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Comparison of Phenolic Compounds and Antioxidant Activities of Fifteen *Chrysanthemum morifolium* Ramat cv. 'Hangbaiju' in China

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Running Title: Bioactive compounds in Chrysanthemums in China

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ABSTRACT

This study investigated the phenolic compounds of 15 *Chrysanthemum morifolium* Ramat cv. 'Hangbaiju', including 6 'Duoju' and 9 'Taiju' using high performance liquid chromatography. The antioxidant activities of these 'Hangbaiju' were estimated by DPPH, ABTS and FPAR assays. Results showed that a total of 14 phenolic compounds were detected in these flowers, including 3 mono-caffeoylquinic acids, 3 di-caffeoylquinic acids, 1 phenolic acid and 7 flavonoids. 'Duoju' and 'Taiju' possessed different concentration of phenolic compounds, and 'Taiju' exhibited higher caffeoylquinic acids and stronger antioxidant activities than 'Duoju'. Caffeoylquinic acids showed a strong correlation with the antioxidant activities of the samples. Principal component analysis revealed an obvious separation between 'Duoju' and 'Taiju' using phenolic compounds as variables. Apigenin-7-*O*-glucoside, 3,5-di-*O*-caffeoylquinic acid, luteolin and acacetin were found to be the key phenolic compounds to differentiate 'Duoju' from 'Taiju'.

Keywords: Chrysanthemum; HPLC; Phenolic compounds; Principal component analysis; Antioxidant capacity

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1. Introduction

Chrysanthemum morifolium Ramat belongs to the family *Asteraceae* and most of these flowering plants are widely planted in East Asia and northeastern Europe [1, 2]. It is called 'Ju Hua' in Chinese, and has been used as an herbal medicine in many Asian countries, including China, Japan, South Korea and Thailand [3, 4]. It is reported in Chinese Pharmacopoeia that drinking *C. morifolium* tea (infusion) could help alleviating headache and preventing the occurrence of cold and fever [5-8]. Additionally, drinking *C. morifolium* tea has the potential to improve the eye function [5-7, 9]. Recent harmacological studies demonstrated that *C. morifolium* possess a wide array of health potentials, such as anti-bacterial, anti-viral and anti-inflammatory capacities [4, 6, 8-12]. During its long evolution, 'Hangju', 'Boju', 'Chuju', and 'Gongju' are the four main varieties of *C. morifolium* cited in the Chinese Pharmacopeia [7]. *C. morifolium* has been reported to contain numerous bioactive compounds such as phenolic compounds, which possess antioxidant activity [1, 13]. Up to date, the main phenolic compounds in *C. morifolium* include chlorogenic acid, 3-O-caffeoylquinic acid, 4-O-caffeoylquinic acid, 3,4-di-O-caffeoylquinic acid, 3,5-di-O-caffeoylquinic acid, 4,5-di-O-caffeoylquinic acid, luteolin, luteolin-7-O-glucopyranoside, acacetin, apigenin, apigenin-7-O-glucoside, acacetin-7-O-rutinoside, caffeic acid, and hyperoside (3-5,11-17]. Among these compounds, 5-O-caffeoylquinic acid and 3, 5-di-O-caffeoylquinic acid are representative caffeoylquinic acids that significantly affected the antioxidant activity of C. morifolium [1, 3]. According to Chinese Pharmacopoeia, the content of 5-O-caffeoylquinic acid, 3,5-di-O-caffeoylquinic acid and luteoloside should be above 0.2 g/100 g DW, 0.7 g/100 g DW and 0.08 g/100 g DW respectively to qualify C. morifolium as an herbal medicine [7].

'Hangbaiju' is a cultivar of *Chrysanthemum morifolium* Ramat which is mainly planted in Zhejiang Province and has been widely used as a functional beverage in China due to its unique sensory attributes and multiple health beneficial features [6]. 'Hangbaiju' can be further classified into two mainly

commercial products, including 'Duoju' (named 'DJ') and 'Taiju' (named 'TJ'), according to their different harvest time [13]. 'Duoju' represent the dried flower heads harvested when their ray florets and tubular florets being fully opened (harvested in November), whereas 'Taiju' are the dried flower heads with opened ray florets but closed tubular florets (harvested in October)[13]. We hypothesize that 'Duoju' and 'Taiju' may possess different phenolic compositions due to their different harvest seasons, which could affect their antioxidant properties. To this end, 6 'Duoju' and 9 'Taiju' were selected in the present study. Their phenolic compositions and antioxidant properties were analyzed and compared. Additionally, multivariate statistical analysis (principal component analysis) was applied to differentiate these 'Hangbaiju' based on their phenolic profiles. This study could have provided useful information on the quality control of 'Hangbaiju' in China.

2. Materials and methods

2.1. Materials

A total of 6 'Duoju' and 9 'Taiju' were collected in multiple supermarkets in Hangzhou, Zhejiang, China. 'DJ1', 'DJ2', 'DJ3' and 'DJ4' samples were planted in Tongxiang, whereas "DJ5' sample was cultivated in Jiaxing and 'DJ6' sample in Hangzhou, Zhejiang, China. Regarding the 'Taiju' samples, 'TJ1', 'TJ2', 'TJ3' and 'TJ4' were from Tongxiang area whereas 'TJ5' to 'TJ8' samples were from Jiaxing area of Zhejiang. 'TJ9' sample was collected from Bozhou, Anhui Province, China.

2.2. Chemicals

Chemical standards including apigenin-7-O-glucoside, 3-O-caffeoylquinic acid, 4-O-caffeoylquinic acid, 3,5-di-O-caffeoylquinic acid, 4,5-di-O-caffeoylquinic acid, 3,4-di-O-caffeoylquinic acid, luteoloside, and linarin were purchased from Shanghai Yongheng Biotechnology Co. Ltd. (Shanghai, China) with the purity of at least 98%. The standards of hyperoside and acacetin, with the purity of 98.2% and 98.5 % respectively, were from Shanghai Ronghe Medical Biotechnology Co. Ltd. (Shanghai,

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China). The standards of 5-O-caffeoylquinic acid (98.8%) and caffeic acid (98.6%) were purchased from Shanghai J&K Biotechnology Co. Ltd. (Shanghai, China). Apigenin (98.5%) and luteolin (98.3%) standards were received from Zhejiang Tiancao Biotechnology Co. Ltd. (Zhejiang, China). 1,1-Diphenyl-2-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS) and 2,4,6-tri(2-pyridyl)-1,3,5-triazine (TPTZ) were purchased from Tokyo Chemical Industry Development Co.; Ltd. (Shanghai, China). 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) and Vc were obtained from J&K Scientific Ltd. (Shanghai, China). Phosphoric acid was of analytical grade and purchased from Sinopharm Chemical Reagent Co. Ltd. (Shanghai, China), whereas the HPLC grade acetonitrile and methanol were purchased from Merck (Darmstadt, Germany). Water was obtained from a MilliQ purification system (Bedford, MA, USA).

2.3. Sample Extraction

The 'Hangbaiju' samples were ground into powder by a Chinese medicine crusher (Shanghai Dianjiu Traditional Chinese Medicine Machinery Manufacturing Co. Ltd, Shanghai, China) and passed through a 60 mesh sieve. About 0.5 g sample was mixed with 100 mL of methanol: water (70:30 v/v) in a glass tube, and sonicated at 50 °C for 40 min. Afterwards, the mixture was cooled to room temperature, and the final extract volume was brought to 100 mL using the methanol : water solution [7]. The extract was filtered through a 0.22 µm PTFE membrane and stored at -20 °C for further analysis.

2.4. HPLC-DAD Analysis

A Waters E2695 high performance liquid chromatography coupled with a 2998 diode array detector (Waters, Milford, MA, USA) was used to analyze the phenolic compounds in the 'Hangbaiju' samples. A Phenomenex Luna C18 column (250 mm × 4.6 mm, 5 µm, Torrance, CA, USA) was used to separate the phenolic compounds under a 0.8 mL/min flow rate. The mobile phase consisted of (A) acetonitrile and (B) 0.1% phosphoric acid in water (v/v). The sample injection volume was 10 µL and

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the column was maintained at 35 °C during the elution program. The gradient was programed as follows, 0 to 11 min, 10% A to 18% A; 11 to 32 min, 18% A isocratic; 32 to 40 min, 18% A to 30% A; 40 to 48 min, 30% A to 35% A; 48 to 50 min, 35% A to 40% A; 50 to 55 min, 40% A isocratic; 55 to 60 min, 40% A to 70% A; and 60 to 70 min, 70% A to 10% A. Phenolic compounds were identified by comparing their retention time with corresponding external standards. The quantitation was also conducted using the standards.

2.5. DPPH Assay

The antioxidant activity of the 'Hangbaiju' extracts and standard solutions using DPPH assay was followed the method of Turkoglu et al [18] with minor modifications. Briefly, 20 mg of DPPH was dissolved in methanol in a 500 mL volumetric flask to a concentration of 0.101 M. The extract or standard solution (0.2 mL) was mixed with 3.8 mL of DPPH solution. The mixture was well vortexed and kept at room temperature for 1 hour. Afterwards, the absorbance of the mixture was recorded at 517 nm on a UV-5200PC spectrophotometer (Metash instrument, Shanghai, China). The reference was prepared by mixing 0.2 mL of 50% methanol solution with 3.8 mL DPPH solution. The DPPH radical inhibition rate of samples was calculated using the equation below,

$$\text{Inhibition rate} = (A_{ref} - A_{sample}) / A_{ref} \times 100\%$$

Where A_{ref} and A_{sample} were the absorbance of the reference and the sample, respectively. IC_{50} represents the sample with its concentration that inhibits 50% of DPPH radicals. Each measurement was carried out in triplicate.

2.6. ABTS Assay

ABTS assay was followed the method of Re et al. [19] with minor modifications. In brief, 176 µL of 140 mM potassium persulfate solution was mixed with 10 mL of 7 mM ABTS solution to yield ABTS working solution. The working solution was kept in the dark for 12 hours. During the analysis,

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the ABTS working solution was diluted by ethanol to an absorbance vale of 0.70 ± 0.02 at 734 nm on the UV-5200PC spectrophotometer. Afterwards, 0.1 mL extract or standard solution was mixed with 3.9 mL ABTS working solution and kept at room temperature for 6 min in the dark. The absorbance of the mixture was also recorded at 734 nm. The 50% methanol solution (0.1 mL) mixed with 3.9 mL ABTS working solution was used as the reference. The ABTS radical inhibition rate of the sample was calculated using the equation below,

$$\text{Inhibition rate} = (A_{ref} - A_{sample}) / A_{ref} \times 100\%$$

Where A_{ref} and A_{sample} were the absorbance of the reference and the sample, respectively. IC_{50} was used to represent the inhibition activity of each sample against 50% of ABTS radical. Each measurement was conducted in triplicate.

2.7. Ferric Reducing Antioxidant Power (FRAP) Assay

FRAP assay was carried out according to Benzie & Strain [20] with minor modifications. In brief, the FRAP working solution was prepared by mixing 0.1 M acetate solution (pH 3.6), 10 mM TPTZ solution and 20 mM ferric chloride solution at a 10:1:1 (v/v/v) ratio. Afterwards, 0.1 mL extract sample or standard solution was mixed with 3.9 mL FRAP working solution and vortexed. The resultant mixture was incubated at a 37 ℃ water bath for 10 min. After cooling to the room temperature, the absorbance of the mixture was recorded at 593 nm. The reference was prepared by mixing 50% methanol with 3.9 mL FRAP working solution. Trolox was used as the external standard. The FRAP value of each sample was expressed as mg TEAC/g dry weight. Each analysis was performed in triplicate.

2.8. Statistical Analysis

All data were expressed as the mean ± standard deviation of triplicate tests. Analysis of variance (ANOVA) was carried out to investigate the significant difference among the means at a significant level of 0.05 using SPSS22.0 software (SPSS Inc, Chicago, IL, USA). Principal component analysis

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(Metabo Analyst 4.0, http://www.metaboanalyst.ca) was carried out using phenolic compounds as variable to elucidate the similarity of 'Hangbaiju' samples.

3. Results

3.1 *Phenolic Composition*

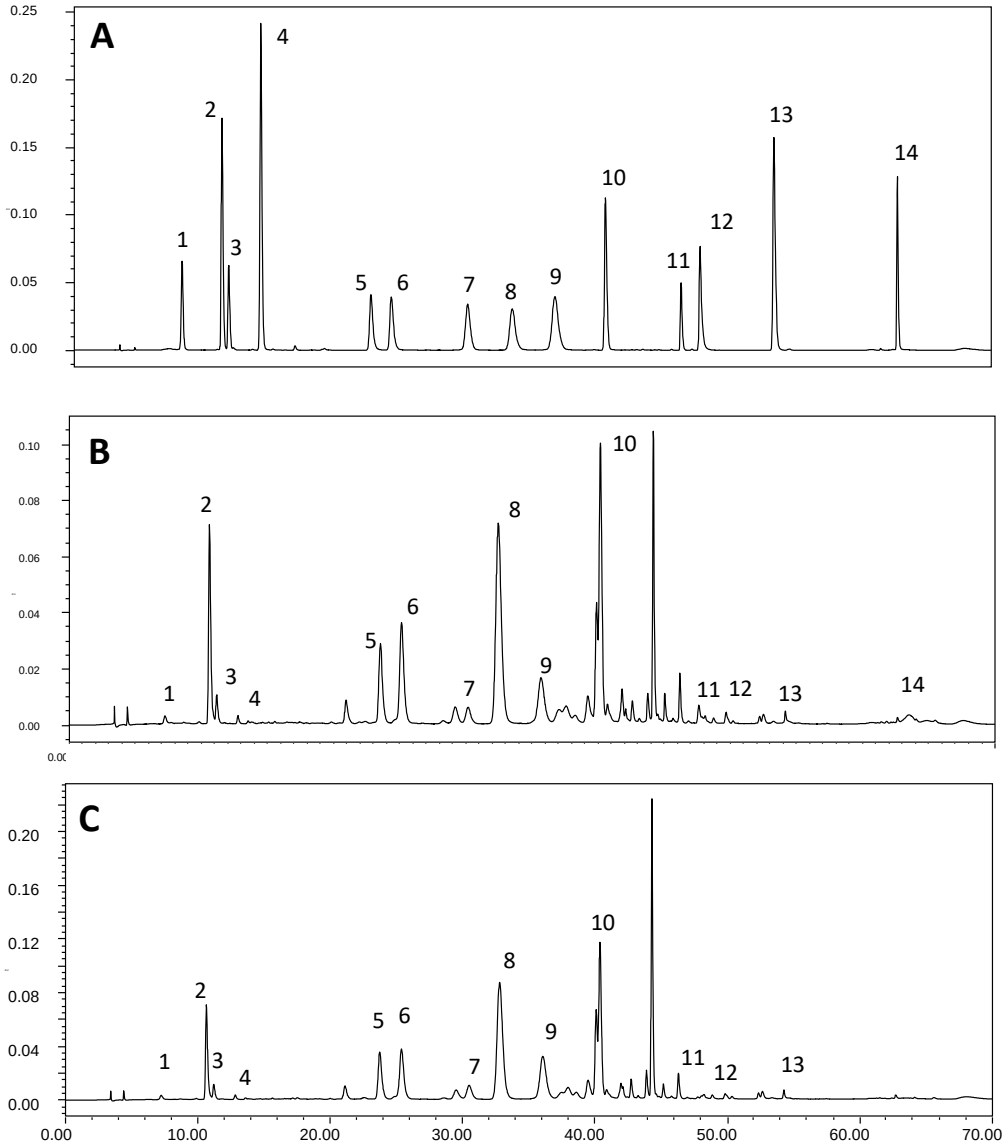

Figure 1. Chromatography of phenolic compounds of (A) standards, (B) 'DJ1' sample and (C) 'TJ4' 'sample. Peak 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 represent 3-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, caffeic acid, hyperoside, luteoloside, 3,4-di-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid, apigenin-7-*O*-glucoside, 4,5-di-*O*-caffeoylquinic acid, linarin, luteolin, apigenin and acacetin, respectively.

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Figure 1 shows the chromatography of phenolic compounds of standards and representative "Hangbaiju" samples of 'DJ2' and 'TJ4'. Phenolic acid and flavonoid are two groups of active substances in 'Hangbaiju'. The contents of individual phenolic compounds and total mono-caffeoylquinic acid contents (TMAC), total di-caffeoylquinic acid contents (TDAC), total phenolic acid contents (TPAC) and total flavonoid contents (TFC) in these samples are listed in **Table 1**.

The TMAC was found to be in the range of 2552.04 to 7402.83 μg/g DW**,** in which the 'Duoju' samples had the content between 2552.04 and 4352.29 μg/g DW and 'Taiju' samples between 2673.11 and 7402.83 μg/g DW. In comparison of the TMAC among 'Duoju', 'DJ6' was higher than others ($P < 0.05$). The contents of 3-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, and 4-*O*-caffeoylquinic acid in the 'DJ6' were found to be 1167.59 μg/g DW, 2392.17 μg/g DW and 792.53 μg/g DW respectively which were also significantly higher than the other 'Duoju' ($P < 0.05$). It is worth noting that 5-*O*-caffeoylquinic acid was the dominant mono-caffeoylquinic acid in the 'Duoju' samples. These results were in consistent with a previous report [13]. Among the 'Taiju' samples, 'TJ3' had the highest TMAC ($P < 0.05$), with 2844.64 μg/g DW of 3-*O*-caffeoylquinic acid, 3139.04 μg/g DW of 5-*O*-caffeoylquinic acid and 1365.16 μg/g DW of 4-*O*-caffeoylquinic acid respectively. 5-*O*-Caffeoylquinic acid was also the predominant individual mono-caffeoylquinic acid in the 'Taiju' materials. Different to 'Duoju', the 3-*O*-caffeoylquinic acid content in 'Taiju' was much higher than 4-*O*-caffeoylquinic acid (**Table 1**).

The TDAC in the 6 'Duoju' were between 8153.62 μg/g DW and 10974.94 μg/g DW, and in the 9 'Taiju' between 7718.79 to 13960.39 μg/g DW (**Table 1**). It was observed that 7 out of 9 'Taiju' samples had higher TDAC than the highest content 'Duoju' ('DJ6', 10974.94 μg/g DW) sample. Among the 6 'Duoju' samples, 'the content of 3,4-di-*O*-caffeoylquinic acid in the 'DJ6' were significantly higher than the rest, whereas the content of 3,5-di-*O*-caffeoylquinic acid in the 'DJ2' and 'DJ6' were significantly higher, and content of 4,5-di-O-caffeoylquinic acid in the 'DJ2', 'DJ5'and 'DJ6' were

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significantly higher than the others (**Table 1**). In both 'Duoju' and 'Taiju' samples, 3,5-di-*O*-caffeoylquinic acid was the dominant individual di-caffeoylquinic acid, followed by 4,5-di-*O*-caffeoylquinic acid and 3,4-Di-*O*-caffeoylquinic acid. 'TJ3' and 'TJ5' contained the highest 3,5-di-*O*-caffeoylquinic acid and 4,5-di-*O*-caffeoylquinic acid among the tested 15 'Hangbaiju' samples. Regarding to caffeic acid content in the 'Taiju' samples, 'TJ3' possessed the highest content (23.03 μg/g DW), but it was not detected in 'TJ1'. Among the 'Duoju' samples, the highest caffeic acid content was found in the 'DJ1' (10.85 μg/g DW), but it was not detected in 'DJ4' and 'DJ6' (**Table 1**).

The TPAC in "Taiju" was ranged between 10405.31 μg/g DW and 20847.76 μg/g DW, and in 'Duoju' between 10709.43 μg/g DW and 15327.22 μg/g DW respectively. It should be noted that the highest and lowest TPAC was all found in 'Taiju' samples, and 7 out of 9 'Taiju' samples had higher TPAC than the highest TPAC 'Duoju' (DJ6, 15327.22 μg/g DW) sample. Among the 6 'Duoju' samples, 'DJ2' showed significantly higher TPAC than 'DJ3' and 'DJ4' ($P < 0.05$), but no significant differences were observed between 'DJ2' with the rest of the 'Duoju' samples. Among the 'Taiju' samples, 'TJ3' had significantly higher TPAC than all others ($P < 0.05$).

In terms of flavonoids, these 'Hangbaiju' samples contained hyperoside, luteoloside, apigenin-7-*O*-glucoside, linarin, luteolin, apigenin and acacetin (**Table 1**). The TFC was ranged from 5183.35 to 9792.01 μg/g DW, and 'Taiju' had higher TFC than that of 'Duoju'. Regarding to the individual flavonoids, all samples contained hyperoside, lutoloside, apigenin-7-O-glucoside, linarin and luteolin. Specifically, 'DJ5' had the highest content of hyperoside (813.68 μg/g DW) and linarin (2605.87 μg/g DW). Both 'DJ5' and 'DJ2' showed similar content on luteolin (247.09 μg/g DW and 238.37 μg/g DW, respectively), and 'DJ3' and 'DJ4' contained similar amount of luteoloside (1524.16 μg/g DW and1476.67 μg/g DW, respectively). 'DJ4' showed the highest content of apigenin-7-*O*-glucoside among the 'Duoju' ($P < 0.05$). The contents of luteoloside and linarin in all 'Taiju' were higher than all

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186 **Table 1**. Contents of phenolic compounds in different 'Duoju' and 'Taiju' (μg/g DW).

Phenolic Compound	Duoju						Taiju								
	DJ1	**DJ2**	**DJ3**	**DJ4**	**DJ5**	**DJ6**	TJ1	TJ2	TJ3	TJ4	TJ5	TJ6	TJ7	TJ8	TJ9
3-*O*-caffeoylquinic acid	691.48±21.98^{d}	889.07±25.98^{c}	597.64±19.87^{e}	644.24±30.34^{e}	965.49±38.17^{b}	1167.59±16.22^{a}	1555.13±50.01^{c}	1246.00±40.11^{e}	2844.64±66.38^{a}	1117.50±37.88^{f}	1641.14±47.32^{b}	1589.85±59.38^{bc}	673.09±28.93^{h}	1403.69±38.29^{d}	1560.38±50.21^{c}
5-*O*-caffeoylquinic acid	1745.29±55.86^{c}	2083.55±81.66^{b}	1413.66±6 5.66^{d}	1370.96±5 4.98^{d}	2189.24±5 8.96^{b}	2392.17±136.86^{a}	2649.68±60.19^{cd}	2180.97±182.93^{e}	3193.04±167.95^{a}	2205.75±12 9.84^{e}	2759.82±16 4.23^{bc}	2941.23±15 6.82^{b}	1487.40±36 .865^{g}	2482.32±13 6.75^{d}	2519.96±16 3.76^{cd}
4-*O*-caffeoylquinic acid	640.83±30.17^{b}	765.78±36.74^{a}	540.74±15.36^{c}	521.76±19.27^{c}	764.92±20.67^{a}	792.53±13.98^{a}	981.08±63.18^{bcd}	869.65±48.95^{e}	1365.16±89.10^{a}	882.50±57.89^{de}	1018.33±87 .85^{b}	990.22±64. 72^{bc}	512.62±37. 16^{f}	916.21±66. 84^{ce}	940.69±67. 09^{be}
TMAC	*3077.60±70.87^{c}*	*3738.40±108.99^{b}*	*2552.04±70.11^{d}*	*2536.96±58.78^{d}*	*3919.65±69.86^{b}*	*4352.29±140.11^{a}*	*5185.89±89.28^{bc}*	*4296.62±199.25^{e}*	*7402.83±196.27^{a}*	*4205.75±152.57^{e}*	*5419.29±211.27^{bc}*	*5521.29±195.845^{b}*	*2673.11±52 .17^{f}*	*4802.21±15 7.28^{d}*	*5021.03±21 1.27^{cd}*
3,4-di-*O*-caffeoylquinic acid	282.62±9.94^{c}	379.66±15.67^{b}	259.12±6.98^{d}	289.24±18.27^{c}	385.30±17.18^{b}	530.91±9.85^{a}	718.39±39.28^{bc}	517.04±15.73^{d}	782.14±23.18^{a}	498.48±38.93^{d}	743.78±28. 33^{ab}	719.32±47. 38^{bc}	229.17±17. 03^{e}	677.70±13. 98^{c}	685.30±20. 17^{c}
3,5-di-*O*-caffeoylquinic acid	5275.20±210.76^{c}	6460.38±201.38^{a}	4736.66±2 86.99^{d}	4918.72±2 29.38^{cd}	5796.97±1 98.35^{b}	6421.88±298.67^{a}	7156.41±301.27^{b}	5913.21±392.83^{c}	8119.70±503.27^{a}	7090.86±41 1.28^{b}	8259.63±36 7.86^{a}	7305.74±52 2.86^{b}	4489.29±28 9.78^{d}	7251.88±29 8.39 b	6717.60±36 3.18^{b}
4,5-di-*O*-caffeoylquinic acid	3156.97±96.38^{c}	3702.25±109.26^{b}	3158.17±1 57.88^{c}	3087.61±6 9.20^{c}	3880.21±1 58.29^{ab}	4022.14±156.76^{a}	4820.02±110.37^{ab}	4217.64±207.81^{b}	4520.06±167.28^{ab}	4360.67±11 2.13^{ab}	4956.98±16 5.32^{a}	4791.11±22 6.83^{ab}	3000.33±16 2.18^{cd}	3250.84±25 5.35^{c}	4551.21±18 2.86^{ab}
TDAC	*8714.80±250.49^{a}*	*1054 2.71±240.56^{a}*	*8153.62±300.37^{a}*	*8295.57±248.27^{a}*	*1006 2.48±210.85^{a}*	*10974.94±371.48^{a}*	*12694.82±398.37^{bc}*	*10647.89±458.76^{e}*	*13421.90±637.81^{ab}*	*11950 .01±502.85^{cd}*	*13960 .39±411.15^{a}*	*12816 .17±628.75^{b} c*	*7718.79±327.27^{f}*	*12515 .29±428.63 de*	*11998 .11±463.37^{c} d*
caffieic acid	10.85±0.36^{a}	9.11±0.33^{b}	3.92±0.55^{c}	-	10.71±0.32^{a}	-	-	4.29±0.11^{f}	23.03±0.98^{a}	7.43±0.26^{e}	11.39±0.28^{c}	13.50±0.09^{b}	13.40±0.36^{b}	4.70±0.12^{f}	9.92±0.81^{d}
TPAC	*1180 3.25±281.19^{ab}*	*1429 0.22±281.01^{a}*	*1070 9.58±328.27^{b}*	*1083 2.53±260.99^{b}*	*1399 2.84±241.33^{ab}*	*15327.22±430.98^{ab}*	*17880.71±41 1.82^{c}*	*14948.80±583.67^{e}*	*20847.76±762.17^{a}*	*16163 .18±598.17^{de}*	*19391 .07±512.28^{b}*	*18350 .97±703.84^{b} c*	*10405 .31±356.83^{f}*	*17322 .21±501.25 de*	*17029 .06±581.25^{c} d*
hyperoside	655.32±25.11^{c}	739.11±30.64^{b}	613.70±40.48^{c}	628.19±12.36^{c}	813.68±20.66^{a}	666.99±10.38^{c}	919.83±38.19^{ab}	875.45±58.91^{bce}	994.81±67.73^{a}	865.66±33.83^{bce}	797.63±68. 39^{e}	919.97±57. 38^{abc}	708.80±46. 86 f	860.22±50. 09^{bce}	875.19±58. 96^{bce}
luteoloside	1135.19±40.14^{d}	1335.69±42.11^{c}	1524.16±6 5.83^{a}	1476.67±4 5.21^{a} b	1407.85±5 0.74^{bc}	1369.87±20.18^{c}	1939.73±60.81^{b}	1878.94±97.95^{bc}	2331.10±96.06^{a}	1775.10±72. 81^{bcd}	1711.19±87 .27^{cd}	1881.30±99 .96^{b}	1614.81±11 8.19^{d}	1923.38±14 8.71^{b}	2416.07±99 .26^{a}
apigenin-7-*O*-glucoside	1293.56±30.85^{bc}	1264.53±49.76^{b} c	1302.82±89.27^{b}	1593.54±40.16^{a}	1211.42±30.34^{c}	1234.12±31.73^{c}	2651.70±56.38^{cd}	2461.46±162.84^{def}	1553.48±98.98^{h}	2493.06±83. 87^{cf}	2143.65±48 .78^{g}	2522.15±13 8.39^{cde}	2905.07±57 .81^{b}	2662.34±18 7.29^{c}	3539.55±16 3.83^{a}
linarin	2057.88±87.21^{c}	1955.80±59.75^{c}	1647.05±61.85^{d}	2194.81±39.11^{b}	2605.87±87.83^{a}	1675.81±20.11^{d}	2816.67±67.38^{cd}	2623.92±162.18^{def}	3470.66±207.48^{ab}	2795.03±15 6.27^{ce}	3239.20±18 7.53^{b}	3573.51±16 5.78^{a}	2518.28±89 .96^{f}	2726.28±12 7.28^{cf}	2898.40±12 0.53^{c}
luteolin	200.10±8.86^{cd}	238.37±9.28^{a}	191.73±3.59^{d}	219.25±4.19^{b}	247.09±15.22^{a}	207.07±4.76^{b} c	40.11±1.99^{e}	52.47±1.08^{c}	70.68±2.83^{a}	55.18±1.87^{b}	46.99±0.99^{d}	24.08±0.57^{f}	41.32±1.28^{e}	51.55±0.98^{c}	53.15±2.55^{b} c

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apigenin	63.36 ±1.87 b	-	-	36.44 ±0.54 c	73.87 ±2.27 a	-	-	94.36± 2.76^{a}	43.29± 0.27^{b}	8.90±0 .26 ^{e}	17.83 ±1.01^{d}	10.67 ±0.72^{e}	23.88 ±0.92^{c}	-	9.65± 0.39^{e}
acacetin	4.67± 0.13^{c}	-	13.87 ±0.40 b	3.9±0 .10^{c}	15.07 ±0.41 b	29.48± 0.67^{a}	-	-	-	-	-	-	-	--	-
TFC	*5410. 06±9 8.37^{bc}*	*5533. 50±2 5.87^{b}*	*5293. 33±7 8.28b c*	*6152. 90±5 0.38^{a}*	*6374. 85±6 3.19^{a}*	*5183.3 5±50.6 7^{c}*	*8368.0 4±98.2 5^{bc}*	*7986.6 0±212. 38 ^{c}*	*8464.0 1±198. 26^{bc}*	*7992. 93±17 8.84^{c}*	*7956. 49±22 3.17^{c}*	*8931. 68±25 6.27 ^{b}*	*7812. 16±17 2.38^{c}*	*8223. 77±16 7.83^{c}*	*9792. 01±18 7.22 ^{a}*
TKPC	*8155. 68±3 21.12 c*	*9880. 04±4 38.21 ab*	*7674. 15±3 81.37 c*	*7766. 35±3 91.5^{c}*	*9394. 06±4 11.82 b*	*10183. 92±50 1.02^{a}*	*11745. 82±42 1.72^{cd}*	*9973.1 2±472. 46 ^{e}*	*13144. 12±65 2.89^{a}*	*11071 .71±54 1.23^{d}*	*12730 .64±3 28.48^{a} b*	*12128 .27±3 31.34^{b} c*	*7591. 50±19 8.62^{f}*	*11657 .58±3 48.80^{c} d*	*11653 .63±3 51.28^{c} d*

Data are the mean ± standard deviation of triplicate tests. "-" represents 'not detected'. Different letters in each raw indicate significant difference of 'Duoju' or 'Taiju' at a significant level of 0.05. TMAC: total mono-caffeoylquinic acid contents, TDAC: total di-caffeoylquinic acid contents, TPAC: total phenolic acid contents, TFC: total flavonoid contents; TKPC: three key phenolic components contents

'Duoju' samples, whereas the contents of lutolin in all 'Taiju' were less than all 'Duoju' samples (**Table 1**). 'TJ3' and 'TJ1' showed the highest hyperoside content (994.81 μg/g DW and 919.83 μg/g DW) and 'TJ3' also showed significant higher luteolin content than other 'Taiju' ($P < 0.05$). 'TJ9' contained the highest content of luteoloside and apigenin-7-*O*-glucoside (2416.07 μg/g DW and 3539.55 μg/g DW), whereas the highest content of linarin was found in 'TJ6' (3573.51 μg/g DW) and 'TJ3' (3470.66 μg/g DW). It should be noted that apigenin was only present in 3 out of 6 'Duoju' samples and 7 out of 9 'Taiju' samples. All 'Taiju' did not contain acacetin, which was only found in 'Duoju', and 'DJ6' possessed the highest content (29.48 μg/g DW).

It has been reported that 5-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid and luteoloside were the most crucial phenolic components in chrysanthemum that influence the antioxidant and medicinal properties [7,13]. Therefore, it is important to compare the total content of these three key phenolic components (TKPC). Among these 15 'Hangbaiju' samples, the TKPC was ranged from 7591.50 μg/g DW to 13144.12 μg/g DW. In the 'Duoju' samples, 'DJ6' and 'DJ2' contained the highest TKPC. It was observed that 7 'Taiju' samples (TJ1, TJ3, TJ4, TJ5, TJ6, TJ8, TJ9) had higher TKPC than any of the

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'Duoju' samples. It should be noticed that 'TJ3' and 'TJ5' had similar TKPC value and were significantly higher than the other 'Taiju' samples ($P < 0.05$).

3.2. Antioxidant Activity

Table 2. Antioxidant activities in different 'Duoju' and 'Taiju'.

Antioxidant Capacity	Duoju						Taiju								
	DJ1	DJ2	DJ3	DJ4	DJ5	DJ6	TJ1	TJ2	TJ3	TJ4	TJ5	TJ6	TJ7	TJ8	TJ9
DPPH*	2.47±0.05^{c}	1.75±0.04^{f}	3.04±0.08^{a}	2.68±0.03^{b}	2.10±0.08^{e}	2.23±0.04^{d}	1.74±0.06^{e}	2.13±0.06^{b}	2.05±0.10^{bc}	1.70±0.7^{e}	1.93±0.10^{cd}	1.69±0.04^{e}	2.56±0.20^{a}	1.78±0.07^{de}	1.97±0.09^{bc}
ABTS*	2.77±0.06^{ab}	2.30±0.05^{d}	2.83±0.04^{a}	2.71±0.03^{b}	2.13±0.06^{c}	2.39±0.03^{e}	1.84±0.07^{de}	2.09±0.06^{b}	1.94±0.10^{cd}	1.82±0.03^{ef}	1.88±0.08^{cde}	1.91±0.04^{c}^{de}	2.42±0.06^{a}	1.88±0.07^{cde}	1.98±0.08^{bc}
FRAP*	222.28±4.10^{d}	247.73±8.45^{b}	236.82±3.19^{c}	255.00±8.20^{b}	266.82±4.16^{a}	273.64±7.10^{a}	387.73±3.28^{b}	390.15±2.78^{b}	362.87±8.45^{cd}	362.88±9.72^{cd}	352.88±1.89^{d}	368.94±4.30^{c}	320.15±4.58^{e}	436.51±5.91^{a}	318.93±8.25^{e}

Data are the mean ± standard deviation of triplicate tests. *: The unit of IC_{50} in ABTS and DPPH assays is mg/mL, whereas the unit for FRAP analysis is mg TEAC/g DW. Different letters in each raw indicate significant difference of 'Duoju' or 'Taiju'at a significant level of 0.05.

Table 2 shows the antioxidant activity of these 'Hangbaiju' samples. In the DPPH assay, antioxidants are worked as hydrogen donors to react with DPPH stable free radical that causes discoloration [21,22]. The IC_{50} of DPPH of these samples was ranged from 1.69 mg/L to 3.04 mg/L. 'DJ2' exhibited the highest DPPH scavenging activity among the 'Duoju' ($P < 0.05$) samples, whereas 'TJ6', 'TJ1' and 'TJ8' had the strongest DPPH scavenging capacity among 'Taiju' samples. In the ABTS assay, the stable colored ABTS radicals are interacted with antioxidants and results in color loss [15, 22]. In the present study, the 'Duoju' samples had the ABTS quenching IC_{50} value of 2.13 mg/mL to 2.83 mg/mL, and between 1.82 mg/mL to 2.42 mg/mL for 'Taiju samples'. The highest ABTS quenching activity of 'Taiju' sampls was found in 'TJ4', whereas 'TJ1', 'TJ5', 'TJ6' and 'TJ8' possessed similar ABTS radicals scavenging capacity. FRAP assay is used to estimate the antioxidant activity of a compound through its capacity of reducing ferric ion into ferrous iron [15]. In this study, the 'Hangbaiju' samples had the FRAP value of 222.28 to 436.51 mg TEAC/g DW, and generally 'Taiju'

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224 samples exhibited higher reduction capacity than ‘Duoju’ samples. Among ‘Duoju’ sampels, ‘DJ1’ and
225 ‘DJ6’ had the highest and lowest FRAP reduction capacity respectively. The highest FRAP reduction
226 ability among ‘Taiju’ was ‘TJ8’ (436.51 mg TEAC/g DW), and ‘TJ9’ and the ‘TJ7’ showed the lowest
227 FRAP value.

228 It has been reported that more hydroxyl groups in the flavonoid molecular structure could enhance
229 the antioxidant capacity [23]. Additionally, the acylation of caffeoyl group could improve the
230 complexity of the caffeoylquinic acid, resulting in a stronger capacity of scavenging free radicals [24].
231 The antioxidant activities of individual phenolic compounds in these ‘Hangbaiju’ samples were also
232 evaluated (**Table 3**). Hyperoside, luteolin, 4,5-di-*O*-caffeoylquinic acid, letuoloside, 3,4-di-*O*-
233 caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid, caffeic acid, and 5-*O*-caffeoylquinic acid showed
234 similar DPPH radical scavenge capacity, but were higher than that of 4-*O*-caffeoylquinic acid, 3-*O*-
235 caffeoylquinic acid, apigenin, apigen-7-*O*-glucoside and acacetin. However, the DPPH radical
236 scavenging capacity of linarin was not detected. In terms of ABTS radical scavenging capacity, 4,5-di-
237 *O*-caffeoylquinic acid, 3,4-di-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid, luteolin, 5-*O*-
238 caffeoylquinic acid, caffeic acid, 4-*O*-caffeoylquinic acid, hyperoside and luteoloside showed similar
239 value, but their ABTS radical scavenging activity was greater than that of 3-*O*-caffeoylquinic acid,
240 apigenin, apigenin-7-*O*-glucoside, acacetin and linarin. The strongest FRAP reduction activity was
241 found to be 5-*O*-caffeoylqunic acid which was much higher than other phenolic compounds.
242 Additionally, 3,4-di-*O*-caffeoylquinic acid and 4,5-di-*O*-caffeoylquinic acid also showed great FRAP
243 reduction ability, followed by 4-*O*-caffeoylquinic acid, 3-*O*-caffeoylquinic acid, 3, 4-di-*O*-
244 caffeoylquinic acid and caffeic acid. Flavonoids used in the present study showed relatively weak FPAR
245 reduction activity, which was in the order of hyperoside > luteolin > luteoloside > apigenin > apigenin-
246 7-*O*-glucoside > acacetin > linarin.

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It has been reported that phenolic compounds play a vital role to its antioxidant activity in chrysanthemums [3]. A correlation study was conducted between the phenolic compounds and antioxidant capacities of these 'Hangbaiju' samples (**Table 4**). It was observed that phenolic compounds in both 'Duoju' and 'Taiju' exhibited a good correlation with their antioxidant activities. For example, a positive correlation was established between 5-*O*-caffeoylquinic acid, total phenolic acids and the three key phenolic components (5-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid and luteoloside) with the DPPH and ABTS quenching activity in the 'Duoju'. However, such a correlation was weak for 'Taiju'. In the FRAP assay system, mono-caffeoylquinic acids and 5-*O*-caffeoylquinic acid showed a weak correlation with the FRAP reducing capacity. This indicated that phenolic acids including 5-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid and luteoloside might be the key compounds that contributed to the antioxidant activity of these 'Hangbaiju' samples.

Table 3. Antioxidant activities of individual phenolic compounds.

Phenolic Compound	DPPH (μmol/L)	ABTS (μmol/L)	FRAP (mg TEAC/g DW)
3-*O*-caffeoylquinic acid	22.81±0.22^{de}	18.41±0.43^{d}	255.92±13.29^{de}
5-*O*-caffeoylquinic acid	17.62±0.33^{df}	10.27±0.21^{de}	366.00±21.13^{a}
4-*O*-caffeoylquinic acid	20.30±0.20^{de}	12.52±0.10^{de}	273.25±14.30^{cd}
caffeic acid	16.73±0.31^{df}	11.57±0.18^{de}	224.23±16.56^{gh}
hyperoside	8.44±0.10^{ef}	14.01±0.37^{de}	235.00±0.10^{fg}
luteoloside	9.99±0.42^{ef}	14.22±0.65^{de}	212.17±0.10^{h}
3,4-di-*O*-caffeoylquinic acid	10.43±0.33^{ef}	6.14±0.33^{e}	297.02±9.18^{b}
3,5-di-*O*-caffeoylquinic acid	10.48±0.22^{ef}	7.14±0.47^{e}	249.94±25.16^{ef}
apigenin-7-*O*-glucoside	307.44±13.10^{b}	158.24±6.22^{b}	53.87±3.89^{j}
4,5-di-*O*-caffeoylquinic acid	9.40±0.31^{ef}	5.47±0.43^{e}	279.09±15.80^{bc}
linarin	ND	256.03±10.18^{a}	6.56±0.34^{k}
luteolin	9.81±0.45^{ef}	8.06±0.50^{e}	229.93±5.87^{g}
apigenin	199.38±19.11^{c}	144.55±7.36^{c}	54.62±1.98^{j}
acacetin	706.27±35.90^{a}	254.17±16.75^{a}	51.08±1.20^{j}
Positive Control (Vitamin C)	*34.69±1.47*^{d}	*11.77±0.33*^{de}	*168.93±8.3*^{0i}

Data are the mean ± standard deviation of triplicate tests. "ND" represents 'not detected'. Different letters in each raw indicate significant difference at a significant level of 0.05.

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Table 4. Correlation between phenolic compounds and antioxidant activities in different 'Hangbaiju'.

Phenolic Compound	DPPH		ABTS		FRAP	
	Duoju	Taiju	Duoju	Taiju	Duoju	Taiju
5-*O*-caffeoylquinic acid	0.8231**	0.5808*	0.7966**	0.6304**	0.2733	0.5166*
3,5-di-*O*-caffeoylquinic acid	0.7134**	0.5761*	0.6871**	0.6147**	0.0831	0.4985*
luteoloside	0.6063**	0.5687*	0.5455*	0.6339**	0.0369	0.1208
TMAC	0.8101**	0.5279*	0.6871**	0.5704*	0.3318	0.6051**
TDAC	0.8433**	0.5917*	0.7982**	0.6599**	0.2568	0.4081*
TPAC	0.8655**	0.5886*	0.8118**	0.6480**	0.2686	0.4987*
TFC	0.7165**	0.5810*	0.6686**	0.6522**	0.0245	0.0835
TLPC	0.8761**	0.5963*	0.8224**	0.6602**	0.2139	0.4265*

'**' represents extremely significant correlation ($P < 0.01$). '*' represents significant correlation ($P < 0.05$); TMAC: total mono-caffeoylquinic acid contents, TDAC: total di-caffeoylquinic acid contents, TPAC: total phenolic acid contents, TFC: total flavonoid contents; TKPC: three key phenolic components contents

3.3. Principal Component Analysis (PCA)

PCA is commonly used to explain differentiation between samples and to obtain information on the variables that mainly influence the sample similarities and differences [25]. In order to differentiate these 'Hangbaiju', PCA was carried out using the detected phenolic compounds as variables. The first component (PC1) and second component (PC2) accounted for 72.8% and 15.3% of the total variance (**Figure 2A**). The 'Duoju' were aggregated together on the left downside of the score plot and segregated from the 'Taiju'. According to the loading plot (**Figure 2B**), apigenin-7-*O*-glucoside and 3,5-di-*O*-caffeoylquinic acid had significant differences between the 'Duoju' and the 'Taiju' samples. Meanwhile, the content of luteolin in the 'Duoju' was about 3-4 times higher than that in the 'Taiju'. Therefore, luteolin also played a vital role in segregating 'Taiju' and 'Duoju' (**Table 1**). It should be noted that acacetin was only present in some 'Duoju' but 'Taiju' contained higher content of apigenin-7-*O*-glucoside than that of 'Duoju'. Therefore, acacetin and apigenin-7-*O*-glucoside also affected the differentiation between 'Taiju' and 'Duoju' (**Table 1**).

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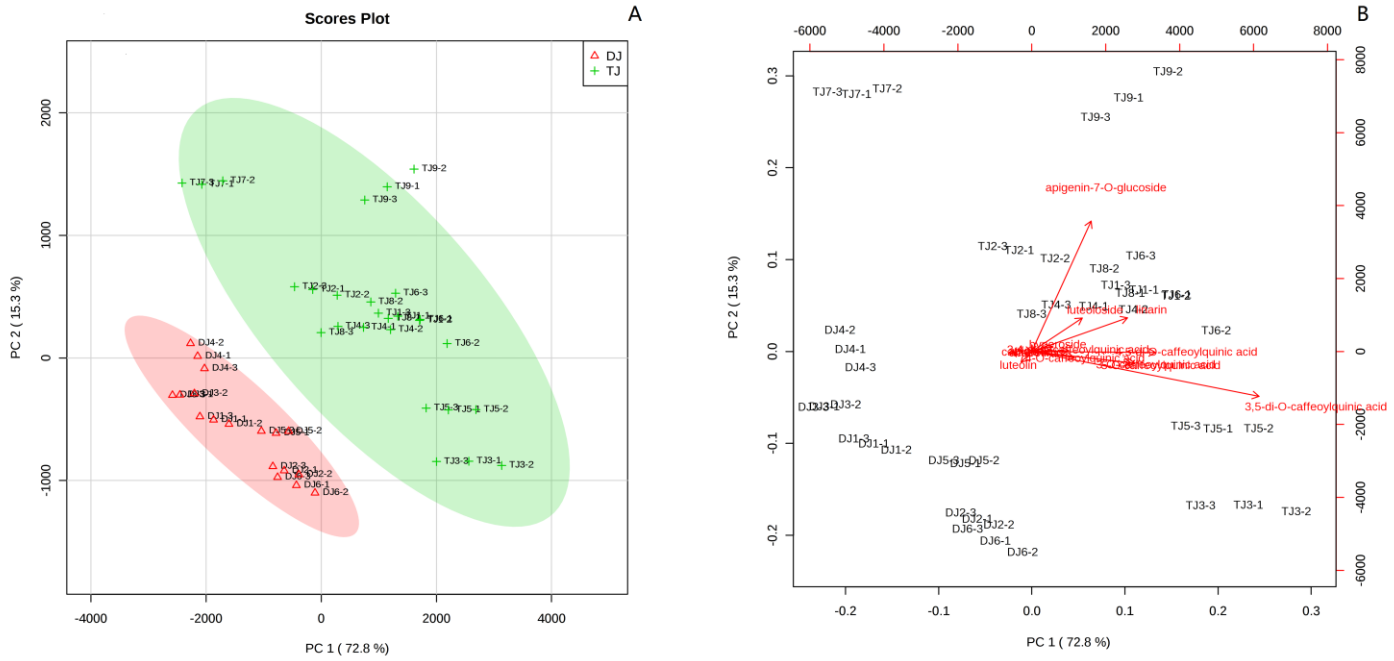

Figure 2. (A) Score plot of principal component analysis. D and T represent 'Duoju' and 'Taiju' chrysanthemum samples. (B) Loading plot of principal component analysis.

4. Disccusion

Mono-caffeoylquinic acids can be converted to each other, as well as di-caffeoylquinic acid [26-28], therefore total mono-caffeoylquinic acid contents (TMAC) and total di-caffeoylquinic acid contents (TDAC) were used rather than the content of single mono-caffeoylquinic acid or di-caffeoylquinic acid.

The flavonoid contents in chrysanthemum rised during the flowering period and then declined; the general trend was a "peak shape" degree of flower openness [3]. The "peak shape" course may relate to the key enzyme in flavonoid biosynthesis — chalcone isomerase (CHI). During early florescence, CHI activity was enhanced, and the flavonoids gradually accumulated; at the end of florescence, CHI activity was inhibited, and the flavonoids gradually decreased [6, 29].

It has been required by the Chinese Pharmacopoeia that the content of 5-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid and luteoloside in chrysanthemum should be above 0.2 g/100 g DW, 0.7 g/100 g DW and 0.08 g/100 g DW to exhibit strong antioxidant activity and medicinal property [7]. In the present study, 3 'Duoju' samples, namely 'DJ2', 'DJ5' and 'DJ6', had more than 0.2 g/100 g DW of 5-

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O-caffeoylquinic acid and more than 0.08 g/100 g DW of luteoloside. However, these 'Duoju' contained less than 0.7 g/100 g DW of 3,5-di-*O*-caffeoylquinic acid content. Therefore, these 'Duoju' were not qualified as the Chinese herb medicine according to the Chinese Pharmacopoeia. However, 'TJ1', 'TJ3', 'TJ4', 'TJ5', 'TJ6' and 'TJ8' can be claimed as Chinese herb medicine because they have met the above criteria (Table 2). It was reported that different drying methods affected the phytochemicals contents, including chlorogenic acid, luteolin-7-O-β-D-glucoside, 3,5-di-caffeoylquinic acid, apigenin-7-β-D-glucopyranoside, luteolin, acacetin-7-O-β-D-glucopyranoside, apigenin, acacetin and antioxidant properties of chrysanthemum flower heads. In this study, chlorogenic acid and 3,5-di-caffeoylquinic acid contents in some "Hangbaiju" samples were lower than threshold of 0.2 g/100g DW and 0.7 g/g DW of Chinese Pharmacopoeia, respectively. However, the level of luteolin-7-O-β-D-glucoside in all tested samples was significantly higher than the level of 0.08 g/100 g DW [13], which is consistent with our results.

Linarin (acacetin 7-O-rutinoside), luteoloside (luteolin-7-O-glucoside) and apigenin-7-O-glucoside are the glycoside of acacetin, luteolin and apigenin, respectively. Compared with apigenin, luteolin has hydroxyl at 3' position, and compared with linarin, the 4' hydroxyl of apigenin was methylated. Bobilya suggested that glycosidation and methylation of hydroxyl group results in decreased antioxidant activity of flavonoids [30]. Numerous studies have shown that the increase of hydroxyl groups in flavonoids can increase their antioxidant activity, especially the formation of o-dihydroxyl groups at 3' and 4' position [30-32]. Our study also echoes this claim. In the three antioxidant systems, luteolin showed higher antioxidant activity than apigenin, followed by acacetin, and luteoloside ahd higher antioxidant activity than apigenin-7-*O*-glucoside and linarin.

5. Conclusion

In conclusion, phenolic compounds and antioxidant capacity were analyzed and compared in 15 'Hangbaiju', including 6 'Duoju' and 9 'Taiju'. The compositions of phenolic compounds were significantly different between 'Duoju' and 'Taiju'. 'Taiju' contained higher content of caffeoylquinic acids and higher antioxidant activities than 'Duoju', suggested that the flowers harvested earlier had higher phenolic contents and antioxidant activity. Correlation study indicated that phenolic compounds, especially caffeoylquinic acids, played a vital role to the antioxidant capacity. Principal component analysis indicated that the difference on the phenolic composition could be used to differentiate 'Duoju' from 'Taiju' chrysanthemums.

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Figure Legends:

Figure 1. Chromatography of phenolic compounds of (A) standards, (B) 'DJ1' sample and (C) 'TJ4' 'sample. Peak 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 represent 3-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, caffeic acid, hyperoside, luteoloside, 3,4-di-*O*-caffeoylquinic acid, 3,5-di-*O*-caffeoylquinic acid, apigenin-7-*O*-glucoside, 4,5-di-*O*-caffeoylquinic acid, linarin, luteolin, apigenin and acacetin, respectively.

Figure 2. (A) Score plot of principal component analysis. D and T represent 'Duoju' and 'Taiju' *Chrysanthemum* samples. (B) Loading plot of principal component analysis.