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Identification of phenolic compounds in Australian grown dragon fruits by LC-ESI-QTOF-MS/MS and determination of their antioxidant potential

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Abstract Dragon fruit is a popular tropical fruit that has a high phenolic content which are the main contributors to the antioxidant potential and health benefits of dragon fruit pulp and peel waste. Although some phenolic compounds in dragon fruit have previously been reported, a comprehensive analysis of complete phenolic profile of the Australian varieties has not been conducted. Thus, the aim of this study was to extract, identify and quantify phenolics from dragon fruits grown in Australia. Phenolic compounds were extracted from the peels and pulps of white and red dragon fruit. Phenolic content was determined by total phenolic content (TPC), total flavonoid content (TFC) and total tannin content (TTC), while antioxidant activities were measured by 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), 2,2′-Azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) and total antioxidant capacity (TAC). The results showed that dragon fruit pulp had a higher total phenolic content and stronger antioxidant capacity than peel, while the peel had a higher content of flavonoids and tannins than the pulp. Liquid chromatography electrospray ionization quadrupole time-of-flight mass spectrometry (LC-ESI-QTOF-MS/MS) was used for the characterization of phenolic compounds, a total of 80 phenolics including phenolic acids (25), flavonoids (38), lignans (6), stilbene (3) and other polyphenols (8) were characterized in all dragon fruits. High performance liquid chromatography equipped with photodiode array detector (HPLC-PDA) quantified the phenolic compounds in different portion of dragon fruit

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and showed that dragon peel had higher concentrations of phenolics than pulp. The results highlighted that both dragon fruit peel and pulp are potential sources of phenolic compounds, with peel in particular being a source of antioxidant phenolics with potential as ingredients for the food and pharmaceutical industries.

1. Introduction

Dragon fruit (*Hylocereus* spp.) is a widely consumed tropical fruit which is considered healthy partly due to its high content of phenolic compounds (Zain et al., 2019). The global market value of dragon fruit reached 4.9 billion US dollars worldwide in 2016 (Chen, 2018). Dragon fruit pulp is edible and it is usually eaten raw or used for making commercial products such as juices, ice cream, jam and yogurt (Nurul and Asmah, 2014). The phenolic compounds in pulp possess antioxidant activity and have a range of potential health benefits (Som et al., 2019). However, the dragon fruit peel is non-edible, and mostly goes to waste, despite its high phenolic content (Kim et al., 2011). Excessive peel waste results in both economic and environmental impacts, particularly as organic waste going to landfill is a major contributor to methane release into the atmosphere (Chen, 2018). Emerging applications to utilise dragon fruit peel waste include fruit spreads and food additives, with isolation or concentration of antioxidants for food, pharmaceutical and cosmetics industries warranting further exploration (Ferreres et al., 2017).

Phenolic compounds are a major group of phytochemical secondary metabolites (Hoda et al., 2019) that exhibit strong antioxidant capabilities due to the presence of phenolic groups that donate electrons or conjugate with metal ions (Hoyweghen et al., 2012). Phenolic compounds can be categorized into different groups such as flavonoids, phenolic acids, stilbenes and lignans based on the number of carbon molecules and the complexity of the structure (Hoda et al., 2019). Each phenolic group has unique attributes due to their specific molecular structure (Campos-Vega and Oomah, 2013). White dragon fruit (*Hylocereus undatus*) and red dragon fruit (*Hylocereus polyrhizus*) are two major varieties found to contain large amounts of phenolic compounds. White dragon fruit has red peel and white pulp, where the pulp was used as an indigenous medicine for healing wounds and bruises in Mexico, partly due to its antioxidant capability (Perez et al., 2005). Red dragon fruit has red peel and red pulp, which can be used for making natural color additives for healthy food due to its pulp color and antioxidant properties. The predominant phenolic compounds identified in these two varieties are flavonols, flavanones and hydroxycinnamic acid derivatives (García-Cruz et al., 2017). In addition, phenolic acids including gallic acid, syringic acid, caffeic acid, *p*-coumaric acid, cinnamic acid and quinic acid have also been characterized in white and red dragon fruits (Castro-Enríquez et al., 2020; Luo et al., 2014; Zain et al., 2019).

Although phenolic compounds are abundant in dragon fruit, their content and availability can be affected by varieties, plant part, growth conditions, terroir and extraction method (Hoda et al., 2019). Thus, developing an optimum extraction method is important, as it allows the accurate identification and quantification of phenolic compounds from and within extracts. The most widely used extraction method currently is solvent extraction using various proportions of organic solvents, for which variations in solvents and extraction conditions result in different proportions and amounts of phenolics being extracted (Chan et al., 2014; Choo et al., 2016). After extraction, antioxidant activity or capacity can be determined by the estimation of phenolic contents by using selected antioxidant assays. Phenolic content has been measured through determining total phenolic content (TPC), total flavonoid content (TFC) and total tannins content (TTC) assays (Sánchez-Rangel et al., 2013). Antioxidant potential can be estimated by 2,2-Diphenyl-1-picrylhydrazyl (DPPH) assay, ferric reducing antioxidant power (FRAP) assay, 3-ethyl benzothiazoline-6-sulphonic acid (ABTS) assay and total antioxidant capacity (TAC) assay (Haida and Hakiman, 2019). For characterization and quantification of phenolic compounds in plant foods, liquid chromatography-mass spectrometry (LC-MS/MS) is the most widely used technique (Lucci et al., 2017). In previous studies, several phenolic compounds had been identified through LC-MS in dragon fruit such as cinnamic acid, quinic acid, quercetin-3-*O*-hexoside, apigenin, 3,4-dihydroxyvinylbenzene and apigenin (Lira et al., 2020; Zain et al., 2019). However, previous studies on phenolic profile of dragon fruit peels and pulps characterized only some major phenolic compounds, while a complete phenolic profile in dragon fruit peel and pulp is lacking for varieties grown in Australia.

In this study, phenolic compounds were extracted from the pulps and peels of two Australian grown dragon fruit varieties. Phenolic content and antioxidant activity of the extracts were determined by different phenolic estimation methods (TPC, TFC and TTC) and antioxidant assays (DPPH, ABTS, FRAP and TAC), while phenolic compounds were further characterized and quantified through liquid chromatography with electrospray ionization-quadrupole time-of-flight mass spectrometry (LC-ESI-QTOF-MS/MS) and high performance liquid chromatography equipped with photodiode array detector (HPLC-PDA). The aim of this study was to provide relatively comprehensive information for the antioxidant activities and phenolic profiles of Australian dragon fruit, as part of assessing the potential value of dragon fruit peel waste as a source of new nutritional, cosmetic or pharmaceutical antioxidant ingredients.

2. Materials and methods

2.1. Chemicals and reagents

Most chemicals for extraction, identification and quantification were purchased from Sigma-Aldrich Corporation (Castle Hill, NSW, Australia). Chemicals for antioxidant assays

including ascorbic acid, quercetin, catechin, aluminum chloride hexahydrate, gallic acid, 2,2′-azino-bis-(3-ethylbenzothiazoline-6- sulfonic acid), 2,4,6-tripyridyl-s-triazine (TPTZ), 2,2-diphenyl-1-picrylhydrazyl, HCl, vanillin, potassium persulfate and Folin-Ciocalteu reagent were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA). Acetic acid, ethanol, ferric chloride ($FeCl_3{\cdot}6H_2O$), sodium acetate, sulfuric acid and sodium carbonate were purchased from Thermo Fisher Scientific (Scoresby, Melbourne, VIC, Australia). For HPLC analysis, chromatographic grade acetic acid, acetonitrile and methanol were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA). Polyphenol standards including kaempferol, kaempferol-3-glucoside, quercetin-3-galactoside, quercetin-3-glucuronide, quercetin-3-rhamnoside, caffeic acid, catechin, epicatechin, chlorogenic acid, epicatechin gallate, quercetin, coumaric acid, syringic acid, protocatechuic acid, *p*-hydroxybenzoic acid, caftaric acid, diosmin and gallic acid were also purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA).

2.2. Sample preparation

White dragon fruit (*Hylocereus undatus*) and red dragon fruit (*Hylocereus polyrhizus*) of 2 kg were purchased from the Queen Victoria Market, Melbourne. The fruits were cleaned, and the peel and pulp were separated into white dragon fruit peel (DWL), white dragon fruit pulp (DWP), red dragon fruit peel (DRL) and red dragon fruit pulp (DRP). Samples were trimmed into slices, freeze dried at −20 ℃ for 48 h and lyophilized at −45 ℃/50 MPa by Dynavac engineering FD3 Freeze Drier (W.A., Australia) and Edwards RV12 oil sealed rotary vane pump (Bolton, England). The dried peels and pulps were made into powders and stored at –20 ℃.

2.3. Extraction of phenolic compounds

Phenolic compounds were extracted from 1 g of sample by 15 mL 80% ethanol, homogenized by the Ultra-Turrax T25 Homogenizer (IKA, Staufen, Germany) and incubated in a ZWYR- 240 shaking incubator (Labwit, Ashwood, Vic, Australia) with 120 rpm at 4 ℃ for 14 h sequentially. When the incubation was finished, samples were centrifuged by the Hettich Refrigerated Centrifuge (ROTINA 380R, Tuttlingen, Baden-Württemberg, Germany) at 24400*g* for 10 min under 10 ℃. After centrifugation, supernatant was collected and filtered with 0.45 μm syringe filter (Thermo Fisher Scientific Inc., Waltham, MA, USA) for antioxidant and LC-MS analysis.

2.4. Estimation of phenolic contents and antioxidant assays

For overall phenolic estimation, TPC, TFC and TTC were performed, while for overall total antioxidant capacity determination, DPPH, FRAP, ABTS and TAC were utilized according to the methods of Suleria et al. (2020), Tang et al. (2020). Absorption data was attained using a Multiskan® Go microplate photometer (Thermo Fisher Scientific Inc., Waltham, MA, USA).

2.4.1. Determination of total phenolic content

Total phenolic content was determined by following the method of Wang et al. (2021) using Folin-Ciocalteu reagent. Dragon fruit sample of 25 μL was added into a 96-well plate (Corning Inc., Midland, NC, USA) together with 25 μL diluted F-C reagent (1:3 diluted with water) and 200 μL water before incubation at room temperature for 5 min. Then 25 μL 10% (*w:w*) sodium carbonate was added for basifying the mixture followed by a 60-min incubation in dark condition. The absorbance of the solutions was determined at 765 nm wavelength with a spectrophotometer (Thermo Fisher Scientific Inc., Waltham, MA, USA) and the standard curve of absorbance verse weight of gallic acid (concentrations ranging from 0 to 200 μg/mL) was plotted. The TPC was calculated with the standard curve and expressed in the form of gallic acid equivalents (GAE) per gram (mg GAE/g) of freeze-dried weight sample.

2.4.2. Determination of total flavonoid content

Total flavonoid content was determined by the aluminum chloride method of Stavrou et al. (2018) with some modifications. Dragon fruit sample of 80 μL was added into a 96-well plate together with aluminum chloride (2% diluted with ethanol) of 80 μL and sodium acetate solution (50 g/L) of 120 μL, followed by an incubation at 25 ∘C for 2.5 h. Then, the absorbance of the solution was determined at 440 nm wavelength by a spectrophotometer, and the standard curve of absorbance verse weight of quercetin (0–50 μg/mL) was plotted. The TFC value was calculated based on the standard curve and expressed as mg of quercetin equivalent per gram (mg QE/g) of dry weight samples.

2.4.3. Determination of total tannin content

The total tannins content was determined by the modification of the vanillin and *p*-dimethylaminocinnamaldehyde methods of Stavrou et al. (2018). Dragon fruit sample of 25 μL was added into a 96-well plate together with 4% vanillin solution (diluted with methanol) of 150 μL and 32% sulfuric acid of 25 μL, followed by an incubation at 25 ∘C for 15 min. The absorbance was measured at 500 nm wavelength by a spectrophotometer, and the standard curve of absorbance verse weight of catechin (0–1000 μg/mL) was plotted. The TTC value was expressed as mg of catechin equivalent per gram (mg CE/g) of dry weight samples.

2.4.4. 2,2-Diphenyl-1-picrylhydrazyl antioxidant assay

DPPH radical scavenging activity was determined by the modification of the DPPH assay method of Sogi et al. (2013). Dragon fruit sample of 40 μL was added into a 96-well plate together with 0.1 mM DPPH methanolic solution of 40 μL, following by a vigorous shake and an incubation at 25 ∘C for 30 min. The absorbance was measured at 517 nm wavelength by a spectrophotometer, and the standard curve of absorbance verse weight of ascorbic acid (0–50 μg/mL) was plotted. The DPPH radical-scavenging activity of the solution was calculated based on the standard curve and expressed as mg of ascorbic acid equivalents per gram (mg AAE/g) of dry weight samples.

2.4.5. Ferric reducing-antioxidant power assay

FRAP assay was performed using a modification of the method of Sogi et al. (2013). The FRAP dye was made by the mix of 300 mM sodium acetate solution, 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) solution as well as 20 mM Fe[III] solution in 10:1:1 ratio. Dragon fruit sample of 20 μL was added into a 96-well plate together with previously prepared FRAP dye solution of 280 μL, followed by a 10 min incubation at 37 ∘C. The absorbance was measured at 593 nm wavelength by a spectrophotometer, and the standard curve of absorbance verse weight of ascorbic acid (0–50 μg/mL) was plotted. The FRAP results were calculated based on the standard curve and expressed as mg of ascorbic acid equivalents per gram (mg AAE/g) of dry weight samples.

2.4.6. 2,2-Azino-bis-3ethylbenzothiazoline-6-sulfonic acid radical scavenging assay

The ABTS radical scavenging activity was determined by the $ABTS^+$ radical cation decolorization assay of Sogi et al. (2013) with slight modifications. The ABTS dye was made by mixing of 5 mL ABTS solution (7 mmol/L) with 88 μL of potassium persulfate solution (140 mM) and a 16-hour dark incubation of the mixture at room temperature. Then, an initial absorbance (0.7 at 734 nm) of the prepared $ABTS^+$ solution was obtained by diluting with analytical grade ethanol. After that, dragon fruit sample of 10 μL was added into a 96-well plate together with previously prepared diluted ABTS solution of 290 μL, following by a 6-minute dark incubation at room temperature. The absorbance was measured at 734 nm wavelength, and the standard curve of absorbance verse weight of ascorbic acid (0–150 μg/mL) was plotted. The ABTS results were calculated based on the standard curve and expressed as mg of ascorbic acid equivalents per gram (mg AAE/g) of dry weight samples.

2.4.7. Total antioxidant capacity assay

Total antioxidant capacity was determined by modifying the phosphomolybdate assay method of Jan et al. (2013); Mashwani et al. (2013). The phosphomolybdate dye was made by mixing 0.6 M H_2SO_4, 28 mM Na_3PO_4 and 4 mM ammonium molybdate in the ration of 1:1:1. Then, dragon fruit sample of 40 μL was added into a 96-well plate together with 260 μL previously prepared phosphomolybdate dye, followed by a 90-minute incubation at 95℃ and a 10-minute cooling at room temperature. The absorbance was measured at 695 nm wavelength, and the standard curve of absorbance verse weight of ascorbic acid (0–200 μg/mL) was plotted. The TAC results were calculated based on the standard curve and expressed as mg of ascorbic acid equivalents per gram (mg AAE/g) of dry weight samples.

2.5. LC-ESI-QTOF-MS/MS analysis

The LC-MS determination was conducted using a modification of the method (Zhong et al., 2020). Phenolic characterization was performed by an Agilent 1200 series HPLC (Agilent Technologies, CA, USA) connected with an Agilent 6520 Accurate-Mass Q-TOF LC-MS (Agilent Technologies, CA, USA). A Synergi Hydro-RP 80A, LC column 250 mm × 4.6 mm, 4 μm (Phenomenex, Torrance, CA, USA) was utilized for compound separation. Mobile phase A was made by the mix of water and acetic acid (in the ratio of 99.5:0.5, *v*/*v*), and mobile phase B was made by the mix of acetonitrile, water and acetic acid (in the ratio of 50:49.5:0.5, *v*/*v*/*v*), followed by a 15-minute degassing at 21 ℃ for both mobile phases. Filtration of the samples was performed with the syringe (Kinesis, Redland, QLD, Australia) coupled with the 0.45 μm syringe filter (Thermo Fisher Scientific Inc., Waltham, MA, USA) before the filtrates were transferred into HPLC vials. The injection volume of each sample was set to be 5 μL and the flow rate was set to be 0.8 mL/min. The program of the gradient elution carried out by a mixture of mobile phase A and B was set as follow: 10% B (0 to 20 min); 25% B (20 to 30 min); 35% B (30 to 40 min); 40% B (40 to70 min); 55% B (70 to 75 min); 80% B (75 to 77 min); 100% B (77 to 79 min); 100% B (79 to 82 min); 10% B (82 to 85 min). For MS/MS, the operational source utilized for both negative and positive modes was electrospray ionization (ESI), and mass spectra in the range 50 to 1300 (*m*/*z*) were attained with collision energy (10, 15 and 30 eV) for fragmentation. The nitrogen gas temperature of the mass spectrometry was set to be 300 ∘C with a flow rate of 5 L/min. The sheath gas temperature was set to be 250 ∘C with a flow rate of 11 L/min, and a nebulizer gas pressure of 45 psi. A 500 V nozzle voltage and a 3.5 kV capillary were also set. For data collection and analysis, an Agilent MassHunter data acquisition software version B.03.01 was used.

2.6. HPLC analysis

Based on the method of Ma et al. (2019), the putative quantification of targeted phenolic compounds was carried out using an Agilent 1200 series HPLC (Agilent Technologies, CA, USA) connected with a PDA detector. Apart from a sample injection volume of 20 μL, the column and conditions utilized in HPLC were the same as that was previously described in LC-ESI-QTOF-MS/MS. The detection was performed under wavelengths of 280, 320, and 370 nm for various phenolic compounds. Specifically, hydroxybenzoic acids were identified under 280 nm wavelength, hydroxycinnamic acids were identified under 320 nm, and flavonol group was identified under 370 nm. Data collection and analysis were carried out by an Agilent LC-ESI-QTOF-MS MassHunter data acquisition software version B.03.01.

2.7. Statistical analysis

The mean differences between different samples were analyzed by one-way analysis of variance (ANOVA) and Tukey's honestly significant differences (HSD) multiple rank test at $p \leq 0.05$. ANOVA was carried out by Minitab for Windows version 19.0 (Minitab, LLC, State College, PA, USA). The results are shown in the form of mean ± standard deviation (SD). Correlations between polyphenol content and antioxidant activities were analyzed by Pearson's correlation coefficient at $p \leq 0.05$.

3. Results and discussion

3.1. Phenolic estimation (TPC, TFC and TTC)

Dragon fruit was reported to contain large amounts of phenolic compounds with strong antioxidant capacity, including fla-

vonoids and phenolic acids. The phenolic contents in dragon fruit pulps and peels were determined by TPC, TFC, and TTC assays mentioned in Table 1.

As for TPC results, DRP had a significantly higher value (0.39 ± 0.02 mg GAE/g) than the rest of the samples, while DWP and DWL has comparative phenolic contents (0.27 ± 0.01 and 0.23 ± 0.01 mg GAE/g) and DRL has the lowest value (0.17 ± 0.01) ($p < 0.05$). The TPC values from our study are close to the study conducted by Choo et al. (2016), in which they determined the TPC of white and red dragon fruit pulps to be 0.29 ± 0.02 and 0.24 ± 0.01 mg GAE/g. However, the pattern of the TPC results of Nurliyana et al. (2010) was contradictory to our research as they found that white and red peel samples had higher phenolic contents than pulp samples. They attributed the higher phenolic content in peels to the abundance of betacyanins, which contributes to TPC value apart from polyphenols (Tenore et al., 2012). An additional reason for the contradictory results between their study and ours might be the freeze-drying process we applied to the peel samples. Shofian et al. (2011) have suggested that freeze-drying can cause degradation of some oxidatively sensitive phenolic compounds, thus lowering the antioxidant activity in tropical fruits. The different varieties and extraction solvent used in the two studies may also contribute to differences in the TPC observed (Choo et al., 2016).

Peel samples including DWL and DRL has significant higher values for TFC (26.23 ± 1.85 and 21.66 ± 1.91 μg QE/g respectively) than DWP (2.39 ± 0.20 μg QE/g), while there was no significant difference in the flavonoid content in both peels. Previously, Wojdyło et al. (2007) reported that although polyphenols were present in both peel and pulp, flavonoids mostly existed in the peels, which is in agreement with the results we observed. However, Tenore et al. (2012) extracted flavonoids from red dragon fruit peel and pulp by 70% methanol which is much higher than for our results. The difference might be attributed to the sub-fraction method they used for extraction which was able to separate flavonoids from other phytochemicals to give a higher TFC value and the Australian varieties were subjected to the assay specifically in our study (Tenore et al., 2012).

The TTC assay only detected measurable levels for the DWL sample, with a value of 24.26 ± 2.04 μg CE/g. Wu et al. (2006) reported tannin contents in red dragon fruit peel and pulp extracted by 80% acetone (83.3 ± 1.1 and 72.1 ± 0.2 mg CE/g respectively). Rebecca et al. (2010) measured tannins in red dragon fruit pulp extracted in 96% ethanol (2.3 ± 0.2 mg CE/g), which is also contradictory with our results. The difference in tannin content may be explained by the difference in variety and the extraction solvents utilized (Sulaiman et al., 2011). Also, the plant varieties may also be an important factor these difference from previous studies, since the dragon fruits studied were from Taiwan and Malaysia, while we used Australian varieties as samples.

3.2. Antioxidant activities (DPPH, FRAP, ABTS and TAC)

A combination of antioxidant assays is often used to determine the antioxidant capacity of food samples containing a complex mix of phytochemicals. In this study, the antioxidant capabilities of dragon fruit pulps and peels were determined using DPPH, FRAP, ABTS and TAC assays. The results are shown in Table 1.

DPPH is the most commonly used assay to characterize free radical scavenging capabilities of food samples based on their hydrogen atom donation ability. From Table 1, DRP has significantly higher activity (0.29 ± 0.02 mg AAE/g) than the other three samples ($p < 0.05$), followed by DWP with 0.09 ± 0.01 mg AAE/g ($p < 0.05$), which is also higher than DWL and DRL (both are 0.07 ± 0.01 mg AAE/g) ($p < 0.05$). Previously, Nurliyana et al. (2010) reported that DRP has higher DPPH value than DWP, which is consistent with our results. The stronger antiradical capability in DRP is likely to be due to the abundance of pigments (betalains) with antioxidant potential. However, these authors indicated that peels have higher antiradical capacities than pulps, which is the reverse of our findings. Kim et al. (2011) also reported higher antiradical capacities in peels compared with pulps, which they attributed to the higher content of phenolic compounds in peels. The reason for the lower DPPH in our peel samples might be plant strain differences (Shofian et al., 2011).

The FRAP assay measures the antioxidant ability of food samples by utilizing a ferric tripyridyltriazine (Fe^{III}-TPTZ) complex to determine their reducing potential. The results of the FRAP assay shared the same pattern as the DPPH results, in which DRP has significantly higher value than the other three samples (53.02 ± 2.76 μg AAE/g), while DWP has a significantly higher value (38.80 ± 0.45 μg AAE/g) than the peels DWL and DRL (25.50 ± 0.73 and 18.12 ± 0.75 AAE/g respectively) ($p < 0.05$), with no significant difference between peels. Choo et al. (2016) indicated that the ferric reducing capability of dragon fruit was rather weak as the antioxidant compounds in this fruit had stronger antiradical capability than metal reducing ability. In addition, Nurliyana et al. (2010) reported that the ferric reducing capabilities of dragon

Table 1 The estimation of polyphenol content and antioxidant activity of white and red dragon fruit.

Antioxidant Assays	DWP	DWL	DRP	DRL
TPC (mg GAE/g)	0.27 ± 0.01[b]	0.23 ± 0.01[b]	0.39 ± 0.02[a]	0.17 ± 0.01[c]
TFC (μg QE/g)	2.39 ± 0.20[b]	26.23 ± 1.85[a]	–	21.66 ± 1.91[a]
TTC (μg CE/g)	–	24.26 ± 2.04	–	–
DPPH (mg AAE/g)	0.09 ± 0.01[b]	0.07 ± 0.01[c]	0.29 ± 0.02[a]	0.07 ± 0.01[c]
FRAP (μg AAE/g)	38.80 ± 0.45[b]	25.50 ± 0.73[c]	53.02 ± 2.76[a]	18.12 ± 0.75[c]
ABTS (mg AAE/g)	0.31 ± 0.01[a]	0.20 ± 0.01[c]	0.29 ± 0.01[b]	0.19 ± 0.01[c]
TAC (μg/g)	0.32 ± 0.02[a]	0.19 ± 0.01[b]	0.30 ± 0.01[a]	0.17 ± 0.01[b]

The data is shown as mean ± standard deviation (n = 3); [a,b] indicate the means in a row with significant difference ($p < 0.05$) using one-way analysis of variance (ANOVA) and Tukey's test. DWP, white dragon fruit pulp; DWL, white dragon fruit peel; DRP, red dragon fruit pulp; DRL, red dragon fruit peel; GAE, gallic acid equivalents; QE, quercetin equivalents; CE, catechin equivalents; AAE, ascorbic acid equivalents.

fruit peels are stronger than that of pulps, which is contrary to our results, and again may be due to either differences in drying methods or strain variation.

The ABTS assay is another widely used method for antiradical capability assessment based on hydrogen atom donation tendency of phenolic compounds. From the ABTS results, pulp samples DWP and DRP has significantly higher value (0.31 ± 0.01 and 0.29 ± 0.01 mg AAE/g respectively) than peel samples DWL and DRL (0.20 ± 0.01 and 0.19 ± 0.01 mg AAE/g respectively) ($p < 0.05$). The ABTS value of DWP is significantly higher than that of the DRP ($p < 0.05$), while no significant difference was found between peel samples ($p > 0.05$). As for former studies, Wu et al. (2006) measured the antiradical capability of dragon fruit peel and pulp by ABTS assay and concluded that the peel extract had better free radical scavenging ability than the pulp extract, which is not consistent with our results. They did however find that the increase of antiradical capability of pulp and peel is positively correlated with the increase in overall antioxidant capacity, which is consistent with our results.

TAC is often used for the determination of total antioxidant capacity of liquid food extracts based on electron transfer mechanism. In this assay, molybdenum (VI) is reduced to molybdenum (V) in the presence of antioxidant compounds (phenolic compounds). The results of TAC indicate that pulp samples DWP and DRP have significantly higher activity (0.32 ± 0.02 and 0.30 ± 0.01 mg AAE/g respectively) than peel samples DWL and DRL (0.19 ± 0.01 and 0.17 ± 0.01 mg AAE/g respectively) ($p < 0.05$), while there was no significant difference in the TAC results between both peel samples or both pulp samples ($p > 0.05$). Previously, Abd Manan et al. (2019) determined the total antioxidant capacity in red dragon fruit pulp by phosphomolybdate assay and indicated that the total antioxidant capacity of this fruit was positively affected by the phenolic content.

3.3. LC-ESI-QTOF-MS/MS characterization of phenolic compounds from dragon fruit

In our study, a qualitative analysis of the phenolic compounds from dragon fruit extracts has been conducted using LC-ESI-QTOF-MS/MS in negative and positive ionization modes (Supplementary Materials). Table 2 shows the compounds that were putatively identified in dragon fruit peels and pulps based on their m/z value and MS spectral data using Agilent MassHunter data acquisition software and Personal Compound Database and Library (PCDL) with database of the Kansas State University, USA. Compounds with scores of higher than 80 (PCDL Score) and mass error < ± 5 ppm were selected for m/z verification and MS/MS identification purposes.

In total, 80 different phenolic compounds were tentatively characterized in dragon fruit, which includes 25 phenolic acids, 38 flavonoids, 6 lignans, 3 stilbenes and 8 other polyphenols mentioned in Table 2.

3.3.1. Phenolic acids

Phenolic acids are one of the major classes of phenolic compounds identified in dragon fruit (García-Cruz et al., 2017). In our study, four subgroups of phenolic acids were detected in dragon fruit samples, including hydroxybenzoic acid derivatives, hydroxycinnamic acid derivatives, hydroxyphenylacetic acids and hydroxyphenylpropanoic acid derivatives. Most of the compounds were identified as hydroxybenzoic acids and hydroxycinnamic acids.

4. Hydroxybenzoic acids derivatives

Hydroxybenzoic acids are commonly found in red fruits with antioxidant potential such as strawberries and raspberries (El Gharras, 2009). In our study, eight hydroxybenzoic acid derivatives were putatively identified in four dragon fruit samples.

Compound **1** with $[M–H]^-$ m/z at 169.0138 was detected from DWP, DRL and DRP, and tentatively characterized as gallic acid based on the product ion at 125 m/z, due to the loss of CO_2 (44 Da) from the precursor ion (Escobar-Avello et al., 2019). Previously, Kim et al. had also tentatively identified gallic acid from white and red dragon fruit peel and pulp samples (Kim et al., 2011).

Compound **2**, **3**, **4**, **5** and **6** were only detected in DRL and putatively identified as galloyl glucose, 2-hydroxybenzoic acid, 4-hydroxybenzoic acid 4-*O*-glucoside, 4-*O*-methylgallic acid and protocatechuic acid 4-*O*-glucoside according to the precursor ions $[M-H]^-$ at m/z 331.0655, 137.0246, 299.076 and 315.0717 for compounds **2**, **3**, **4** and **6**, and the precursor ion $[M+H]^+$ at m/z 185.0444 for compound **5**, respectively. The identification of galloyl glucose was confirmed by the product ions at m/z 169 and 125, formed by the neutral loss of a glucose moiety and further loss of CO_2 from the parent ion (Rajauria et al., 2016). The identification of 2-hydroxybenzoic acid was further confirmed by the product ion at m/z 93, formed by the neutral loss of a CO_2 (44 Da) from the parent ion (Escobar-Avello et al., 2019). In the MS^2 experiment of 4-hydroxybenzoic acid 4-*O*-glucoside and protocatechuic acid 4-*O*-glucoside, the spectra displayed the product ions at m/z 137 and m/z 153 respectively, corresponding to the loss of hexosyl moiety (162 Da) from the precursor ions (Escobar-Avello et al., 2019). Previously, Zain et al. had also tentatively identified protocatechuic in red dragon fruit peels (Zain et al., 2019). Besides, the MS^2 spectrum of 4-*O*-methylgallic acid displayed the product ions at m/z 170 and m/z 142, indicating the loss of CH_3 (15 Da) and CH_3CO (43 Da) (Zhang et al., 2018).

Paeoniflorin (Compound **7**) was detected in both negative (ESI−) and positive (ESI+) modes in DWP and DRL with an observed $[M-H]^-$ m/z at 479.1558. In the MS^2 spectrum of paeoniflorin, the product ions at m/z 449, 357 and 327 were due to the loss of CH_2O (30 Da), $C_7H_6O_2$ (122 Da) and CH_2O plus $C_7H_6O_2$ (152 Da) from the parent ion respectively, which was comparable with the fragmentation rules of paeoniflorin (Wang et al., 2017b). Although paeoniflorin was reported to be abundant in Chinese herbal plants such as *Paeonia lactiflora* with strong anti-inflammatory and immunomodulatory effects, this compound was tentatively identified in dragon fruit for the first time in the present study to our best knowledge (He and Dai, 2011).

4.1. Hydroxycinnamic Acids, hydroxyphenylpropanoic acids and other derivatives

According to previous study, hydroxycinnamic acids are more common than hydroxybenzoic acids in fruits (El Gharras,

Table 2 Characterization of phenolic compounds in dragon fruits by LC-ESI-QTOF-MS/MS.

No.	Proposed compounds	Molecular Formula	RT (min)	Ionization (ESI^+/ ESI^-)	Molecular Weight	Theoretical (*m*/*z*)	Observed (*m*/*z*)	Mass Error (ppm)	MS/MS Product ions	Dragon fruits
Phenolic acid										
Hydroxybenzoic acids										
1	Gallic acid	$C_7H_6O_5$	9.7000	**$[M-H]^-$	170.0215	169.0142	169.0138	−2.36	125	*DWP, DRL, DRP
2	Galloyl glucose	$C_{13}H_{16}O_{10}$	10.222	$[M-H]^-$	332.0743	331.067	331.0655	−4.53	169, 125	DRL
3	2-Hydroxybenzoic acid	$C_7H_6O_3$	11.034	$[M-H]^-$	138.0317	137.0244	137.0246	1.46	93	DRL
4	4-Hydroxybenzoic acid 4-*O*-glucoside	$C_{13}H_{16}O_8$	11.051	$[M-H]^-$	300.0845	299.0772	299.076	−4.01	255, 137	DRL
5	4-*O*-Methylgallic acid	$C_8H_8O_5$	12.904	$[M+H]^+$	184.0372	185.0445	185.0444	−0.54	170, 142	DRL
6	Protocatechuic acid 4-*O*-glucoside	$C_{13}H_{16}O_9$	15.772	$[M-H]^-$	316.0794	315.0721	315.0717	−1.27	153	DRL
7	Paeoniflorin	$C_{23}H_{28}O_{11}$	17.827	**$[M-H]^-$	480.1632	479.1559	479.1558	−0.21	449, 357, 327	DWP, *DRL
8	3,4-O-Dimethylgallic acid	$C_9H_{10}O_5$	20.125	$[M+H]^+$	198.0528	199.0601	199.0596	−2.51	153, 139, 125, 111	DWL
Hydroxycinnamic acids										
9	3-*p*-Coumaroylquinic acid	$C_{16}H_{18}O_8$	4.447	**$[M-H]^-$	338.1002	337.0929	337.0932	0.89	265, 173, 162, 127	DWL, *DWP, DRL, DRP
10	Caffeic acid 3-*O*-glucuronide	$C_{15}H_{16}O_{10}$	15.375	$[M-H]^-$	356.0743	355.067	355.0666	−1.13	179	DRL
11	3-Caffeoylquinic acid	$C_{16}H_{18}O_9$	16.915	**$[M-H]^-$	354.0951	353.0878	353.0873	−1.42	253, 190, 144	DWL, *DRL
12	Caffeoyl glucose	$C_{15}H_{18}O_9$	23.559	$[M-H]^-$	342.0951	341.0878	341.0878	0	179, 161	DRL
13	*p*-Coumaric acid 4-*O*-glucoside	$C_{15}H_{18}O_8$	23.675	$[M-H]^-$	326.1002	325.0929	325.0922	−2.15	169	DRL
14	*m*-Coumaric acid	$C_9H_8O_3$	23.708	**$[M-H]^-$	164.0473	163.04	163.0404	2.45	119	DWL, DWP, *DRL
15	Ferulic acid 4-*O*-glucoside	$C_{16}H_{20}O_9$	28.904	$[M+H]^+$	356.1107	357.118	357.118	0	195, 177, 145, 117	*DWL, DWP, DRL
16	Sinapic acid	$C_{11}H_{12}O_5$	30.334	**$[M-H]^-$	224.0685	223.0612	223.0617	2.24	205, 179, 163	DWL, *DRL
17	1,5-Dicaffeoylquinic acid	$C_{25}H_{24}O_{12}$	31.118	** $[M-H]^-$	516.1268	515.1195	515.1208	2.52	353, 335, 191, 179	DWL, DWP, *DRL
18	5–5′-Dehydrodiferulic acid	$C_{20}H_{18}O_8$	32.124	**$[M+H]^+$	386.1002	387.1075	387.1064	−2.84	369	DRL, *DRP
19	3-Feruloylquinic acid	$C_{17}H_{20}O_9$	38.19	**$[M-H]^-$	368.1107	367.1034	367.1038	1.09	298, 288, 192, 191	*DWL, DRL
20	Cinnamic acid	$C_9H_8O_2$	43.773	**$[M-H]^-$	148.0524	147.0451	147.0454	2.04	103	*DWL, DWP, DRP
21	Verbascoside	$C_{29}H_{36}O_{15}$	54.749	$[M+H]^+$	624.2054	625.2127	625.2098	−4.64	477, 461, 315, 135	DWL, *DRP
22	3-Sinapoylquinic acid	$C_{18}H_{22}O_{10}$	62.49	$[M-H]^-$	398.1213	397.114	397.1135	−1.26	223, 179	DWL, *DRL
Hydroxyphenylacetic acids										
23	2-Hydroxy-2-phenylacetic acid	$C_8H_8O_3$	14.546	**$[M-H]^-$	152.0473	151.04	151.0399	−0.66	136, 92	DWL, DWP, *DRL, DRP
Hydroxyphenylpropanoic acids										
24	Dihydrocaffeic acid 3-*O*-glucuronide	$C_{15}H_{18}O_{10}$	25.232	$[M-H]^-$	358.09		357.0833	1.68	181	DRL
25	Dihydroferulic acid 4-*O*-glucuronide	$C_{16}H_{20}O_{10}$	27.386	$[M-H]^-$	372.1056	371.0983	371.0995	3.23	175	DWL, *DRL
Flavonoids										
Anthocyanins										
26	Isopeonidin 3-*O*-arabinoside	$C_{21}H_{21}O_{10}$	16.77	$[M+H]^+$	433.1135	434.1208	434.1229	4.84	271, 253, 243	*DWP, DRP

(*continued on next page*)

Table 2 (*continued*)

No.	Proposed compounds	Molecular Formula	RT (min)	Ionization (ESI^+/ ESI^-)	Molecular Weight	Theoretical (*m*/*z*)	Observed (*m*/*z*)	Mass Error (ppm)	MS/MS Product ions	Dragon fruits
27	Petunidin 3-*O*-(6′'-acetyl-glucoside)	$C_{24}H_{25}O_{13}$	17.631	$[M+H]^+$	521.1295	522.1368	522.1354	−2.68	317	DWP
28	Delphinidin 3-*O*-glucoside	$C_{21}H_{21}O_{12}$	24.289	$^{**}[M+H]^+$	465.1033	466.1106	466.1095	−2.36	303	DWL, DRL, *DRP
29	Cyanidin 3-*O*-diglucoside-5-*O*-glucoside	$C_{33}H_{41}O_{21}$	34.519	$[M+H]^+$	773.214	774.2213	774.2205	−1.03	610, 464	DWL
30	Peonidin 3-*O*-sambubioside-5-*O*-glucoside	$C_{33}H_{41}O_{20}$	37.077	$^{**}[M+H]^+$	757.2191	758.2264	758.2257	−0.92	595, 449, 287	DWL, *DWP, DRL
31	Peonidin 3-*O*-diglucoside-5-*O*-glucoside	$C_{34}H_{43}O_{21}$	38.007	$^{**}[M+H]^+$	787.2297	786.2224	786.2252	3.56	625, 478, 317	DWL, *DRL
32	Cyanidin 3,5-*O*-diglucoside	$C_{27}H_{31}O_{16}$	42.857	$^{**}[M+H]^+$	611.1612	612.1685	612.1698	2.12	449, 287	DWL, *DWP, DRL
33	4-*O*-Methyldelphinidin 3-O-D-glucoside	$C_{22}H_{23}O_{12}$	48.482	$^{**}[M+H]^+$	479.119	480.1263	480.1257	−1.25	317, 302, 285, 271	DWL, *DRL
Dihydrochalcones										
34	Phloridzin	$C_{21}H_{24}O_{10}$	42.116	$^{**}[M-H]^-$	436.1369	435.1296	435.1303	1.61	273	*DWL, DWP, DRL, DRP
Dihydroflavonols										
35	Dihydromyricetin 3-*O*-rhamnoside	$C_{21}H_{22}O_{12}$	39.53	$^{**}[M-H]^-$	466.1111	465.1038	465.1034	−0.86	301	*DWP, DRL
Flavanols										
36	4′-*O*-Methyl-(-)-epigallocatechin 7-O-glucuronide	$C_{22}H_{24}O_{13}$	25.999	$^{**}[M-H]^-$	496.1217	495.1144	495.1163	3.83	451, 313	*DWP, DRP
37	Prodelphinidin dimer B3	$C_{30}H_{26}O_{14}$	42.907	$[M+H]^+$	610.1323	611.1396	611.1363	−5.4	469, 311, 291	DRL, *DRP
Flavanones										
38	Hesperetin 3′,7-*O*-diglucuronide	$C_{28}H_{30}O_{18}$	12.614	$^{**}[M-H]^-$	654.1432	653.1359	653.1337	−3.37	447, 301,286, 242	DRL
39	Hesperidin	$C_{28}H_{34}O_{15}$	16.322	$[M+H]^+$	610.1898	611.1971	611.1992	3.44	593, 465,449, 303	DWP, *DRP
40	Naringin 4′-*O*-glucoside	$C_{33}H_{42}O_{19}$	29.026	$^{**}[M-H]^-$	742.232	741.2247	741.2234	−1.75	433, 271	DWL, *DRL
41	8-Prenylnaringenin	$C_{20}H_{20}O_5$	48.597	$[M+H]^+$	340.1311	341.1384	341.1397	3.81	323, 271, 137	DWL
42	Hesperetin 3′-*O*-glucuronide	$C_{22}H_{22}O_{12}$	52.934	$^{**}[M-H]^-$	478.1111	477.1038	477.1055	3.56	301, 175, 11385	*DWL, DRL
Flavones										
43	Cirsilineol	$C_{18}H_{16}O_7$	24.654	$^{**}[M+H]^+$	344.0896	345.0969	345.0968	−0.29	330, 312, 297, 284	*DWP, DRP
44	Apigenin 6,8-di-*C*-glucoside	$C_{27}H_{30}O_{15}$	44.237	$^{**}[M-H]^-$	594.1585	593.1512	593.1531	3.2	575, 503, 473	*DWL, DWP, DRL
45	Chrysoeriol 7-*O*-glucoside	$C_{22}H_{22}O_{11}$	49.939	$[M+H]^+$	462.1162	463.1235	463.1248	2.81	445, 427, 409, 381	*DWL, DRL
46	6-Hydroxyluteolin 7-*O*-rhamnoside	$C_{21}H_{20}O_{11}$	51.606	$^{**}[M-H]^-$	448.1006	447.0933	447.0931	−0.45	285	DWL, *DRL
47	Isorhoifolin	$C_{27}H_{30}O_{14}$	55.081	$[M+H]^+$	578.1636	579.1709	579.1729	3.45	433, 415, 397, 271	DRP
Flavonols										
48	Quercetin 3-*O*-glucosyl-xyloside	$C_{26}H_{28}O_{16}$	12.68	$[M-H]^-$	596.1377	595.1304	595.1308	0.67	265, 138, 115, 144	DWP
49	Quercetin 3-*O*-(6″-malonyl-glucoside)	$C_{24}H_{22}O_{15}$	24.68	$[M+H]^+$	550.0959	551.1032	551.1053	3.81	303	DWL
50	Kaempferol 3-*O*-glucosyl-	$C_{33}H_{40}O_{20}$	37.756	$^{**}[M-H]^-$	756.2113	755.204	755.204	0	285	DWL, DWP, *DRL

Table 2 (*continued*)

No.	Proposed compounds	Molecular Formula	RT (min)	Ionization (ESI^+/ESI^-)	Molecular Weight	Theoretical (m/z)	Observed (m/z)	Mass Error (ppm)	MS/MS Product ions	Dragon fruits
	rhamnosyl-galactoside									
51	Kaempferol 3,7-*O*-diglucoside	$C_{27}H_{30}O_{16}$	39.976	**[M - H]$^-$	610.1534	609.1461	609.1468	1.15	449, 287	DWL, *DRL
52	Kaempferol 3-*O*-(2″-rhamnosyl-galactoside) 7-*O*-rhamnoside	$C_{33}H_{40}O_{19}$	40.125	**[M - H]$^-$	740.2164	739.2091	739.2093	0.27		DWL, *DRL, DRP
53	Quercetin 3-*O*-xylosyl-glucuronide	$C_{26}H_{26}O_{17}$	42.684	[M + H]$^+$	610.117	611.1243	611.1236	−1.15	479, 303, 285, 239	DRL
54	Myricetin 3-*O*-rhamnoside	$C_{21}H_{20}O_{12}$	45.162	**[M - H]$^-$	464.0955	463.0882	463.0882	0	317	DWL, DWP, *DRL
55	Quercetin 3′-*O*-glucuronide	$C_{21}H_{18}O_{13}$	45.169	**[M - H]$^-$	478.0747	477.0674	477.0667	−1.47	301	DRL
56	3-Methoxysinensetin	$C_{21}H_{22}O_8$	45.749	[M + H]$^+$	402.1315	403.1388	403.1397	2.23	388, 373, 355, 327	DWL
57	Isorhamnetin	$C_{16}H_{12}O_7$	49.509	[M + H]$^+$	316.0583	317.0656	317.0656	0	302, 285, 274, 257	DWL, *DRL
58	Spinacetin 3-*O*-(2″-p-coumaroylglucosyl) (1- > 6)-[apiosyl(1- > 2)]-glucoside	$C_{43}H_{48}O_{24}$	58.316	[M - H]$^-$	948.2536	947.2463	947.2416	−4.96	741, 609, 301	DRL
Isoflavonoids										
59	Dihydrobiochanin A	$C_{16}H_{14}O_5$	21.351	[M + H]$^+$	286.0841	287.0914	287.0918	1.39	269, 203, 201, 175	DWL
60	3′-Hydroxygenistein	$C_{15}H_{10}O_6$	44.026	[M + H]$^+$	286.0477	287.055	287.055	0	269, 259	DWL
61	5,6,7,3′,4′-Pentahydroxyisoflavone	$C_{15}H_{10}O_7$	45.285	[M + H]$^+$	302.0427	303.05	303.0504	1.32	285, 257	*DWL, DWP, DRL
62	Glycitin	$C_{22}H_{22}O_{10}$	50.32	[M + H]$^+$	446.1213	447.1286	447.1303	3.8	285, 270, 253, 225	*DWL, DWP
63	2′-Hydroxyformononetin	$C_{16}H_{12}O_5$	80.879	**[M + H]$^+$	284.0685	285.0758	285.0771	4.56	270, 253, 229, 225	*DWL, DRL
Lignans										
64	Episesamin	$C_{20}H_{18}O_6$	25.122	[M - H]$^-$	354.1103	353.103	353.104	2.83	338, 163	DWP
65	7-Oxomatairesinol	$C_{20}H_{20}O_7$	27.502	**[M + H]$^+$	372.1209	373.1282	373.1296	3.75	358, 343, 328, 325	DWP
66	Schisandrin C	$C_{22}H_{24}O_6$	32.682	**[M + H]$^+$	384.1573	385.1646	385.1651	1.30	370, 315, 300	DWL
67	Secoisolariciresinol-sesquilignan	$C_{30}H_{38}O_{10}$	38.134	**[M - H]$^-$	558.2465	557.2392	557.2393	0.18	539, 521, 509, 361	DWL
68	Todolactol A	$C_{20}H_{24}O_7$	41.522	**[M - H]$^-$	376.1522	375.1449	375.1445	3.45	313, 137	*DWP, DRL
69	Matairesinol	$C_{20}H_{22}O_6$	48.793	[M - H]$^-$	358.1416	357.1343	357.1349	1.68	342, 327, 313, 221	*DWL, DRL
Stilbenes										
70	3′-Hydroxy-3,4,5,4′-tetramethoxystilbene	$C_{17}H_{18}O_5$	17.276	**[M + H]$^+$	302.1154	303.1227	303.1234	2.31	229, 201, 187, 175	DWP, *DRL
71	Resveratrol 3-*O*-glucoside	$C_{20}H_{22}O_8$	42.864	**[M - H]$^-$	390.1315	389.1242	389.1252	2.50	389, 227	DWP
72	4′-Hydroxy-3,4,5-trimethoxystilbene	$C_{17}H_{18}O_4$	63.256	[M + H]$^+$	286.1205	287.1278	287.1283	1.74	271, 241, 225	DWL

(*continued on next page*)

Table 2 (*continued*)

No.	Proposed compounds	Molecular Formula	RT (min)	Ionization (ESI^+/ ESI^-)	Molecular Weight	Theoretical (*m/z*)	Observed (*m/z*)	Mass Error (ppm)	MS/MS Product ions	Dragon fruits
Other polyphenols										
Alkylmethoxyphenols										
73	4-Vinylsyringol	$C_{15}H_{14}O_3$	23.57	$[M+H]^+$	242.0943	243.1016	243.1024	3.29	225, 211, 197	DWL
Curcuminoids										
74	Bisdemethoxycurcumin	$C_{19}H_{16}O_4$	13.036	$[M+H]^+$	308.1049	309.1122	309.1128	1.94	291, 263	DRL
Furanocoumarins										
75	Isopimpinellin	$C_{13}H_{10}O_5$	5.954	$[M+H]^+$	246.0528	247.0601	247.0607	2.43	232, 217, 205, 203	DRP
Hydroxybenzaldehydes										
76	4-Hydroxybenzaldehyde	$C_7H_6O_2$	30.518	**[M - H]$^-$	122.0368	121.0295	121.0301	4.96	92, 77	DWL
77	Esculin	$C_{15}H_{16}O_9$	13.086	$[M+H]^+$	340.0794	341.0867	341.0853	−4.1	179, 151	DWL
78	2-Methoxy-5-prop-1-enylphenol	$C_{10}H_{12}O_2$	40.448	$[M+H]^+$	164.0837	165.091	165.0905	−3.03	149, 137, 133, 124	DWL
79	3,4-DHPEA-AC	$C_{10}H_{12}O_4$	37.974	**[M - H]$^-$	196.0736	195.0663	195.0663	0	135	*DWL, DWP
80	Lithospermic acid	$C_{27}H_{22}O_{12}$	31.151	**[M - H]$^-$	538.1111	538.1111	537.1049	2.05	493, 339, 295	DWP

* Compound was detected in more than one dragon fruit samples, data presented in this table are from asterisk sample. ** Compounds were detected in both negative [M - H]- and positive [M + H] + modes of ionization while only single mode data was presented. *Sample coding - White dragon fruit pulp (DWP), White dragon fruit peel (DWL), Red dragon fruit pulp (DRP) and Red dragon fruit peel (DRL)

2009). This is in consistent with our present study, which detected more hydroxycinnamic acid derivatives (14) as compared to hydroxybenzoic acid derivatives (08). Besides, one hydroxyphenylacetic acid and two hydroxyphenylpropanoic acids were also tentatively identified in our study.

Compound **9** was tentatively characterized as 3-*p*-coumaroylquinic acid found in DWL, DWP, DRL and DRP in both negative and positive modes with an observed $[M-H]^-$ *m/z* at 337.0932. The identification was further supported by the MS^2 spectrum, which exhibited typical product ions at *m/z* 265, 173, 162 and 127, formed by the neutral loss of four H_2O, $C_9H_7O_3$, $C_7H_{11}O_5$ and HCOOH-$C_9H_7O_3$ from precursor ion respectively (Lin et al., 2019).

Compound **10**, **12** and **13** only detected in DRL were tentatively identified as caffeic acid 3-*O*-glucuronide, caffeoyl glucose and *p*-coumaric acid 4-*O*-glucoside according to the precursor ions $[M-H]^-$ at *m/z* 355.0666, 341.0878 and 325.0922 respectively. In the MS^2 experiment of Caffeic acid 3-*O*-glucuronide, the spectra displayed the product ion at *m/z* 179, indicating the presence of caffeic acid ion resulted by the loss of glucuronide moiety (176 Da) from the precursor ion (Wang et al., 2017c). The identification of caffeoyl glucose was confirmed by the product ions at *m/z* 179 and *m/z* 161, formed by the neutral loss of hexosyl moiety and further loss of H_2O (Wang et al., 2017c). The MS^2 spectrum of *p*-Coumaric acid 4-*O*-glucoside displayed the product ion at *m/z* 169, indicating the loss of shikimate moiety (156 Da) (Abu-Reidah et al., 2015). Previously, caffeoyl glucose and caffeic acid derivatives were tentatively identified in fruits such as berries and plums, but these compounds were identified in dragon fruit for the first time to our best knowledge (Fang et al., 2002; Patras et al., 2018).

Compound **11, 16, 19, 22** were putatively identified in peel samples DWL and DRL. Compound **11** was putatively characterized as 3-caffeoylquinic acid found in DWL and DRL in both negative and positive modes with an observed $[M-H]^-$ *m/z* at 353.0873. With the MS^2 spectrum, the identification was further supported by typical product ions at *m/z* 253, 190 and 144, formed by the neutral loss of three H_2O (18 Da) and HCOOH (82 Da); three H_2O (54 Da) and $C_6H_5O_2$ (109 Da); H_2O (18 Da) and $C_7H_{11}O_6$ (191 Da), respectively (Lin et al., 2019). The characterization of 3-caffeoylquinic acid is in consistency with previous study of Castro-Enríquez et al., which also identified caffeoylquinic acid in dragon fruit (Castro-Enríquez et al., 2020). Compound **16** detected in both modes with an observed $[M-H]^-$ *m/z* at 223.0617 exhibited characteristic fragment ions at *m/z* 205 $[M-H-H_2O]$, 179 $[M-H-CO_2]$ and 163 $[M-H-CH_2O]$, and was identified as sinapic acid (Geng et al., 2014). Compound **19** detected in both modes with an observed $[M-H]^-$ *m/z* at 367.1038 exhibiting characteristic fragment ions at *m/z* 298 $[M-H-3H_2O-CH_3]$, 288 $[M--H-H_2O-CH_3--HCOOH]$, 192 $[M-H-C_7H_{11}O_5]$ and 191 $[M-H-C_{10}H_8O_3]$ was identified as 3-Feruloylquinic acid (Lin et al., 2019). Compound **22** was also tentatively identified in DWL and DRL, and tentatively characterized as 3-sinapoylquinic acid based on $[M-H]^-$ *m/z* at 397.1135. In the MS^2 spectrum, the product ions at *m/z* 223 and *m/z* 179 indicating the presence of sinapic acid ion and the further loss of COO respectively (Lin and Harnly, 2008).

Compounds **14** and **15** were both detected in DWL, DWP and DRL. Compound **14** detected in both modes with an

observed $[M-H]^-$ m/z at 163.0404 with characteristic fragment ions at m/z 119 [M – H – CO_2] was identified as *m*-coumaric acid (Wang et al., 2017a). This compound was also previously tentatively identified by Castro-Enríquez et al. from dragon fruit (Castro-Enríquez et al., 2020). Compound **15** with $[M+H]^+$ m/z at 357.118 exhibiting characteristic fragment ions at m/z 195 [M−H−glucoside], m/z 177 [M−H−glucoside−H_2O], m/z 145 [M – H−glucoside−H_2CO_2] and m/z 117 [M−H – glucoside−H_2CO_2−CH_3OH] was identified as ferulic acid 4-*O*-glucoside (Polturak et al., 2018).

Cinnamic acid (Compound **20**) was detected in DWL, DWP and DRP in negative and positive modes and observed $[M-H]^-$ m/z at 147.0454. The compound was confirmed by the product ion at m/z 103, due to neutral loss of CO_2 (44 Da) (Lai et al., 2015). The result of our study is inconsistent with that of Zain et al. (2019), who putatively identified cinnamic acid only in red dragon fruit peel by UHPLC-ESI-QTRAP/MS/MS. This difference is probably related to variation in plant variety.

Two hydroxyphenylpropanoic acids were also detected, which were compounds **24** and **25**. Compound **24** was tentatively identified as dihydrocaffeic acid 3-*O*-glucuronide with $[M-H]^-$ m/z at 357.0833, and further confirmed with product ions at m/z 181 due to neutral loss of glucuronide from precursor ion (Sasot et al., 2017). Similarly, compound **25** was tentatively identified as dihydroferulic acid 4-*O*-glucuronide with $[M-H]^-$ m/z at 371.0995, and further confirmed with product ion at m/z 175 due to neutral loss of glucuronide from precursor ion (Sasot et al., 2017).

4.2. Flavonoids

Flavonoids were previously identified as the major group of phenolic compounds in dragon fruit (García-Cruz et al., 2017). The largest number of compounds detected in the dragon fruit samples were from this phenolic class. Eight subgroups of flavonoids were identified, including anthocyanins, dihydrochalcones, dihydroflavonols, flavanols, flavanones, flavones, flavonols and isoflavonoids. Most of the flavonoids detected were in the glycoside forms.

4.3. Anthocyanins derivatives

Anthocyanins are a main subclass of flavonoids, which are known to be abundant in red dragon fruit peel and have anti-inflammation and anticarcinogenic potential (Prabowo et al., 2019). In our study, compound **27** with $[M+H]^+$ m/z at 521.1295 was only detected from pulp sample DWP, and characterized as petunidin 3-*O*-(6''-acetyl-glucoside) based on the product ion at 317 m/z, corresponding to the loss of glucose moiety (162 Da) plus acetyl moiety (42 Da) from precursor ion (Tourino et al., 2008).

In DWL, DRL and DRP, compound **28** was detected in both modes with an observed $[M+H]^+$ m/z at 465.1033 and exhibited characteristic fragment ion at m/z 303 [M+H−glucoside], which was tentatively identified as delphinidin 3-*O*-glucoside (Tourino et al., 2008). Compound **32** was putatively characterized as cyanidin 3,5-*O*-diglucoside found in DWL, DWP and DRL based on the observed $[M+H]^+$ m/z at 611.1612. The identification was further supported by the MS^2 spectrum, which exhibited typical product ions at m/z 449 and 287, formed by the successive loss of two glucosides (Dincheva et al., 2013). Previously, cyanidin derivatives were reported to be identified in white dragon fruit peels by Vargas, Cortez, Duch, Lizama, and Méndez (Vargas et al., 2013).

4.4. Dihydrochalcones, dihydroflavonols and flavanols derivatives

Dihydrochalcones, dihydroflavonols and flavanols derivatives are widely present in plants, and were reported to possess diverse biological activities including antioxidant, anti-inflammatory and antimicrobial effects, which were important and beneficial for plants as stress-resistant agents (Wen et al., 2014). In our study, only one dihydrochalcones was identified, which was compound **34**. It was identified as phloridzin in DWL, DWP, DRL and DRP based on the observed precursor ion $[M-H]^-$ at m/z 435.1303, with product ion at m/z 273 representing the existence of phloretin aglycon (Kelebek et al., 2017). Prodelphinidin dimer B3 (Compound **37**) was a flavanol derivative found in red dragon fruit samples DRL and DRP. It was tentatively identified with a $[M+H]^+$ m/z at 611.1363, which yielded product ion at m/z 469 (formed by heterocyclic ring fission followed by removal of phloroglucinol), m/z 311 (formed by the breakdown of dimer into monomer via quinone methide fission cleavage) and m/z 291 (formed by the formation of catechin from gallo-catechin molecule by loss of OH group).

4.5. Flavanones derivatives

Flavanones derivatives are flavonoids that possess antioxidant potential, and were identified in fruits such as citrus with the function of imparting bitter taste (Tripoli et al., 2007). Five flavanones derivatives were putatively characterized in the present study.

In pulp samples, hesperidin (Compound **39** with $[M+H]^+$ ion at m/z 611.1992) present in DWP and DRP was identified and confirmed by MS^2 experiments. In the MS^2 spectrum of m/z 611.1992, the product ions at m/z 593, 465, 449 and 303 were due to the loss of H_2O (18 Da), rhamnose (146 Da), glucose (162 Da) and rhamnosylglucose (308 Da) from the parent ion (Zheng et al., 2013).

In peel samples, compounds **40** and **42** were both detected in DWL and DRL. Compound **40** detected in both modes with an observed $[M-H]^-$ m/z at 741.2234 exhibiting characteristic fragment ions at m/z 433 [M−H−rhamnoside - glucoside and 271 [M−H−rhamnoside−2 glucosides] was identified as naringin 4′-*O*-glucoside (Castro et al., 2020). Compound **42** detected in both modes with an observed $[M-H]^-$ m/z at 477.1055 showing characteristic fragment ions at m/z 301.0734 [M – H - glucuronyl moiety], 175.0226 [M – H−hesperetin], 113.0248 [M – H – hesperetin−CO_2−H_2O] and 85.0355 [M – H – hesperetin−CO_2−H_2O−CO] was identified as hesperetin 3′-*O*-glucuronide (De Leo et al., 2017). Compound **41** was identified as 8-prenylnaringenin that was only detected in DWL based on the precursor ion $[M+H]^+$ at m/z 341.1397, with product ions at m/z 323, 271 and 137 formed by neutral loss of H_2O, C_5H_9 and RDA cleavage respectively (Yu et al., 2020). Previously, flavanones were found to be abundant in citrus fruits, however, this is the first time for these flavanones derivatives to be identified in dragon fruit

through LC-MS/MS to our best knowledge (Kawaii et al., 1999).

4.6. Flavones and flavonols derivatives

Flavones and flavonols are the most widely distributed antioxidant flavonoids in plants (Hoda et al., 2019).

In the present study, only compound **44** was identified in both dragon fruit peel and pulp samples DWL, DWP and DRL in both modes. Compound **44** was tentatively characterized as apigenin 6,8-di-C-glucoside based on the observed $[M - H]^-$ at m/z 593.1531. The MS/MS fragmentation yielded the product ions at m/z 575, 503, 473, exhibiting the fragment pattern of apigenin 6,8-di-C-glucoside (Hussain et al., 2018). Previously, Zain et al. has also reported tentative identification of apigenin derivatives in red dragon fruit peel samples (Zain et al., 2019), while it is the first time to identify this compound in dragon fruit pulp sample.

Compounds **45** and **46** were both flavones detected in peel samples DWL and DRL. Compound **45** with $[M+H]^+$ m/z at 463.1248 exhibiting characteristic fragment ions at m/z 445 [M – H−H_2O], 427 [M−H−$2H_2O$], 409 [M−H−$3H_2O$] and 381 [M−H−$3H_2O$-CO] was identified as chrysoeriol 7-*O*-glucoside (Liao et al., 2018). Compound **46** detected in both modes with an observed $[M-H]^-$ m/z at 447.0931 exhibiting characteristic fragment ions at m/z 285 was identified as 6-hydroxyluteolin 7-*O*-rhamnoside (Shi et al., 2014).

In pulp samples, only isorhoifolin (compound **47** with $[M+H]^+$ m/z at 579.1729) was identified in DRP. The identity of isorhoifolin was confirmed by the product ions at m/z 433 [M−H−146], 415 [M−H−164], 397 [M−H−182] and 271 [M−H−308], corresponding to the characteristic loss of rhamnoside; rhamnoside and H_2O; rhamnoside and two H_2O; rhamnoside and glucoside, respectively (Yang et al., 2017).

Only three flavonols were identified in both peel and pulp of dragon fruit. Compounds **50** and **54** were tentatively identified as kaempferol 3-*O*-glucosyl-rhamnosyl-galactoside and myricetin 3-*O*-rhamnoside in both negative and positive modes with observed $[M-H]^-$ at m/z 755.204 and 463.0882 respectively in DWL, DWP and DRL. The MS^2 spectrum of kaempferol 3-*O*-glucosyl-rhamnosyl-galactoside displayed the product ion at m/z 285, indicating the loss of a sugar unit (470 Da) (Wan et al., 2019). The MS^2 spectrum of myricetin 3-*O*-rhamnoside displayed the product ions at m/z 317, indicating the presence of a desoxyhexose sugar part which is characteristic for the compound (Wang et al., 2018). In DWL, DRL and DRP, only compound **52** was identified. Compound **52** detected in both modes with an observed $[M-H]^-$ m/z at 739.2093 exhibited characteristic fragment ions at m/z 593.1466 [M – H - $C_6H_{10}O_4$], 447.0882 [M – H – $2C_6H_{10}O_4$] and 285.0379 [M – H – $2C_6H_{10}O_4$ - $C_6H_{10}O_5$], and was identified as kaempferol 3-*O*-(2′′-rhamnosyl-galactoside) 7-O-rhamnoside (Sekuła and Zuba, 2013). Myricetin derivatives were tentatively identified in peel and pulp samples of white and red dragon fruits by Kim et al. (Kim et al., 2011). Zain et al. also reported myricetin derivatives as well as isorhamnetin derivatives in red dragon fruit peel samples (Zain et al., 2019). Moreover, Lira et al. (2020) also tentatively characterized isorhamnetin derivatives and quercetin-3-*O* derivatives in red dragon fruit pulp and peel samples. In addition, Yi et al. reported to identify kaempferol-3-*O* derivatives in red dragon fruit pulp, which was in consistent with our study (Yi et al., 2012).

In DWL and DRL, compound **51** was tentatively identified as kaempferol 3,7-*O*-diglucoside in both modes with an observed precursor ion $[M-H]^-$ at m/z 609.1468, while compound **57** was tentatively identified as isorhamnetin in positive mode with $[M+H]^+$ at m/z 317.0656. Kaempferol 3,7-*O*-diglucoside was further confirmed with product ions at m/z 449 and 287, indicating loss of one glucoside (162 Da) and two glucosides (324 Da) respectively (Reed, 2009). The MS^2 spectrum of isorhamnetin displayed the product ions at m/z 302, 285, 274 and 257, indicating the loss of CH_3 (15 Da), CH_3OH (32 Da), CH_3 - CO (43 Da) and CH_3OH - CO (60 Da) (Zhang et al., 2016). Previously, kaempferol derivatives were also identified in several studies on dragon fruits (Ibrahim et al., 2018).

Compound **49** (quercetin 3-*O*-(6′′-malonyl-glucoside)) displaying the $[M+H]^+$ m/z at 551.1053 was found in DWL and confirmed by the characteristic product ion at m/z 303 [M + H−malonyl-hexose unit] (Ye et al., 2009). Previously, malonyl-glucosides were also tentatively identified by Esquivel et al. in white dragon fruit (Esquivel et al., 2007).

Compound **53** and **58** with $[M+H]^+$ at m/z 611.1236 and $[M-H]^-$ at 947.2416 respectively were tentatively characterized as quercetin 3-*O*-xylosyl-glucuronide and spinacetin 3-*O*-(2′′-p-coumaroylglucosyl)(1- > 6)-[apiosyl(1- > 2)]-glucoside in DRL. Quercetin 3-*O*-xylosyl-glucuronide was further confirmed with product ions at m/z 479 [M + H−xyloside], 303 [M + H−xylo side−glucuronide], 285 [M + H−xyloside-glucuronide – $2H_2O$ – CO] and 239 [M + H – xyloside – glucuronide−$3H_2O$−CO] (Wang et al., 2020). Spinacetin 3-*O*-(2′′-p-coumaroylglucosyl) (1- > 6)-[apiosyl(1- > 2)]-glucoside was confirmed with product ions at m/z 741 [M−H−sinapoyl group], 609 [M – H – sinapoyl group – pentose moiety] and 301 [M−H−sinapoyl group – pentose moiety−deoxyhexose moiety−hexose moiety] (De Leo et al., 2017).

Quercetin 3-O-glucosyl-xyloside (compound **48** with $[M-H]^-$ m/z at 595.1308) was tentatively identified with main product ions at m/z 265.0264 [M – H – glucoside – xyloside], 138.0156 [M – H – glucoside – xyloside – H_2O – $C_6H_5O_2$], 115.9991 [M – H – glucoside – xyloside−$C_8H_6O_3$] and 144.0485 [M – H – xyloside – $C_{15}H_9O_7$] only in DWP (Willför et al., 2004).

4.7. Isoflavonoid derivatives

Isoflavonoids are heterocyclic phenolic compounds that are present in plants with strong antioxidant potential and important pharmacological activities such as anti-diabetic, anti-cancer and anti-inflammatory (Raju et al., 2015).

In our study, compounds **61** and **62** were detected in both peel and pulp samples. Compound **61** was putatively characterized as 5,6,7,3′,4′-pentahydroxyisoflavone found in DWL, DWP and DRL with an observed $[M+H]^+$ m/z at 303.0504. With the MS^2 spectrum, the identification was further supported by typical product ions at m/z 285 and 257, formed by the neutral loss of three H_2O (18 Da) and H_2O plus CO (46 Da) respectively (Zain et al., 2019). Compound **62** with $[M+H]^+$ m/z at 447.1303 exhibiting characteristic fragment

ions at m/z 285 [M−H−glucose moiety], 270 [M−H−glucose moiety−CH_3], 253 [M−H−glucose moiety−CH_3−OH] and 225 [M−H−glucose moiety−CH_3 – OH−CO] was identified as glycitin (He and Dai, 2011).

In peel samples, compound **60** with $[M+H]^+$ m/z at 287.055 was only detected from DWL, and characterized as 3′-hydroxygenistein based on the product ions at m/z 269 and 259, corresponding to the loss of H_2O (18 Da) and CO (28 Da) from precursor ion (Kim et al., 2011). Although isoflavonoids were widely identified in plants, to our best knowledge, most of the isoflavonoids derivatives characterized were the first time detected in dragon fruits (Barnes et al., 2002).

4.8. Lignans and stilbenes

Lignans and stilbenes are commonly present in vegetables and fruits (Cassidy et al., 2000). These compounds can act as phytoestrogens as they have both hormonal and non-hormonal activities in animals (Cassidy et al., 2000). Stilbenes also have antibacterial capability that is essential for plant inducible defense system, but also possess antioxidant potential that benefits human health (Chong et al., 2009). Lignans also have strong antioxidant capabilities with high medicinal value (Cassidy et al., 2000).

In our study, three stilbenes were tentatively identified, which were 3′-hydroxy-3,4,5,4′-tetramethoxystilbene, resveratrol 3-O-glucoside and 4′-hydroxy-3,4,5-trimethoxystilbene. Previously, stilbenes were identified in fruits and plants such as grape, pine, peanut and sorghum. However, to our best knowledge, it is the first time for these stilbenes to be characterized in dragon fruit.

Matairesinol (Compound **69** with $[M-H]^-$ m/z at 357.1349) was identified in DWL and DRL with the product ions at m/z 342 (M−H−15), 327 (M−H−30), 313 (M−H−44) and 221 (M−H−136), representing the loss of CH_3, C_2H_6, CO_2 and $C_8H_8O_2$ from the parent ion respectively (Wen et al., 2014). Six other lignans were also identified in our study. Lignans were previously found in the *Leguminosae*, which also have strong antioxidant capability (Cassidy et al., 2000). To our best knowledge, the lignans identified in our study were the first time detected by LC-MS/MS in dragon fruits.

5. Other polyphenols

Some other phenolic compounds identified from dragon fruit samples could not be categorized in the earlier identified classes.

Compound **75** with $[M+H]^+$ m/z at 247.0607 was only detected from DRP, and characterized as isopimpinellin based on the product ions at m/z 232, 217, 205 and 203, corresponding to loss of CH_3 (15 Da), two CH_3 (30 Da), CO-CH_2 (42 Da) and CO_2 (44 Da) from the precursor ion (Esquivel et al., 2007). To our best knowledge, isopimpinellin was identified for the first time in dragon fruit though it was previously identified in other fruit such as citrus (Peroutka et al., 2007).

Compounds **77**, **78** and **79** were only tentatively identified in DWL. Compound **77** (esculin) displayed the $[M+H]^+$ m/z at 341.0853 and was confirmed by the characteristic ions at m/z 179 [M+H−hexoside] and m/z 151 [M+H−hexoside−CO] (Barnes et al., 2002). Compound **78** with $[M+H]^+$ m/z at 165.0905 was characterized as 2-methoxy-5-prop-1-enylphenol based on the product ions at m/z 149, 137, 133 and 124, corresponding to loss of O (16 Da), C_2H_4 or CO (28 Da), CH_3OH (32 Da) and C_3H_5 (propenyl radical) (41 Da) from the precursor ion (Cassidy et al., 2000). Compound **79** was tentatively identified in both negative and positive mode as 3,4-DHPEA-AC with an observed $[M-H]^-$ m/z at 195.0663. The MS^2 spectrum of 3,4-DHPEA-AC displayed the characterized product ions at m/z 135, indicating the loss of $C_2H_4O_2$ (60 Da) (Chong et al., 2009). To our best knowledge, these compounds were identified for the first time in dragon fruit.

Dragon fruit contain a wide range of phenolics compounds and is therefore a good source of both individual and mixtures of phenolics that may be utilized in food, feed, cosmetics and medicinal industries.

5.1. Distribution of phenolic compounds – Venn diagram

The Venn diagrams summarizes the distribution of phenolic compounds in dragon fruit varieties and the difference between peel and pulp (Fig. 1). A total of 315 phenolic compounds were identified in dragon fruit samples.

Venn diagram A shows that 200 phenolic compounds were identified in both varieties, while white and red dragon fruits had equivalent amounts (57 and 58 respectively) of exclusive

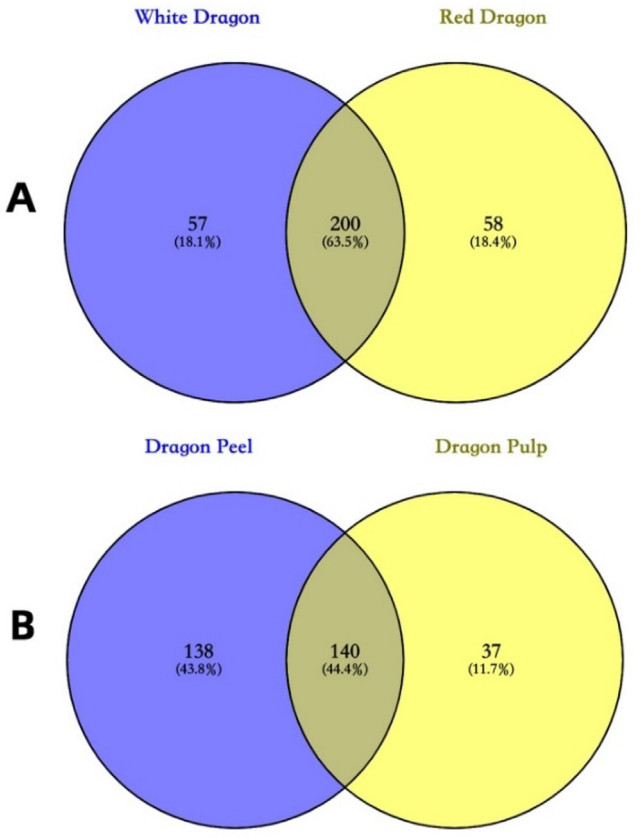

Fig. 1 Venn diagram of phenolic compounds presented in different dragon fruit varieties and parts. (A) shows the relations of total phenolic compounds present in red and white dragon fruits. (B) shows the relations of total phenolic compounds present in dragon fruit peel and pulp.

compounds, which showed that there is no significant difference in the quantity of phenolic compounds present in each of the two varieties. Previously, Sekar et al. (2016) reported higher antioxidant activity in red dragon fruit than in white dragon fruit extract. We found that although the number of phenolic compounds are equivalent for the two varieties, red dragon fruit have higher total levels of polyphenols compared to the white variety, resulting in higher antioxidant activities.

Venn diagram B shows that dragon fruit peel and pulp shared 140 common phenolic compounds. However, the peel has more exclusive compounds (138 phenolic compounds) than pulp (37 phenolic compounds), indicating that dragon fruit peel might be a better source for extracting phenolic compounds than dragon fruit pulp. Previously, Kim et al. (2011) found higher quantities of phenolic compounds in dragon fruit peels than in pulps through an HPLC-tandem MS analysis, which is in consistent with our results from HPLC-PDA quantification. The higher amounts of phenolic compounds in dragon fruit peel is consistent with Morais et al. (2015), who suggested that the peel of tropical fruits usually have higher amounts of phenolic compounds than their respective pulps.

5.2. Heatmap and hierarchical cluster analysis of quantified phenolic compounds in dragon fruit

A heat map was constructed along with hierarchical clusters for further analyzing HPLC-PDA quantified phenolic compounds in dragon fruits Fig. 2. Correlation was used as the distance measure for determining the similarity between dragon fruit samples and compounds. For columns and rows, clustering method was used based on average. For tree ordering, tightest clusters were grouped first.

In the heat map, four clusters in rows and two clusters in columns were generated and highlighted by the hierarchical clustering, which indicated the differences and similarities in phenolic profiles among samples. The color difference showed the concentrations of flavonoids and phenolic acids in different fruit peels. From the results, two clusters of samples were generated and highlighted by the hierarchical clustering, which were DS-1 (including DWP and DRP) and DS-2 (including DWL and DRL). These two clusters indicated significant differences in phenolic profiles between dragon fruit peel and pulp. The color difference showed higher abundance of phenolic compounds in dragon fruit peels than in the pulp samples. This result agreed with the previous study of Kim et al. (2011), who reported higher phenolic contents and stronger antioxidant activities in red and white dragon fruit peels than pulp extracts. Some compounds with significant high concentrations in a certain sample are highlighted by the red color, including quercetin-3-galactoside in DRL as well as epicatechin derivatives, ferulic acid, diosmin and kaempferol in DWL. A comparative study of Sekar et al. (2016) suggested that red dragon fruit extract have higher antioxidant activities than the white variety. However, from our heat map result, DWP and DWL showed more red zones than DRP and DRL, respectively, indicating higher phenolic content in the

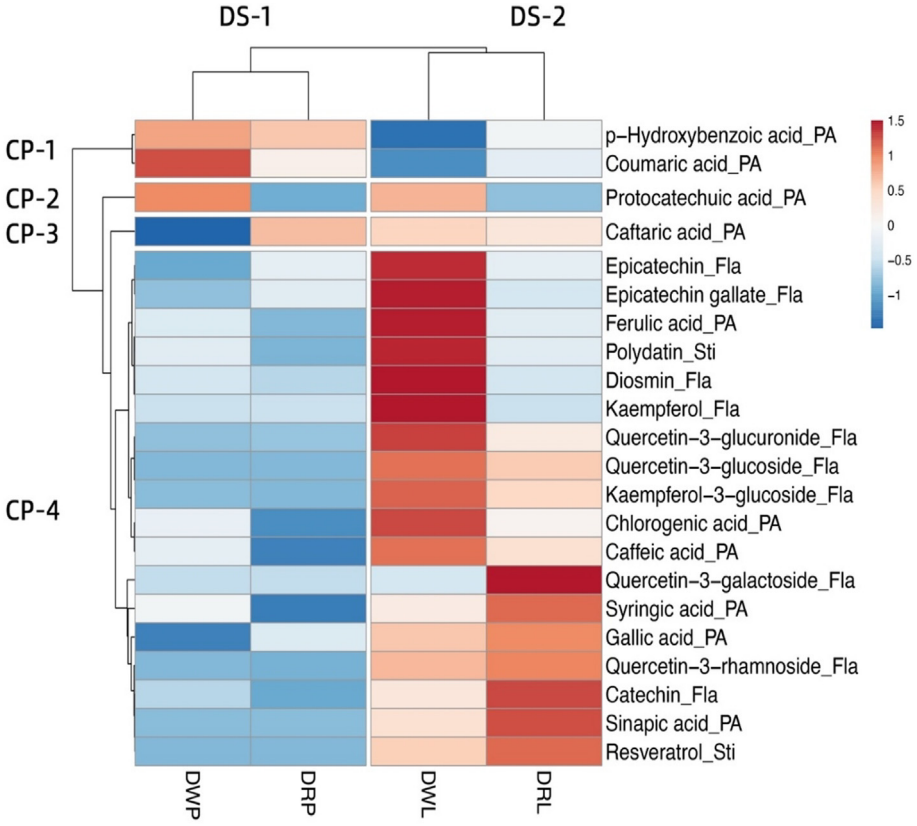

Fig. 2 Heatmap showing phenolic compounds distribution and concentration among dragon fruit samples. Red boxes mean higher concentrations. Blue boxes mean lower concentrations. DWP, white dragon fruit pulp; DWL, white dragon fruit peel; DRP, red dragon fruit pulp; DRL, red dragon fruit peel; PA: phenolic acids; Fla: flavonoids; Sti: stilbenes; DS 1–2: dragon fruit sample clusters; CP 1–4: phenolic compound clusters.

white variety, which differs from the previously published result. The differences might be attributed to the difference in varieties and maturity of the dragon fruit (Hoda et al., 2019).

Selected phenolic compounds were grouped into four clusters (CP 1–4) and were further grouped into different sub-clusters according to the differences of their concentration patterns in the dendrogram. Two phenolic acids (*p*-hydroxybenzoic acid and coumaric acid) formed the cluster CP-1, both of which showed the highest concentration in DWP and the lowest in DRL. Protocatechuic acid and caftaric acid made their own clusters (CP-2 and CP-3, respectively), while six other phenolic acids, ten flavonoids and two stilbenes formed the cluster CP-4, and were further grouped into different sub-clusters according to the similarity of their concentration pattern among the four samples.

5.3. Correlation between phenolic compounds; targeted phenolics quantified through HPLC-PDA and antioxidant assays

Correlations between phenolic contents (TPC, TFC, TTC, phenolic acids and flavonoids—quantified through HPLC-PDA) and antioxidant activities (DPPH, FRAP, ABTS, and TAC) were performed with a Pearson's correlation test (Table 3). The phenolic acid content and flavonoid content were calculated by summarizing the content of ten selected phenolic acids and ten flavonoids, as an estimate for correlation between overall phenolics and their antioxidant activities.

A strong positive correlation between total phenolic content and FRAP was observed, with a Pearson's correlation coefficient $r = 0.982$ ($p < 0.01$). The correlation of FRAP with TPC showed that the reducing capability of dragon fruit is mainly attributed to the phenolic contents of the extracts. This result is in agreement with Mokrani and Madani (2016).

The TAC was observed to be strongly correlated with ABTS ($r = 0.999$, $p < 0.01$). ABTS determines the hydrogen donation and chain-breaking capabilities of antioxidants by scavenging ABTS radicals. TAC estimates the total antioxidant activity of a sample by reducing phosphomolybdate ions. The correlation indicates that the antioxidants with strong hydrogen donation capabilities that scavenge ABTS radicals can also effectively reduce phosphomolybdate ion and are the major contributors to the total antioxidant capacity of dragon fruit. The results agree with Farkas and Mohácsi-Farkas (2011), in which they reported a good correlation between ABTS and TAC. However, the DPPH activity, which also determines the antiradical capability of antioxidant, is not significantly correlated with TAC in this study. The reason might be that the ABTS assay was reported to be more effective than the DPPH assay when the food sample contains lipophilic, hydrophilic, and high-pigmented antioxidant compounds (Floegel et al., 2011).

Significant negative correlations were observed between total flavonoid content with ABTS and TAC ($r = -0.957$ and $r = -0.953$, $p < 0.01$). The result is similar to the study of Fidrianny et al. (2014), who reported a negative correlation between TFC and overall antioxidant capability. The TFC assay only targets specific flavonoids including flavonols and flavone luteolin (Pękal and Pyrzynska, 2014). Previously, Mokrani and Madani (2016) reported a strong negative correlation between TFC and antiradical capability in peach samples. They concluded that the negative correlation showed the antioxidant capacity of peach might come from the synergism of different polyphenols or other antioxidant compounds present in the extract rather than flavonoids. In our study, the negative correlation indicates that the overall antioxidant capacity and the antiradical capacity of dragon fruit are not caused by the presence of flavonoids, it can be postulated that the main compounds contribute to the antioxidant capabilities might be other phenolic compounds such as phenolic acids or non-phenolic compounds such as betalains.

In our study, no significant difference was observed between phenolic acids and DPPH, FRAP and ABTS. The result was contradictory with the correlation results between the TPC value and FRAP. Besides, these is no significant correlation found between flavonoids and antioxidant assays, which was contradictory with the correlation results between the TFC value and ABTS or TAC. The reasons might be that only 10 of the most abundant phenolic acids and 10 most abundant flavonoids were selected for quantification purposes, while TPC and TFC assays specifically react with all types of phenolic acids and flavonoids respectively.

6. Conclusion

In conclusion, dragon fruit pulp was found to have higher content of phenolic compounds and stronger antioxidant activities than dragon fruit peel. The LC-ESI-QTOF-MS/MS technique was successfully applied for separation and characterization of the phenolic compounds in dragon fruits, with 80 phenolic compounds tentatively identified in total. The quantification by HPLC-PDA showed that dragon fruit peel has higher levels of most of the selected phenolic compounds, while the pattern of phenolic composition is different between pulps and peels.

Table 3 Pearson's correlation coefficients (r) for the relationships between antioxidant assays and phenolic contents.

Variables	TPC	TFC	TTC	DPPH	FRAP	ABTS	TAC	Phenolic acids
TFC	−0.799							
TTC	−0.251	0.685						
DPPH	0.925	−0.695	−0.374					
FRAP	0.982**	−0.894	−0.362	0.873				
ABTS	0.746	−0.957*	−0.517	0.538	0.858			
TAC	0.770	−0.953*	−0.483	0.557	0.875	0.999**		
Phenolic acids	0.802	−0.773	−0.079	0.518	0.859	0.890	0.909*	
Flavonoids	0.157	0.436	0.885	0.094	0.003	−0.351	−0.306	0.100

** Significant correlation with $p < 0.01$; * Significant correlation with $p < 0.05$.

The obtained results indicated that Australian dragon fruit peel by-products and pulp waste are potential sources of phenolic compounds, with potential as antioxidants for the food, cosmetic, pharmaceutical and nutraceutical industries.

Supplementary Materials:

Author Contributions

All authors have read and agreed to the published version of the manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.arabjc.2021.103151.

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