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ORIGINAL PAPER

# Phytochemical accumulation of anthocyanin rich mulberry (*Morus laevigata*) during ripening

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## Abstract

The goal of the study was to determine the differences in phytochemical components of mulberry (*Morus laevigata*) fruits at different stages of ripeness. In this study, the highest total phenolic (1310.3 µg gallic acid equivalents/g fresh weight) and anthocyanin (925.6 µg cy-3-glu/g fresh weight) contents and antioxidant capacity (12.8 µmol trolox equivalents/g fresh weight) were observed in black ripening stage. The major sugars in mulberry fruits were fructose (17.55 g/kg). It was determined that the main organic acid in mulberry was citric acid ranging from 8.97 g/kg (pink stage) to 5.80 g/kg (black ripening stage), followed by malic acid ranging from 0.31 (pink ripening stage) to 5.67 (black ripening stage) g/kg. Looking at the contents of phenolic compounds, chlorogenic acid (average 27.48 mg/100 g) was found to be the predominant phenolic compound. Current study shows that *M. laevigata* fruits are a good source of healthy phytochemicals.

**Keywords** Bioactive compounds · *Morus laevigata* · Mullberry · Phenolics

## Introduction

Mulberry (*Morus* sp.) has been domesticated over thousands of years and has been adapted to a wide area of tropical, subtropical, and temperate zones of Europe, Asia, North and South America, and Africa [1]. The black and purple mulberries are widely cultivated in the Mediterranean and Middle Eastern countries. Located at the junction of the Middle East and the Mediterranean, Turkey has important mulberry populations and the cultivation of these fruits has been known for more than 400 years [2]. Its cultivation mostly oriented on fruit production with *Morus alba, Morus nigra, Morus rubra and Morus laevigata* species [3].

Conventional medicines show reliance on phytochemicals rich plants extracts to cure different diseases because medicines obtained from natural origin are considered to be less toxic and free from undesirable effects as compared to unnatural ones [4]. This increases the interest in fruit species with rich phytochemical content such as mulberry. Studies on different mulberry species have shown that mulberry fruit is an important antioxidant because of their high bioactive content [5, 6]. Due to their high bioactivities, some selected species of this plant have been used as folk medicine, e.g. fruit juice of mulberry has been used as folk remedies for asthma, cough, cold, dyspepsia, edema, fever, diarrhea headache, hypertension and tumors of fauces [7]. It was reported that *M. laevigata* fruits extracts had higher total phenolic acid content and showed higher antioxidant activity than *M. nigra* and *M. alba* fruit extracts [7]. Many reports had studied the organic acid, carotene, dry matter and anthocyanin content of mulberry, as well as their flavor, total acidity, ascorbic acid and phytochemical content [7–10]. However, as far as we know there have been no any reports to date compiled on the sugars, organic acids and specific phenolic contents, and antioxidant activity of *M. laevigata* fruits at different stages of maturity.

Fruit ripening is a process in which many series reactions occur and significant changes in phytochemical content of fruit [11]. Significant changes were reported in phenolic content during fruit ripening of different types of berries [12]. Lee et al. [13] who are studied on *M. alba* species, showed that sugar, organic acid and phenolic content of fruit varied according to maturation stages. Researchers on fruit ripening are of special interest because they allow the optimum maturity point to be determined for harvesting and enable delivery of fruit to consumers in its best condition in terms of nutritional and functional properties. Especially for

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fruits used in different ways such as mulberry, it is important to determine the appropriate harvesting time depending on the purpose of use. In this study, it was aimed to determine antioxidant capacities, organic acid, sugar and specific phenolic contents of *M. laevigata* fruits at different maturity stages.

## Materials and methods

### Plant material

Mulberry (*M. laevigata*) fruit were hand harvested from Agricultural Research Station in Gaziosmanpasa University, Tokat, Turkey. Fruits were sorted by visual color inspection into four ripeness stages: black, red–black, red, and pink. Samples were frozen immediately and then stored (about 15 days) in about 200 g batches at − 80 °C prior to analysis. For each fruit sample, four replicates were thawed at room temperature for 4 h (in the dark) and homogenized in a food blender; excess fruits (50–60 individual fruits) were used to minimize naturally occurring fruit-to-fruit variation. Slurries were used to assay for all analysis.

### Total monomeric anthocyanins (TMA)

TMA were estimated by a pH differential method [14], using a UV–Vis spectrophotometer (T60U-UV/visible, PG Instruments, London, UK). Absorbance was measured at 531 and 700 nm in buffers at pH 1.0 and 4.5 using $A = (A_{531} - A_{700})$ pH 1.0—$(A_{531} - A_{700})$ pH 4.5 with a molar extinction coefficient of 28,000. Results were expressed as µg of cyanidin-3-glucoside equivalents in g fresh weight basis (µg cy-3-glu/g fw).

### Determination of total antioxidant capacity (TAC)

Total antioxidant capacity was estimated by two standard procedures, ferric reducing ability of plasma (FRAP) and trolox equivalent antioxidant capacity (TEAC) assays. Ferric reducing ability of plasma (FRAP) was determined according to the method of Benzie and Strain [15]. Assay was conducted using three aqueous stock solutions containing 0.1 M acetate buffer (pH 3.6) and 10 mM 2,4,6-tris(2-pyridyl)-1,3,5-triazine (TPTZ) acidified with concentrated hydrochloric acid (1000:3:3 v/v/v), and 20 mM ferric chloride. These solutions were prepared and stored in the dark under refrigeration. Stock solutions were combined (10:1:1 v/v/v) to form the FRAP reagent just prior to analysis. For each assay laboratory duplicate, 2.98 ml of FRAP reagent and 20 µl of sample extract were mixed. After 10 min, the absorbance of the reaction mixture was determined at 593 nm in a spectrophotometer. For the standard trolox equivalent antioxidant capacity (TEAC) assay, 2,2′-Azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) was dissolved in acetate buffer and prepared with potassium persulfate, as described by Saracoglu et al. [16]. The mixture was diluted in acidic medium of 20 mM sodium acetate buffer (pH 4.5) to an absorbance of $0.700 \pm 0.01$ at 734 nm for longer stability [16]. For the spectrophotometric assay, 2.97 ml of the ABTS solution and 30 µl of fruit extract were mixed and incubated for 10 min and the absorbance was determined at 734 nm.

### Determination of total phenolics (TP)

TP content was measured according to Singleton and Rossi [17] procedure. An aliquot of fruit slurry was extracted with buffer containing acetone, water and acetic acid (70:29.5:0.5 v/v/v) for 1 h in the dark. Three parallel extracts were obtained from each accession. Then, extract, Folin–Ciocalteu's reagent and water were incubated for 8 min, followed by adding 7% sodium carbonate. After 2 h, the absorbance was measured by an automated UV–VIS spectrophotometer at 750 nm. Gallic acid ($C_7H_6O_5$) was used as a standard (standard curve equation: $y = 0.0013x + 0.0095$, $r^2 = 0.9999$). The results were expressed as µg gallic acid equivalents in g fresh weight basis (µg GAE/g fw).

### Extraction and determination of specific phenolic compounds

The phenolic compounds were determined using the HPLC separation method described by Rodriguez-Delgado et al. [18]. About 100 g of samples were fragmented and 5 g from each sample was transferred to centrifuge tubes. The samples were mixed homogenously then diluted 1:1 (v/v) with distilled water and centrifuged at 15,000 rpm for 15 min. The supernatant was passed through 0.45 µm membrane filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA), then injected into HPLC system (gradient). The chromatographic separation in Agilent 1100 series HPLC took place in DAD detector (Agilent, USA) with 250 mm × 4.6 mm, 4 µm ODScolumn (HiChrom, USA). The following solvents in water with a flow rate of 1 ml/min and 20 µl injection volume were used for spectral measurements at 254, and 280 nm: as mobile phase solvent A, methanol–acetic acid–water (10:2:88 v/v/v) and Solvent B, methanol–acetic acid–water (90:2:8 v/v/v).

### Extraction and determination of specific sugars

The samples were prepared according to the method described by Melgarejo et al. [19] with minor modifications. Briefly, the samples of 5 g fruit was centrifuged at 12,000 rpm for 2 min at 4 °C. Then the supernatant was

filtrated with SEP-PAK $C_{18}$ cartridges and transferred into a vial and used for analysis. Analysis of sugars was performed by HPLC (isocratic program) with μbondapak-$NH_2$ column and refractive index (RI) detector using 85% acetonitrile as a mobile phase. The calculation of concentrations was based on standards prepared in the laboratory.

### Extraction and determination of specific organic acids

For organic acid extraction, the method by Gundogdu et al. [20] was modified. About 200 g of samples was fragmented and 5 g from each sample was transferred to centrifuge tubes. The 10 ml of 0.009 N $H_2SO_4$ was added to the samples and the samples were homogenized with Heidolph Silent Crusher M, Germany. Then, the samples were mixed for an hour with a shaker (Heidolph Unimax 1010, Germany) and centrifuged at 15,000 rpm for 15 min. The supernatant were passed through coarse filter paper, then twice in 0.45 mm membrane filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA), and last in the SEP-PAK C18 cartridge.

The concentration of organic acids was determined by HPLC using an Aminex column (HPX-87H, 300 mm × 7.8 mm, Bio-Rad) fitted on an Agilent 1100 series HPLC G 1322 A, Germany [20]. Organic acids were detected at 214 and 280 nm wavelengths. As the mobile phase, 0.009 N $H_2SO_4$ were passed through 0.45 μm filter membrane.

### Extraction and determination of ascorbic acid (vitamin C)

Ascorbic acid content was determined following the modified HPLC (isocratic program) (Agilent 1100 series HPLC G 1322 A, Germany) analytical procedure outlined by Gundogdu et al. [21]. The 5 g of sample was transferred to a 50 ml volumetric flask including 10 ml 6% (weigth/volume) metaphosphoric acid (Sigma, M6285, 33.5%). The sample was then homogenized at 24,000 rpm for 15 s, and centrifuged at 14,000 rpm for 10 min at 1 °C. 5 ml of the supernatant was filtered through 0.45 μm PTFE syringe filters (Phenomenex, UK) and placed in an amber colored vial (AIM, Screw vial, SV-15A). Quantification of ascorbic acid was made by an external standard method using an L-ascorbic acid Standard (Sigma A5960). Samples were separated on a Luna C18 column (250 mm × 4.60 mm, 5 μm from Phenomenex) at 25 °C by an HPLC. The mobile phase was 25 mM $KH_2PO_4$ (adjusted to pH 2.2 with phosphoric acid) with a flow rate of 1 ml/min. L-Ascorbic acid was detected at 254 nm.

### Statistical analysis

Data was analyzed by means of analysis of variance. Analyses of variance were carried out by GLM procedure. The means were separated using the least significant difference (LSD) method at the 0.05 significance level. All statistical analyses were performed with SAS Version 9.3 (SAS Institute Inc., Cary, NC, USA).

## Results and discussion

As fruit progressed from pink maturity to black maturity stage, TP and TMA contents of fruits increased from 553.8 to 1310 μg GAE/g fw and from 36.6 to 925.6 μg cy-3-glu/g fw respectively (Table 1). These results are in agreement with the findings of Mahmood et al. [8] who found that total phenolic and total flavonoids increased as fruit maturity progressed in two strawberry cultivars. TAC (TEAC and FRAP) also increased in corresponding with increase in TP and TMA during fruit ripening. These results indicated that phenolics and anthocyanins are important bioactive compounds contributing to antioxidant activity, in accordance with previous studies [22]. TAC values, measured by TEAC and FRAP method, increased from 2.89 to 12.09 and from 3.91 to 12.8 μmol TE/g fw respectively as the fruit ripening progressed (Table 1). TEAC value of the mulberry fruits studied in this work was within the range of the reports for the black mulberries by Ozgen et al. [23], except for pink maturity stage. The phenolic content of *M. laevigata* fruit examined in this study found relatively low compared to the results reported by Gungor and Sengul [24] for white mulberry fruits.

**Table 1** Total phenolic content (TP), total monomeric anthocyanin (TMA) content, and antioxidant capacity (TEAC and FRAP) of *M. laevigata* fruits sampled from different maturation stages

| | Ripening stages | | | |
|---|---|---|---|---|
| | Pink | Red | Red–black | Black |
| TP (μg GAE/g fw) | $553.8 \pm 38.96^{d}$ | $1003.6 \pm 64.05^{c}$ | $1155.3 \pm 28.77^{b}$ | $1310.3 \pm 32.23^{a}$ |
| TMA (μg cy-3-glu/g fw) | $36.6 \pm 2.35^{d}$ | $538 \pm 5.43^{c}$ | $680.2 \pm 16.93^{b}$ | $925.6 \pm 9.26^{a}$ |
| TEAC (μmol TE/g fw) | $2.89 \pm 0.17^{c}$ | $8.48 \pm 0.93^{b}$ | $9.52 \pm 0.92^{b}$ | $12.09 \pm 0.70^{a}$ |
| FRAP (μmol TE/g fw) | $3.91 \pm 0.24^{d}$ | $8.32 \pm 0.62^{c}$ | $11.21 \pm 1.04^{b}$ | $12.80 \pm 0.50^{a}$ |

The difference between mean values shown with same letter on the same column is not significant ($p < 0.05$). Means of three replicates ± standard deviation

The fructose, glucose, and sucrose contents of the fruit increased with the progression of fruit ripening (Table 2). An increase in the fructose and glucose contents of mulberry fruit with maturity has also been reported by Lee et al. [13]. Similar results have been reported for strawberry [25], grape [26] and black raspberry [27]. In black ripening stage, fructose, glucose, and sucrose contents of fruits were measured as 21.25, 13.66 and 2.75 g/kg respectively. Sanchez et al. [28] determined that glucose varied between 4.22 and 5.37 g/100 g, fructose between 6.53 and 8.55 g/100 g in Spanish white mulberries, and that glucose ranged from 3.19 to 7.45 g/100 g, fructose from 4.82 to 11.7 g/100 g in black mulberries in full mature stage. Mahmood et al. [8] detected that fructose and glucose as 5.36 and 2.50 g/100 g for black mulberry fruits, and as 4.97 and 3.21 g/100 g for white mulberry fruits respectively.

When values of black ripening stage were considered, citric acid was the predominant organic acid with a content of 5.80 g/kg. Citric acid was followed by malic, oxalic and succinic acids with contents of 5.67, 3.33 and 2.20 g/kg (Table 3). Sanchez et al. [28] extracted malic acid as 0.58–0.79 and 0.41–0.79 g/100 g, citric acid as 0.04–0.18 and 0.14–0.66 g/100 g, fumaric acid as 0.03–0.07 and 0.01–0.07 g/100 g, and tartaric acid as 0.02–0.03 and 0.03–0.04 g/100 g from Spanish white and black mulberries that were fully ripened, respectively. Citric acid content first increased as fruits progressed from pink stage to red maturity stage, then decreased in red–black maturity stage. A similar change was observed in the course of the oxalic acid content. During fruit ripening, a fluctuation in malic acid content was observed. Malic acid contents of red and black fruit were higher than those of pink and red–black fruits. Succinic acid increased with progression of fruit ripening. Fumaric acid content increased until red–black ripening stage, and then decreased. Mahmood et al. [8] found that citric and malic acid increased with ripening in *M. laevigate* and *M. nigra*. These results show that the organic acids contents in the ripening process can vary depending on the growing conditions and variety. The results achieved regarding increase in ascorbic acid content during ripening were in agreement with those reported by previous studies for different mulberry species [8] and for other fruit species [29–31].

Chlorogenic acid, rutin, and gallic acid were the main phenolics for mulberry fruits investigated in this study (Table 4). These results are consistent with the findings of Gundogdu et al. [21] and Natic et al. [32]. Memon et al. [7] using three different extraction techniques (sonication, magnetic stirring, and homogenization) found that gallic acid (5.81, 4.32, and 3.57 mg/100 g), vanillic acid (4.57, 3.95, and 3.70 mg/100 g), chlorogenic acid (20.47, 17.03, and 24.45 mg/100 g) and syringic acid (9.19, 6.31 and 8.48 mg/100 g) were main phenolic compounds in the fruits of white mulberry (*M. alba*). Chlorogenic acid content of *M. laevigata* fruits showed a steady increase from pink stage (14.17 mg/100 g) to black ripening stage (43.99 17 mg/100 g). This result was in agreement with that reported by Mahmood et al. [8] for *M. laevigata*

**Table 2** Spesific sugar contents of *M. laevigata* fruits sampled from different maturation stages (g/kg)

| | Ripening stages | | | | Average | % |
|---|---|---|---|---|---|---|
| | Pink | Red | Red–black | Black | | |
| Fructose | $12.80 \pm 0.45^{d}$ | $16.76 \pm 0.62^{c}$ | $19.39 \pm 0.17^{b}$ | $21.25 \pm 0.21^{a}$ | 17.55 | 56.59 |
| Glucose | $8.34 \pm 0.19^{c}$ | $10.72 \pm 0.45^{b}$ | $13.15 \pm 0.63^{a}$ | $13.66 \pm 0.15^{a}$ | 11.47 | 36.98 |
| Saccharose | $1.27 \pm 0.04^{d}$ | $1.88 \pm 0.05^{c}$ | $2.08 \pm 0.04^{b}$ | $2.75 \pm 0.24^{a}$ | 2.00 | 6.43 |
| Total sugar | $22.42 \pm 0.24^{d}$ | $29.36 \pm 1.11^{c}$ | $34.61 \pm 0.68^{b}$ | $37.65 \pm 0.22^{a}$ | 31.0 | 100.0 |

The difference between mean values shown with same letter on the same column is not significant ($p < 0.05$). Means of three replicates ± standard deviation

**Table 3** Spesific organic acid contents of *M. laevigata* fruits sampled from different maturation stages

| | Ripening stages | | | | Average | % |
|---|---|---|---|---|---|---|
| | Pink | Red | Red–black | Black | | |
| Citric acid (g/kg) | $8.97 \pm 0.24^{b}$ | $10.05 \pm 0.34^{a}$ | $5.16 \pm 0.06^{d}$ | $5.80 \pm 0.10^{c}$ | 7.49 | 40.3 |
| Malic acid (g/kg) | $3.31 \pm 0.52^{b}$ | $5.80 \pm 0.16^{a}$ | $3.62 \pm 0.13^{b}$ | $5.67 \pm 0.17^{a}$ | 4.60 | 24.7 |
| Oxalic acid (g/kg) | $4.79 \pm 0.22^{b}$ | $5.50 \pm 0.11^{a}$ | $3.24 \pm 0.11^{c}$ | $3.33 \pm 0.06^{c}$ | 4.21 | 22.6 |
| Succinic acid (g/kg) | $1.23 \pm 0.02^{b}$ | $1.13 \pm 0.05^{c}$ | $1.11 \pm 0.08^{c}$ | $2.20 \pm 0.08^{a}$ | 1.41 | 7.6 |
| L-Ascorbic acid (mg/100 g) | $79.9 \pm 7.25^{b}$ | $82.3 \pm 0.76^{b}$ | $90.7 \pm 6.00^{a,b}$ | $98.6 \pm 13.24^{a}$ | 87.9 | 4.7 |
| Fumaric acid (mg/kg) | $6.23 \pm 1.13^{c}$ | $8.30 \pm 0.31^{b}$ | $10.29 \pm 0.18^{a}$ | $7.62 \pm 0.21^{b}$ | 8.11 | 0.04 |
| Total organic acid (g/kg) | $19.09 \pm 0.88^{b}$ | $23.31 \pm 0.50^{a}$ | $14.05 \pm 0.05^{d}$ | $17.99 \pm 0.20^{c}$ | 18.61 | 100.0 |

The difference between mean values shown with same letter on the same column is not significant ($p < 0.05$). Means of three replicates ± standard deviation

**Table 4** Spesific phenolic matter contents of *M. laevigata* fruits sampled from four maturation stages (mg/100 g)

| | Ripening stages | | | | Average | % |
|---|---|---|---|---|---|---|
| | Pink | Red | Red–black | Black | | |
| Chlorogenic acid | $14.17 \pm 0.29^{d}$ | $18.84 \pm 1.29^{c}$ | $32.9\ 2 \pm 1.54^{b}$ | $43.99 \pm 2.10^{a}$ | 27.48 | 25.18 |
| Rutin | $17.98 \pm 1.68^{b}$ | $30.41 \pm 1.75^{a}$ | $27.74 \pm 2.89^{a}$ | $32.35 \pm 2.24^{a}$ | 27.12 | 24.86 |
| Gallic acid | $23.15 \pm 1.12^{b}$ | $28.90 \pm 2.25^{a}$ | $23.59 \pm 2.02^{b}$ | $19.46 \pm 0.89^{c}$ | 23.77 | 21.79 |
| Ellagic acid | $9.05 \pm 1.32^{b}$ | $10.05 \pm 0.24^{a,b}$ | $9.36 \pm 0.22^{b}$ | $10.76 \pm 0.21^{a}$ | 9.80 | 8.98 |
| *O*-Coumaric acid | $5.06 \pm 0.23^{d}$ | $6.13 \pm 0.09^{c}$ | $7.20 \pm 0.21^{b}$ | $8.92 \pm 0.50^{a}$ | 6.83 | 6.26 |
| Ferulic acid | $4.01 \pm 0.48^{b}$ | $5.96 \pm 0.87^{a}$ | $5.30 \pm 0.85^{a}$ | $5.26 \pm 0.46^{a}$ | 5.13 | 4.70 |
| Protocatechuic acid | $1.71 \pm 0.04^{b}$ | $2.47 \pm 0.09^{a}$ | $2.54 \pm 0.15^{a}$ | $2.47 \pm 0.13^{a}$ | 2.30 | 2.11 |
| *p*-Coumaric acid | $2.38 \pm 0.02^{c}$ | $2.52 \pm 0.05^{c}$ | $3.30 \pm 0.67^{b}$ | $4.46 \pm 0.08^{a}$ | 3.16 | 2.90 |
| Quercetin | $1.87 \pm 0.03^{c}$ | $2.04 \pm 0.18^{b,c}$ | $2.68 \pm 0.14^{a}$ | $2.27 \pm 0.24^{b}$ | 2.22 | 2.03 |
| Syringic acid | $1.78 \pm 0.15$ | $1.32 \pm 0.04^{b}$ | $1.15 \pm 0.07^{c}$ | $0.92 \pm 0.03^{d}$ | 1.29 | 1.18 |
| Phenolic total | $81.2 \pm 4.16^{c}$ | $108.7 \pm 2.15^{b}$ | $115.8 \pm 7.23^{b}$ | $130.8 \pm 6.02^{a}$ | 109.1 | 100.0 |

The difference between mean values shown with same letter on the same column is not significant ($p < 0.05$). Means of three replicates ± standard deviation

fruits. On the other hand, Lee et al. [13] working on *M. alba*, found that semi-mature fruits had higher chlorogenic acid than immature and mature ones. This suggests that chlorogenic acid synthesis or accumulation may vary depending on the species and growing conditions. Rutin content increased two times from pink stage to red ripening stage, then continued at the same level until black ripening stage. Mahmood et al. [8], working on different mulberry species, reported that gallic acid increased in all species examined as the fruit ripening progresses. In the present study, gallic acid increased from pink ripening stage to red ripening stage, and then decreased until black ripening stage. The highest ellagic acid, *o*-coumaric acid, and *p*-coumaric acid contents were measured at black ripening stage. Mahmood et al. [8] reported similar results for *p*-coumaric acid change during fruit development of *M. laevigata* and other three mulberry species. Some studies indicated that some plant phenols such as quercetin, had powerful antioxidant properties [26, 33]. In a study on different mulberry species, it was found that *M. laevigata* had the highest amount of quercetin among tested species [8]. In the present study, quercetin contents changed significantly depending on maturity stage and the highest quercetin content measured at red–black stage ($p < 0.05$). The significant changes were also observed in amount of syringic acid, ferulic acid and protocatechuic acid during fruit ripening ($p < 0.05$). Unlike the others phenolic, syringic acid content decreased with fruit ripening. A similar result has also been reported by Gruz et al. [34], who worked on medlar fruits.

## Conclusion

It was determined that the antioxidant properties, organic acid, sugar, and phytochemical contents of *M. laevigata* fruits changed significantly during the ripening period ($p < 0.05$). Black ripening stage provided richer contents in total phenolic (1310.3 µg GAE/g fw) and sugar (37.65 g/kg). However, higher contents in gallic acid (28.90 mg/100 g) and ferulic acid (5.96 mg/100 g) were obtained from red ripening stage. Such information will be important for deciding the appropriate harvest stage depending on the purpose. In addition, this study indicated that the *M. laevigata* fruits are rich source of organic acid, phenolics and antioxidants, demonstrating its potential use as a functional food. On the other hand, further investigations are required to ascertain an inclusive phenolic antioxidant system of this fruit and develop its application for functional food or nutraceutical purposes.

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