Phenolic Compounds in Mulberry

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Contributor: Tao Wu, Yang YunYun, Min Zhang

Mulberry, which belongs to the genus Morus of the Moraceae family, is an aggregated berry that is oval-shaped, rich in nutrition, sweet and soft, with a unique flavor. Mulberry is distributed in east, west and southeast Asia, southern Europe, southern North America, northwestern South America and some areas of Africa. There are 24 species of Morus and one subspecies, with at least 100 known varieties.

Keywords: mulberry ; composition

1. Introduction

Mulberry, which belongs to the genus Morus of the Moraceae family, is an aggregated berry that is oval-shaped, rich in nutrition, sweet and soft, with a unique flavor [1][2]. Mulberry is distributed in east, west and southeast Asia, southern Europe, southern North America, northwestern South America and some areas of Africa [3]. There are 24 species of Morus and one subspecies, with at least 100 known varieties [4]. Studies have shown that mulberry is beneficial for human health, which may be related to the compounds it contains, such as phenols, amino acids and sugars [5][6]. Since ancient times, mulberries have been used as fruits and herbs and have been listed by the Chinese Ministry of Health as one of the “food and medicine” agricultural products. The fruit is a high-quality natural raw material that is used for the production of modern food and diet regimens. It is commonly eaten, often dried, or processed into wine, syrups, canned food, fruit juice, jam and beverages [3][4][7][8][9][10]. The anthocyanin content in mulberry wine is much higher than that of red wine, and regular consumption can increase immunity.

There are many varieties of mulberry, with the most common species consisting of black mulberry (*Morus nigra* L.), white mulberry (*Morus alba* L.) and red mulberry (*Morus rubra* L.) [11]. Some studies have revealed that black mulberry has a higher content of total phenolics, total flavonoids, total anthocyanins and more antioxidant compounds than red mulberry or white mulberry [4][12][13]. Some authors point out that the nutrient and plant chemistry of mulberry are closely related to the area in which it was cultivated [14][15][16].

2. Composition of Mulberry

Mulberry is rich in nutrients, approximately 0.5–1.4% protein and about 7.8–9% carbohydrates [17]. Mulberry contains neutral sugars such as arabinose, galactose, glucose, rhamnose, xylose, mannose and also contains a large amount of uronic acid, namely in the form of galacturonic acid and glucuronic acid [18][19][20][21]. The most abundant amino acid in mulberry is glutamate, which accounts for approximately 20%, followed by glycine and aspartate [22]. It also contains lysine, leucine, isoleucine, histidine, threonine, tryptophan and glycine, among others. Among these amino acids, leucine, threonine, isoleucine, glycine, threonine, valine, tryptophan, arginine, aspartic acid and serine are found in a higher content in white mulberry when compared with black mulberry. In contrast, the content of lysine, histidine, and proline are higher in black mulberry and lower in white mulberry [23]. The fat content of mulberry is extremely low, and linoleic acid, oleic acid, palmitic acid and stearic acid make up 69.66–78.02% of the total fatty acids [24]. The vitamins in mulberry are mainly vitamin C, vitamin A and some B groups [16]. The organic acids of mulberry are succinic acid, acetic acid, malic acid, citric acid and tartaric acid [3]. The content of titrable acid is 0.20–2.65%, and the content in black mulberry is higher than that in white mulberry [4][23][25][26][27]. The minerals in mulberry are potassium, calcium, phosphorus, sodium, zinc, copper and selenium. Studies have shown that the content of potassium in black mulberry is much higher than that in other fruits [13]. Soluble solids mainly include sugar, acid, vitamins and minerals, and their content can directly affect the taste of fruits and vegetables. The total soluble solid content of mulberry is 6.2–25.8% [4][23][25][26].

Mulberry contains many phenolic compounds, and **Table 1** contains the results of the determination of total phenol and total flavonoids from recent years. In addition to the above ingredients, mulberry also contains alkaloid compounds (quinine, 1-deoxynojirimycin) and α-glucosidase inhibitors [28][29][30]. Different varieties of mulberry possess different chemical compositions and nutritional statuses, which are related to the climate, topography and soil conditions [7].

Table 1. Total phenol and total flavonoid content in mulberry.

Element	Mulberry	Origin	Concentration	Reference
Total phenolic	*M. alba, M. Nigra, M. rubra*	Olur town, Erzurum, Turkey	181–1422 mg GAE/100g FW	[4]
	M. nigra L. and *M. alba* L.	Jinhua, Zhejiang, China	879–6585 mg GAE/kg FW	[12]
	8 different varieties	Orihuela (latitude 38°04′08″ N × longitude 0°58′58″ W, 27 m above sea level) Alicante (South-Eastern Spain)	6.98–13.59 mg GAE/g DW	[13]
	M. alba L.	Qinshui County, Shanxi province in China	23.00 mg/g MFP	[15]
	22 different varieties	Quanxi town, Wuyi county of Zhejiang Province, China	199.45–2330.40 μg GAE/g FW	[25]
	4 different varieties	northern regions of Pakistan	880–1650 mg/100 g FW	[27]
	M. alba L.	Taichung, Taiwan	1515.9 mg GAE/100 g FM	[31]
	different varieties		7.0–2392.0 mg GAE/100 g	[32]
	Morus Microphylla Buckl	Yangpyeong, Korea	24.01 mg/g DW	[33]
	M. nigra L.	Istanbul, Turkey	1451.4 mg GAE/100 g DW	[34]
	M. alba L.	Silk Innovation Center, Mahasarakham University, Thailand	104.78–213.53 mg GAE/100 g DW	[35]
	Morus alba L., *Hongguo no.2*	Shaanxi, China (34°16′–56°24′ N, 108° 4′–27°95′ E)	524.06 mg/100 g DW	[36]
	M. alba L.	Suncheon City, Korea	11.2 mg FAE/kg DW	[37]
	10 different varieties	Yinchuan, Ningxia; Zaozhuang (Shandong); Jurong (Jiangsu); Guangzhou (Guangdong)	670–7700 mg GAE/kg FW	[38]
	M. alba L.	National Institute of Agricultural Science and Technology, Suwon, Korea	959.9–2570.4 μg GAE/g dried extracts	[39]
	M. alba L.	Hangzhou, China	547.60 mg GAE/g MAE	[40]
	M. nigra L.	Yesilyurt, Malatya (38.321059, 38.217478)	192.67 mg GAE/g	[41]
		Guangzhou, Guangdong, China	35.53% in the proportion of dry matter	[42]
	M. alba L.	Anji and Fuyang, Zhejiang, China	11.67–690.83 mg GAE/g	[43]
	Dried mulberry fruits juice (*Morus* sp.)	Xinjiang, China	3.21 mg GAE/g	[44]
	M. nigra L.	Puerto Real region (Spain)	1301.67 μg/g FW	[45]
	11 different varieties	Zhejiang province, China	100.97–586.23 mg GAE/100 g FW	[46]
	M. nigra L.	Ordu, Turkey	2032.87 mg GAE/100 g DW	[47]
	Mulberry fruit	Sang-ju Silkworm Farming Association, Sang-ju, Korea	5.16 mg/100 g	[48]
	M. alba L.	Jinhua, Zhejiang, China	185–344 mg 100/g FW	[49]
	M. nigra and *M. rubra*	Turkey	1005–3488 μg GAE/g FW	[50]

Element	Mulberry	Origin	Concentration	Reference
Total flavonoids	*M. nigra* L.		1375 mg GAE/100 g DW	[51]
	M alba, M. nigra, M. rubra	Olur town, Erzurum, Turkey	29–276 mg QE/100 g FW	[4]
	M. nigra L. and *M. alba* L.	Jinhua, Zhejiang, China	663–1292 mg QE/kg FW	[12]
	M. alba L.	Qinshui County, Shanxi, China	3.90 mg/g MFP	[15]
	M. alba L.	Taichung, Taiwan	250.1 mg QE/100 g FM	[31]
	Morus alba L., *Hongguo no.2*	Shaanxi, China (34°16′–56°24′ N, 108° 4′–27°95′ E)	463.62 mg/100 g DW	[36]
	38 different varieties	all around China	0.178–2.485 mg RE/g lyophilized mulberry fruit	[52]
	M. alba L.	National Institute of Agricultural Science and Technology, Suwon, Korea	5.6–65.4 μg/g DW	[39]
	M. alba L.	Hangzhou, China	893.73 mg RE/g mulberry anthocyanin extract	[40]
	M. nigra L.	Yesilyurt, Malatya (38.321059, 38.217478)	125.86 mg QE/g	[41]
		Guangzhou, Guangdong, China	7.53% in the proportion of dry matter	[42]
	M. alba L.	Anji and Fuyang, Zhejiang, China	94.53–965.63 mg RE/g	[43]
	ML juice	Xinjiang, China	53.85 mg QE/g	[44]
	11 different varieties	Zhejiang province, China	16.38–368.16 mg RE/100g FW	[46]
	Mulberry fruit	Sang-ju Silkworm Farming Association, Sang-ju, Korea	9.73 mg/100g	[48]
	M. nigra L.		1473 mg RE/100g DW	[51]

FW: fresh weight; DW: dry weight; MAE: mulberry anthocyanin extract; RE: rutin equivalents; GAE: gallic acid equivalents; FAE: ferulic acid equivalents; FM: fresh matter; QE: equivalent of quercetin; MFP: powder of mulberry (*Morus alba* L.) fruit (MFP).

3. Content of Phenolic Compounds

Polyphenols play an important role in promoting human health and are the most relevant family of phytochemicals [53].

3.1. Flavonoids

Among them, flavonoids constitute a very wide range of groups and are distributed in a variety of vegetables and fruits. They have a common basic structure: C6-C3-C6, which usually forms an oxygen-containing heterocycle. Flavonoids are usually associated with sugars (glycosides), and therefore, they tend to be water-soluble.

3.2. Anthocyanins

Mulberries are especially rich in flavonoids, specifically anthocyanin [4][31][32][54][55]. Anthocyanin is the main active ingredient and chromogenic substance of mulberry, which is why mulberry is considered to be an important source of anthocyanin in the diet [33]. Its anthocyanin content is high, pigment is stable, can dissolve completely in water and has increased bioactive activity; therefore, it becomes a fruit pigment that cannot be replaced. Mulberry is an optimal source for extracting anthocyanin from pine bark, pine needles and grape seeds. Therefore, together with sea buckthorn, it is listed as a functional health food with the international development of the third generation of “fruit resources”. The most abundant anthocyanin in mulberry is cyanidin-3-glucoside (C3G), representing 53.94–78.23% of the total anthocyanins; cyanidin-3-rutinoside (C3R) accounts for 19–43.83%, and pelargonidin-3-glucoside (P3G) is measured in a proportion close to 5% [34][56][57][58][59][60]. The content of mulberry anthocyanins is shown in **Table 2**; white varieties do not contain any anthocyanins [24][25]. The content of anthocyanin in mulberry is related to mulberry variety, maturity, climate, soil, pruning of mulberry trees, pest control and other factors [3][7][61].

Table 2. Anthocyanin in mulberry.

Mulberry	Anthocyanin	Origin	C3G	C3R	Reference
4 different varieties	184.3–227.0 mg/100g	Van province			[3]
M. alba L.		Jinhua, Zhejiang, China	1698 mg/kg FW	693 mg/kg FW	[12]
M. alba L.	0.01–1.88 mg/g DW	Orihuela (latitude 38°04′08″ N × longitude 0°58′58″ W, 27 m above sea level) Alicante (South-Eastern Spain)	0.004 –1.26 mg/g DW	0.004–0.08 mg/g DW	[13]
M. alba L.	0.87 mg/g	Qinshui County, Shanxi, China			[15]
22 different varieties	306.91–1422.11μg/g	Quanxi town, Wuyi county of Zhejiang Province, China			[25]
Morus Microphylla Buckl.	2.3 mg/g DW	Yangpyeong, Korea			[33]
different varieties		Zhejiang, China	1.25–3.35 g/kg	0.25–1.50 g/kg	[56]
Morus nigra L.		Istanbul, Turkey	1221 mg/100 g DW		[34]
41 different varieties	0.87–96.08 mg/g lyophilized mulberry fruit	all around China	0.57–62.93 mg/g lyophilized mulberry fruit	0.05–12.70 mg/g	[52]
M. alba L.	137.3–2057.3 μg/g	National Institute of Agricultural Science and Technology, Suwon, Korea	93.2–1364.9 μg/g DW	30.6–486.7 μg/g DW	[39]
M. alba L.	77.9% of the whole extract	Hangzhou, China			[40]
M. alba L.	24.10–383.49 mg/g	Anji and Fuyang, Zhejiang, China	19.30–272.00 mg/g DW		[43]
11 different varieties	4.20–121.56 mg catechin equivalents/100 g FW	Zhejiang province, China			[46]
M. nigra L.		Ordu, Turkey	1572.41 mg/100 g DW		[47]
Mulberry fruits		Sang-ju Silkworm Farming Association, Sang-ju, Korea	97.68 mg/100 g	71.18 mg/100 g	[48]
M. nigra L., *M. rubra* L.	3–830 μg/g	Turkey			[50]
M. alba L.	669 mg/100g DW		371 mg/100g DW		[51]
M. alba L.		São Paulo city, Brazil	79% of anthocyanin	19% of anthocyanin	[62]
	0.19–3.29 mg/g				[63]
31 kinds cultivated mulberry juices	147.68–2725.46 mg/L	Quanxi town, Wuyi county of Zhejiang Province, China			[64]
180 different varieties	0.035–2.192 mg/g	Huzhou Academy of Agricultural Sciences, China			[65]

FW: fresh weight; DW: dry weight.

3.3. Phenolic Acids

Mulberries contain phenolic acids (chlorogenic acid, gallic acid, protocatechuic acid, p-coumaric acid, O-coumaric acid, ferulic acid, caffeic acid, and vanillic acid), rutin, quercetin and resveratrol [3][15][56][66][67]. The main phenolic acids in mulberry are hydroxycinnamic acid derivatives [25]. Gallic acid and protocatechuic acid are the main derivatives of hydroxybenzoic acid in black mulberry [35][66]. The content of phenolic acids in mulberry is 0.02952–0.17564 mg/g fw [68]. Chlorogenic acid is the main phenolic component in black mulberry, while ruin is the dominant phenolic in white and red mulberry [3]. Chlorogenic acid is the main acid in the sugarless extract of black and white mulberry [36]. Gundogdu et al. described the concentration range of chloric acid in mulberry as 0.119–3.106 mg/g fw [3]. Butkhup et al. found that its concentration in white mulberry was 0.01 to 0.06 mg/g dw [35], and the concentration range of chlorogenic acid in white mulberry and black mulberry was reported by Sanchez-Salcedo et al. as 0.15–0.97 mg/g dw and 0.35–3.18 mg/g dw [13], respectively. The amount of chlorogenic acid in black mulberry was higher than that in white mulberry. As mulberry matures, the amount of chlorogenic acid and its isomers gradually decreases [69]. Song et al. detected resveratrol in 38 mulberry varieties from China at 0.0021–0.0053 mg/g [52]. Chon et al. found a significant difference in the total phenol content measured by different solvents [37]. The content of total phenolic compounds in mulberry is shown in **Table 1**, with black mulberry containing a higher amount than white mulberry [12][38].

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