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ANALYSIS OF NUTRIENTS AND FLAVOR OF JUJUBE AND THEIR SUITABILITY AS HIGH VALUE FOOD IN INDUSTRIAL DEVELOPMENT, LVLIANG CITY, CHINA

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Key words: Jujube, Nutrient composition, Sensory characteristics, Principal component analysis, Regression model, Condiment development

Abstract

Taking jujube from 13 counties of Lvliang City as the research object, the relationship between main nutrients and flavor characteristics of jujube was analyzed. The difference of flavoring potential of jujube in different counties was explored. Through correlation matrix analysis, principal component analysis, cluster analysis and regression analysis models, the results showed that sugars (sucrose, fructose and glucose) were the main contributing factors to sweetness. Acids (total acids) were significantly correlated with sour taste. Fat and protein show a nonlinear relationship in the influence of texture and flavor intensity. Specifically in terms of distribution area, the high-sugar jujube produced in Linxian County is suitable for the production of sweet food. The sugar content of jujube in Linxian County is 569.64 mg/g, the glucose content is 166.84 mg/g, and the fructose content is 175.75 mg/g, and its sweetness has obvious advantages. Xingxian jujube has high acidity and total acid content is 4.76 mg/g, which is suitable for developing functional sour food. The water content of jujube in Shilou County is 19.5%, the protein content of jujube in Liulin County is 3.59 g /100g, and the ash content of jujube in Fenyang City is 2.79g/100g. These three places are suitable for making functional food and high value-added products. This research provides technical support for the development of high-quality jujube products for sensory optimization and industrial development.

Introduction

Jujube (*Ziziphus jujuba*) is an important traditional fruit in China, also known as Red dates or Chinese dates. As a major producing area in Shanxi Province, jujube produced in Lvliang City has unique flavor, rich in nutrition and significant homology characteristics of medicine and food (Shen *et al*. 2023). Jujube is rich in carbohydrates, dietary fiber, amino acids and vitamin C, and has various functions such as antioxidant, immune regulation and intestinal health protection (Cai *et al*. 2024). In recent years, with the growing market demand for healthy diet and natural flavoring, the development potential of red dates has attracted more and more attention (Li *et al*. 2024). The sugar, acid and water components of red jujube have an important impact on its sweetness, acidity and flavor characteristics, which not only provides a scientific basis for the development of natural flavoring, but also lays a foundation for the research of fermented foods such as fruit wine and fruit vinegar (Zhao *et al*. 2024). This study systematically analyzed the nutritional composition and flavoring characteristics of jujube in 13 counties of Lvliang City, evaluated its application potential in natural flavoring and fermented food to provide theoretical and technical support for resource optimization and industrial development.

Materials and Methods

In this study, red date samples from 13 counties in Lvliang City were selected as the research object (3 sampling points were randomly selected in each county, and 3 groups of samples were collected at each point). The samples had significant regional representation to ensure the consistency and accuracy of the data.

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The nutritional components of jujube samples were determined according to respective national standards and established methods. Moisture, ash, fat, and protein contents were analyzed in compliance with Chinese National Food Safety Standards GB 5009.3-2016, GB 5009.4-2016, GB 5009.6-2016, and GB 5009.5-2016, respectively (Tang *et al.* 2023, Fan *et al.* 2020; Forouzesh *et al.* 2023; Mæhre *et al.* 2018). Vitamin C (ascorbic acid) and total acid were determined based on GB 5009.86-2016 (Doseděl *et al.* 2021) and GB/T 12456-2021 (Yue *et al.* 2022). The sugar content was quantified using high-performance liquid chromatography (HPLC) as described by Crha and Pazourek (2020), wherein individual sugars (glucose, fructose, and sucrose) were separated and quantified via the standard curve method.

In order to study the effect of nutrient composition on flavoring characteristics of red jujube, linear regression and multiple regression analysis were used in this study. The independent variables include the main nutrients of jujube (water, sugar, total acid, etc.), and the dependent variables are flavoring characteristics (sweetness, acidity, etc.). SPSS 26.0 and Origin 2021 software were used for data fitting and regression analysis to quantify the influence of nutrients on flavoring characteristics and evaluate the development potential of jujube products.

The experimental data were preliminarily processed using Excel 2019 for statistical analysis of mean value, standard deviation and coefficient of variation. SPSS 26.0 was used for significance analysis, combined with principal component analysis (PCA) and cluster analysis (CA), to reveal the key correlation and regional characteristics of jujube nutrients. Origin 2021 is used for visual analysis of the data to visually demonstrate the relationship between the nutritional composition and flavoring characteristics of red dates.

Results and Discussion

The regional variations in the nutritional composition of jujubes from 13 areas of Lvliang City are presented in Fig. 1. Significant geographical differences were observed in the contents of major nutrients, including water, sugar, fat, protein, total acid, ash, and vitamin C. Jujubes from Linxian exhibited the highest total sugar content (569.64 mg/g), indicating a pronounced sweetness advantage (Liao *et al.* 2024). In contrast, those from Xingxian had a total acid content of 4.76 mg/g, highlighting their distinct sourness. Jujubes from Lanxian contained the highest vitamin C level (175.13 mg/kg), suggesting strong antioxidant potential. Additionally, samples from Liulin County showed a protein content of 3.59 g/100 g, while ash content was highest in jujubes from Fenyang City (2.79 g/100 g), reflecting a relatively high mineral composition. Jujubes from Shiliou County had a moisture content of 19.5%, which contributes to their soft texture and suitability for storage and processing.

Based on the regional differences of jujube nutrients, differentiated development strategies can be formulated. The high sugar content of Linxian jujube is suitable for sweet flavoring such as jujube, jujube syrup and high quality raw materials for fruit wine brewing. The high acidity of Xingxian jujube makes it an ideal choice for the development of fruit vinegar and sour seasoning, and has the potential for research and development of functional food; Red dates in Lanxian county are rich in Vit. C, which is suitable for the production of antioxidant fermented food and meets the market demand of health food (Ma *et al.* 2013). In addition, because of the high content of protein and ash, jujube in Liulin County and Fenyang City is suitable for the production of functional jujube powder and mineral fortified food; Shilou County jujube high moisture content makes it more suitable for low temperature processing and fresh food applications. By combining regional characteristics and ingredient advantages, Lvliang jujube has significant development potential in the field of natural flavoring and fermented food, which can effectively promote industrial diversification and high value-added development.

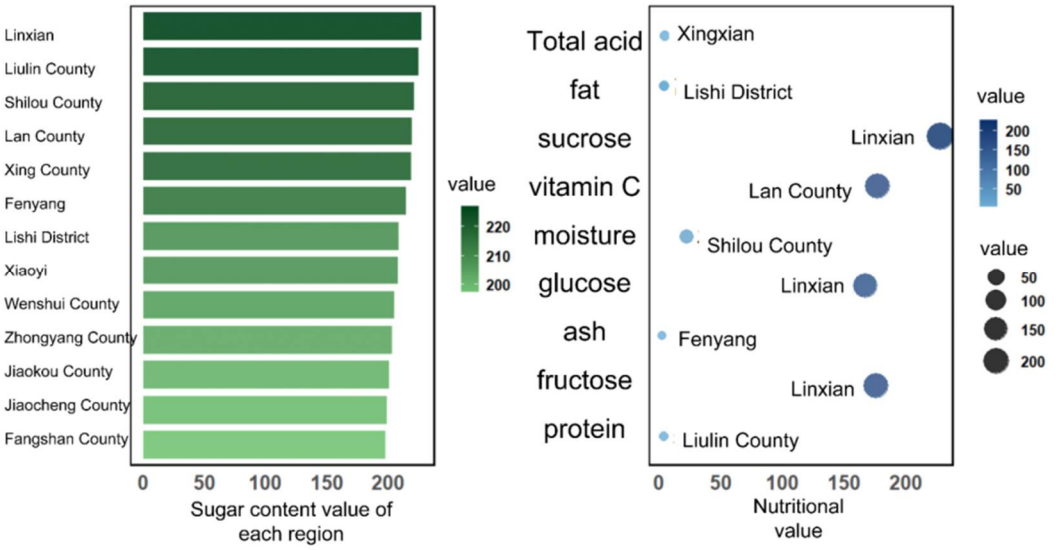

Fig. 1. Distribution of nutrients of red jujube in Lvliang City.

The correlation between flavor and nutritional components of Lvliang jujube is shown in Fig. 2. It shows the distribution of sensory characteristics (sweetness, acidity, flavor intensity and texture) of red jujube in 13 regions of Lvliang City, showing obvious regional differences. Linxian jujube has the highest sweetness due to its high content of glucose, fructose and sucrose, and is an

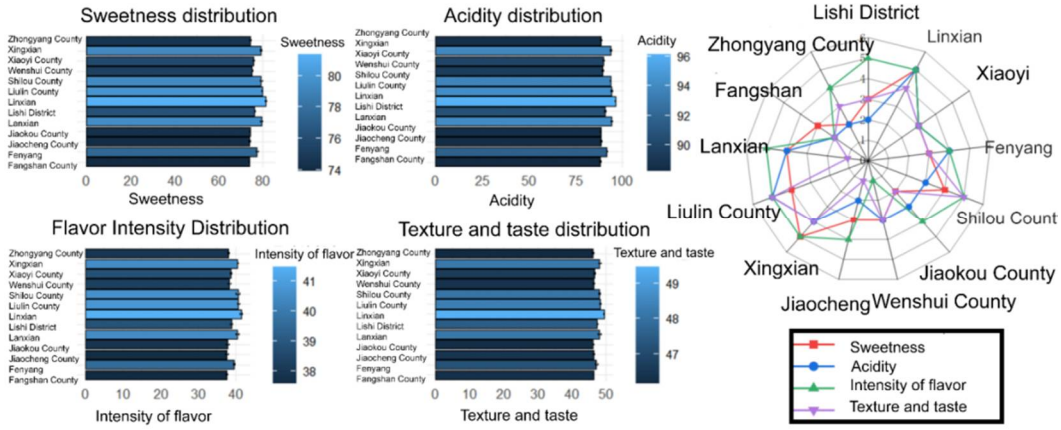

Fig. 2. Correlation between flavor and nutrient content of red jujube in Lvliang city.

ideal raw material for sweet flavoring such as candied fruit and jujube syrup (Al-Hilphy *et al*. 2023). The acidity of Xingxian jujube is significant, which is suitable for developing functional food such as sour seasoning and fruit vinegar. Jujube in Lishi District, with its outstanding flavor intensity and soft taste, is suitable for the production of high-quality snacks and compound condiments (Singh *et al*. 2023). In addition, Shilou County jujube is more suitable for fresh food and low-temperature processing products due to its high moisture content, soft meat and good chewing sensation (Huang *et al*. 2021).

The radar map comprehensively shows the difference of sensory characteristics of red jujube in different regions of Lvliang City, which provides data support for the accurate positioning of regional resources. The high sweetness of Linxian jujube is suitable for developing sweet food such as jujube, syrup and fruit wine. The outstanding acidity of Xingxian jujube provides a natural advantage for the production of fruit vinegar and sour seasoning (Budak 2022). Due to its rich flavor and excellent texture, jujube in Lishi District may be related to its high fat content (Fu *et al.* 2021), which has the potential to develop multi-functional compound condiments and high-end snacks. Shilou County jujube due to high moisture content, soft texture, suitable for fresh food market and soft processing product development, to meet consumer demand for high-quality jujube.

The results of principal component analysis of jujube nutrients are shown in Fig. 3. It highlights the results of principal component analysis (PCA) of jujube nutrients in Lvliang City. Principal component 1 (PC1) explains 69% of the variance and is dominated by sugars such as sucrose, fructose and glucose, revealing the key role of sugars in sweetness properties. Principal component 2 (PC2) explains 14.5% of the variance, correlated with fat and water content, indicating that these components significantly influence the texture and flavor intensity of jujube. Specifically, fat enhances flavor intensity by improving the solubility of flavor substances, while increased moisture endows jujube with soft texture (Liu *et al.* 2022). The double coordinate diagram of principal components shows that the load of carbohydrate variable is the highest in PC1 axis, and the contribution of fat and water is prominent in PC2 axis. These analysis results confirm the key role of nutrients in sensory properties and provide scientific basis and data support for resource optimization and product development of red jujube (Belayneh *et al.* 2022).

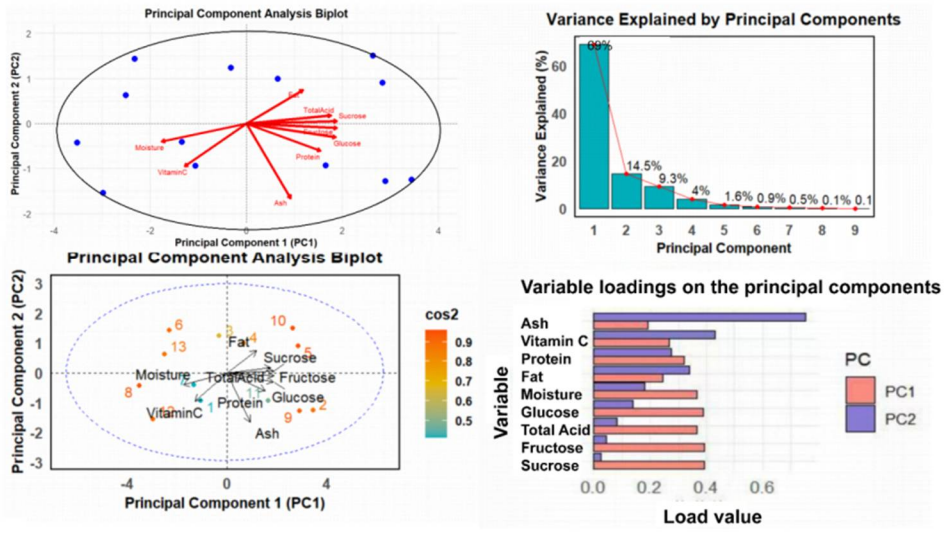

Fig. 3. Principal component analysis of nutritional composition of red jujube.

Based on the results of principal component analysis, jujube in high sugar region (such as Linxian) is suitable for developing sweet products such as jujube, jujube syrup and fruit wine brewing by virtue of its sweetness advantage. The fat and water advantages revealed by PC2 make jujube more intense and soft texture, and this kind of jujube (such as some jujube in Lishi area) is suitable for processing into high-end snacks and soft functional foods. Combined with the above results, jujube product development can focus on key ingredients such as sugar, fat and water, and

achieve precise regulation of sensory characteristics by optimizing processing technology and fermentation conditions to meet diversified market demands. The region with superior sweetness is suitable for the development of sweet flavoring and fermented food, while jujube with excellent flavor and texture can be applied to the complex flavoring and functional food market (Cai *et al.* 2024). These strategies will promote the efficient use of Lvliang jujube resources and industrial diversification, and provide strong support for the promotion of regional brand competitiveness.

As shown in Fig. 4, the results of correlation and cluster analysis of nutrients in jujube trees were shown. It shows the correlation matrix and cluster analysis results of nutrients of red jujube in Lvliang City. The correlation matrix shows that sucrose, fructose and glucose are highly positively correlated (the correlation coefficient is close to 1), indicating that these sugars are the core determinants of sweetness (Wang *et al.* 2018). There was a significant negative correlation between water and sugar (r = -0.82), possibly due to the dilution effect of water, which weakened sensory sweetness (Mao *et al.* 2024). In addition, Vit. C was positively correlated with total acid, which directly affected the sour characteristics of jujube. Fat and ash play different roles in texture and flavor: fat enhances flavor intensity by enhancing the release of flavor substances, while ash imparts a stronger sense of mineral structure and chewing experience to jujube (Li *et al.* 2007). According to the clustering tree diagram, jujube in Lvliang City can be divided into four categories: high sweetness (such as Linxian County, Liulin County), high acidity (such as Xingxian County), high quality land (such as Liulin County, Fenyang City) and comprehensive flavor. High-sweetness jujube is suitable for processing jujube, jujube syrup and sweet drinks because of its rich sugar content (Abdul-Hamid *et al.* 2018). Jujube with high acidity has significant sour taste, which is suitable for the development of fruit vinegar and sour seasoning to meet the market demand of health food (Zhang *et al.* 2023). With high protein and ash content, high quality jujube has shown significant application advantages in functional jujube powder and high quality food development.

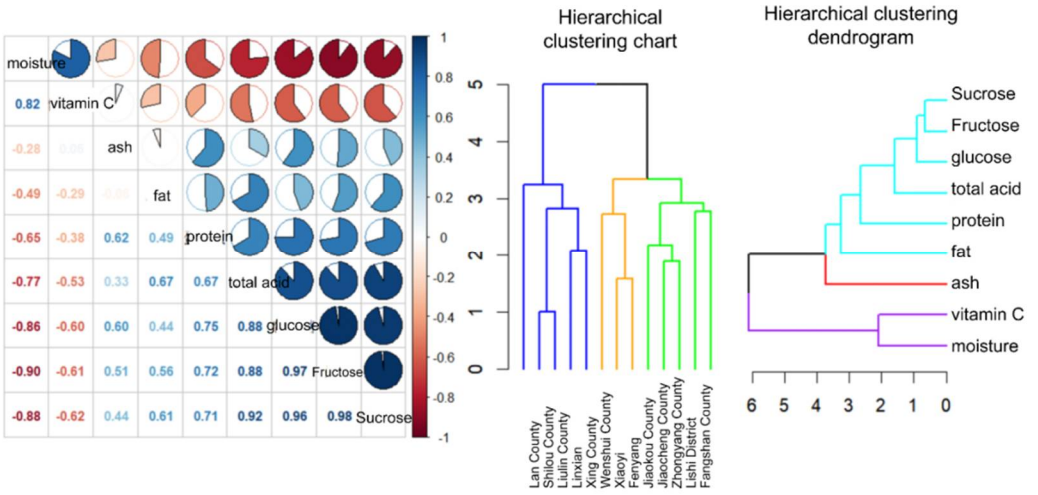

Fig. 4. Correlation and cluster analysis of nutrient composition of red jujube.

Correlation and cluster analysis revealed the combination characteristics of nutrients of jujube in different regions and the correlation with sensory characteristics, which provided scientific basis for resource optimization and classification development. High-sweetness red dates (such as Linxian and Liulin counties) are suitable for developing sweet products such as dates, syrup and fruit wine (Abdul-Hamid *et al.* 2018). High-acidity red dates (such as Xingxian) can be used in the

research and development of fruit vinegar and sour functional food due to their rich acidic components, providing a new direction for the health food market (Zhang *et al*. 2023). In addition, high-quality local jujube with high protein and ash content (such as Liulin County and Fenyang City) is suitable for use in functional jujube powder and compound flavoring foods to meet consumers' demand for high value-added products with both nutrition and taste. Comprehensive flavor red dates have wide application potential, and can be used as high-quality raw materials for high-end snacks and compound condiments. By combining correlation and cluster analysis, the classification development and market positioning of jujube resources can be accurately optimized, providing strong support for the brand promotion and market expansion of Lvliang jujube (Gulzar *et al*. 2022).

Fig. 5 is the result of the regression relationship between nutritional components and flavor characteristics. It shows the regression relationship between nutrients and flavoring characteristics of red jujube in Lvliang City. Fig. 5A shows a significant linear regression between sweetness and sugars (glucose, sucrose and fructose), with a fitting degree of $R^2 = 0.85$ ($P < 0.0001$), indicating that sugars are the core contributing factors of sweetness characteristics and provide data support for the development of sweet flavoring (Sun *et al*. 2016). Fig. 5B shows a significant regression relationship between acidity and total acid (citric acid), with a fitting degree of $R^2 = 0.63$ ($P = 0.00124$), confirming that acids are the main determinant of the formation of sour taste, laying a scientific foundation for the research and development of sour food and fruit vinegar. In contrast, the regression fit of Fig. 5C (flavor intensity, $R^2 = 0.55$) and Fig. 5D (texture and taste, $R^2 = 0.50$) is low, suggesting that the effects of fat, water, and protein on these sensory properties are more complex and may involve non-linear relationships or multi-factor synergies.

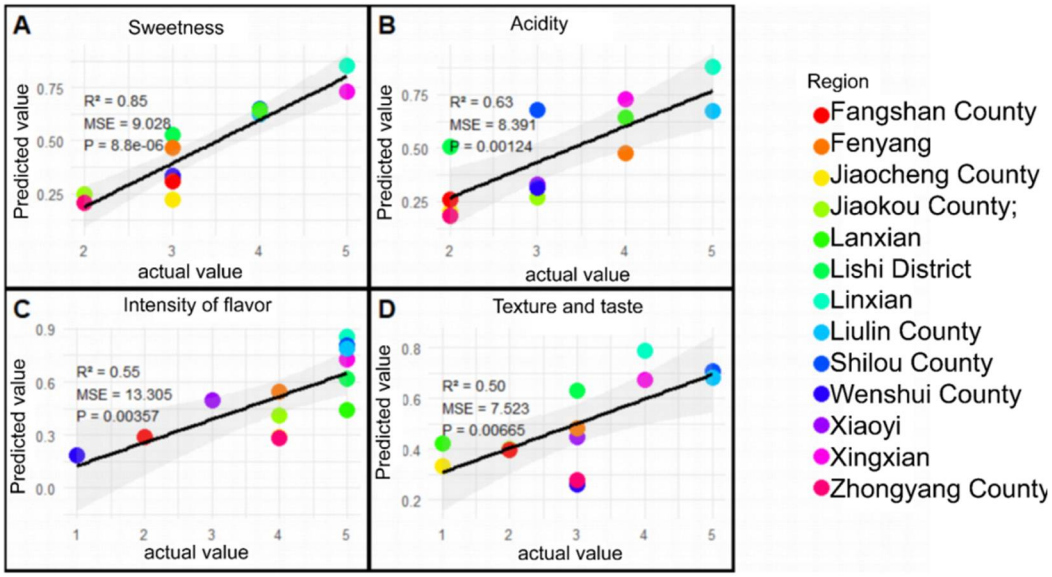

Fig. 5. Regression relationship between nutrient composition and flavoring characteristics of Lvliang red jujube.

The results of regression analysis showed that the contribution of carbohydrate components to sweetness characteristics was the most significant ($R^2 = 0.85$). High-sugar jujube (such as Linxian and Liulin counties) is suitable for the development of sweet foods such as jujube, jujube syrup and fruit wine, showing clear market application value (Sun *et al*. 2016). The strong correlation between acidity and total acid ($R^2 = 0.63$) indicates that jujube in areas with outstanding sour taste

(such as Xingxian) is suitable for the development of fruit vinegar and sour functional food to meet the needs of health food market. The low fat of flavor intensity and texture ($R^2 = 0.55$ and $R^2 = 0.50$) suggests that these properties are strongly influenced by the non-linear effects of fat, water, and protein. For example, fat enhances flavor intensity by increasing the solubility of flavor substances, while water and protein influence texture performance through a synergistic effect: higher water content gives dates a soft taste, while protein enhances structural stability and chewiness. In addition, external factors such as processing processes and storage conditions can also significantly affect these sensory properties.

In addition to the above research results, the relationship between regional differences and jujube resource optimization, the relationship between nutrients and sensory characteristics, and the guiding role of principal component analysis and regression analysis were also discussed.

First, significant regional variations were observed in the main nutrients (sugar, water, total acid, protein) of jujube in Lvliang, providing a basis for resource optimization. High-sugar jujube (e.g., Linxian, Liulin) is suitable for sweet products like preserves and wine; high-acid jujube (e.g., Xingxian) for vinegar and seasonings; high-protein and high-ash jujube (e.g., Liulin, Fenyang) for functional powder and high-value foods. Sugar and acid were identified as core flavor components, with fat and water influencing texture and intensity. These findings support targeted applications in sweet flavorings, fermented foods, and compound seasonings. Regional differentiation and process optimization can enhance product value and brand competitiveness.

In addition, the sensory properties of jujube (sweetness, acidity, flavor intensity and texture) are determined by a combination of nutrients. The significant linear relationship between sugars and sweetness and acids and acidity indicates that they are key factors affecting flavor characteristics (Hernández *et al*. 2016). In contrast, the effects of fat and protein on flavor intensity and texture are complex and non-linear, which may be due to the synergistic effect of fat on flavor solubility and water and protein on taste structure. These correlations provide a scientific basis for accurate seasoning and texture optimization of jujube products, especially in the development of sweet flavoring, sour food and compound flavoring, through ingredient regulation can effectively improve product flavor quality and market competitiveness.

Last but not least, Principal component analysis and regression model revealed the quantitative effects of nutrients on sensory properties of red jujube. Sugar is the main contributing factor to sweetness, and fat and water play a key role in texture and flavor expression (Wang *et al*. 2023). Principal component analysis showed that sugar dominated sweetness, while fat and moisture synergically affected flavor intensity and texture. The regression model further verified the specific contribution of each component to sensory characteristics such as sweetness and acidity. Combined with these results, jujube product development can improve sensory quality and optimize market positioning through precise nutritional regulation. Especially in the fields of sweet food, fruit vinegar and compound condiments, scientific control of nutritional components will promote the innovative development of Lvliang jujube industry and enhance brand value.

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