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Study on nutritional characteristics and antioxidant capacity of mung bean during germination

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Abstract: In this study, 22 mung bean varieties from different producing areas in China were used as materials to provide a theoretical basis for the breeding and utilisation of special mung bean sprout varieties. Principal component analysis and cluster analysis were used to comprehensively evaluate the overall quality. Finally, 22 germinated mung bean varieties were divided into 3 edible quality grades according to their quality scores. The results showed that Lvfeng 2 and Ankang mung bean sprouts with better comprehensive characters were varieties with higher scores, which could be developed and utilised as characteristic mung bean sprouts. The content of protein, total phenol and antioxidant capacity of edible parts of Lvfeng 2 and Ankang mung bean after germination are higher than those of other varieties, so they are suitable for research and development as functional mung bean sprouts.

Keywords: sprouting; total phenolics; quality; principal component analysis

Mung bean sprouts are popular vegetables worldwide, especially in Asia. Mung bean sprouts have the characteristics of being easy to produce and not affected by season. In recent years, the physiological functions of bean sprouts and the benefits to the human body have received increasing attention. It has been reported that mung bean sprouts can reduce the antinutritional factors in mung bean seeds. Therefore, certain nutrients and functional compounds in mung bean sprouts (e.g. proteins, vitamins) will be significantly higher than those in mung bean seeds (Huang et al. 2014; Tang et al. 2014; Ebert et al. 2017). Protein is one of the key food quality factors. Germinated beans are rich in proteins and certain limiting amino acids (Bau et al. 1997; Liu et al. 2014). Vitamin C has been demonstrated to be an excellent antioxidant and found to prevent the formation of N-nitroso compounds which could cause cancer (Kaur and Kapoor 2001). Phenolics, as secondary metabolites, play a key role in plant growth and reproduction (Song et al. 2010). The flavonoids in phenols have high biological activity and are beneficial to human health, such as antitumour activity (Souček et al. 2006). Collectively, vitamin C, etc., as the key substances of bean sprouts, play an important role in the antioxidation and nutritional quality of bean sprouts.

Currently, the Chinese national crop gene bank has deposited more than 5 000 mung bean accessions (Shi et al. 2016). However, China's mung bean germplasm resources are relatively abundant, but there are few studies on the bean sprout quality of different mung bean varieties after germination. At present, the research of mung bean sprouts mainly focuses on the analysis of the changes in phenolic antioxidant capacity during the germination process, and artificial treatment is used to improve

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the nutritional value and antioxidant capacity of mung bean sprouts (Huang et al. 2014; Gan et al. 2016; Gui et al. 2018). Therefore, twenty-two mung bean varieties were selected from the major production areas in China, and the nutrient composition and antioxidant activity of mung bean after germination and their correlation were studied. By using the method of principal component analysis, we evaluated the overall quality attributes of bean sprouts. At the same time, according to the overall quality attributes, the cluster analysis method was used to classify the quality of twenty-two bean sprout varieties, and finally, the most suitable mung bean varieties for germination were screened out.

MATERIAL AND METHODS

Material. Twenty-two mung bean varieties were collected from the major production areas of China. All samples were manually selected. As shown in Table 1, source and grain colour of tested varieties.

Chemicals and reagents. Folin-Ciocalteu reagent, 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,4,6-Tri(2-pyr--idyl)-s-triazine (TPTZ), 2,6-dichloroindo-phenol (DIP) were purchased from Beijing Solarbio Science & Technology Co., Ltd. (Beijing, China). Rutin, anthrone, and salicylic acid were provided by Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Sulfuric acid, acetone and hydrochloric acid were purchased from Luoyang Haohua Chemical Reagent Co., Ltd. (Luoyang, China). Acetic acid, ethanol, aluminum nitrate, petroleum ether and gallic acid were provided by Chengdu Cologne Chemical Co., Ltd. (Chengdu, China). Sodium carbonate, copper sulfate and ferric chloride hexahydrate were provided by Guangdong Chemical Reagent Engineering Technology Research and Development Center (Guangdong, China). Sodium hydroxide and hydrogen peroxide were provided by Guangdong Guanghua Technology Co., Ltd. (Guangdong, China). All the chemicals were of the analytical grade.

Germination. Seeds (8 g) were accurately weighed (ME204 micrometer balance; Mettler Toledo Instrument Co., Ltd., Shanghai, China), and sterilised for 5 min by immersion in ethanol and then washed 3 times. The seeds were steeped in deionised water in a ratio of 1 : 10 (m/v) for 6 h under dark conditions. After pouring off the soaking water, the seeds were spread on sterile stackable trays. The trays were placed in a dark incubator at an average temperature of 25°C and were washed every 8 h using deionised water to avoid microbial growth. Each variety was performed in triplicate. Sprouted seeds were harvested after 4 days of growth.

Table 1. Source and grain colour of tested varieties

No.	Varieties	Grain colour	Source
1	Jilv 13	bright green	Shijiazhuang, Hebei
2	Jilv 7	bright green	Shijiazhuang, Hebei
3	Zhonglv 5	bright green	Zhengzhou, Henan
4	Ji 0816-3	hairy green	Shijiazhuang, Hebei
5	Huaillv 2	hairy green	Weifang, Shandong
6	lvfeng 5	bright green	Qiqihar, Heilongjiang
7	lvfeng 2	bright green	Qiqihar, Heilongjiang
8	Bailv 8	bright green	Baicheng, Jilin
9	Bailv 11	bright green	Baicheng, Jilin
10	Ankang lvdou	hairy green	Ankang, Shaanxi
11	Longbo 9	bright green	Taonan, Jilin
12	Taolv 8	bright green	Chifeng, Inner Mongolia
13	Dayinggelv lvdou	bright green	Hulanhot, Inner Mongolia
14	Yulv 1	bright green	Hengshan, Shaanxi
15	Yangyuanlv 1	bright green	Yangyuan, Hebei
16	Yangyuanlv 2	bright green	Yangyuan, Hebei
17	Xinzhou lvdou	bright green	Xinzhou, Shanxi
18	Chongqing lvdou	hairy green	Qianjiang District, Chongqing
19	Xilv 1	bright green	Yangling, Shaanxi
20	Anlv 7	bright green	Anyang, Henan
21	Shenmu lvdou	bright green	Shenmu, Shaanxi
22	Baolv 200520-2	black	Baoding, Hebei

The sprouts for each sample were divided into three parts. Part one was used to measure the water content, lengths, diameters and output ratio of bean sprouts. Part two was stored at –80 °C (DW-86L390; Haier Co., Ltd., Qingdao, China) for moisture and vitamin C measurements. Part three was freeze-dried and then stored at –20 °C until further analyses (BCD--196DTA, Haier Co., Ltd., Qingdao, China).

Growth measurement. The output ratio of mung bean sprouts was the sprout weight/seed weight. Twenty sprouts were randomly taken from one replication. The lengths and the diameters of the sprouts were measured using a ruler and a vernier calliper (D15TX; Mitutoyo, Kawasaki, Japan).

Nutrient composition analyses. The water contents of the mung bean sprouts were measured according to Wolfe and Liu (2003). Briefly, 2 g of a sprout sample were oven-dried at 102 °C to a constant weight (DGX--9243B blast drying oven; Langxuan equipment Co., Ltd., Shanghai, China). The fat was analysed by Soxhlet ex-

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traction and the solvent was petroleum ether (boiling point 60–90 °C). In order to determine the protein content, the Kjeldahl method was used to calculate the protein content (%) from the nitrogen content (N × 6.25). The total starch content was measured according to the method of Gao (2006).

Phenolics content and antioxidant capacity analyses. The extraction method was following the method developed by Nithiyanantham et al. (2012) with some modifications. In detail, 0.5 g of a sample were weighed (ME204 micrometer balance, Mettler Toledo Instrument Co., Ltd., Shanghai, China), placed into a tube filled with 5 mL of 70% acetone, and shaken in dark at 150 rpm for 3 h (2YF-161; Dongtuo Instrument Manufacturing Co., Ltd., Heilongjiang, China). The extract thus obtained was centrifuged at 4 000 rpm for 10 min (TDL-5A centrifuge; Fichar Analytical Instrument Co., Ltd., Shanghai, China) and its supernatant was removed and transferred into a new centrifuge tube. After removing of supernatant, the remaining part was extracted with 5 mL of 70% acetone. The two extracts were mixed as one extract sample and stored at –4°C (SC-350L, Haier Co., Ltd., Qingdao, China). The extraction for each variety was repeated three times.

The total phenolic contents of the sprout samples were determined according to the method of Xu and Chang (2008). In detail, 100 μL of the extract sample, 1 mL of Folin-Ciocalteu reagent and 3 mL of 10% Na_2CO_3 were added into a tube; then the distilled water was added into the tuber until it was filled to 10 mL. The mixture was kept at ambient temperature for 2 h and then its absorbance was measured at the wavelength of 765 nm (Bluestar B ultraviolet visible spectrophotometer, Leiberteco Instrument Co., Ltd., Beijing, China). A standard curve was drawn based on the absorbance of gallic acid, and the measured absorbance was calculated and expressed in terms of gallic acid equivalents per gram (mg GAE g^{-1}).

The total flavonoid contents of the samples were determined following the method of Jia et al. (1999). In detail, 1 mL of the sample extract, 4 mL of 40% ethanol, 300 μL of 5% $NaNO_2$ solution were mixed; 6 min later, the mixture thus obtained was mixed with 300 μL of 10% $Al(NO_3)_3$ solution and allowed to stand for another 6 min, and then mixed with 4 mL of 1 M NaOH until it became a homogenous mixture; its absorbance was measured at the wavelength of 510 nm. The measured absorbance was calculated and expressed in rutin equivalents (mg of RE g^{-1}).

The DPPH radical-scavenging activity was measured according to Sánchez-Moreno et al. (1998). DPPH (100 μmol L^{-1}) was dissolved in ethanol. The sample extract solution (0.2 mL) was taken and mixed with DPPH solution (3.8 mL). It was shaken for 1 min (2YF--161; Dongtuo Instrument Manufacturing Co., Ltd., Heilongjiang, China) and allowed to stand in the dark for 30 min. The mixture was marked as an A sample. Extraction solvent (0.2 mL of each) was mixed with DPPH to form a sample marked as an A control sample. The absorbances of the two samples were measured at the wavelength of 517 nm and converted to free radical scavenging rate (%).

The ferric reducing antioxidant power (FRAP) was measured according to the method of Benzie and Strain (1996). In the measurement, the FRAP working solution was prepared by mixing 3.63 mmol L^{-1} sodium acetate solution, 20 mmol L^{-1} $FeCl_3$ solution and 10 mmol L^{-1} TPTZ solution in a volumetric ratio of 10 : 1 : 1. The working solution (3 mL) was added into the test tube and after 5 min at 37 °C (DK-S26 electrothermal constant temperature water bath; Jinghong Experimental Equipment Co., Ltd., Shanghai, China), 100 μL of the sample extract and 300 μL of distilled water were added into the test tube; after reaction for 4 min, the absorbance at 593 nm measured the mixture thus obtained. Aligned with a calibration curve plotted against the absorbance of ferrous sulphate, the measured absorbance was calculated and expressed in mmol L^{-1} Fe^{2+} 100 g^{-1} dry weight (DW).

Scores of the general sprout qualities. The indices of mung bean sprouts were reduced by the principal component analysis. The new principal components thus obtained were based on eigenvalues greater than 1. According to their different load amounts and the square root of the corresponding eigenvalue, a linear combination of the different principal components was obtained. The composite scores were determined depending on their contribution rates of variance.

Statistical analysis. Data processing was performed on a triplicate basis SPSS 19.0 and all the values were expressed as the mean ± standard deviation (SD). Correlations were considered highly significant at $P < 0.01$.

RESULTS AND DISCUSSION

Lengths, diameters, and output ratio of mung bean sprouts

There were significant differences in sprout length, diameter, and output ratio of the twenty-two mung bean cultivars as shown in Table 2. The sprout lengths ranged from 6.18 cm to 8.72 cm. The sprout diameter ranged from 1.79 mm to 2.31 mm. The output ratio

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Table 2. Sprout length, diameter, and output ratio of the different cultivars (mean ± SE; n = 22)

Cultivar	Length (cm)	Diameter (mm)	Output ratio
Jilv 13	6.7 ± 0.13^{gh}	2.0 ± 0.02^{fg}	5.6 ± 0.14^{fgh}
Jilv 7	6.2 ± 0.03^{l}	2.1 ± 0.03^{def}	5.5 ± 0.16^{gh}
Zhonglv 5	6.3 ± 0.06^{jkl}	2.2 ± 0.08^{b}	4.9 ± 0.06^{j}
Ji 0816-3	6.9 ± 0.13^{g}	2.2 ± 0.01^{bc}	5.3 ± 0.09^{hi}
Huaillv 2	7.9 ± 0.08^{d}	2.2 ± 0.01^{bc}	6.1 ± 0.12^{cd}
lvfeng 5	6.6 ± 0.13^{hi}	2.1 ± 0.05^{cde}	5.5 ± 0.24^{gh}
lvfeng 2	8.0 ± 0.11^{cd}	1.9 ± 0.07^{h}	6.3 ± 0.07^{bc}
Bailv 8	7.2 ± 0.15^{f}	2.1 ± 0.05^{ef}	5.5 ± 0.06^{fgh}
Bailv 11	7.4 ± 0.08^{ef}	2.1 ± 0.09^{cd}	5.9 ± 0.16^{de}
Ankang lvdou	7.9 ± 0.09^{d}	1.9 ± 0.03^{gh}	6.4 ± 0.09^{b}
Longbo 9	8.1 ± 0.14^{bc}	2.1 ± 0.02^{cde}	6.5 ± 0.10^{b}
Taolv 8	8.0 ± 0.19^{cd}	2.3 ± 0.02^{a}	5.8 ± 0.07^{ef}
Dayinggelv lvdou	6.5 ± 0.16^{hij}	2.3 ± 0.03^{a}	5.5 ± 0.22^{gh}
Yulv 1	6.4 ± 0.16^{ijkl}	2.2 ± 0.06^{bc}	5.0 ± 0.11^{j}
Yangyuanlv 1	6.4 ± 0.12^{ijk}	2.1 ± 0.02^{def}	5.5 ± 0.20^{gh}
Yangyuanlv 2	8.3 ± 0.09^{b}	1.8 ± 0.03^{i}	6.9 ± 0.14^{a}
Xinzhou lvdou	7.6 ± 0.10^{e}	2.1 ± 0.03^{def}	5.6 ± 0.31^{fg}
Chongqing lvdou	8.7 ± 0.09^{a}	1.9 ± 0.04^{h}	7.1 ± 0.08^{a}
Xilv 1	7.2 ± 0.14^{f}	2.2 ± 0.06^{bc}	6.1 ± 0.16^{d}
Anlv 7	6.5 ± 0.14^{hij}	2.2 ± 0.05^{bc}	5.0 ± 0.09^{j}
Shenmu lvdou	7.9 ± 0.07^{d}	2.1 ± 0.01^{def}	6.0 ± 0.06^{d}
Baolv 200520-2	6.2 ± 0.05^{kl}	2.1 ± 0.01^{cde}	5.2 ± 0.08^{ij}
Mean ± SD	7.2 ± 0.78	2.1 ± 0.13	5.8 ± 0.60

$^{a-l}$Different superscript lowercase letters in the same columns mean significant differences (P < 0.05) using Duncan's multiple range test; SE – standard error; SD – standard deviation

yields of these twenty-two mung bean cultivars ranged from 4.91 to 7.06. Zhonglv 5 presented the lowest output ratio, and Chongqing lvdou presented the highest output ratio. These results were consistent with the result of Kang et al. (2011) that the hypocotyl lengths of sprouts ranged from 7.21 cm to 11.79 cm and the hypocotyl diameter ranged from 0.245 cm to 0.353 cm. Kang et al. (2014) found that the sprout output ratio of soybean was 1 : 5.12 to 1 : 6.95. However, Huang et al. (2014) found that the sprout length of mung bean was 14 cm 4 days after germination. Therefore, the sprout lengths of mung beans might be related to different sprout growth environments. In addition, the higher the output ratio, the more economic benefit was harvested. Therefore, Chongqing lvdou had a greater potential for profit than the other cultivars.

Nutrient composition

Water, total fat, protein contents, total starch, vitamin C contents. Table 3 presents the water, total fat, protein contents, total starch, and vitamin C contents of the twenty-two mung bean varieties. Water was one of the important factors that affect the tenderness, freshness, and taste of fruits and vegetables. The water content of mung bean sprouts was higher than that of seeds, and the water content of buds of different varieties was obviously different. The sprout water contents of the different cultivars in this study ranged from 85.98% to 91.61%. However, Guo et al. (2012) reported that the water content of mung bean sprout was 89.22% and reached a maximum of 6 days after germination. In their study, the sprouts were rinsed with running water every 12 h instead of every 8 h. The different rinsing frequency probably contributed to the great difference in sprout water content between the previous results and the result of this study.

In this study, the total fat content of mung bean sprouts of twenty-two varieties ranged from 0.55% to 1.26%. Among them, the fat content of Ji 0816-3 after germination was the lowest, while the total fat con-

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Table 3. Sprout water contents, fat, protein and starch totals and vitamin C contents of the different mung bean varieties (mean ± SE; n = 22)

Cultivar	Water content	Total fat	Protein	Total starch	Vitamin C
	(%)				(mg 100 g^{-1} FW)
Jilv 13	87.58 ± 0.95^{efg}	1.21 ± 0.06^{ab}	30.07 ± 0.11^{fg}	38.67 ± 2.06^{de}	11.30 ± 0.28^{efg}
Jilv 7	85.98 ± 0.54^{h}	0.94 ± 0.02^{d}	28.87 ± 0.33^{i}	40.20 ± 1.05^{cd}	12.05 ± 0.28^{de}
Zhonglv 5	86.81 ± 0.77^{gh}	0.65 ± 0.02^{hi}	31.12 ± 0.15^{c}	45.79 ± 0.93^{a}	12.45 ± 0.46^{cd}
Ji 0816-3	87.75 ± 0.63^{def}g	0.55 ± 0.04^{j}	29.81 ± 0.11^{gh}	45.02 ± 0.28^{a}	14.00 ± 0.50^{b}
Huaillv 2	89.63 ± 0.79^{b}	0.84 ± 0.05^{f}	28.67 ± 0.05^{ij}	35.63 ± 0.46^{gh}	11.79 ± 0.20^{def}
lvfeng 5	88.80 ± 0.27^{bcdef}	1.10 ± 0.04^{c}	27.75 ± 0.23^{k}	45.16 ± 0.91^{a}	13.14 ± 0.35^{c}
lvfeng 2	87.56 ± 0.68^{fg}	1.15 ± 0.06^{bc}	33.64 ± 0.36^{a}	34.66 ± 0.81^{h}	14.75 ± 0.57^{a}
Bailv 8	91.61 ± 1.80^{a}	0.89 ± 0.03^{def}	31.25 ± 0.06^{c}	45.16 ± 1.37^{a}	10.10 ± 0.22^{hij}
Bailv 11	88.61 ± 0.44^{bcdef}	0.83 ± 0.02^{f}	30.17 ± 0.27^{ef}	34.98 ± 0.83^{h}	10.13 ± 0.36^{hij}
Ankang lvdou	88.99 ± 0.78^{bcde}	0.85 ± 0.03^{f}	33.54 ± 0.13^{a}	31.46 ± 0.53^{i}	11.80 ± 0.46^{def}
Longbo 9	89.47 ± 0.55^{bc}	0.59 ± 0.04^{ij}	30.71 ± 0.05^{d}	37.80 ± 1.69^{ef}	11.30 ± 0.31^{efg}
Taolv 8	89.07 ± 0.38^{bcd}	0.89 ± 0.04^{def}	31.11 ± 0.31^{c}	39.40 ± 1.68^{de}	14.59 ± 0.72^{ab}
Dayinggelv lvdou	87.54 ± 0.36^{fg}	0.96 ± 0.03^{d}	29.71 ± 0.13^{h}	37.53 ± 0.55^{efg}	9.98 ± 0.30^{ij}
Yulv 1	87.85 ± 0.96^{defg}	1.26 ± 0.03^{a}	29.56 ± 0.19^{h}	30.95 ± 0.80^{i}	11.27 ± 0.42^{efg}
Yangyuanlv 1	88.10 ± 0.82^{cdefg}	0.66 ± 0.04^{h}	28.41 ± 0.14^{j}	42.42 ± 1.13^{b}	11.58 ± 0.44^{efg}
Yangyuanlv 2	90.91 ± 0.20^{a}	0.92 ± 0.03^{de}	28.93 ± 0.09^{i}	36.00 ± 0.35^{fgh}	11.10 ± 0.36^{fg}
Xinzhou lvdou	87.79 ± 0.42^{defg}	0.68 ± 0.03^{gh}	28.81 ± 0.35^{i}	42.03 ± 1.55^{bc}	10.82 ± 0.72^{gh}
Chongqing lvdou	89.54 ± 0.47^{b}	1.09 ± 0.04^{c}	32.13 ± 0.24^{b}	29.94 ± 0.95^{i}	10.34 ± 0.26^{hi}
Xilv 1	88.01 ± 0.87^{defg}	1.16 ± 0.04^{bc}	30.11 ± 0.13^{efg}	38.93 ± 1.12^{de}	11.67 ± 0.37^{def}
Anlv 7	88.02 ± 0.25^{defg}	0.73 ± 0.03^{g}	30.19 ± 0.09^{ef}	37.48 ± 0.47^{efg}	10.06 ± 0.45^{hij}
Shenmu lvdou	89.07 ± 0.66^{bcd}	0.87 ± 0.01^{ef}	29.66 ± 0.07^{h}	37.56 ± 0.91^{efg}	11.84 ± 0.40^{def}
Baolv 200520-2	88.26 ± 0.63^{bcdef}	0.59 ± 0.06^{ij}	30.44 ± 0.06^{de}	41.50 ± 1.01^{bc}	9.43 ± 0.39^{j}
Mean ± SD	88.50 ± 1.38	0.88 ± 0.21	30.21 ± 1.49	38.56 ± 4.64	11.61 ± 1.48

$^{a-k}$Different superscript lowercase letters in the same columns mean significant differences (P < 0.05) using Duncan's multiple range test; SE – standard error; SD – standard deviation; FW – fresh weight

tent of Yulv 1 after germination was the highest, almost 2.29 times that of Ji 0816-3. Mubarak (2005) reported that the fat content of germinated mung bean seeds was 1.45 g 100 g^{-1} on a dry weight, which is consistent with the research results.

There are significant differences in the content of mung bean sprouts protein of these twenty-two varieties, ranging from 27.75% to 33.64%. Ebert et al. (2017) reported that mung bean sprouts had lower protein contents ranging from 3.38 g 100 g^{-1} to 5.19 g 100 g^{-1} fresh weight (FW). which was inconsistent with the results of this study. The reason for this may be that the measurement methods in the two studies are different. In the previous study, the sprout protein contents were expressed in a FW basis. Whereas, the sprout protein contents were expressed in a dry weight basis in the study. Mung beans of different cultivars, especially Lvfeng 2, had higher sprout protein content and thus their sprouts could be a good source of protein.

The average total starch content in these mung bean sprouts was 38.56%. Zhonglv 5 has the highest total starch content of 45.79% among the studied mung bean sprouts. The difference in sprout starch content was probably caused by different mung bean varieties. Therefore, Zhonglv 5 could be considered for bread and pasta production.

The average content of vitamin C in mung bean sprouts at the germination stage was 2.7% higher than that in mature mung beans (Ebert et al. 2017). The average vitamin C content of the sprouts of the twenty-two mung bean varieties was 11.61 mg 100 g^{-1} FW. There were significant differences in vitamin C contents among these mung bean sprouts. Moreover, Lvfeng 2 had the highest sprout vitamin C contents and could be a good source of vitamin C.

Phenolics content and antioxidant capacity of the mung bean sprouts. Table 4 presents the total phenolic and antioxidant activities of the twenty-two mung bean

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Table 4. Total phenolic and flavonoid and antioxidant activities in sprouts of the twenty-two mung bean cultivar (mean ± SE; n = 22)

Cultivar	Total phenolic (mg GAE g^{-1})	Total flavonoid (mg g^{-1})	DPPH (%)	FRAP (mmol Fe^{2+} 100 g^{-1})
Jilv 13	2.40 ± 0.06^{bc}	1.45 ± 0.11^{g}	28.91 ± 0.76^{fgh}	1.36 ± 0.07^{efg}
Jilv 7	2.42 ± 0.06^{bc}	1.59 ± 0.03^{efg}	28.78 ± 1.23^{gh}	1.38 ± 0.03^{def}
Zhonglv 5	2.03 ± 0.06^{efg}	1.72 ± 0.10^{de}	34.5 ± 0.99^{d}	1.36 ± 0.04^{efg}
Ji 0816-3	2.21 ± 0.09^{de}	1.76 ± 0.12^{d}	37.51 ± 1.75^{c}	1.30 ± 0.14^{efg}
Huaillv 2	2.53 ± 0.07^{ab}	1.81 ± 0.08^{d}	30.24 ± 0.95^{efgh}	1.50 ± 0.04^{cd}
lvfeng 5	1.67 ± 0.04^{h}	1.13 ± 0.09^{hi}	24.79 ± 0.59^{ij}	1.06 ± 0.06^{j}
lvfeng 2	2.63 ± 0.06^{a}	2.46 ± 0.05^{a}	47.00 ± 0.63^{a}	1.84 ± 0.06^{a}
Bailv 8	1.68 ± 0.07^{h}	1.18 ± 0.11^{hi}	25.68 ± 0.63^{ij}	1.15 ± 0.04^{hij}
Bailv 11	2.54 ± 0.06^{ab}	1.98 ± 0.12^{c}	34.45 ± 1.44^{d}	1.53 ± 0.14^{c}
Ankang lvdou	2.64 ± 0.12^{a}	2.31 ± 0.08^{b}	42.64 ± 0.59^{b}	1.67 ± 0.07^{b}
Longbo 9	2.06 ± 0.07^{ef}	1.82 ± 0.02^{d}	28.20 ± 1.46^{h}	1.36 ± 0.09^{efg}
Taolv 8	1.95 ± 0.09^{fg}	1.47 ± 0.05^{fg}	24.96 ± 0.34^{ij}	1.14 ± 0.06^{ij}
Dayinggelv lvdou	1.86 ± 0.11^{g}	1.24 ± 0.08^{h}	24.54 ± 1.03^{ij}	1.22 ± 0.04^{ghi}
Yulv 1	1.54 ± 0.17^{h}	1.13 ± 0.07^{hi}	25.76 ± 1.54^{ij}	1.29 ± 0.09^{fg}
Yangyuanlv 1	1.68 ± 0.13^{h}	1.06 ± 0.06^{j}	23.83 ± 1.79^{j}	0.90 ± 0.05^{k}
Yangyuanlv 2	2.59 ± 0.06^{ab}	1.61 ± 0.08^{ef}	30.88 ± 0.72^{efg}	1.43 ± 0.08^{cde}
Xinzhou lvdou	1.98 ± 0.09^{fg}	1.61 ± 0.05^{ef}	31.14 ± 0.78^{e}	1.34 ± 0.04^{efg}
Chongqing lvdou	2.33 ± 0.16^{cd}	1.70 ± 0.05^{de}	28.94 ± 1.55^{fgh}	1.28 ± 0.03^{fgh}
Xilv 1	2.20 ± 0.16^{de}	2.05 ± 0.15^{c}	37.09 ± 2.28^{c}	1.53 ± 0.06^{c}
Anlv 7	2.31 ± 0.12^{cd}	1.84 ± 0.08^{d}	31.01 ± 0.69^{ef}	1.50 ± 0.08^{cd}
Shenmu lvdou	1.95 ± 0.12^{fg}	1.85 ± 0.06^{d}	36.39 ± 0.30^{cd}	1.52 ± 0.1^{c}
Baolv 200520-2	2.27 ± 0.13^{cd}	1.26 ± 0.04^{h}	26.09 ± 1.19^{i}	1.23 ± 0.08^{ghi}
Mean ± SD	2.16 ± 0.34	1.64 ± 0.38	31.06 ± 6.13	1.36 ± 0.21

[a–k]Different superscript lowercase letters in the same columns mean significant differences (P < 0.05) using Duncan's multiple range test; SE – standard error; SD – standard deviation; GAE – gallic acid equivalents; DPPH – 1,1-diphenyl--2-picrylhydrazyl; FRAP – ferric reducing antioxidant power

varieties. Studies have shown that beans were a rich source of antioxidants (Xu and Chang 2007) and a large number of phenolics are synthesised after germination of legumes (Dueñas et al. 2015). The study of Cevallos--Casals and Cisneros-Zevallos (2010) showed that on the day 7 after the germination of mung bean seeds, the total phenol accumulation in bean sprouts reached 95%. Therefore, mung bean sprouts were the most abundant seed vegetables with the highest phenolic contents. In this study, the total phenol content in the mung bean sprouts of twenty-two varieties was significantly different. Ankang lvdou has the highest total phenolic content in sprouts, which is 2.64 mg GAE g^{-1}. Yulv 1 has the lowest total phenolics content of the sprouts, which was 1.54 mg GAE g^{-1}. Therefore, Ankang lvdou can be processed as a functional mung bean with antioxidant capacity.

Studies proved higher flavonoid content in germinated mung bean sprouts, almost three times higher total flavonoid content in the sprouts than in the seeds (Kim et al. 2013), and better application values. The average total flavonoid content of sprouts of the twenty-two mung bean varieties in this study was 1.64 mg RE g^{-1} FW. Xue et al. (2016) found that the sprouts of the mung bean had the fastest growth rate on the day 3 of germination and reached the highest value of 5.58 mg RE g^{-1} FW on the germination day 5. The huge difference between this study and the previous study in the total flavonoid content of sprouts may be due to the different extraction methods of these two studies.

DPPH and FRAP were used to evaluate the antioxidant activity of different mung bean sprouts. DPPH was widely accepted as one of the indicators of anti-

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oxidant activity in plant extracts. In this study, the sprouts of Yangyuanlv 1 had the lowest DPPH radical scavenging capacity of 23.82%, and Lvfeng 2 had the highest DPPH radical scavenging capacity of 47.00%. Therefore, Lvfeng 2 mung bean sprouts had a high antioxidant capacity.

The mung bean varieties had significant influences on the FRAP of bean sprouts. The FRAP of sprouts ranged from 0.90 mmol Fe^{2+} 100^{-1} g to 1.84 mmol Fe^{2+} 100 g^{-1}, with an average of 1.36 mmol Fe^{2+} 100 g^{-1}. Lvfeng 2 had the highest FRAP among the twenty-two mung bean varieties. Pająk et al. (2014) reported that the FRAP of mung bean sprouts was 1.20 mmol Fe^{2+} 100^{-1} g, and the result was consistent with this study.

Correlation analyses of the overall quality indexes of mung bean sprout

The correlations of the overall quality indexes were shown in Figure 1. In the sprouts of different mung bean varieties, the lengths were significantly negatively related to the widths and total starch but positively correlated with the output ratio, water content, and total flavonoid. The width of mung bean sprouts was significantly negatively related to the output ratio (R^2 = –0.621, P < 0.01) and total phenolic (R^2 = –0.465, P < 0.05). The output ratio was positively correlated with moisture, total phenolic, and total flavonoid, and significantly negatively related to total starch (R^2 = –0.566, P < 0.01). The content of total fat was significantly negatively related to total starch. The protein contents were positively correlated with total flavonoid, DPPH, and FRAP. The content of total starch was significantly negatively related to total phenolic and FRAP. Total phenolics of mung bean sprouts were highly correlated to the total flavonoid contents, DPPH, and FRAP. Total flavonoid contents of mung bean sprouts were also highly correlated to the contents of DPPH and FRAP. DPPH of mung bean sprouts was also highly correlated to the FRAP. Shi et al. (2016) and Xue et al. (2016) demonstrated high-level correlations among total phenolic and total flavonoid and their antioxidant capacities, a result which was consistent with the result in this current study.

The score of the overall quality of the mung bean sprouts and the cluster analysis

By the principal component analysis, the original indicators were replaced by four new principal components, of which each had different loadings on the four principal components (Table 5). According to the different load amounts and the square root of corresponding eigenvalues for each principal component,

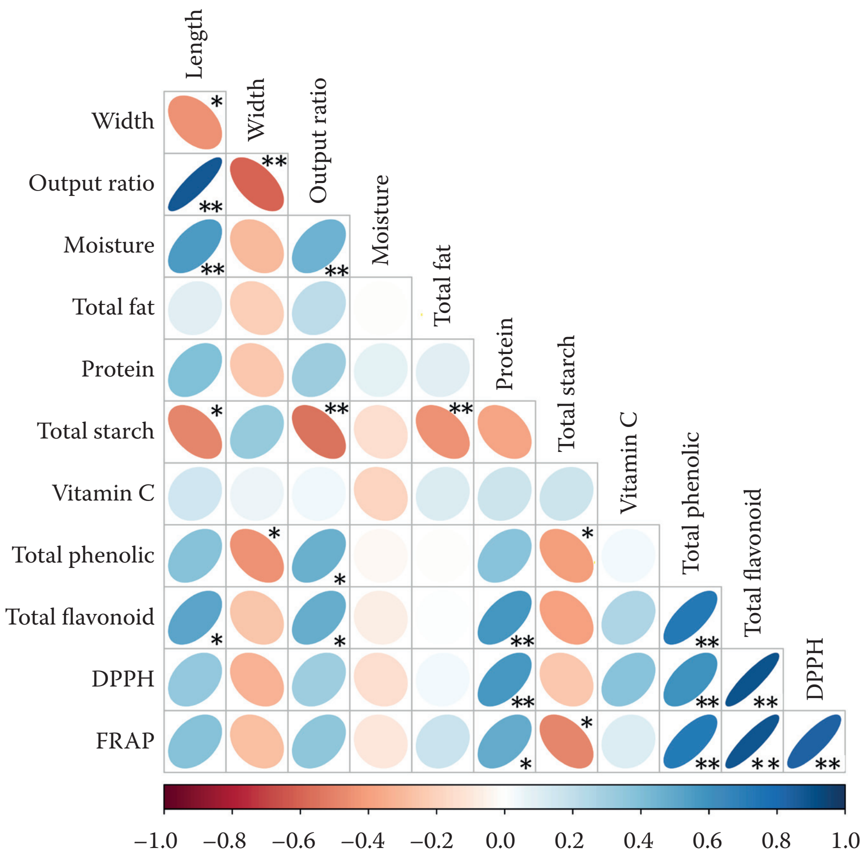

Figure 1. Correlation analysis of the overall quality indexes of mung bean sprout

*, **Significantly different at P < 0.05 and P < 0.01, respectively (2-tailed test); DPPH – 1,1-diphenyl-2-picrylhydrazyl; FRAP – ferric reducing antioxidant power

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Table 5. Loadings, eigenvalue and variance contribution of mung bean sprouts overall quality on each principal

Quality index	PC1	PC2	PC3	PC4
Length	0.742	–0.485	0.267	0.235
Diameter	–0.589	0.393	0.051	0.074
Percentage yield	0.757	–0.534	0.099	0.120
Water content	0.204	–0.803	0.361	0.072
Total fat	0.224	–0.182	–0.824	0.398
Protein	0.657	0.147	0.031	0.068
Total starch	–0.644	0.280	0.520	0.150
Vitamin C	0.192	0.430	0.170	0.821
Total phenolic	0.774	0.181	0.039	–0.353
Total flavonoid	0.879	0.393	0.142	–0.054
DPPH	0.789	0.510	0.115	0.048
FRAP	0.846	0.370	–0.113	–0.175
Eigenvalue	5.158	2.222	1.242	1.100
Variance contribution	0.430	0.185	0.103	0.092

PC – principal component; DPPH – 1,1-diphenyl-2-picrylhydrazyl; FRAP – ferric reducing antioxidant power

the linear combination of four principal components could be obtained.

$$F_1 = 0.327X_1 - 0.259X_2 + 0.334X_3 + 0.090X_4 + 0.098X_5 + 0.289X_6 - 0.284X_7 + 0.085X_8 + 0.341X_9 + 0.387X_{10} + 0.347X_{11} + 0.372X_{12};$$

$$F_2 = -0.325X_1 + 0.264X_2 - 0.358X_3 - 0.539X_4 - 0.122X_5 + 0.099X_6 + 0.188X_7 + 0.288X_8 + 0.122X_9 + 0.264X_{10} + 0.342X_{11} + 0.248X_{12};$$

$$F_3 = 0.240X_1 + 0.046X_2 + 0.089X_3 + 0.324X_4 - 0.740X_5 + 0.027X_6 + 0.467X_7 + 0.153X_8 + 0.035X_9 + 0.127X_{10} + 0.103X_{11} - 0.101X_{12};$$

$$F_4 = 0.224X_1 + 0.070X_2 + 0.115X_3 + 0.069X_4 - 0.380X_5 + 0.065X_6 + 0.143X_7 + 0.783X_8 - 0.336X_9 - 0.051X_{10} + 0.046X_{11} - 0.167X_{12}.$$

The normalised vectors X_1–X_{12} were specified as the length, diameter, output ratio, water content, total fat, protein, total starch, vitamin C, total phenolic, total flavonoid, DPPH, FRAP. The composite score of sprouts of different varieties was weighted according to the contribution rate of variance of each principal component. The linear combination of composite score was $F = 0.430F_1 + 0.185F_2 + 0.103F_3 + 0.092F_4$. The scores of the overall quality of the mung bean sprouts were presented in Table 6. The overall quality of mung bean sprouts can be ranked in terms of the scores. Lvfeng 2 has the best quality because of its overall quality score. Based on the overall quality scores, the cluster analyses method was used to classify twenty-two varieties of mung bean sprouts into three grades. Lvfeng 2 and Ankang lvdou with relatively good comprehensive characters were high-scoring varieties and clustered into the same class (Figure 2).

Table 6. The scores and rankings of the overall qualities of the sprouts of the different mung bean varieties

Cultivar	Score	Rank
Jilv 13	–0.238	14
Jilv 7	–0.244	15
Zhonglv 5	–0.012	11
Ji 0816-3	0.387	8
Huaillv 2	0.356	9
lvfeng 5	–1.275	21
lvfeng 2	2.716	1
Bailv 8	–1.042	18
Bailv 11	0.505	5
Ankang lvdou	1.951	2
Longbo 9	0.245	10
Taolv 8	–0.135	13
Dayinggelv lvdou	–1.205	20
Yulv 1	–1.187	19
Yangyuanlv 1	–1.552	22
Yangyuanlv 2	0.472	7
Xinzhou lvdou	–0.289	16
Chongqing lvdou	0.532	4
Xilv 1	0.622	3
Anlv 7	–0.127	12
Shenmu lvdou	0.498	6
Baolv 200520-2	–0.977	17

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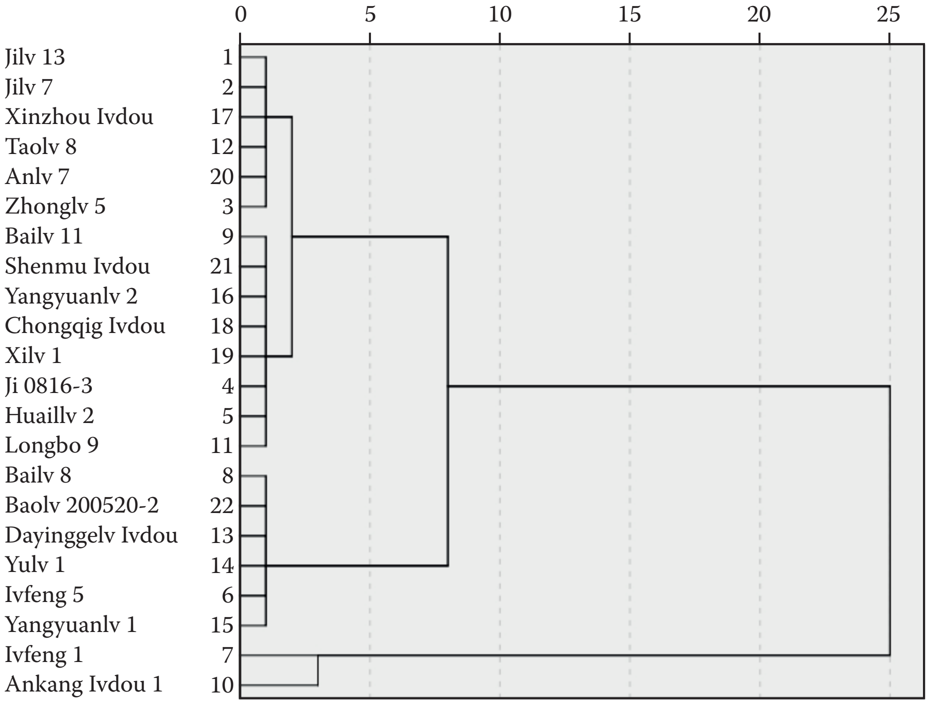

Figure 2. Clustering analysis of the overall quality of mung bean sprout

CONCLUSION

The comparison of sprouts from different sources is very important. This study found that there are differences in nutrients and antioxidant activity between different varieties of mung bean after germination. In addition, the protein, vitamin C content and antioxidant capacity of mung beans are significantly improved after germination. Through the cluster analysis of the overall quality of mung bean sprouts, different mung bean sprouts can be divided into three grades. Chongqing mung bean has greater profit potential than other varieties. In addition, the total flavonoids, FRAP and DPPH free radical scavenging rates of Lvfeng 2 and Ankang mung bean sprouts are significantly higher than other varieties, and their comprehensive quality scores are relatively high. Therefore, they can become sprouted mung bean varieties. These findings provide valuable information for the development of functional bean sprouts, and at the same time provide help for evaluating the overall quality of Chinese mung bean sprouts.

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