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Comparison of fatty acid profile and mineral content of black mulberry (*Morus nigra*), white mulberry (*Morus alba*) and red mulberry (*Morus rubra*) grown in Bahrain

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ABSTRACT

Mulberries are a rich source of many nutrients and have various health-promoting benefits. Nevertheless, their growth conditions can influence their nutritional composition and thus their benefits. Thus, this study examines the fatty acid profile and mineral content of three mulberry varieties: black (*Morus nigra* L.), white (*Morus alba* L.), and red (*Morus rubra* L.) grown in Bahrain for the first time. Fatty acid analysis, using gas chromatography-flame ionization detector (GC-FID), revealed that linoleic acid (C18:2n6) and palmitic acid (C16:0) were the primary fatty acids present in mulberry fruits, while minor fatty acids varied among the cultivars. Black mulberries exhibited a composition of 33.08 % saturated fatty acids (SFAs) and 66.92 % unsaturated fatty acids (UFAs), while red mulberries had 34.48 % SFAs and 66.52 % UFAs, and white mulberry had 27.15 % SFAs and 72.85 % UFAs. The mineral content analysis using inductively coupled plasma-optical emission spectroscopy (ICP-OES) revealed variations in the content of magnesium (Mg), iron (Fe), sodium (Na), potassium (K), and calcium (Ca) among the mulberry varieties. Black mulberries displayed the highest levels of Mg (706.67 mg/100 g), Fe (31.33 mg/100 g), Na (1406 mg/100 g), K (4161.33 mg/100 g), and Ca (1008.67 mg/100 g). Mulberries reported moderate levels of Mg (442.33 mg/100 g), Fe (45.6 mg/100 g), Na (635.68 mg/100 g), K (3278 mg/100 g), and Ca (583.1 mg/100 g). These findings indicate that black mulberries exhibit a superior mineral content across all parameters, whereas red mulberry has lower levels among the three varieties.

1. Introduction

Mulberry (*Morus* spp.) is a widely cultivated fruit-bearing tree known for its nutritional and medicinal properties (Donno et al., 2015). It belongs to the *Moraceae* family and is native to Asia, Europe, and North America (Rohela et al., 2020; Singhal et al., 2010). Mulberry fruits are rich in various bioactive compounds, including lipids, fatty acids, minerals, phenolics, flavonoids, and antioxidants, which contribute to their potential health benefits (Yuan & Zhao, 2017). It is important to highlight that mulberries are considered an ideal species for sustainable development (Rohela et al., 2020). Mulberries can be utilized in several industries to support economic growth and can positively impact the sericulture, food, beverage, pharmaceutical, and cosmetic sectors (Baciu et al., 2023; Rohela et al., 2020).

Black mulberries (*Morus nigra*) are known for their deep purple to black-colored fruits. They are native to Southwest Asia and have been

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cultivated for centuries (Lim & Choi, 2019). Black mulberries are often praised for their rich, sweet flavor and juicy texture (Wang et al., 2023). They are generally larger in size compared to other mulberry varieties (Singhal et al., 2010). Black mulberries are also known to contain high levels of anthocyanins, which contribute to their dark color and antioxidant properties (Khalifa et al., 2018). White Mulberries (*Morus alba*) are native to Northern China but have been widely cultivated in different regions (Liu & Willison, 2013). The fruits of white mulberry trees are typically pale yellow, pink, or white when ripe (Hussain et al., 2021). They have a milder and slightly sweet flavor compared to black mulberries (Hashemi & Khadivi, 2020). White mulberries are recognized for their nutritional value and are particularly rich in vitamin C, iron, and dietary fibre (Jiang & Nie, 2015). The leaves of white mulberry trees have also been traditionally used as food for silkworms (Singhal et al., 2010). Red Mulberries (*Morus rubra*) are native to North America and are commonly found in regions such as the eastern United States (Burgess & Husband, 2006). The fruits of red mulberries are deep red to purple-black in color when fully ripe (Singhal et al., 2010). They have a sweet and tangy flavor, similar to black mulberries. Red mulberries are known to contain various beneficial compounds, including anthocyanins and resveratrol, which contribute to their antioxidant and anti-inflammatory properties (Ramappa et al., 2020).

Black, white, and red mulberry varieties are distinct in terms of their fruit color and flavor, there can be some variation within each variety due to factors such as growing conditions, genetic diversity, and specific cultivars (Iqbal et al., 2012). It is noteworthy that mulberry fruits, even within the same species, can exhibit variations in their chemical composition (Kim & Lee, 2020). Therefore, the development of different cultivars is crucial to cater to specific applications, such as consumption as fresh fruits, production of juices, marmalades, and liquors, or for use in the food processing, natural dye, and cosmetics industries. In recent years, there has been a growing interest in exploring the nutritional composition of locally grown fruits, as the variation in growing conditions and geographical location can influence the content of nutrients (Giulia et al., 2020). Understanding the nutrient composition of mulberries is crucial as it provides valuable information for consumers, researchers, and policymakers. The comparison between different varieties and regions can shed light on the potential variations in nutrient content, enabling the selection of mulberry varieties with higher nutritional value for cultivation or consumption. While some mulberry species in China (Jiang & Nie, 2015; Liang et al., 2012; Song et al., 2009) have been analyzed for their nutritional composition and utilized for food or food additives, there is a lack of conclusive reports regarding the nutritional value and chemical composition of mulberry cultivars in other regions in the worlds. In fact, less attention has been paid to the fatty acid profile and mineral content of different mulberries.

Bahrain, as an arid island located in the Middle East, has a unique climate and soil conditions that may influence the nutrient profile of fruits grown locally. Thus, this research aims to explore and compare the lipid content, fatty acid profile and mineral content (Mg, Mn, Fe, Zn, Na, K, Ca, and Cu) in three varieties of mulberries grown locally in Bahrain, for the first time, and compare them with those grown in different areas worldwide, providing valuable insights into their nutrient content and potential health benefits.

2. Materials and methods

2.1. Chemicals and reagents

Isooctane and nitric acid were purchased from Honeywell Fluka™, USA. Hydrogen peroxide, methanolic sulfuric acid, sodium chloride, hexane, potassium bicarbonate, and standard solutions of Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn were purchased from Sigma-Aldrich, Germany.

2.2. Sample preparation

An amount of 1.5 kg of three varieties of mulberries (black, white, and red) grown locally in North Bahrain farms and harvested in Spring 2022 season were obtained. Samples were brought immediately to the lab, washed with deionized water, and dried in a 40 °C oven for 4 days until reaching a constant weight. Then, samples were turned into fine powder using a commercial grinder and stored in sealed plastic bags in −18 °C in dark until use.

2.3. Fatty acid analysis

2.3.1. Extraction of lipids

Mulberry lipids were extracted according to a previously published method with some modifications (Kaewmanee et al., 2009). Briefly, a 15 mL mixture of hexane and isopropanol in a 3:2 (V/V) ratio was used and blended with 5 g of each mulberry sample (using a mini commercial blender) to form a homogenized mixture. The homogenized sample was centrifuged twice, once at 5000 rpm for 10 min and once at 11,000 rpm for 30 s at 4 °C. The hexane/isopropanol phase was collected and filtered through a Whatman® qualitative filter paper, Grade 1. A volume of 10 mL of the filtrate was accurately measured using a pipette and used for further analysis.

2.3.2. Preparation of fatty acid methyl esters (FAMEs)

Fatty acids methylation was performed according to a previously published method (Ozogul et al., 2012). The extracted lipids in the hexane/isopropanol phase were mixed with 5 mL of 2 % methanolic sulfuric acid and vortexed. The mixture was then kept in the oven for 15 h at 50 °C to facilitate methylation. Following this time, the tubes were allowed to cool at room temperature before being filled with 5 mL of 5 % sodium chloride and thoroughly agitated. The produced methyl esters were extracted with 5 mL of hexane, the hexane phase was removed, and 5 mL of 2 % of $KHCO_3$ was added. The phases were then left to stand for 4 h to separate. At 45 °C, the solvent was removed from a mixture of methyl esters under nitrogen flow. Then, 1 mL of hexane was used to dissolve the remainder.

2.3.3. Gas chromatography analysis of FAMEs

FAMEs were analyzed using gas chromatography-flame ionization detector (GC-FID) (Clarus 500, Perkin Elmer, USA) (Mohammed et al., 2023). A fused carbon-silica column (Stabilwax, Crossbond, Carbowax, polyethylene glycol) was used for separation of samples with a temperature range of 40–260 °C. The column had a length of 30 m with and internal diameter (width) of 0.25 mm and a particle size (df) = 0.25 µm. The temperature of the injector was kept constant at 250 °C with a split ratio of 1:20. The sample injected volume was 5 µL. Nitrogen gas was used as a carrier gas which had a total flow rate of 0.76 mL/min. The oven temperature was set at 200 °C. This constant temperature was maintained for 80 min. The total run for each sample was 80 min. The temperature of the FID was set at 300 °C. Two other gases used were air and hydrogen. Flow rate of 450 mL/min for air and flow rate for hydrogen was 45 mL/min. A sampling rate of 12.5 Hz was used. FAMEs were identified by comparing the peak of samples against the standard used. The standards used were PUFA No.1 (marine source) and PUFA No. 2 (animal source), supplied by Merck, USA, comprised of saturated fatty acids (14:00 myristic acid, 16:0 palmitic acid, C18:0 stearic acid), monosaturated fatty acids (C16:1n7 palmitoleic acid, C18:1n9 oleic acid, C20:1n9), and polyunsaturated fatty acids (C18:2n6 linoleic acid, C18:3n6 γ-linolenic acid, C22:4n6 arachidonic acid, C18:3 n3 alpha-linolenic acid, C18:4n3 stearidonic acid, C20:5n3 eicosapentaenoic acid (EPA), C22:6n3 docosahexaenoic acid (DHA), and C22:5n3 docosapentaenoic acid).

2.4. Mineral content

2.4.1. Digestion of mulberry samples

Mulberry samples were digested using a microwave oven (MARS 6, CEM Corp., USA) following a previously reported method (Mostafidi et al., 2016). First, 0.5 g of each mulberry sample was taken and placed within special microwave-safe containers (EasyPrep iWave). Next, 1 mL of 30 % hydrogen peroxide and 5 ml of 65 % nitric acid were added. The digestion process was then initiated after the microwave containers were transferred to the MARS6 microwave digestion system for 1 h. The mixture turned yellowish-watery inside the unique microwave containers before being emptied into 25 mL volumetric flasks. Varying volumes of 2 % of HNO_3 was used to dilute the mixture until to reach 25 mL. All samples were filtered using a membrane filter with a 0.45 m pore size. Triplicate samples of each mulberry variety were used.

2.4.2. Inductively coupled plasma-optical emission spectroscopy (ICP-OES)

Mineral analysis was performed using inductively coupled plasma optical emission spectroscopy (ICP-OES) (Avio® 220 Max, Perkin Elmer, USA) (Pereira et al., 2018). The instrument was operated at radio frequency power of 1400 W with a plasma argon flow rate of 15 L/min, auxiliary argon flow rate of 0.7 L/min, and a nebulization gas flow rate of 0.7 L/min. Sarstedt tubes used for the analysis were first washed with 2 % HNO_3. Standard solutions of Ca, Cu, Fe, Zn, Mg, Mn (1–5 mg/L from 10 mg/L stock solution), Na (5–25 mg/L from 50 mg/L stock solution), and K (10–50 mg/L from 100 mg/L stock solution) were used to develop the calibration curve. Triplicate samples of each mulberry variety were used. For each mineral, samples were examined using ICP-OES at the following wavelengths: P (213.618 nm), Ca (317.993 nm), Cu (324.748 nm), Fe (259.940), Zn (202.548 nm), Na (589.592 nm), K (766.474 nm), Mn (257.610 nm), and Mg (279.077 nm). To analyse the minerals of interest, a volume of 0.5 mL of each digested sample was diluted with 9.5 mL of 2 % HNO_3 (20x dilution). Triplicate samples of each mulberry variety were used.

2.5. Statistical analysis

The statistical analysis was conducted using IBM SPSS Statistics version 22 and Microsoft Excel (Microsoft 365). The complete dataset was collected and processed, and descriptive statistics analysis was performed, including the calculation of median, interquartile range and mean. Non-parametric statistical test was conducted to find the p-value.

3. Results

3.1. Fatty acid profile

The mean and standard error (SE) of the total lipids and fatty acid contents of black, red, and white mulberries are shown in Table 1. In terms of total lipids, the highest value is observed in white mulberry (0.45 ± 0.02 g), indicating a relatively higher lipid content compared to black mulberry (0.42 ± 0.03 g), and red mulberry (0.39 ± 0.05 g) ($P < 0.05$). For individual fatty acids, the highest value for C16:00 is found in black mulberry (24.71 ± 0.59 %), while the lowest value is observed in white mulberry (23.21 ± 0.36 %) ($P < 0.05$). In terms of PUFAs, it was found that the highest value of C18:2n6 is seen in black mulberry (36.24 ± 0.14 %), while the lowest value is observed in red mulberry (24.76 ± 0.49 %) ($P < 0.05$). The highest value for C18:3n6 is observed in black mulberry (9.90 ± 0.07 %) ($P < 0.05$), while the lowest value is found in red mulberry (6.97 ± 0.46 %) ($P < 0.05$).

Black mulberry has the highest SFAs percentage (33.08 %), followed by red mulberry (34.48 %), and white mulberry with the lowest percentage (27.15 %). This indicates that black mulberry and red mulberry contain relatively higher amounts of SFAs compared to white mulberry. Red mulberry has the highest MUFAs percentage (33.79 %), followed by white mulberry (31.41 %), and black mulberry with the lowest percentage (20.78 %). This suggests that red mulberry has a higher content of MUFAs compared to the other two varieties. Black mulberry has the highest PUFAs percentage (46.14 %), followed by white mulberry (41.44 %), and red mulberry with the lowest percentage (31.73 %). This indicates that black mulberry and white mulberry contain higher amounts of PUFAs compared to red mulberry.

Table 1

Total lipid content (g ± standard error) and fatty acid profile (% ± standard error) of different mulberry varieties.

	Black mulberry	Red mulberry	White mulberry	*P*-value
Total lipid (g/g DW)	0.42 ± 0.03	0.39 ± 0.05	0.45 ± 0.02	0.554
Fatty acids (%)				
C16:00	24.71 ± 0.59	24.59 ± 0.12	23.21 ± 0.36	0.073
C16:1n7	6.88 ± 0.08	8.23 ± 0.03	7.26 ± 0.25	0.002
C17:00	–	1.91 ± 0.08	–	0.001
C18:00	6.03 ± 0.21	2.44 ± 0.06	0.93 ± 0.29	0.002
C18:1n7	1.30 ± 0.06	1.79 ± 0.02	–	0.001
C18:2n6	36.24 ± 0.14	24.76 ± 0.49	32.34 ± 0.30	0.001
C18:3n6	9.90 ± 0.07	6.97 ± 0.46	9.10 ± 0.12	0.001
C19:1n6	7.44 ± 0.31	12.09 ± 0.15	14.11 ± 0.22	0.001
C19:1n7	2.31 ± 0.20	3.96 ± 0.27	4.42 ± 0.25	0.001
C20:00	1.82 ± 0.10	3.02 ± 0.16	1.95 ± 0.39	0.001
C22:00	0.52 ± 0.05	2.52 ± 1.34	1.06 ± 0.24	0.254
C22:01	2.85 ± 0.06	7.71 ± 0.15	5.61 ± 1.04	0.001

Abbreviations: dry weight (DW), palmitic acid (C16:0); palmitoleic acid (C16:1n7); heptadecanoic acid (C17:0); stearic acid (C18:0); vaccenic acid (C18:1n7); linolic acid (C18:2n6), γ-linolenic acid (C18:3n6), arachidic acid (C20:0); behenic acid (C22:0); erucic acid (C22:01).

3.2. Mineral content

The mean content of Mg, Mn, Fe, Zn, Na, K, Ca, and Cu present in black, red, and white mulberries is shown in Table 2. The highest value of Mg is seen in black mulberry (706.67 ± 67.04 mg/100 g), indicating a significantly higher Mg content compared to red mulberry (442.33 ± 33.96) and white mulberry (461.92 ± 7.79 mg/100 g) ($P < 0.05$). The value of Mn is relatively similar among the three mulberry varieties: black mulberry has a value of 7.33 ± 0.27 mg/100 g, red mulberry has a value of 7.07 ± 0.18 mg/100 g, and white mulberry has a value of 7.32 ± 0.00 mg/100 g. In terms of Fe content, black mulberry (31.33 ± 2.67 mg/100 g), and white mulberry (31.06 ± 1.00 mg/100 g) contain similar content, while red mulberry has a significantly higher value (45.6 ± 2.00 mg/100 g) ($P < 0.05$). For Zn, the highest value is observed in red mulberry (9.33 ± 1.63 mg/100 g) but without statistical significance, indicating a relatively higher Zn content compared to black mulberry (7.13 ± 0.35 mg/100 g), and white mulberry (6.15 ± 1.63 mg/100 g). The highest value of Na is detected in black mulberry (1406.00 ± 154.87 mg/100 g), indicating a relatively higher Na content compared to red mulberry (635.68 ± 29.87 mg/100 g), and white mulberry (960.19 ± 19.53 mg/100 g) ($P < 0.05$). The highest value of K

Table 2

Average mineral content (mg/100 g ± standard error) present in different mulberry varieties.

Minerals	Black mulberry	Red mulberry	White mulberry	*P*-value
Mg	706.67 ± 67.04	442.33 ± 33.96	461.92 ± 7.79	0.010
Mn	7.33 ± 0.27	7.07 ± 0.18	7.32 ± 0.00	0.550
Fe	31.33 ± 2.67	45.60 ± 2.00	31.06 ± 1.00	0.003
Zn	7.13 ± 0.35	9.33 ± 1.63	6.15 ± 1.63	0.303
Na	1406 ± 154.87	635.68 ± 29.87	960.19 ± 19.53	0.003
K	4161.33 ± 347.65	3278.00 ± 189.17	4358.66 ± 36.11	0.034
Ca	1008.67 ± 172.88	583.10 ± 94.40	605.02 ± 3.15	0.066
Cu	6.40 ± 0.42	7.27 ± 0.58	6.70 ± 0.40	0.470

is observed in black mulberry (4161.33 ± 347.65 mg/100 g), indicating a relatively higher K content compared to red mulberry (3278 ± 189.17 mg/100 g), and white mulberry (4358.66 ± 36.11 mg/100 g) ($P < 0.05$). With respect to Ca content, black mulberry (1008.67 ± 172.88 mg/100 g) has a higher value compared to red mulberry (583.10 ± 94.40 mg/100 g), and white mulberry (605.02 ± 3.15 mg/100 g). The value of Cu is relatively similar among the three mulberry varieties.

4. Discussion

4.1. Fatty acid profile

Red mulberries have a slightly different lipid distribution in comparison to the other varieties, with SFAs comprising 34.48 % of the total FAs, and UFAs accounting for 66.52 %. On the other hand, white mulberries have a distinct FAs composition, where SFAs constitute 21.15 % of the total FAs, and UFAs make up 72.85 %. According to the study by Jelled et al. (2017), black mulberries had an average SFAs proportion (16.77 %), while UFAs accounted for 83.23 % of the total fatty acids. These results differ significantly from the current study, which observed a higher SFAs content of 33.08 % and UFAs accounting for 66.92 %. On the other hand, Jelled et al. (2017) reported that white mulberries had SFAs representing 27.4 % of the total fatty acids, while UFAs accounted for 72.6 % (Jelled et al., 2017). In comparison, the present study showed similar proportions of SFAs (21.15 %) and UFAs (72.85 %) for white mulberries. Regarding red mulberries, Jelled et al. (2017) reported an SFAs content of 13.06 % and UFAs of 86.95 %, which differs from the present study where SFAs accounted for 34.48 % and UFAs for 66.52 % (Jelled et al., 2017).

With respect to the fatty acid profile, in black mulberries, the present study found higher levels of C16:0 (24.71 %), C16:1n7 (6.88 %), and C18:2n6 (36.24 %) compared to the study conducted in Spain, which reported lower levels of these fatty acids (12.21, 0.10, and 74.30 % respectively) (Sánchez-Salcedo et al., 2015). However, the levels of C18:0 were similar between the two studies, but with a higher percentage of C18:1n7 (7.26 %). Furthermore, the present study reported a relatively higher content of C18:3n6 (9.90 %) compared to both the Spanish study (1.42 %) (Sánchez-Salcedo et al., 2015), and the study conducted in China (1.48 %) (Liang et al., 2012). A study conducted in Turkey reported a higher C18:2n6 content (63.83 %) but lower C16:0 content (13.89 %) in comparison to our study (Özcan et al., 2019).

For red mulberry, the present study from Bahrain determined higher levels of C16:0 (24.59 %) compared to the study conducted in China (9.66 %) (Liang et al., 2012). Additionally, the present study reported lower levels of C18:0 (2.44 %) compared to the Chinese study (2.92 %) (Liang et al., 2012). However, the Chinese study reported a significantly higher content of C18:2n6 (79.98 %) compared to the present study (24.76 %) (Liang et al., 2012). Another study from Egypt found lower percentages for C16:1n7 (6.22 %) compared to present study (8.23 %) and higher percentage of C18:1n7 (3.41 %) compared to precent study (1.79 %), with no data available for C19:1n6 and C19:1n7, and C22:01 have slightly similar to recent study (7.47 %) (El-baz et al., 2017). Bahrain grown mulberries, particularly the black variety, are abundant in SFAs, and MUFAs and lower PUFA (n-6) compared to mulberries grown in other countries.

For white mulberry, the present study from Bahrain showed the following fatty acid percentages: C16:1n7 (7.26 %), C19:1n6 (14.11 %), C19:1n7 (4.42 %), and C22:01 (5.61 %). A study conducted in Spain reported a lower percentage of C16:1n7 (0.13 %), and higher percentage of C18:1n7 (6.51 %) (Sánchez-Salcedo et al., 2015). However, the present study reported a lower content of C18:2n6 (32.34 %) compared to the Spanish study (76.21 %) (Sánchez-Salcedo et al., 2015). Overall, the present study found higher levels of C16:0 (23.21 %) compared to the Spanish study (11.05 %) (Sánchez-Salcedo et al., 2015), while the levels of C18:0 were similar. In contrast, the study conducted in China reported higher levels of C18:2n6 (57.26 %) but lower levels of C16:0 (21.20 %) and C18:3n6 (4.26 %) compared to the present study (Liang et al., 2012). Another study from Egypt reported lower percentages for C16:1n7 (4.81 %), C18:1n7 (5.48 %) compared to present study, and higher percentage of C22:01 (10.55 %) compared to present study (5.61 %), with no data available for C19:1n6 and C19:1n7 (El-baz et al., 2017). A study conducted in Turkey reported a higher C18:2n6 content (58.89 %) but lower C16:0 content (12.46 %) in comparison to our study (Özcan et al., 2019). Climatic, topographical, and soil properties are among the key factors that could influence the nutritional composition of mulberries (Imran et al., 2010).

4.2. Mineral content

Mulberries are not only known for their unique taste but also for their potential health benefits due to their rich nutrient profile. In addition to vitamins, fibre, and antioxidants, mulberries are a good source of various minerals that play vital roles in maintaining overall health and well-being (Paunović et al., 2020). The mineral content of mulberries may vary depending on the species and growing conditions (Memete et al., 2022). Key minerals found in mulberries include potassium, calcium, iron, magnesium, and zinc, among others. These minerals contribute to the nutritional value of mulberries and offer potential health benefits. Understanding the mineral contents of mulberries is important for discussing their impact on human health and exploring their potential therapeutic uses.

Moreover, another study found higher levels of Mg, Fe, and K in white mulberries compared to the present study in Bahrain (Micić et al., 2013). The values reported were Mg (647 mg/100 g), Fe (12.2 mg/100 g), and K (2780 mg/100 g). Additionally, a study conducted in Turkey reported even higher levels of Ca in white mulberries compared to the Bahrain study (Pehluvan et al., 2012). The value observed was 2780 mg/100 g. In comparison, a study conducted in Turkey reported lower levels of Mg (115 mg/100 g), Fe (4.5 mg/100 g), Na (61 mg/100 g), K (834 mg/100 g), and Cu (132 mg/100 g) in red mulberries (Micić et al., 2013). These findings suggest that red mulberries from Turkey have relatively lower amounts of these nutrients compared to the Bahrain study. Furthermore, another Turkish study also reported lower amounts of the analyzed minerals in the black, red, and white mulberries they analyzed from Malatya province in Turkey (Akbulut & Ozcan, 2009). In It is important to note that nutrient levels can vary widely even within the same species of mulberries due to genetic diversity and environmental factors. Pakistani mulberries may have higher levels of Fe and Zn due to the specific soil characteristics and climatic conditions in Pakistan (Bajwa & Khan, 2015). The soil in this region may naturally contain higher concentrations of these minerals or provide conditions that enhance their absorption by the plants. Conversely, Bahraini mulberries tend to have higher amounts of Mg, K, Ca, and Na, which can be attributed to the unique soil composition and environmental factors in Bahrain.

5. Conclusions

The present study conducted in Bahrain has revealed that black mulberry possesses higher levels of essential minerals such as K, Mg, Na, Ca, and Fe. While the amount of K in white mulberry is higher than black mulberry, and the amount of Fe is higher in red mulberry than black and white mulberries. Additionally, the study has identified higher levels of specific fatty acids, including SFAs, in which black mulberry contained greater amounts of C18:0 and C18:2n6 than others. Red mulberry had the highest C16:1n7 and C20:00 content. White mulberry has a higher amount of C19:1n6 and C19:1n7 fatty acids compared to black and red mulberries. These fatty acids are important for various physiological functions in the body and are essential components of a healthy diet.

Further studies are required to assess the nutritional properties of local mulberries, this includes characterising the phytochemicals present in these fruits. Once a complete understanding of the nutritional properties of locally grown mulberries is achieved, research could move towards developed mulberry-based food products with functional properties. A combination of the three mulberry types can be considered, with different proportions, to develop functional foods with high nutritional value.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Data available within the article or its supplementary materials.

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CRediT authorship contribution statement

Ali Ali Redha: Validation, Visualization, Writing – original draft, Writing – review & editing. **Afnan Freije:** Conceptualization, Methodology, Supervision. **Chamali Kodikara:** Writing – original draft. **Mariangela Rondanelli:** Conceptualization. **Eman Aqeel:** Investigation. **Wajiha Zafar:** Investigation. **Heba Albunni:** Investigation. **Hawraa Merza:** Investigation. **Aysha Khonji:** Investigation. **Mona Aljar:** Investigation. **Simone Perna:** Conceptualization, Project administration.

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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