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ANALYSIS OF QUALITY CHARACTERISTICS OF LOCAL LINE PEPPER (*CAPSICUM ANNUUM)* IN DIFFERENT REGIONS OF GUIZHOU

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Abstract

22 local line chilli varieties of Guizhou were used to conduct quality analysis of different varieties and origin, along with correlation analysis and principal component analysis of different quality indicators, as well as comprehensive evaluation and cluster analysis of different varieties in this study. The results showed that the coefficient of variation of indicators related to pungency ranged between 103.05%-117.86%, and the difference of capsaicinoid-like substance was the largest among all quality indicators. Guizhou local line chilli had distinct characteristics of origin. Fruit from Anshun was large and long with largest size, flesh thickness and weight. Fruit from Bijie was thin and long with the least flesh thickness and weight. Fruit from Qiannan was thin and short. Moreover, certain correlations were also found among the product quality indicators, and the flavour quality indicators, as well as between the processing and commodity quality in Guizhou local line chilli. Among the 22 varieties, the comprehensive quality score of line chilli from Qiannan (named Pingtangxianjiao) was highest. The 22 local line chilli varieties of Guizhou were divided into 5 clusters with different fruit shape. Clusters I and II was classified as the ultra-long group, Cluster III was classified as the thin and long group, Cluster IV was classified as the thick and long group, and Cluster V was classified as the thick and short group. This analysis of the quality of Guizhou's local line chilli will contribute to identify its origin and promote its creation and utilization.

Key words: *Capsicum annuum* L. in Guizhou; Different regions; Quality analysis.

Introduction

Chilli is a plant belonging to the genus *Capsicum* L of the family Solanaceae Juss. (Mongkolporn & Taylor, 2011; Sun *et al*., 2014). The planting area of chillis in China has remained stable at 2.1 million hectares in recent years, making it the largest vegetable in China (Wang *et al*., 2021) Chilli, as an important global vegetable and seasoning, plays an important role in ensuring the annual balanced supply of vegetable consumption and enriching people's lives (Khan *et al*., 2014). Guizhou is the main production area of high-quality chilli in China with the largest planting area of chilli in China. The chilli industry is one of the important pillar industries in the province. The chilli industry has become an important way to adjust agricultural structure and increase farmers' income (Jin *et al*., 2021). Local line chilli is one of the types with the widest distribution range and the largest consumer group in Guizhou. There are many famous local line chilli. Representative varieties include Huangping line chilli, Dafang line chilli, Dafang wrinkled chilli, Yutang line chilli, Dushan line chilli, etc. They are distributed in areas such as Bijie, Qiannan, Tongren, and Anshun. Local line chilli is highly favored by consumers for their unique quality (Ren *et al*., 2015). Clarifying the quality and regional characteristics of local line chilli is an important way to transform resource advantages of local chilli into economic advantages. It is also an important task for the current chilli industry.

Indexes including fruit size, fruit shape and fruit flesh thickness constitute the product quality of chilli (Xiang *et al*., 2022). Fruit size determines its appearance, directly affecting economic benefits and the storage capacity of chillis (Ma *et al*., 2022; Liu *et al*., 2022). Fruit shape is not only the basis for fruit shape classification but also an important index of chilli grading (Borovsky *et al*., 2022). Fruit flesh thickness endows chilli with different processing properties, and also determines fruit cavity size, leading to different storage and transportation capabilities of chilli (Dwivedi *et al*., 2015). At present, there was only a general description of the product quality of Guizhou local line chilli, especially for the fruit size, fruit shape, and flesh thickness. The product quality of Guizhou local line chilli cannot be quantified. The research on the regional characteristics of local line chilli has not been carried out. The dry matter content is an important criteria for measuring the suitability of chilli variety for dry chilli. The research on dry matter content of very few local line chilli varieties was conducted. The research showed that the dry matter content of local line chilli was 18.5-22.7% (Fu *et al*., 2018). Capsaicin like substance is mainly composed of capsaicin and dihydrocapsaicin. It is an important indicator of variety quality, spiciness, and product quality (Zhu *et al*., 2019; Ye *et al*., 2021). Compared with the spiciness of other fruit shape such as finger shape, cone shape, sheep horn shape, and cow horn shape, the spiciness of Guizhou local line chilli was moderate, with an average capsaicin content of 1.39 mg/g (Peng *et al*., 2017).

At present, research on the quality characteristics of Guizhou local line chilli is limited (Fu *et al*., 2018; Peng *et al*., 2017; Su *et al*., 2017). The research on product quality, processing quality, and flavor quality is rather unsystematic. There is a lack of quantitative research on the product quality indicators of different local line chilli varieties. The research on the regional characteristics of local line chilli is almost non-existent. In order to make up for the shortcomings of existing research on the quality characteristics of Guizhou local line chilli, this study was carried out an analysis and evaluation of product quality, the content of dry matter and capsaicinoids of 22 local line

chilli from different regions in Guizhou. This research will provide intuitive regional identification data for Guizhou local line chilli. The public awareness of Guizhou local line chilli will be enhanced. It will provide a scientific basis for its product development, resource creation and utilization, and gene mining for quality traits.

Material and Methods

Materials: A total of 22 local line chilli varieties from Guizhou were used in this study, which were provided by the Guizhou Pepper Research Institute. The 22 varieties were all high-generation inbred lines of chilli from 4 cities in Guizhou, with linear fruit shape (Table 1). All the varieties were planted in mesh greenhouses, with 50 plants per variety.

Product quality measurement: During the maturity stage of chilli products, 5 plants were randomly sampled from each variety, from which 10 normal fruits reaching product maturity were harvested. The length from the fruit peduncle to the apex was measured, and the average was taken as the longitudinal diameter of the fruit. The diameter of the maximum transverse plane perpendicular to the longitudinal diameter was measured, and the average was obtained as the transverse fruit diameter. The fruit was cut transversely at the maximum transverse diameter, and the thickness of the fruit flesh was measured, with the average as the fruit flesh thickness. The fruit was weighed and the average was taken as the single fruit weight. Fruit shape index = vertical fruit diameter/transverse fruit diameter.

Determination of dry matter content: The red mature fruits of the third and fourth layers were harvested on chilli plant with consistent growth. The red fruit was cut into small pieces and then placed in an aluminum weighing bottle. It was placed in a drying oven at 101-105 ℃ and dried to a constant weight. The dry matter content was calculated based on the weight of the fruit before and after drying based on the direct drying method in GB5009.3-2016.

Determination of capsaicinoid content: Twenty chilli plants with consistent growth were selected, and the fully red and ripe fruits and free from plant diseases and insect pests in the 3rd and 4th layers were harvested. After drying by hot air at 80℃ to constant weight, and removal of fruit stalks, the fruits were crushed and sieved through 40 and 80 mesh sieves respectively, and stored in a dryer in the dark for determining the content of capsaicinoids according to the GB/T 21266-2007 Determination of Total capsaicin-like substances and Representation of Pungency Degree in Capsicum and Its Products (GB/T 21266-2007).

Data analysis: Excel 2013 (Microsoft Corporation, USA) was used to analyze the maximum, minimum, average, and standard deviation of fruit traits of Guizhou local line chilli. Coefficient of variation=standard deviation/average x 100%. SPSS 19.0 (International Business Machines Corporation, USA) was used for principal component analysis and comprehensive evaluation. Origin 2022 (Origin Lab Corporation, USA) was used for correlation analysis and clustering analysis in mapping.

Results and analysis

Quality analysis of different varieties of Guizhou local line chilli: Some differences was observed in product quality, processing quality, and flavour quality of different varieties (Table 2). The main indicator of product quality included the transverse fruit diameter, vertical fruit diameter, shape index, fruit flesh thickness, and single fruit weight. The coefficients of variation (CVs) of these indicators ranged between 16.12%~29.96%. The CV of shape index was 29.96%, with the highest value. The CV of transverse fruit diameter was 16.12%, with the lowest value. Dry matter content was an important indicator of processing quality. The CV of dry matter content was the smallest among those of all quality indicators. It indicated that there was little difference in dry matter content of different chilli varieties in comparison with other quality indicators. The content of capsaicinoid-like substance was a key indicator of flavour quality. The CVs of capsaicin content, dihydrocapsaicin content, and capsaicinoid-like substance content were 103.05%~117.86%, all of which were larger than 100.00%, suggesting significant differences in capsaicinoid-like substance content among different pepper varieties.

Quality analysis of different origin of Guizhou local line chilli: The product, processing, and flavor qualities of Guizhou local line chilli had distinct characteristics of origin. In product quality (Fig. 1), the average value of transverse fruit diameter, fruit flesh thickness, and single fruit weight was Anshun > Tongren > Qiannan > Bijie. The average value of vertical fruit diameter was Anshun > Tongren > Bijie > Qiannan. The average value of shape index was Bijie > Anshun > Tongren > Qiannan. In general, fruit from Anshun was large and long with largest size, flesh thickness and weight. Fruit from Bijie was thin and long with the least flesh thickness and weight. Fruit from Qiannan was thin and short. In processing and flavor qualities (Fig. 2), the average value of dry matter content, capsaicin content, dihydrocapsaicin content, and capsaicinoid-like substance content was Tongren > Qiannan > Bijie > Anshun. Therefore, fruit from Tongren had the highest dry matter content and spiciness, which was most suitable for processing into dry fruit. Fruit from Anshun had the lowest dry matter content and spiciness, which was most suitable for fresh food. Fruit from Qiannan and Bijie had moderate dry matter contents and spiciness, which were suitable for both fresh and dry use.

Correlation analysis among product, nutritional and flavor qualities of local line chilli in Guizhou: Transverse fruit diameter and vertical fruit diameter were strongly correlated with shape index and moderately correlated with single fruit weight but were lowly correlated with other quality indicators, with absolute correlation coefficients of 0.01-0.34 (Fig. 3). The shape index was lowly correlated with other quality indicators, having absolute correlation coefficients of 0.13-0.22. Flesh thickness was moderately and positively correlated with single fruit weight, having a correlation coefficient of 0.55, but was lowly correlated with other quality indicators, with the absolute correlation coefficients of 0.13-0.33. Single fruit weight was weakly negatively correlated with dry matter content, with a

correlation coefficient of -0.46, but was not correlated with other quality indicators, with the absolute correlation coefficients ≤0.03. Apart from being weakly correlated with single fruit weight, dry matter content was not correlated with other quality indicators. Capsaicin content formed a significant positive correlation with dihydrocapsaicin content, with a 0.92 correlation coefficient, but was lowly correlated with other quality indicators, with the absolute correlation coefficient ≤0.26. Total capsaicinoid-like substance content had significant positive correlations with capsaicin and dihydrocapsaicin contents but were not correlated with other quality indicators. Therefore, for Guizhou local line chilli, certain correlations existed among product quality indicators, among flavor quality indicators, and between processing quality and product quality. However, there was no correlation between product quality and flavor quality, as well as between processing quality and flavor quality.

Table 1. Distribution and fruit shape of 22 chilli resources.

Number	Fruit shape	Distribution	Number	Fruit shape	Distribution
1	linear	Bijie	12	Linear	Qiannan
2	linear	Bijie	13	Linear	Qiannan
3	linear	Bijie	14	Linear	Qiannan
4	linear	Bijie	15	Linear	Qiannan
5	linear	Bijie	16	Linear	Tongren
6	linear	Bijie	17	Linear	Tongren
7	linear	Bijie	18	Linear	Tongren
8	linear	Bijie	19	Linear	Anshun
9	linear	Qiannan	20	Linear	Anshun
10	linear	Qiannan	21	Linear	Anshun
11	linear	Qiannan	22	Linear	Anshun

Table 2. The variety characteristic of quality of Guizhou Local line chilli.

Descriptive Statistics	Transverse fruit diameter (mm)	Vertical fruit diameter (cm)	Fruit shape index	Fruit flesh thickness (mm)	Single fruit weight (g)	Dry matter content (%)	Capsaicin content ($g.kg^{-1}$)	Dihydrocap-saicin content ($g.kg^{-1}$)	Total capsaicin-like substances content ($g.kg^{-1}$)
Maximum value	16.52	40.80	38.71	2.85	16.15	34.55	1.70	0.54	2.38
Minimum value	9.36	17.98	11.38	1.13	5.87	18.75	0.00	0.00	0.00
Mean value	12.46	26.55	21.95	2.02	10.33	23.79	0.49	0.14	0.70
Standard deviation	2.01	5.99	6.57	0.37	2.44	3.40	0.51	0.16	0.73
Coefficient of variation (%)	16.12	22.57	29.96	18.45	23.62	14.27	103.05	117.86	104.83

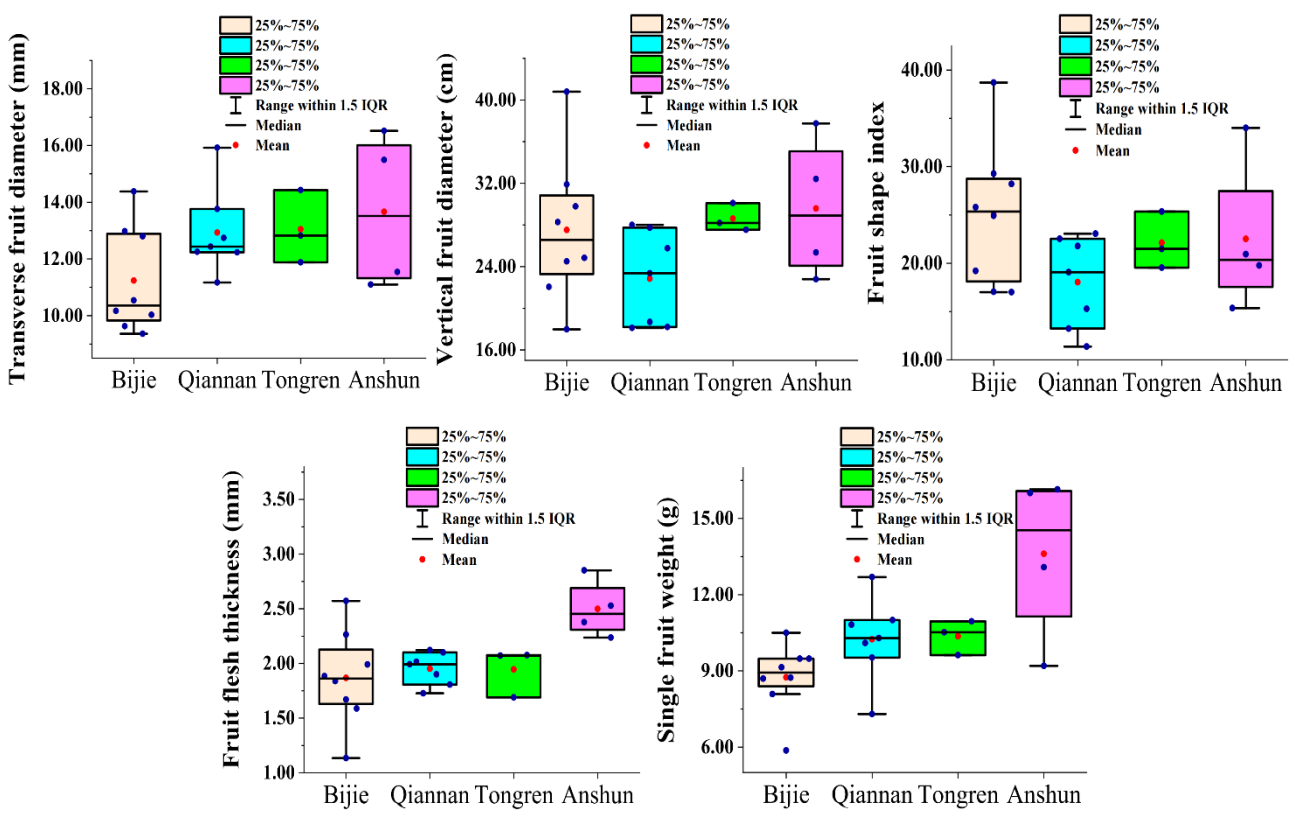

Fig. 1. The origin characteristic of product quality of Guizhou local line chilli.

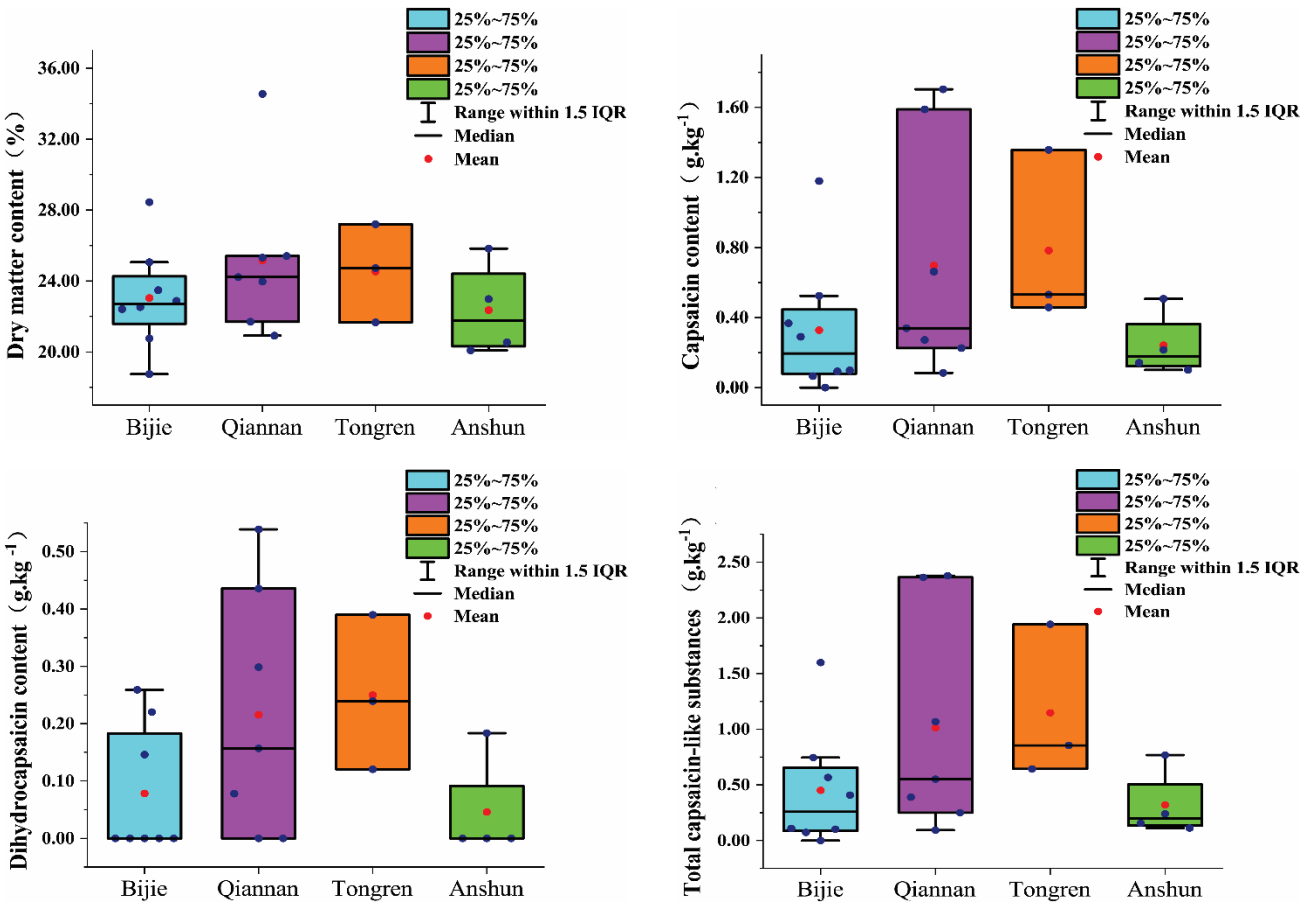

Fig. 2. The origin characteristic of processing quality and flavor quality of Guizhou local line chilli.

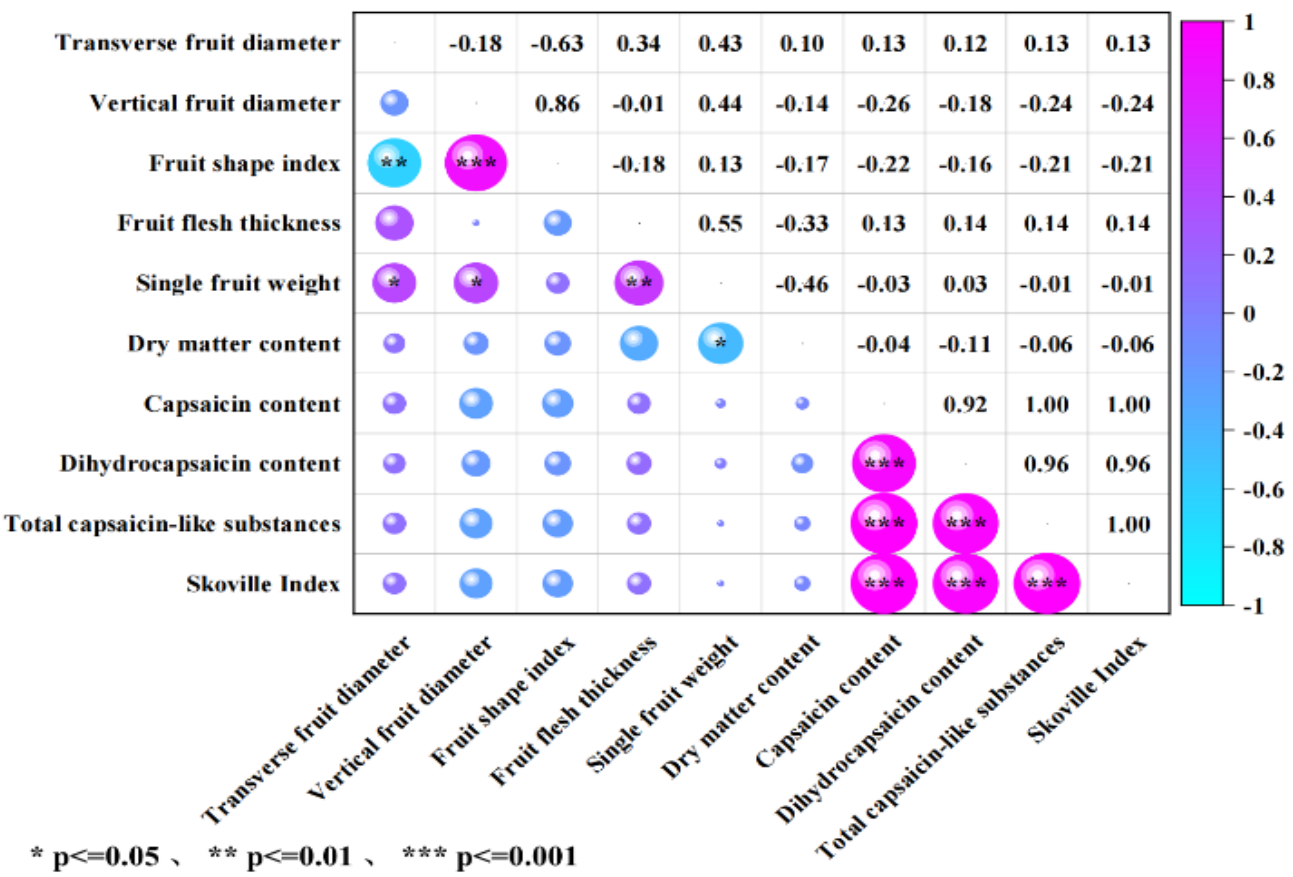

Fig. 3. Correlation analysis among product quality, processing quality and flavor quality of Guizhou local line chilli varieties.

Table 3. The principal component of 9 quality indicators of Guizhou local line chilli.

Quality indicator	The first principal component	The second principal component	The third principal component
Tansverse fruit diameter	0.392	0.137	-0.743
Vertical fruit diameter	-0.513	0.63	0.372
Fruit shape index	-0.563	0.429	0.686
Fruit flesh thickness	0.277	0.596	-0.459
Single fruit weight	0.016	0.867	-0.342
Dry matter content	-0.035	-0.653	-0.023
Capsaicin content	0.914	0.08	0.358
Dihydrocap-saicin content	0.881	0.162	0.38
Total capsaicin-like substances content	0.919	0.102	0.368
Eigenvalue	3.270	2.176	1.897
Variance contribution rate (%)	36.33	24.18	21.08
Cumulative variance contribution rate (%)	36.33	60.51	81.59

Table 4. The comprehensive scores of quality for Guizhou local line chilli.

Variety	F_1	F_2	F_3	F	Rank
Dafangxianjiao	-3.46	-0.50	1.90	-1.20	21
Zhuyuanzhoujiao	-1.54	0.14	-0.30	-0.72	17
Yangchangzhoujiao	-0.83	-1.01	-0.90	-0.90	19
Zhongzhaixianjiao	-0.85	0.97	1.07	0.19	9
Yinaxianjiao	-1.20	-2.44	0.31	-1.18	20
Chadianxianjiao	-0.30	-1.22	-0.55	-0.64	15
Zhijinxianjiao	-0.08	0.72	0.46	0.29	7
Qianxizhoujiao	1.01	0.28	1.66	0.96	4
Baiquanxianjiao	0.94	0.72	0.28	0.70	5
Yushuixianjiao	-1.37	0.65	-0.49	-0.54	14
Jichangzhoujiao	-0.08	-1.53	-0.62	-0.65	16
Yunwuxianjiao	-0.88	-2.89	-0.29	-1.32	22
Longlixianjiao	4.51	-0.32	-0.31	1.84	2
Pingtangxianjiao	3.27	0.53	1.59	2.02	1
Sanduzhoujiao	0.77	-1.26	-1.08	-0.31	13
Baishaxianjiao	2.50	0.22	0.90	1.41	3
Yutangxianjiao	0.69	-0.05	-0.38	0.20	8
Longjingxianjiao	-0.64	0.32	0.57	-0.04	12
Xinchangxianjiao	-0.75	-0.87	-0.52	-0.73	18
Laojiazhaixianjiao	-0.85	2.55	-1.55	-0.02	11
Houchangxianjiao	-2.21	3.48	0.09	0.07	10
Mengzhouxianjiao	1.35	1.52	-1.86	0.57	6

Principal component analysis and comprehensive evaluation of quality of Guizhou local line chilli: A principal component analysis of the product, processing, and flavor qualities of Guizhou local line chilli was conducted and three principal components with eigenvalue >1.0 were extracted. The variance contribution rates of the three principal components were 36.33%, 24.18%, and 21.08%, respectively, which corresponded to a cumulative variance contribution rate of 81.59% (Table 3). It indicated that the three principal components represented major information of the 9 quality indicators, which made them suitable for the comprehensive evaluation of the quality. Based on the proportion of quality indicators and their corresponding principal components, the scores of three principal components were calculated as follows:

$F_1=0.22x_1-0.28x_2-0.31x_3+0.15x_4+0.01x_5-0.02x_6+0.51x_7+0.49x_8+0.51x_9$;
$F_2=0.09x_1+0.43x_2+0.29x_3+0.40x_4+0.59x_5-0.44x_6+0.05x_7+0.11x_8+0.07x_9$;
$F_3=-0.39x_1+0.20x_2+0.36x_3-0.24x_4-0.18x_5-0.01x_6+0.19x_7+0.20x_8+0.19x_9$.

$X_1 \sim X_9$ denoted the nine quality indicators and F_1, F_2, and F_3 denoted the scores of the principal component factors 1, 2 and 3, respectively. Using the eigenvalue ratios of the three principal components as weights, a score function for 22 chilli varieties was obtained as follow: $F=0.45F_1+0.30F_2+0.26F_3$ (Table 4). The comprehensive scores of quality for 22 chilli varieties were as follows: Pingtangxianjiao > Longlixianjiao > Baishaxianjiao > Qianxizhoujiao > Baiquanxianjiao > Mengzhouxianjiao > Zhijinxianjiao > Yutangxianjiao > Zhongzhaixianjiao > Houchangxianjiao > Laojiazhaixianjiao > Longjingxianjiao > Sanduzhoujiao > Yushuixianjiao > Chadianxianjiao > Jichangzhoujiao > Zhuyuan zhoujiao > Xinchangxianjiao > Yangchangzhoujiao > Yinaxianjiao > Dafangxianjiao > Yunwuxianjiao.

Cluster analysis of the quality of Guizhou local line chilli: A cluster analysis of 22 Guizhou local line chilli was conducted baesd on Euclidean distances using data processing software Origin (Fig. 4). 22 chilli varieties were divided into 5 clusters. Cluster I was Houchangxianjiao, accounting for 4.5%. Cluster II was Dafangxianjiao, accounting for 4.5%. Cluster III consisted of six varieties, including Zhuyuan zhoujiao, Zhongzhaixianjiao, Zhijinxianjiao, Qianxizhoujiao, Baiquanxianjiao, and Yushuixianjiao, which accounted for 27.3%. Cluster IV consisted of seven varieties, including Pingtangxianjiao, Baishaxianjiao, Yutangxianjiao, Longjingxianjiao, Xinchangxianjiao, Laojiazhaixianjiao and Mengzhouxianjiao, which accounted for 31.8%. Cluster V consisted of seven varieties, including Yangchangzhoujiao, Chadianxianjiao, Yinaxianjiao, Jichangzhoujiao, Longlixianjiao, Sanduzhoujiao, and Yunwuxianjiao, which accounted for 31.8%. Clusters I and II had the highest shape indexes and was classified as the ultra-long group. But the fruit flesh thickness and single fruit weight of Cluster I were significantly higher than those of Cluster II. Cluster III had high fruit shape index and medium single fruit weight, which was classified as the thin and long group. Cluster IV had medium fruit shape index and high single fruit weight, which was classified as the thick and long group. Cluster V had the smallest fruit shape index and single fruit weight, which was classified as the thick and short group.

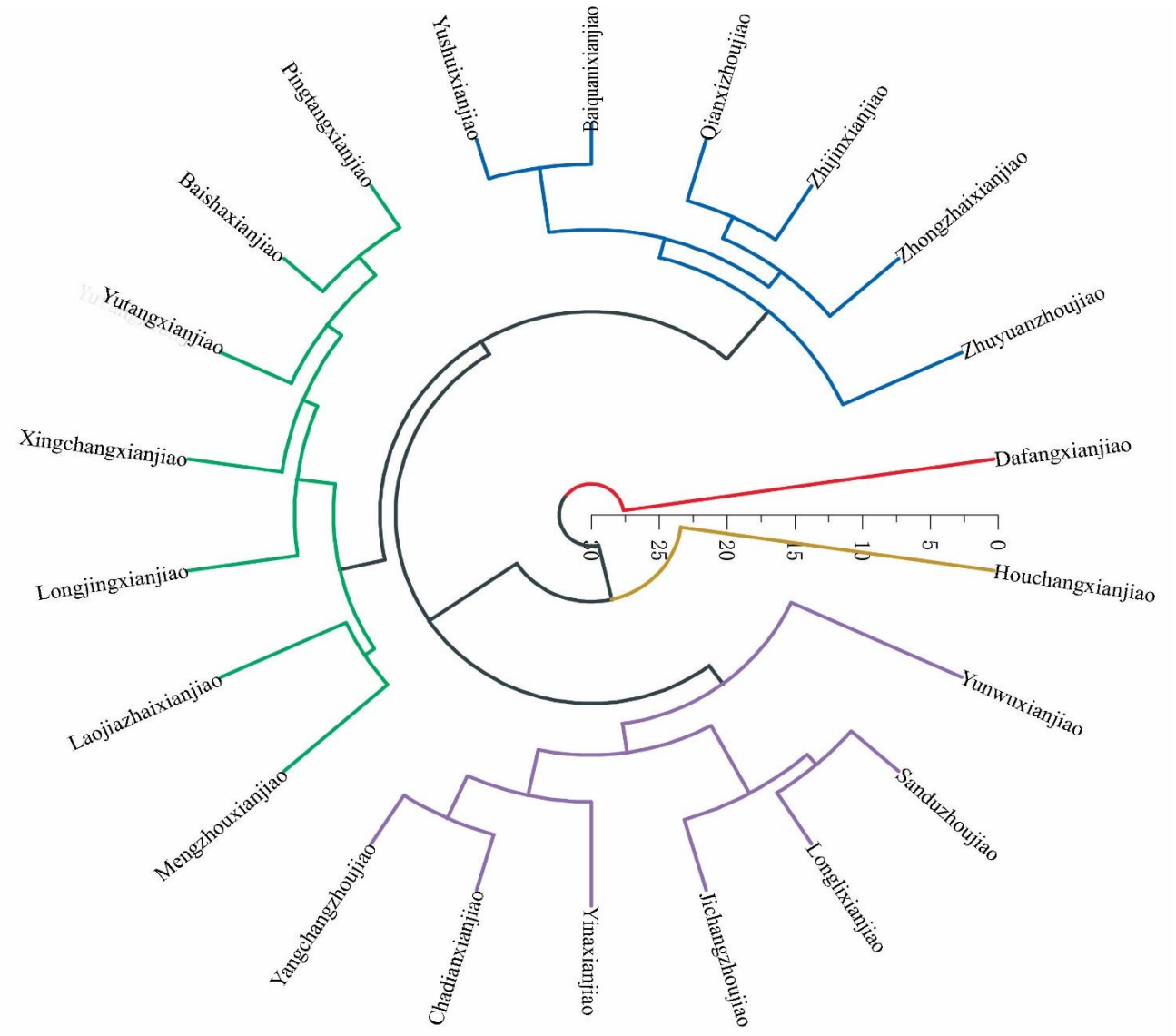

Fig. 4. The cluster analysis of the quality of Guizhou local line chilli.

Discussion

Differences in quality characteristics and influencing factors of Guizhou local line chilli: The quality of chilli fruit mainly refers to product quality, nutritional quality, and flavor quality. The product quality constitutes of fruit shape, fruit size, and fruit flesh thickness. In this study, it was found that the transverse fruit diameter of local line chilli in Guizhou ranged from 9.36 to 16.52 mm, the vertical fruit diameter was within 17.98~40.80 cm, and single fruit weight was 5.87~16.15 g. The transverse fruit diameter and single fruit weight were similar to previous research results. Previous studies found that the maximum vertical diameter of local line chilli fruit in Guizhou was 25.00 cm. This study found that the maximum vertical diameter of the fruit was 40.80 cm, which was 1.63 times higher than earlier studies (Ren *et al*., 2015; Tu *et al*., 2014), which was mainly caused by different varieties involved. In addition, our study revealed that the fruit shape index of local line chilli in Guizhou was 11.38-38.71. The fruit shape index is the ratio of vertical fruit diameter to transverse fruit diameter, which is an important product quality index for chillis. Clarifying the fruit shape index will provide a scientific basis for identifying local line chilli varieties in Guizhou, mining fruit shape-related genes, and breeding varieties with different fruit shapes.

Dry matter content not only is a constituent element of nutritional quality but also determines the processing and use of chillis. In this study, the maximum dry matter content of local line chilli in Guizhou was 34.55%. Prior research indicated that the Guizhou local line chilli had a maximum dry matter content of 22.70%. In this study, the dry matter content was 1.52 times greater. (Fu *et al*., 2018). Varieties with high dry matter content will broaden the germplasm resources for dried chillis and lay the material foundation for the breeding of specialized varieties for dried chillis. Capsaicin and dihydrocapsaicin accounted for more than 90% of the capsaicinoid-like substances, collectively referred to as capsaicinoids, which determine the spicy flavors of chillis and are unique to chilli fruits, contributing to their various flavors (Kozukue *et al*., 2005). Different from previous studies (Peng *et al*., 2017; Su *et al*., 2017), some chillis in this study had neither capsaicin nor dihydrocapsaicin without spicy flavors, which may

result from the Pun1 gene encoding acyltransferase mutates in these chillis, causing the loss of spicy flavors (Blum *et al*., 2002, 2003; Stewart *et al*., 2005; 2007).

The influence of origin on the quality of Guizhou local chilli: *C. annuum* is the most widely distributed variety of chilli in Guizhou, with obvious regional characteristics in its fruit shape. The fruit shape index of local line chilli in Bijie was the highest, while that in Qiannan was the lowest. In Guizhou, Bijie is a high-altitude area with an average altitude of 1,600 m, while Qiannan has a lower altitude with an average altitude of 997 m. The difference in altitude can cause changes in natural environmental factors such as temperature, water content and light, thereby affecting a series of physiological and biochemical processes of chillis such as morphology, growth, photosynthesis, respiration, material transfer and transportation, which result in differences in fruit shape of chillis. Previous study has confirmed that fruit volume changed with altitude (Charles *et al*., 2018). Therefore, we speculate that the difference in fruit shape of local line chilli in Guizhou is caused by regional altitude differences.

The total content of capsaicinoids in local line chilli from Guizhou also presented an obvious regional characteristic: the highest in Tongren, while the lowest in Anshun. This regional characteristic may be related to two factors, one is the transmission path of C. annuum in Guizhou, and the other is the genetic control of spicy flavors. The chillis in Guizhou originated from the ancient Sizhou region, including Tongren, and later gradually spread to Bijie and Anshun (Zhan *et al*., 2015). Therefore, the spicy food eating trend was the earliest formed in Tongren, with a high demand for spicy flavors. Against this background, after a long period of artificial selection, the pungency degree of C. annuum in Tongren is the highest, while that in Anshun is the lowest. The pungency degree is a quantitative trait that is regulated by multiple QTLs including cap, cap7.1, cap7.2, cap8.1, dhc4.1 and total 3.1, and vulnerable to environmental impacts (Blum *et al*., 2002; 2003; Ben Chaim *et al*., 2001; 2006; Yarnes *et al*., 2013). The quantity or expression level of spicy flavor-related QTLs in local line chilli varies in different regions. Moreover, their interactions with the regional environment result in varying pungency degrees in chillis.

Conclusion

The quality characteristic of Guizhou local line chilli was analyzed in this study. It was found that the quality of Guizhou local line chilli had obvious variety characteristic. Different varieties were found to have the least difference in dry matter content and the largest difference in capsaicin-like substances content. The quality of Guizhou local line chilli had distinct origin characteristic. Fruit from Anshun was large and long with largest size, flesh thickness and weight, but had lowest dry matter content and spiciness which made it most suitable for fresh use. Fruit from Tongren had no distinct visual characteristic but it had the highest dry matter content and spiciness, which made it most suitable for dry use. Fruit from Bijie was thin and long with the least flesh thickness and weight, but had moderate dry matter content and spiciness, making it suitable for both fresh and dry use. The correlation analysis of 9 quality indicators showed that there was no correlation between product quality and flavor quality. Therefore, it was impossible to indirectly estimate invisible flavor quality based on visible product quality. A comprehensive evaluation of the quality of different chilli varieties was conducted based on the principal component analysis, which revealed that varieties with high capsaicin-like substance content were also better in quality. 22 chilli varieties were divided into five clusters including ultra-long group, thin and long group, thick and long group, as well as thick and short group. Understanding the quality characteristic and internal relation among the quality indicators will promote the development and utilization of Guizhou local line chilli.

Acknowledgments

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