Analysis of Chemical Composition Content and Coordination in Different Locations of Tobacco Leaf Based on Entropy-weight TOPSIS Method

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Abstract. [Objective] To clarify the quality difference in different parts of flue-cured tobacco leaves and to provide theoretical support for the selection of cutting methods in threshing and redrying procedures. [Methods] After removing 10cm petioles, each single leaf was evenly divided into 9 locations according to the "#" shape. The differences and characteristics of conventional chemical components and coordination indexes in different locations of leaves were analyzed, and on this basis, entropy-weight TOPSIS analysis and cluster analysis were conducted, so as to evaluate the comprehensive quality of different locations of tobacco leaves. Finally, the sensory quality of the samples was evaluated. [Results] (1) There were significant differences in chemical composition and coordination indexes between different locations of tobacco leaf; (2) Tobacco leaf can be divided into three parts: (I, III, IV, VI), (II, V, VII, IX) and VIII. On the whole, the quality of middle and upper edges of the leaf(I, III, IV, VI) was better, especially the middle edges, but the quality of the base was poor, and the base near the stem(VIII) was the worst in the whole leaf; (3) After tobacco leaf cutting, there are differences in sensory quality between different location combinations, the sensory quality of the middle and upper edges(I, III, IV, VI) of the leaf is the best, and the sensory quality of the leaf base near the stem(VIII) is the worst. [Conclusion] In conclusion, there are certain differences and similarities in the quality of tobacco leaf in different locations, the industrial availability and utilization rate of tobacco raw materials can be effectively improved by cutting.Considering the practical situation, it is more suitable to divide tobacco leaf into middle and upper edges and the rest for separate utilization.

Keywords: Tobacco leaf; Location; Quality; Entropy-weight TOPSIS

1 Introduction

Chemical components are the important material basis for determining the quality and style characteristics of tobacco leaves, greatly reflecting the quality of tobacco leaves,

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and are therefore commonly used for the evaluation of the intrinsic quality and industrial usability of tobacco leaves [1, 2]. Affected by the structural characteristics of the tobacco plant itself, external environment, and differences in threshing and redrying conditions, the substances contained in different regions of a single tobacco leaf often accumulate and transform to varying degrees[3-5], thus, the chemical components in different regions of a single tobacco leaf are not uniformly consistent [6, 7]. Based on this leaf quality distribution difference, selecting appropriate cutting and processing methods according to the quality characteristics of different regions will more effectively expand the industrial usability of tobacco leaves and improve the utilization rate of raw materials. With the increasing structural contradictions in the supply side of high-quality tobacco leaf raw materials, research on tobacco leaf cutting has become a hot research area in the tobacco industry [8-11]. Scientifically analyzing the quality differences between different regions of tobacco leaves is a prerequisite for reasonable cutting and processing of tobacco leaves. Previous studies have used various methods, such as Liu Chao et al.[12]who conducted a study on the differences in the quality fraction of volatile organic acids in different regions of tobacco leaves using single-factor variance and correlation regression analysis; Ma YiQiong et al.[13] who used principal component analysis and cluster analysis to classify the quality of tobacco leaf chemical components and sensory quality; Long MingHai et al.[14] who used principal component analysis combined with Fisher's optimal partitioning method to cut tobacco leaves and found significant differences in the content of total sugar, reducing sugar, nicotine, and sensory quality scores of the cut tobacco leaves; Wang YuZhen et al.[15]who used regression analysis combined with cluster analysis to study the trends of physicochemical characteristic indexes in different regions, thereby determining the appropriate number of segments and cutting ratios for tobacco leaves. The entropy weight TOPSIS method, as a comprehensive evaluation method for multiple indicators, is widely used in various industries because it can avoid subjectivity in data and objectively display the quality differences between evaluation objects [16-19]. Previous studies have also shown that this method can objectively evaluate the quality of crops[20, 21] . Henan tobacco leaves, as one of the most widely used raw materials in Sichuan Zhongyan products, have great potential for development and utilization. Utilizing the analytical advantages of the entropy weight TOPSIS method can effectively meet the comprehensive evaluation needs for the quality of different regions of Henan tobacco leaves, thereby deeply exploring the value of Henan tobacco leaves. Based on this, this study uses the entropy weight TOPSIS method to study the differences in chemical component content and coordination indexes of different regions of tobacco leaves cut in a "#" shape, combined with sensory quality evaluation, to explore the quality differences of different regions of flue-cured tobacco leaves and provide theoretical support for the cutting, threshing and redrying processing of tobacco leaves.

2 Materials and Methods

2.1 Experimental Materials

The experimental tobacco leaves were C3F grade from Luoyang, Henan in 2022, with the variety Yunyan 87. A 5 kg sample of intact and undamaged tobacco leaves was provided by Sichuan Zhongyan Industrial Co., Ltd.

2.2 Experimental Methods

2.2.1 Sample Preparation

As shown in Figure 1, after removing a 10 cm petiole from each leaf, one part was cut into nine equal sections along the horizontal and vertical directions in a "#" shape, and the cutting positions were marked as I to IX from left to right and from top to bottom. After removing the midribs from the same positions, they were evenly mixed, placed in an oven for drying at 45°C for 2 hours, crushed, and sifted through a 60-mesh screen for routine chemical component testing. The other part was cut according to the clustering results, shredded, evenly mixed, and balanced for 48 hours in an environment with a temperature of (22±2)°C and relative humidity of (60±2)%, then rolled into cigarettes for sensory quality evaluation.

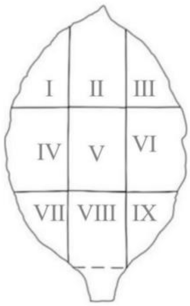

Fig. 1. Tobacco leaf slitting location

2.2.2 Detection of Chemical Components in Tobacco Leaves

In accordance with industry-standard methods, a continuous flow analyzer was utilized to measure the content of conventional chemical components in tobacco leaf samples, including reducing sugars, total sugars, total plant alkaloids, potassium, total nitrogen, and chlorine. The sugar-alkaloid ratio is the quotient of total sugars to total plant alkaloids, the nitrogen-alkaloid ratio is the quotient of total nitrogen to total plant alkaloids, and the potassium-chloride ratio is the quotient of potassium to chlorine.

2.2.3 Comprehensive Evaluation of Tobacco Leaf Quality

Normalization of Tobacco Leaf Indexess : The chemical component indicators of tobacco leaves are normalized using a fuzzy mathematical membership function. Based on previous research, the membership degree functions for reducing sugars, total sugars, total plant alkaloids, chlorine, total nitrogen, sugar-alkaloid ratio, and nitrogen-alkaloid ratio are determined to be parabolic in shape. The calculation formula is as follows:

$$f(x)=\begin{cases}0.1 & x\le L,\ x\ge U\\ 0.1+0.9(x-L)/(O_1-L) & L<x<O_1\\ 1.0 & O_1\le x\le O_2\\ 1.0-0.9(x-O_2)/(U-O_2) & O_2<x<U\end{cases} \tag{1}$$

The membership degree functions for potassium and the potassium-chloride ratio are determined to be of the S-shape type. The calculation formula is as follows:

$$f(x)=\begin{cases}0.1 & x\le L\\ 0.1+0.9(x-L)/(U-L) & L<x<U\\ 1.0 & x\ge U\end{cases} \tag{2}$$

Considering the characteristics of different membership functions, referring to the quality standards for flue-cured tobacco, and combining the actual situation of the "Kuanzhai Jingpin" tobacco leaf raw materials from Sichuan Zhongyan, the threshold values for each chemical component indexes are determined (Table 1).

Table 1. Membership function types and thresholds of chemical composition indexes of tobacco leaf

Chemical composition index	Membership function type	Lower Limit (L)	Optimal Lower Limit (O1)	Optimal Upper Limit (O2)	Upper Limit (U)
Reducing sugar(%)	Parabolic	12	24	30	35
Total sugar(%)		20	26	32	40
Total alkaloid(%)		1.2	2.2	3	4
Chlorine(%)		0.1	0.3	0.8	1
Total nitrogen (%)		1.1	2	2.3	3.4
TS/TA		6	10	12	20
TN/TA		0.5	0.7	0.9	1.5
P/C	S	1			8
Potassium(%)		0.8			2.5

Weights of Chemical Component Indexes of Tobacco Leaves To avoid the influence of subjective assignment of weights, the weights of the chemical component indexes of tobacco leaves are calculated using the entropy weight method. The calculation formula is as follows:

$$W_j = \frac{1-\left[-\frac{1}{\ln n}\sum_{i=1}^{n}\left(\frac{x'_i}{\sum_{i=1}^{n} x'_i}\right)\ln\left(\frac{x'_i}{\sum_{i=1}^{n} x'_i}\right)\right]}{\sum_{j=1}^{m}\left\{1-\left[-\frac{1}{\ln n}\sum_{i=1}^{n}\left(\frac{x'_i}{\sum_{i=1}^{n} x'_i}\right)\ln\left(\frac{x'_i}{\sum_{i=1}^{n} x'_i}\right)\right]\right\}} \tag{3}$$

$$Z_{ij}=W_j \times x'_i \tag{4}$$

In the formula, x'_i represents the normalized data of the chemical component indexes for the *i*-th sample, where i=1, 2, ..., m; W_j represents the weight value of the *j*-th evaluation index with $0 < W_j < 1$, where j=1, 2, ..., n; Z_{ij} represents the weighted value of the *j*-th evaluation indexe for the *i*-th sample.

TOPSIS Evaluation: By using the positive and negative ideal solution values ($Z^+$and Z^-) of the evaluation indicators, the distances ($D^+$and D^-) of each sample to the positive and negative ideal solutions are calculated. Ultimately, the relative closeness (C) of each sample to the optimal solution is determined, and the quality of different tobacco leaf samples is evaluated based on the magnitude of the C values

$$Z^+ = \max(Z_{11}, Z_{21}, \ldots\ldots, Z_{mn}) \quad Z^- = \min(Z_{11}, Z_{21}, \ldots\ldots, Z_{mn}) \tag{5}$$

$$D_i^+ = \sqrt{\sum_{j=1}^{m}(Z^+ - Z_{ij})^2} \quad D_i^- = \sqrt{\sum_{j=1}^{m}(Z^- - Z_{ij})^2} \tag{6}$$

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad 0 < C < 1 \tag{7}$$

2.2.4 Sensory Quality Evaluation

Experts from the Technical Center of China Tobacco Sichuan Industrial Co., Ltd. score the rolled samples on 10 individual indicators, including aroma quality, aroma quantity, off-flavors, concentration, strength, smoothness, cohesion, irritation, aftertaste, and sweetness. The total sensory score is then calculated by summarizing the scores from these individual indicators.

2.3 Data Analysis

Data organization was conducted using Excel 2016; multiple comparisons were performed using SAS 9.1; and cluster heat map analysis after data standardization was carried out through the Hiplot platform.

3 Results and Analysis

3.1 Analysis of Differences in Chemical Component Indicators of Tobacco Leaves from Different Positions

As shown in Table 2, there are significant differences in the content and coordination of conventional chemical components in different positions of tobacco leaves. The content of reducing sugars is relatively high in regions I, III, and VI, and significantly lower in region VIII compared to other regions; the content of total sugars is relatively high in regions III, IV, and VI, and significantly lower in region VIII compared to other regions; the content of total plant alkaloids is relatively high in regions I and III, and lower in regions V and VIII; the content of chlorine is significantly higher in region VIII and lower in regions I, II, and III; the content of potassium is significantly higher in region VIII and significantly lower in region III compared to other regions; the content of total nitrogen is relatively high in regions VII and VIII, and lower in regions I, II, and III; the sugar-alkaloid ratio is significantly higher in region V and lower in regions I and VII; the nitrogen-alkaloid ratio is significantly higher in region VIII and lower in regions I, II, and III; the potassium-chloride ratio is relatively high in regions I and II, and lower in regions V, VII, VIII, and IX.

Table 2. Comparison of chemical composition indexes in different locations of tobacco leaf

Location	Reducing sugar (%)	Total sugar (%)	Total alkaloid (%)	Chlorine (%)	Potassium(%)	Total nitrogen (%)	TS/TA	TN/TA	P/C
I	30.89±0.36ab	36.02±0.54b	2.23±0.04a	0.28±0.03d	1.11±0.02e	1.75±0.02c	16.14±0.10e	0.78±0.02e	4.03±0.37a
II	28.28±0.33c	33.75±0.39cd	1.94±0.03c	0.30±0.02cd	1.22±0.03d	1.73±0.03c	17.31±0.35cd	0.89±0.01de	4.09±0.16a
III	31.59±0.36a	37.55±0.40a	2.16±0.07ab	0.29±0.03d	0.99±0.06f	1.76±0.03c	17.39±0.30cd	0.81±0.03e	3.47±0.14b
IV	30.10±0.19b	37.31±0.19a	2.05±0.09b	0.36±0.02c	1.26±0.02d	1.87±0.03b	18.25±0.73bc	0.91±0.03d	3.46±0.07bc
V	26.99±0.21d	33.90±0.20cd	1.72±0.06d	0.48±0.03b	1.52±0.03b	1.86±0.02b	19.77±0.45a	1.08±0.03b	3.14±0.20bcde
VI	30.73±0.17ab	36.84±0.38ab	1.98±0.08c	0.36±0.04c	1.21±0.02d	1.89±0.03b	18.60±0.44b	0.95±0.02cd	3.38±0.28bcd
VII	26.35±0.20d	33.54±0.32d	1.99±0.03c	0.52±0.02b	1.47±0.03b	2.03±0.04a	16.81±0.17de	1.02±0.03bc	2.81±0.04e
VIII	22.76±0.28e	30.51±0.36e	1.65±0.02d	0.69±0.05a	1.95±0.09a	1.98±0.05a	18.44±0.34bc	1.20±0.02a	2.84±0.07e

IX	28.13±0.90c	34.41±0.29c	1.97±0.07c	0.47±0.04b	1.36±0.03c	1.90±0.04b	17.44±0.46bcd	0.96±0.03cd	2.90±0.13cde

Note: Different lowercase letters in the same column represent significant differences at the P < 0.01 level.

3.2 Entropy Weight TOPSIS Analysis of the Comprehensive Quality of Tobacco Leaves from Different Positions

During the comprehensive evaluation process, weights represent the importance of each indicator. As shown in Table 3, after the calculation of entropy values, the weight coefficients for the conventional chemical component content and coordination indicators of tobacco leaves are ultimately determined, with the weight set Wj = {0.0473, 0.0204, 0.0429, 0.4757, 0.1982, 0.0144, 0.0174, 0.0881, 0.0956}. Among these, the content of chlorine and potassium has a larger weight, indicating that the content of chlorine and potassium is the most important factor affecting the quality differences among different positions of tobacco leaves.

As shown in Table 4, based on the relative closeness C values for ranking, the order is as follows: VI, IV, III, I, IX, II, V, VII, VIII. The larger the C value, the better the quality of the evaluated object. The C values of the 9 tobacco leaf positions range from 0.377 to 0.638. The average C values for I, III, IV, and VI are relatively large, all greater than 0.6, leading to the conclusion that these areas, specifically the upper-middle edge of the tobacco leaf, have better quality, especially the middle edge of the leaf. On the other hand, the average C values for VII, VIII, and IX are relatively small, all less than 0.5, indicating that these areas, particularly the base of the leaf near the petiole, have poorer quality overall, with the base near the petiole being the worst quality area of the entire leaf.

Table 3. Weights of comprehensive quality evaluation indexes in different locations of tobacco leaf

Index	Reducing sugar %	Total sugar %	Total alkaloid %	Chlorine %	Potassium %	Total nitrogen%	RS/TA	TN/TA	P/C
Weights coefficient	4.73%	2.04%	4.29%	47.57%	19.82%	1.44%	1.74%	8.81%	9.56%

Table 4. Comprehensive quality evaluation ranking of different locations of tobacco leaf

Location	Positive ideal solution distance	Negative ideal solution distance	C Relative closeness	Rank
I	0.271	0.419	0.607	4
II	0.298	0.301	0.503	6
III	0.281	0.447	0.614	3
IV	0.231	0.387	0.626	2
V	0.281	0.266	0.486	7
VI	0.232	0.409	0.638	1
VII	0.319	0.236	0.425	8
VIII	0.459	0.278	0.377	9
IX	0.266	0.292	0.524	5

3.3 Cluster Analysis of Conventional Chemical Component Indexes from Different Positions

The results of the cluster analysis of the conventional chemical component content and coordination indicators from different positions of tobacco leaves are shown in Figure 2. Based on the values of various indicators, the leaf surface positions of tobacco leaves can be divided into three categories: The first category is position VIII, which has relatively low levels of total plant alkaloids, reducing sugars, total sugars, and potassium-chloride ratio, with other indexes being relatively high; the second category includes positions I, III, IV, and VI, which have relatively high levels of total plant alkaloids, reducing sugars, total sugars, and potassium-chloride ratio, with other indexes being relatively low; the third category consists of positions II, V, VII, and IX, with indexes being relatively moderate. The classification results are generally consistent with the entropy weight TOPSIS ranking, thereby indicating that the differences in chemical component content and coordination indexes from different positions of tobacco leaves can provide theoretical support for the cutting processing and classified use of tobacco leaves.

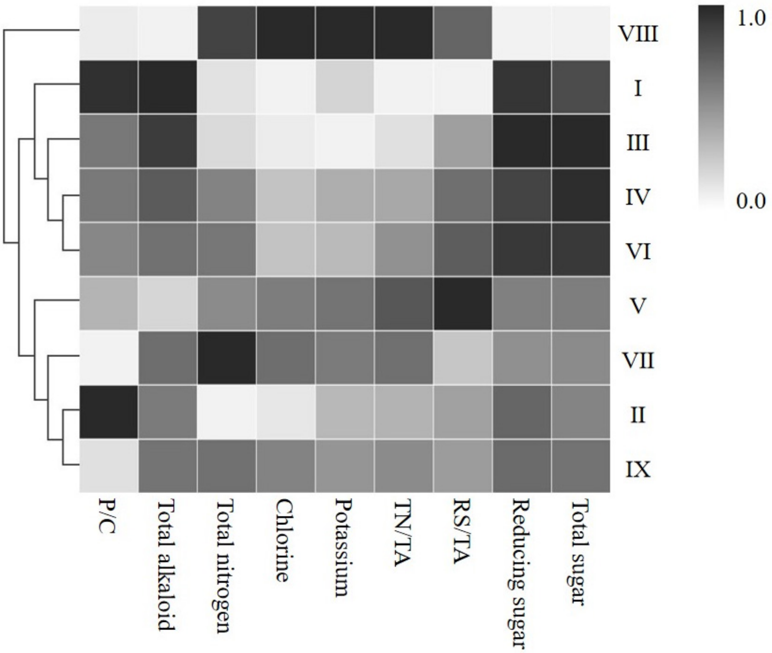

Fig. 2. Clustering heatmap of chemical composition indexes in different locations of tobacco leaf

3.4 Sensory Quality Evaluation of Combined Cut Tobacco Leaves

Based on the results of the entropy weight TOPSIS and cluster analysis, tobacco leaves were combined and cut into samples of (I, III, IV, VI), (II, V, VII, IX), and VIII for sensory quality comparison. The results, as shown in Table 5, indicate that the (I, III, IV, VI) combination scored relatively higher in aroma quality, Offensive taste, concentration, fineness, and irritancy compared to the other two groups. The (II, V, VII, IX) combination scored relatively higher in aroma quantity and glometaration compared to the other groups, while VIII scored lower in all individual evaluation items. Overall, the ranking by total sensory quality score is (I, III, IV, VI) > (II, V, VII, IX) > VIII, further indicating that there are sensory quality differences in different positions on the leaf surface, and that reasonable cutting can more effectively highlight the style characteristics of the tobacco leaves.

Table 5. Evaluation of sensory quality of tobacco leaf in each group

Location	Aroma characteristic			Smoke characteristics				Mouthfeel characteristics			Total points
	Aroma quality	Aroma quantity	Offensive taste	Concentration	Strength	Fineness	Glometaration	Irritancy	After taste	Sweet after taste	
I, III, IV, VI,	6	5.5	6	5.5	5.5	6	5.5	6	5.5	5.5	57
II, V, VII, IX,	5	6	5.5	5	5.5	5.5	6	5.5	5.5	5.5	55
VIII	5	5.5	5	5	5	5.5	5	5.5	5	5	51.5

4 Discussion

In this study, significant differences in the distribution of chemical component content and coordination indicators were observed among different positions of tobacco leaves, but the distribution results of some indicators slightly differed from previous studies. In the research by Wang Xiaodong et al.[6], chlorine content was higher at the leaf tip, whereas in this study, it was higher at the leaf base (positions VII, VIII, IX). Yin Quanyu et al.[22] believed that there was no significant difference in reducing sugars and total sugars across horizontal positions, while this study found significant differences. These discrepancies may be related to the different leaf cutting methods selected, further indicating the substantial differences in chemical component content and coordination indicators among different positions of tobacco leaves, and that different cutting methods may lead to different tobacco qualities.

The entropy weight TOPSIS analysis results show that chlorine and potassium content are the most important factors affecting the quality differences among different positions of tobacco leaves. It also ranks the quality of different leaf positions as VI, IV, III, I, IX, II, V, VII, VIII. Further cluster analysis reveals that the leaves can be grouped into three categories: (I, III, IV, VI), (II, V, VII, IX), and VIII. In terms of chemical components, the comprehensive quality of the middle and upper edge of the leaf is better, especially at the middle edge position, while the base of the leaf has poorer quality, particularly near the petiole. The differences and similarities in quality across different sections of the leaf can further provide theoretical support for cutting, threshing, and re-drying processes.

Sensory evaluation can directly reflect the intrinsic quality of tobacco leaves and their products. Quan Jiafeng et al. [23] showed that the sensory quality of medium and low-grade cut tobacco leaves was improved and could be used for higher-grade tobacco leaf modules. Han Wei et al. [24] demonstrated that cutting processing increased the proportion of high-grade tobacco in the middle, enhancing the compatibility and usability of tobacco leaves. In this study, there were significant differences in sensory quality indicators among different position combinations after cutting, further validating that the cutting method effectively distinguished between areas of lower and higher tobacco quality. This cutting processing method is beneficial for highlighting the style characteristics of tobacco leaves, enhancing their usability, and thus meeting the demand for high-quality raw materials.

In terms of selecting tobacco leaf cutting methods, previous researchers mainly considered longitudinal quality differences. Niu Yangyang[25] believed that "cutting the leaf base and body separately and processing them individually," "one cut into two with the base entering the four-stage process," and "three cuts into four sections" could significantly improve the rate of large and medium-sized leaves after stemming. Wang Yuzhen et al.[15] suggested that cutting Zhusha tobacco from the leaf tip to the base in a ratio of 12.31%:55.38%:32.31% is more conducive to enhancing the utilization value of tobacco leaf raw materials and their contribution to cigarette products. Li Shaopeng et al.[26] proposed that processing C3F-grade Cuibi No.1 by cutting off 20cm of the leaf base could maximize the value of individual tobacco leaves. This study considered the quality differences of tobacco leaves in both longitudinal and latitudinal directions, proposing to divide the leaves into three groups: the middle and upper edge, the base, and the remaining parts. However, for the convenience of the actual processing process, the leaves could be divided into two groups: the middle and upper edge and the remaining parts. The higher-quality middle and upper edge could be used in better tobacco leaf module formulas. Since tobacco leaf formulas have a certain degree of tolerance, the remaining parts of the tobacco leaves could still be used in the original module formulas to maximize the retention of tobacco leaf value.

Cutting can effectively distinguish tobacco leaves by quality, improving their usability and utilization rate. The higher-quality parts after cutting can be used in better tobacco leaf module formulas, which can compensate for the shortage of high-quality tobacco leaf raw materials to some extent and is of great significance for enhancing the security of cigarette raw materials. Based on this research, the next step could expand to specific module formulas to carry out cutting tobacco leaf adaptability studies.

5 Conclusion

There are significant differences in the distribution of chemical component content and coordination indexes among different positions of tobacco leaves. Overall, the comprehensive quality of the middle and upper edge of the leaf is better, especially at the middle edge position, while the quality at the leaf base is poorer, particularly near the petiole. Additionally, the sensory quality of the middle and upper edge of the leaf is the best, mainly characterized by good aroma quality, off-flavors, concentration, smoothness, and irritation, while the sensory quality of the base near the petiole is the worst, with all individual indicators performing averagely. By cutting, tobacco leaves can be divided into the middle and upper edge parts and the remaining parts for separate use.

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