Extraction of Pectin and Antioxidant and Antifungal Polyphenols

Romeo Rojas¹ · Olga B. Alvarez-Pérez¹ · Juan C. Contreras-Esquivel¹ · António Vicente² · Abril Flores² · Jose Sandoval¹ · Cristobal N. Aguilar¹

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Abstract

Mango peels is a by-product obtained during mango processing, which is currently discarded causing environmental pollution. In the present study, mango peels were used as source of polyphenols and pectin. Additionally, antioxidant and antifungal activities were measured. The extraction condition to recover pectin and polyphenols at the same time was using water, 121 °C/10 min at 1:40 w/v ratio (9.38 g/100 g dry peels and 72.61 mg/g dry peels, respectively). With this treatment, higher antioxidant capacity was obtained (72.18, 37.73 and 39.23 ppm of total polyphenols from mango peels to inhibit 2,2-diphenyl-1-picrylhydrazyl and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) free radical; also the lipid oxidation inhibition reaction in 50%, respectively). Furthermore, this extract inhibited the radial growth of *Colletotrichum gloeosporioides*, *Sclerotinia sclerotiorum* and *Mucor* sp. in 50% and *Fusarium oxysporum* in 33.33%. Thus, the results suggest that total polyphenols from mango peels is as attractive alternative source for bioactive compounds, like antioxidants and antifungal molecules.

Keywords Mango peels · Polyphenols · Antioxidant · Antifungal · Pectin

Statement of Novelty

Mango processing includes the production of juices, nectars, concentrates, jams, jelly powders, fruit bars, flakes, and dried fruit. However, by-products such as peels and kernel represent 24% and 40% of fresh fruit, respectively, generating an abundant quantity of wastes which represents an attractive source of value-added compounds. The present study describes an integrated alternative for the combined recovery of phenolic compounds and pectin from mango peels giving an attractive valorisation of this waste.

Introduction

Mango Ataulfo (*Mangifera indica* L.) is one of the most appreciated fruits around the world by their sensorial and organoleptic properties, however, one of the most important problems of its commercialization is the short shelf life of this product. By this reason, mango is transformed in juices, nectars, concentrates, jams, jelly powders, fruit bars, flakes, and dried fruit [1]. However, by-products such as peels and kernel represent 24% and 40% of fresh fruit, respectively.

Mango kernels have been studied as a source of natural antioxidants, starch, flour, and feed [2–6], but studies on peels from Ataulfo variety are scarce. Some studies have been reported regarding their use to produce biogas [7, 8] or dietary fiber with antioxidant activity [9–11]. Other studies have been dealing with their use as a source of pectin [12–16]. The high quality of this product is due to the degree of esterification between 56 and 66% [1]. Additionally, mango peels have been shown to be a rich source of compounds such as flavonol *O*- and xanthone *C*- glycosides [1, 17], gallotannins and benzophenone derivatives [18]. These compounds have antioxidant, antifungal, antiproliferative,

✉ Cristobal N. Aguilar
cristobal.aguilar@uadec.edu.mx

¹ Bioprocesses and Bioproducts Research Group (BBG-DIA).
Food Research Department, School of Chemistry,
Universidad Autónoma de Coahuila, 25280 Saltillo,
Coahuila, Mexico

² Centre of Biological Engineering, University of Minho,
Campus de Gualtar, 4710-057 Braga, Portugal

anti-atherogenic, anti-thrombotic, and anti-inflammatory effects [19–30].

Nowadays, there are methodologies to recover bioactive compounds from agro industrial residues. However, these methodologies are specific and with only one purpose. Seeram et al. [31] and Ascasio-Valdés et al. [32] described methods to recovery total polyphenols from agroindustrial wastes using only water. Contreras-Esquivel et al. [33] described a method to extract pectin from mango peels using water and a citric acid solution with yields up to 39%. However, the combination of both methodologies can be an alternative to recover pectin and total polyphenols from mango peels.

Earlier, our research group has published relevant information about the agroindustrial potential [34], the functional and nutritional properties [35] of mango, also, the microwave-assisted extraction optimization for antioxidative compounds [36] making emphasis in functional properties of pentagalloylglucose [37]. In the present study, we report a combined strategy methodology for the recovery of pectin and polyphenols from mango peels. Total polyphenols and pectin present in the mango peels were evaluated characterized and quantified. Finally, the antifungal activity of a rich-polyphenols extracts against some phytopathogenic fungi was evaluated.

Materials and Methods

Fruits

A lot of 49 mangoes were acquired from the local market (Benito Juarez) of Saltillo, Coahuila, Mexico. Peels were removed with a stainless-steel knife and blanched with water vapor at 105 °C/15 min to inactivate enzymes. Mango peels were dried in a circulating drying oven at 60 °C for 5 h, until a drying loss of 80%. After, dry peels were stored in black sealed polyethylene bags at room temperature until use.

Extraction of Total Polyphenols

Six methods to extract total polyphenols from mango peels (TPMP) were used. (1.1) and (1.2) were according to Seeram et al. [31] and Ascasio-Valdés et al. [32], dehydrated and pulverized mango peels were placed in a baker in a ratio of 0.20 g/mL. TPMP extraction was performed at 60 °C/30 min. 2.1 and 2.2 were carried out according to Contreras-Esquivel et al. [33], dehydrated and crashed mango peels were placed in an autoclave (121 °C/10 min) in a ratio 1:40 w/v. 3.1 and 3.2 were evaluated, dehydrated and crushed mango peels were placed in an autoclave (121 °C/20 min) in a ratio 1:40 w/v. After that, the obtained extracts were centrifuged at 7000 rpm/30 min to eliminate

insoluble-water particles. For each extract the pectin was precipitated with isopropanol. Column chromatography was performed using Amberlite XAD-16. First, water was used as the eluent to discard undesirable compounds, and then, ethanol was employed as the eluent to obtain a TPMP. The residual ethanol was eliminated placing the ethanolic fraction in glass Petri dishes at 60 °C/24 h; the polyphenols were recovered as a fine powder and stored in an amber bottle at –20 °C until use. (Fig. 1).

Yield and Chemical Analysis

Polyphenols yield was calculated gravimetrically. Total sugars were evaluated with the Dubois et al. [38] method. Hydrolysable tannins were evaluated with the Folin–Ciocalteu method [39, 40] and reported as gallic acid equivalents and condensed tannins quantified with the HCl–Butanol method [41] using catechin as standard. Each analysis was performed in triplicate.

Antioxidant Assay

The total antioxidant activity of the extracts was tested by four different methods, namely, two different free radical scavenging assays [1,1-diphenyl-1-2-picrylhydrazyl (DPPH) and 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS⁺) radical inhibition], a oxidation inhibition assay using linoleic acid as the lipid source lipid and a voltametric method.

DPPH[•]-Scavenging Capacity (DSC) Assay

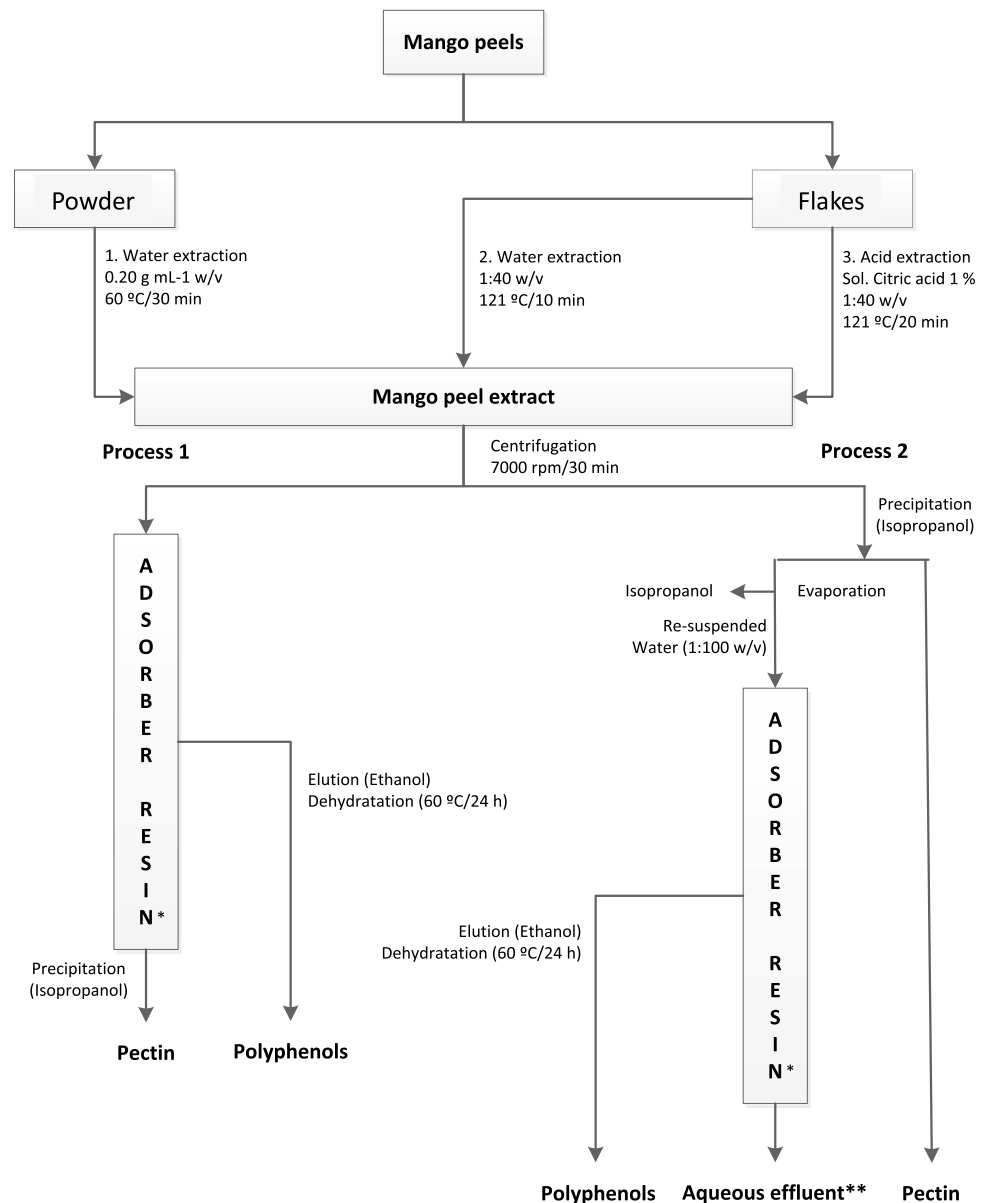
The DPPH[•] assay was carried out according to the methodology reported by Molyneux [42]. Briefly, 193 µL of 60 µM DPPH[•] radical was added to 7 µL of each sample in a microplate. The microplate was placed in the dark and after 30 min the absorbance (Abs) was measured at 517 nm. Controls contained 7 µL of distilled water. The evaluated concentrations were 0, 20, 40, 60, 80 and 100 ppm of polyphenols in distilled water. The radical-scavenging capacity of the extracts was calculated using the following Eq. (1) and expressed as the DPPH percentage of inhibition.

$$\text{Inhibition (\%)} = \left[\frac{(\text{Abs}_{\text{control}} - \text{Abs}_{\text{sample}})}{\text{Abs}_{\text{control}}} \right] \times 100 \quad (1)$$

ABTS⁺-scavenging capacity (ASC) assay

The ABTS⁺ assay was carried out according to the methodology proposed by Re et al. [43]. For radical (ABTS⁺) formation, 12.5 mL of 2.45 mM potassium persulfate was mixed with 25 mL of a 7 mM ABTS solution; the mixture

Fig. 1 Processes 1 and 2 for the combined recovery of phenolic compounds and pectin from mango peels. *Amberlite XAD-16, **the aqueous effluent was discarded



was then allowed to stand in the dark at room temperature for 12–16 h before use. Absorbance was measured at 734 nm, and the ABTS⁺ solution was diluted with ethanol until an absorbance value of 0.7 ± 0.01 . For this study, 950 μL of ABTS⁺ adjusted solution was added to 50 μL of each concentration of extract, and absorbance was measured immediately. Controls contained 50 μL of distilled water. The evaluated concentrations were 0, 20, 40, 60, 80 and 100 ppm of polyphenols in distilled water. The radical-scavenging capacity of the extracts was calculated with the following Eq. (2) and expressed as the ABTS⁺ percentage inhibition:

$$\text{Inhibition (\%)} = \left[\frac{(Abs_{control} - Abs_{sample})}{Abs_{control}} \right] \times 100 \quad (2)$$

Lipid Oxidation Inhibition Assay

The lipid oxidation inhibition (LOI) was performed using linoleic acid as the lipid source according to the method described by Starzynska-Janiszewska et al. [44] with slight modifications proposed by Martinez-Avila et al. [45]. The linoleic acid solution was prepared by diluting 0.56 g of linoleic acid and 1.5 g of Tween 20 in 8 mL of 96% ethanol. Each concentration of extract from Hojasen (50 μL) was mixed with 100 μL linoleic acid solution and 1.5 mL of 0.02 M acetate buffer, pH 4. Controls contained 50 μL of distilled water. All samples were homogenized in a vortex (Velp® Scientifica Zx³) and sonicated in ultrasonic bath (Bransonic 2510R-MTH; Banson, Danbury, CT) for 3 min. Obtained emulsions were incubated at 37 °C (Yamato IC

400); after, 1 min, 750 μL of 50 M FeCl_2 solution were added to induce the oxidation of linoleic acid. After the chosen incubation times (1 and 24 h), 1 mL of 0.1 M NaOH in 10% ethanol was added to 250 μL of the mixture to stop the oxidation process. After mixing, 2.5 mL of 10% ethanol was added and the absorbance measured at 232 nm against a 10% ethanol blank. The evaluated concentrations were 0, 20, 40, 60, 80 and 100 ppm of polyphenols in distilled water. The percentage of antioxidant capacity was calculated according to the Eq. (3):

$$\text{Inhibition (\%)} = (A - B/A) \times 100 \quad (3)$$

where “A” is the difference between the absorbance of the control sample after 24 and 1 of incubation, and “B” is the difference between the absorbance of each concentration sample after 24 h.

Electrochemical Assay

Experiments were performed in the cyclic voltammetry (CV) and differential pulse voltammetry (VDP). These techniques are based on the oxidation or reduction of an electroactive compound at the working electrode while a constant potential is applied; the measured current in nA is a direct measurement of the electrochemical reaction rate. The CV and VDP were performed in a potentiostat/galvanostat basic Epsilon, the electrochemical cell consisted of three electrodes: working platinum electrode, coiled platinum electrode as a counter electrode and a silver–silver chloride (Ag/AgCl) electrode as a reference to the potential. Before the tests are performed a routine sweep using cyclic voltammetry for the reaction of $\text{Fe}^{3+}/\text{Fe}^{2+}$ is performed for the characterization of the platinum electrode; after this, the electrode was washed with water. Analyses were performed at room temperature using a carrier solution made of acetate buffer 0.1 M (pH 5). Electrochemical evaluation of the antioxidant power of TPMP extracted with method 2.2 at a concentration of 39.23 ppm were evaluated by measuring the current resulting from the oxidation of the electroactive compound at the established potential in the range of 100 to 900 mV.

Antifungal Activity

Four microorganisms (*Colletotrichum gloeosporioides*, *Fusarium oxysporum*, *Sclerotinia sclerotiorum* and *Mucor* sp.) were provided by the Food Research Department of the School of Chemistry (Autonomous University of Coahuila). Microorganisms were activated in PDA medium by 7 days at 28 ± 2 °C. To determine minimum inhibition concentration (MIC_{50}) PDA medium (previously sterilized) was supplemented with PTMP at concentrations of 0 (control without PTMP), 150, 300, 450, 750, 1000 and 1250 ppm (w/v). After that, an explant of 0.5 cm of diameter of each microorganism

was placed in the centre of the petri dish. Radial growth was measured at final time of incubation at 28 ± 2 °C (72 h to *Colletotrichum gloeosporioides* and *F. oxysporum* and 48 h to *S. sclerotiorum* and *Mucor* sp.). The mycelial growth of the control was considered as 100% growth, percent inhibition was calculated with Eq. (4).

$$\text{Inhibition (\%)} = \left(\frac{\text{mm Growth}_{\text{control}} - \text{mm Growth}_{\text{sample}}}{\text{mm Growth}_{\text{control}}} \right) \times 100 \quad (4)$$

After that, dates were adjusted to a polynomial equation to determine the minimum inhibition concentration (MIC_{50}).

Statistical Analysis

For DPPH $^{\cdot}$, ABTS $^{\cdot+}$, and lipid oxidation inhibition assay, the measurements were made in triplicate. To determine the medium concentration inhibition (MCI_{50}) was used a simple linear regression to obtain the line equation ($y = mx + b$) where “y” is the percentage of inhibition (50% in all cases), “m” is the slope of the line, “x” is the mg of TPMP to inhibit in 50% the oxidation reaction and “b” is the intercept. In the case of antifungal activity to determine medium concentration inhibition (MIC_{50}) was employed a polynomial equation ($y = ax^3 + bx^2 + cx + d$) where “x” is the mg of TPMP to inhibit in 50% the fungal growth. Finally, a selection index (S-I) was used to determine the best treatment to obtain pectin and polyphenols at the same time. The following Eq. (5) was used to consider by relevance the analysis used:

$$S - I = (P \times 2) + (Y \times 2) + (T \times 1) + (H \times 2) + (C \times 0.5) + (D \times 0.5) + (A \times 0.5) + (L \times 1.5) \quad (5)$$

where “P” is the pectin yield; “Y” is the yield of TPMP; “T” is the total sugars of TPMP; “H” is the hydrolysable tannins of TPMP; “C” is the condensed tannins of TPMP; “D” is the DPPH activity of TPMP; “A” is the ABTS activity of TPMP and “L” is the lipid oxidation inhibition of TPMP. The best treatment was used to determine antifungal activity and electrochemical assay. The results were analyzed using a completely randomized design and the means were compared with Tukey test at a confidence level of 0.95.

Results and Discussion

Mango var. Ataulfo fruit is a Mexican variety and its waste (peels) is an underestimated source of polyphenols with higher antioxidant and antifungal capacities. The selection of this fruit was based on the seasonal production period

(March–June), its present importance in Mexico and the limited or no information about its functional properties.

Chemical Analysis

The pectin yield and chemical analysis of TPMP is shown in Table 1. The mango peels had a pectin yield in the range of 3.33–16.01 g/100 g dry peels. Sirisakulwat et al. [46] reported a yield of pectin from mango peels (25–42 g/100 g), however, with Tai mango using H₂SO₄ 1 mol/L and lasts 1 h in the extraction. Contreras-Esquivel et al. [33] reported a value of 39.05 mg/100 g of pectin from mango pomace using citric acid but not consider the possibility of recovering of TPMP. Similarly, mango pectins' yields (5.8–24 mg/100 g) were obtained by Kratchanova et al. [47] by using an acid extraction. In this method it is necessary to use only 20 min for extraction and citric acid to release the pectin without compromising the stability of TPMP. For all these results it is important to remark that our proposal reflect advantages as recovering and stability of TPMP. Our proposed extraction method does not present the disadvantages of the acid extraction such as the longer extraction time and the use of a corrosive and pollutant extractant solution.

Polyphenols content (hydrolysable tannins) in the TPMP varied from 137 to 509 mg GAE/g TPMP. Using the 1.1 method the content was significantly higher. This variability may be ascribed to factors such as soils conditions, exposition to UV radiation, ripening state and phytosanitary status. Furthermore, storage conditions may also affect polyphenol contents [1]. However, to prevent enzymatic pectin degradation and microbial spoilage of the peels they were scalded immediately after being separated from the mango. Phenolic compounds are known to be heat-sensitive. Therefore, the impact of time–temperature regime during the extraction process plays an important role in the contents of phenolic compounds. Earlier, Larrauri et al. [9] reported the total polyphenols content in aqueous methanol extract of ripe peel of Hayden variety to be 70 mg/g. These values are low compared with the reported in the present study. Berardini et al. [1] reported amounts of TPMP from 71 mg/100. These results are similar with those of our study and corroborate

the high potential use of mango peels as a source of pectin and bioactive compounds. This behaviour may due to the fact that a large percentage of phenolic compounds are bound to cellular structures and time, temperature and the presence of an acid release bound phytochemicals from the matrix thus making them more accessible during extraction [48].

Antioxidant Capacity of TPMP

ABTS⁺ (ASC) and DPPH[•]-Scavenging Capacity (DSC)

The ABTS assay is commonly applied to determine antioxidant activity in plants. It is based on the ability of antioxidants to scavenge the long-life radical cation ABTS⁺. DPPH, a stable free radical, decreases significantly on exposure to proton radical scavengers. This assay is used to evaluate the free radical scavenging activity in foods and biological systems [49]. It has also been used to evaluate the free radical scavenging activity of natural antioxidants [50]. The degree of discoloration indicates the scavenging potential of the antioxidant extract, which is due to the hydrogen donating ability [51].

Depending of the extraction method of TPMP the quantity to inhibit the reaction of oxidation was significantly different (Fig. 2). The ASC of TPMP varied from 34.61 ± 2.23 to 58.62 ± 2.47 for MIC₅₀. The highest ASC was found for the 1.1 extraction method, this effect is due to the highest content of hydrolysable tannins. The mango peels had higher DSC ranging from 60.96 ± 2.64 to 99.15 ± 13.20 ppm of polyphenols to inhibit in a 50% the DPPH free radical (MIC₅₀). The 1.1 extraction method best preserved the antioxidant properties, whereas the 3.2 extraction method was found to exert the most negative effect. Statistical analysis revealed that the antioxidant capacity in the polyphenols from mango peels changed significantly with the extraction techniques employed ($p \leq 0.05$).

Kim et al. [25] reported 67.49% of inhibition using a concentrated ethanolic extract at 200 ppm for ASC and 6.67% of inhibition at 25 ppm for DSC assay. The reduced levels on phenolic compounds found in the TPMP (extraction method

Table 1 Yield and chemical analysis of TPMP

Parameters	Treatment					
	1.1	1.2	2.1	2.2	3.1	3.2
Pectin yield (g/100 g dry peel)	5.20 ± 0.16 ^d	7.05 ± 0.31 ^d	3.33 ± 1.43 ^e	9.38 ± 0.73 ^c	11.68 ± 0.71 ^b	16.01 ± 1.82 ^a
Yield (mg TPMP/g dry peel)	25.01 ± 1.55 ^c	21.25 ± 0.74 ^c	72.93 ± 6.07 ^b	72.61 ± 14.5 ^b	125.47 ± 2.37 ^a	136.64 ± 18.84 ^a
Total sugars (mg/g TPMP)	147.91 ± 32.86 ^b	109.75 ± 9.50 ^b	134.58 ± 20.13 ^b	142.75 ± 10.11 ^b	112.58 ± 34.93 ^b	252.58 ± 2.75 ^a
Hydrolysable tannins (mg GAE/g TPMP)	509.07 ± 9.39 ^a	323.07 ± 16.59 ^c	495.03 ± 12.60 ^a	427.06 ± 17.68 ^b	296.58 ± 4.83 ^d	137.15 ± 3.19 ^e
Condensed tannins (mg CE/g TPMP)	92.39 ± 0.78 ^b	92.94 ± 1.36 ^b	106.27 ± 1.36 ^a	108.78 ± 1.86 ^a	83.78 ± 3.81 ^c	107.94 ± 5.44 ^a

Different lower-case letters represent significant statistical differences among treatments (mean values)

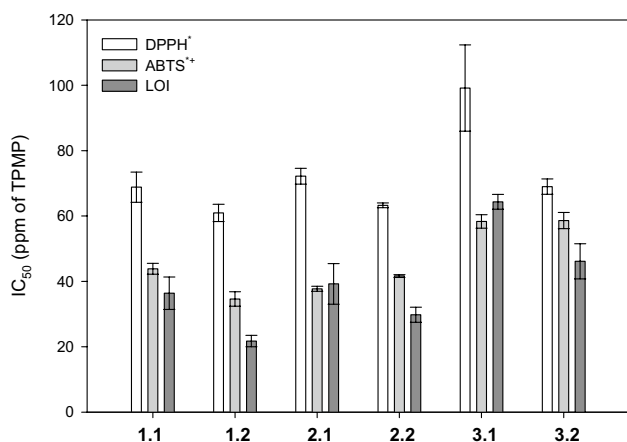


Fig. 2 Minimum inhibition concentration (MIC₅₀) of TPMP of all extraction methods

3.1 and 3.2) obtained from highest times and temperatures of extraction is correlated well to the ASC resulted from the degradation of phenolic compounds at high temperature and the use of citric acid, due to chemical or thermal decomposition [48]. Similar behaviour was reported by Larrauri et al. [10] observing that the drying temperature increased (140 °C) a decrease up to 50% of the antioxidant capacity of the samples was registered. Another possible explanation is that the polyphenols in an intermediate state of oxidation can exhibit higher radical scavenging efficiency than the non-oxidized ones, although, a subsequent loss in the antioxidant properties have been found for advanced enzymatic oxidation steps [29, 48].

Lipid Oxidation Inhibition Assay (LOI)

Although DPPH and ABTS analysis are widely used for measuring *in vitro* free radical scavenging of extracts from several plants samples, they can provide only limited information about the antioxidant properties of these extracts in real biological systems. Therefore, an additional assay should be carried out to simulate the oxidization conditions in food systems. According to Huang et al. [52], the use of linoleic acid as a lipid source in the LOI assay simulates the lipids presents in food systems. Figure 2 shows the results for LOI of each extraction method. The results indicate that to inhibit the reaction of LOI in 50% it is only necessary the use of TPMP in a range of 21.74 ± 1.74 (1.1 extraction method) to 64.34 ± 2.26 ppm (3.2 extraction method). This result is consistent with the total content of polyphenols and related with the extraction method. Dorta et al. [29] reported that the use of elevated temperatures of drying of extract diminishes the antioxidant capacity resulting in the degradation of phenolic compounds, while the presence of air leads to phytochemical compounds oxidation. We can assume that

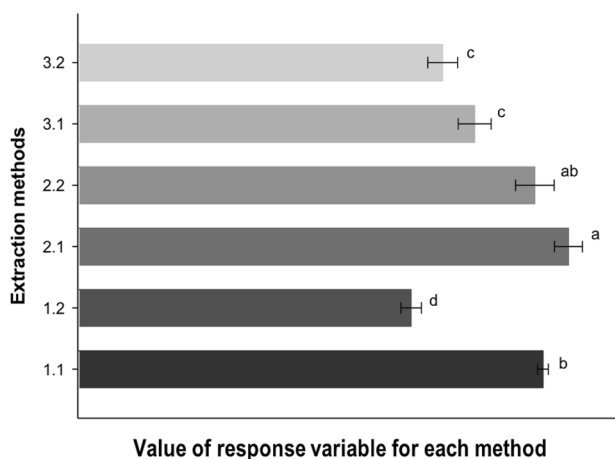


Fig. 3 Selection index

the phenolic compounds in the analyzed samples are capable of resisting linoleic acid peroxidation under assay conditions, however it is important to consider the presence of a big quantity of phenolic compounds in the samples that are capable of resisting lipid oxidation.

Selection Index

The weighting of the response variables according to their importance was necessary for the next steps of this study (electrochemical and antifungal assay). The best treatment was 2.2 due to the higher recovery of pectin, TPMP, hydrolysable tannins and higher antioxidant and antiradical activities (Fig. 3).

Electrochemical Assay

The antioxidant activity of natural compounds depends not only on the amount of specific molecules present in the matrix but also on structural factors, such as the number and positions of phenolic hydroxyl or methoxyl groups, etc [53]. Considering that the electrochemical behaviour of these compounds depends on their structural features, useful information on their antioxidant functionality can be drawn. For this purpose differential pulse voltammetry (VDP) experiments for each analyte of interest (gallic acid and quercetin) were performed. These compounds were chosen on the basis of the data reported in literature about their presence in mango under study. Figure 4 shows differential pulse voltammograms of the extract and the standards.

These results indicate the possible presence of gallic acid and quercetin in the sample. Figure 5 shows deconvolution of the differential pulse voltammogram of the behaviour of selected method (2.2) at 39.23 ppm. To verify how many peaks generate the signal, the deconvolution of

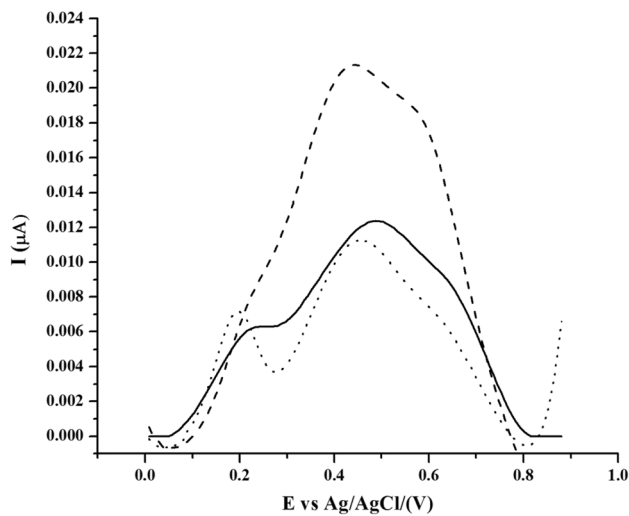


Fig. 4 Differential pulse voltammetry of extract 39.23 ppm (lines), quercetin 33.61 ppm (dotted lines) and gallic acid 105.28 ppm (short dashed lines)

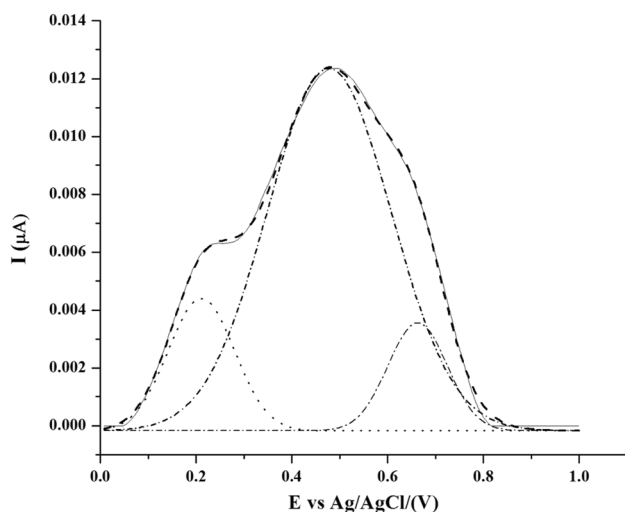


Fig. 5 Deconvolution of the differential pulse voltammogram of an extract at 29.23 ppm: experimental (lines), calculated (short dashed lines), peak 1 (dotted lines), peak 2 (short dash dots) and peak 3 (dash dots)

differential pulse voltammogram of the extract was carried out. As shown in Fig. 5 the magnitude of the current recorded during the oxidation of the extract is generated by three independent oxidative processes with potentials 0.2, 0.5 and 0.47 mV. This is sufficient to ensure the presence of quercetin and gallic acid in the extract because the oxidation of these molecules goes on between 0.45 and 0.2 mV and 0.5 mV for quercetin and gallic acid, respectively. This does not discard the presence of other compounds such as mangiferin, isomangiferin, mangiferin

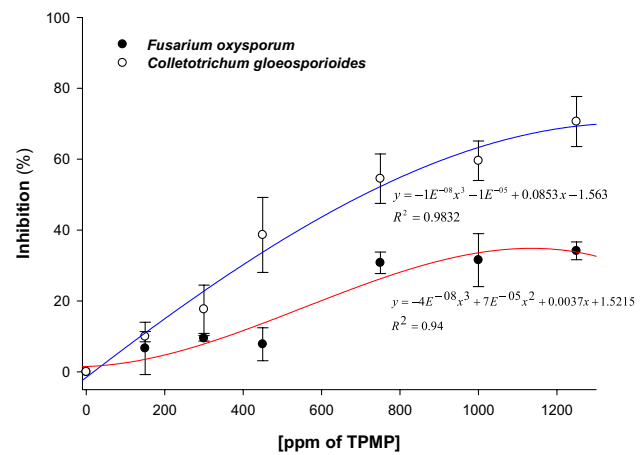


Fig. 6 Minimum inhibition concentration (MIC_{50}) of TPMP selected (2.2 extraction method) against *Fusarium oxysporum* (filled circles) and *Colletotrichum gloeosporioides* (open circles)

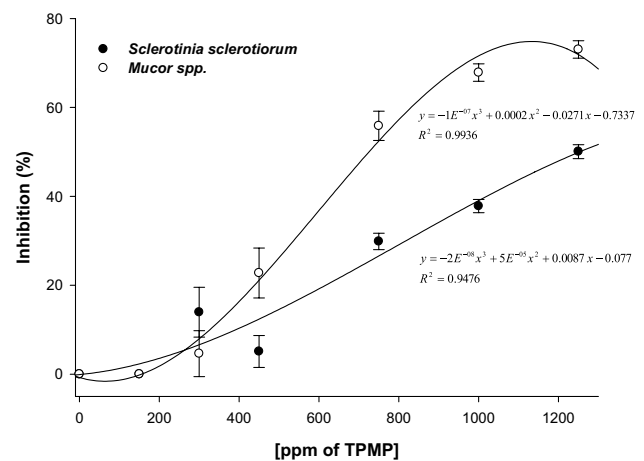


Fig. 7 Minimum inhibition concentration (MIC_{50}) of TPMP selected (2.2 extraction method) against *S. sclerotiorum* (filled circles) and *Mucor sp.* (open circles)

gallate, isomangiferin gallate, kaempferol 3-o-glucoside, rhamnetin 3-o-galactoside/glucoside and ellagic acid [1, 21, 25].

Antifungal Assay

Figures 6 and 7 show MIC_{50} of antifungal activity of TPMP. Many researchers have reported antifungal activities of different plant species and stressed the importance of plants as a possible source of natural fungicides [54–58]. The quantity of TPMP to inhibit in 50% the radial growth was 703.239 ppm to *C. gloeosporioides* ($r=0.983$), 757.178 ppm to *Mucor sp.* ($r=0.993$), 1275.70 ppm to *S. sclerotiorum* ($r=0.947$) and 930.07 ppm to *Fusarium oxysporum* (to inhibit in 33.33% the radial growth) using the TPMP from

selected method (2.2). In the case of *F. oxysporum* it was necessary to increase the concentration of TPMP due to the specie's antifungal resistance. The antifungal properties of TPMP have been attributed to various modes of action, in particular to their ability to interact with proteins and to inhibit enzyme activity [59, 60]. Furthermore, hydrolysable tannins were shown to damage lipid bilayer membranes allowing the release of intracellular components [61]. A third mode of action by which hydrolysable tannins may inhibit the fungal growth is related to the complexation of metal ions [62–64]. Other authors reported similar results using essential oil of *Lippia berliandieri* against *F. oxysporum* [65]. Soylu et al. [66] too reported that the essential oil of *O. syriacum* var. *bavani* showed stronger antifungal activity against the mycelial growth of *S. sclerotiorum* under in vitro conditions. Ogbekor and Adekunle [57] reported 100% of inhibition of mycelial growth of *C. gloeosporioides* using extracts from *A. sativum* and *O. basilicum* and three other plants, *A. conyzoides*, *J. curcas* and *V. amygdalina* inhibit the mycelial growth in 56.83%, 49.90% and 48.32%, respectively. These results demonstrated that this TPMP create an inappropriate environment for the growth of *Colletotrichum gloeosporioides*, *S. sclerotiorum*, *Mucor* sp. and *Fusarium oxysporum*. Additionally, and complementing the technological development for valorisation of mango peels reported previously by Rojas et al. [67], TPMP have an enormous antifungal potential replacing chemical fungicides and which may be used for formulating new, safer and eco-friendly fungicides.

Conclusions

Six evaluated methods were highly suitable for the combined recovery of phenolic compounds and pectin from mango peels and may be integrated in the bioactive compounds production. Due to the high percentage of the bioactive compounds that was degraded during the extraction of the peels, more investigations into the optimization of the extraction parameters are necessary to improve the yield of polyphenols and pectin. Finally, investigations need to be directed at the use of TPMP as natural antioxidant and antifungal additives into the food or feed supplements.

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