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Aroma Analysis of Table Grape Berries Based on Electronic Nose Detection

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Abstract: In this study, the aroma of 182 table grapes was detected using a PEN3.5 electronic nose in order to explore the aroma components of table grape berries and provide a reference for aroma evaluation and quality improvements. Table grape varieties from the Zhengzhou Fruit Research Institute of the Chinese Academy of Agricultural Sciences were used as research materials. All of them were harvested in fruit trees over 10 years old from August to October 2023, which provided a reference for aroma evaluation and quality improvement of the table grapes. Radar analysis, correlation analysis, principal component (PCA) analysis, cluster analysis, and difference analysis were used to study these aroma substances. The results show that the sensor contribution rate from high to low is W5S (nitrogen oxides), W2S (alcohols and some aromatic compounds), W1S (alkanes), and W2W (sensor contribution rate from high to low). Cluster analysis can distinguish the varieties of table grapes a with common aroma content, and the varieties with a higher content are in the second category (II). PCA showed that the contribution rate of the first and second principal components of the three main sensors was 97.6% and 2.3%, respectively, and the total contribution value was 99.9%. The contribution rates of the first and second principal components of the three aromatic sensors are 79.5% and 15.9%, respectively, and the total contribution value is 95.4%. The results showed that there were significant differences in the content and composition of aroma substances in different grape varieties. Eight special germplasm with strong aroma (organic compounds of nitrogen oxides, alcohols, alkanes and sulfur) were selected: 'Spabang', 'Neijingxiang', 'Zaotian Muscat', 'Jinmeigui', 'Zhengguo 6', 'Muscat Angel', 'Zizao', and 'Qiumi'. This study confirmed that electronic nose technology can effectively distinguish different varieties of table grapes. This study not only provides a scientific basis for the variety selection for the table grape processing industry, but it can also be used for male or female grape hybridization, which provides valuable data resources for table grape breeding.

Keywords: aroma; electronic nose; germplasm resources; table grape

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1. Introduction

As one of the most important economic perennial fruit plants, grapesare widely cultivated around the world. Particularly, table grapes are highly popular with consumers due to their unique aroma and high natural antioxidants [1,2]. China is the world's largest producer of table grapes, accounting for about 50% of the world's total output. Since

2011, the output of table grapes in China has ranked first in the world [3]. Aroma is an important component of table grape quality and a key indicator to judge berry maturity and commodity value [4]. Aroma substances in grape berries include alcohols, acids, aldehydes, esters, terpenes, etc. [5]. Table grapes have a higher floral, sweet, and balsam flavor than wine grapes [6].

Research on aroma substances of grape germplasm resources is of great significance to the utilization, development, evaluation, and innovation of grapes. The study of grape aroma shows that the flavor of wine is affected by the aroma compounds in grape fruits, which directly affects the sensory characteristics of wine. Different wine grapes, juice grapes, and table grapes have different aroma components and varieties that are the internal key factors affecting the aroma characteristics of grape fruits [7,8]. Cao et al. used HS-GC-IMS technology to analyze the changes in volatile flavor substances in different varieties of raw wine samples. A total of 52 volatile flavor substances were identified, including 20 esters, 16 alcohols, 8 aldehydes, 4 ketones, and 1 terpene and furan. The contents of volatile flavor substances in different varieties of wine were significantly different. The results showed that ethyl isobutyrate, ethyl caproate-D, 2-methylpropanal, ethyl caprylate, ethyl butyrate-D, and isoamyl acetate may be the compounds that affect the change in aroma [9]. Jana et al. tested grape mash samples for aroma substances, which were released under tasting conditions. The aroma compounds were grouped according to their sensory characteristics, and a correction model was established for the determination of sensory properties by near-infrared spectroscopy (NIR). According to the GC-MS analysis results of grape mash samples, the sensory evaluation of four different grape model solutions was carried out. Despite large variations in individual values, for most of the assessed sensory attributes, the mean of a given score for odor and taste intensity showed differences between model solutions, the abundance of aroma compounds in grape fruits, and differences between varieties [10]. Grape berries are rich in aroma compounds and vary greatly between varieties. At present, there are more comprehensive and in-depth studies on wine grape aroma at home and abroad, but there are few studies on table grape aroma germplasm groups, especially table grape aroma. Therefore, in order to systematically identify aroma components of table grape germplasm resources and improve the consumption and market competitiveness of grape products, electronic nose technology was used to detect aroma substances in ripe table grape berries [11].

At the end of the 20th century, the rapid development of sensor technology and the advent of electronic nose with high detection accuracy opened up a new field of non-destructive detection of fruit aroma. Because the electronic nose has the advantage of non-destructive testing, its determination results are close to the first olfactory feeling of market consumers in contact with fruit, and it has a more direct and practical application value [12,13]. Over time, the application of the electronic nose has expanded to a variety of agricultural products including tea [13], coffee [14], and cocoa beans [15], and it has also been used for the analysis of berry-related aroma detection. Huang et al. showed that PCA based on GC-IMS and E-nose signal strength showed that loquat berries had good differentiation abilities at different shelf lives [16]. With increasing storage time, taste characteristics change with increasing pH, while the content of total soluble solids, vitamin C, and total phenols also decreases. Michela et al. used the electronic nose technique to distinguish the ripening stage (semi-red or red) of strawberries harvested at three different times. Principal component analysis (PCA) performed on the electronic nose allows us to clearly differentiate samples according to maturity stage. Just as in fractional space, samples are clustered in different regions of the plot and the electronic nose sensor can give different responses to samples with different tastes [17]. Schroeder et al. demonstrated the ability of the electronic nose to classify wine and berry samples [18], especially in the identification and classification of samples that had undergone specific treatment. Electronic nose systems play a key role in evaluating and identifying berries with unique aroma characteristics, not only helping to reveal the aroma differences between grape products, but also providing data resources and support for the selection of new grape varieties.

In the current study, an electronic nose was employed to ascertain the aromatic profiles of 182 table grape germplasm resources. Utilizing a variety of analytical techniques, this study preliminarily investigated and identified the aromatic compounds present in mature berries. This exploration offers a substantial foundation of material and data, crucial for the assessment of aroma, the breeding process, and the practical application in table grape cultivation. The insights gained from this research are instrumental in advancing the understanding of grape aroma characteristics and in guiding future breeding strategies to enhance the sensory quality of table grapes.

2. Materials and Methods

2.1. Plant Material

A comprehensive collection of 182 table grape germplasm samples was meticulously gathered from the Zhengzhou Fruit Research Institute of the Chinese Academy of Agricultural Sciences (34°39′ N, 113°41′ E, 110 m, Zhengzhou). Prior to the sampling process, the berry of color was recorded, and the artificial sensory aroma was evaluated (Appendix A). Grapes grow at an average annual temperature of 14.5 °C, an average annual sunshine duration of 2426 h, and an average annual precipitation of 651.0 mm; the frost-free period is about 210 days, the soil structure is loose and has good permeability, the grapes grow in a weak alkaline soil environment. Each material is obtained from 3 vines that are more than 10 years old and grow from their roots. Their row spacing is 1.5 × 2 m, and they run north–south. They are in the shape of a single tree with two arms, and the rain shelter and management of water and fertilizer are unified. Samples were collected from August 2023 and continued until the end of October, at a fixed time of 8 a.m. to 10 a.m. An amount of 100 g of pest-free, uniformly sized, fully ripe fruits (seeds black and brown, stable sugar content) were collected from each tree, and 300 g of each germplasm was quickly sent to the laboratory for testing. Each tree was used as a biological replicate, and each fruit was tested separately, and this was repeated three times.

2.2. Measurement of Grape Berry Aroma

A portable electronic nose instrument (Developed by German AIRSENSE company, purchased from China Beijing Yingsheng Hengtai Technology Co., Ltd., model PEN3.5) is used, which consists of 10 sensors, each of which responds perfectively to a class of volatile substances (Table 1). After the grape samples to be tested were juiced and filtered, 3 mL of the sample was placed in a 20 mL screw-top cavity bottle and left for 30 min at 25 °C. The needle of an electronic nose instrument was inserted into the bottle without the needle touching the sample. The data were determined and repeated 3 times. The measurement of grape aroma was based on the work of Li et al. [19]. During the detection process using the electronic nose, when the sensor interacts with a specific compound, it causes fluctuations in the electrical conductivity (G), which in turn leads to changes in the relative conductivity ratio (G/G0 or G0/G), where G0 is the initial conductivity. If the ratio is close to or exactly equal to 1, this usually indicates that the aroma component being tested is less concentrated in the grape juice. When the relative conductivity ratio deviates significantly from 1, it indicates the presence of a higher concentration of aroma components.

Table 1. Sensitive substances of PEN 3.5 electronic nose sensor [20].

Number	Sensor Name	Performance Specification
1	W1C	Sensor of aromatic benzene
2	W5S	Sensor of NOx compound
3	W3C	Sensor of ammonia
4	W6S	Sensor of hydrogen
5	W5C	Sensor of arom-aliph
6	W1S	Sensor of methane compounds
7	W1W	Sensor of hydrogen sulfide
8	W2S	Sensor of broad-alcohol
9	W2W	Sensor of Organic sulfide
10	W3S	Sensor of methane-aliph

2.3. Statistical Analysis

The Win Muster program in PEN3.5 (Developed by German AIRSENSE company, purchased from China Beijing Yingsheng Hengtai Technology Co., LTD) and Origin 2021 (version 2021, developed by Origin Lab) are used for descriptive statistical analysis, principal component (PCA) analysis, cluster analysis, and variance analysis.

3. Results

3.1. The Response of the Sensor to the Grape

The volatile compounds in the grape berry are measured, and the response of each sensor is represented by a curve (Figure 1). Figure 1 refers to the "cardinal" variety. Each data point on the curve corresponds to the relative resistivity change in the aromatic components released by the grape berry as they pass through the sensor, that is, the relative resistivity ratio (G/G0), which reflects the resistivity change in the sensor under the influence of different gasses. The relative resistivity is low in the early stage, and the conductivity of the sensor increases sharply with the flow of volatiles in the sensor, and finally tends to be flat and reaches a stable state. It can be seen from Figure 1 that the sensor signal tends to be stable after 60 s, and any three stable signals within 66~70 s can be used as the analysis time points.

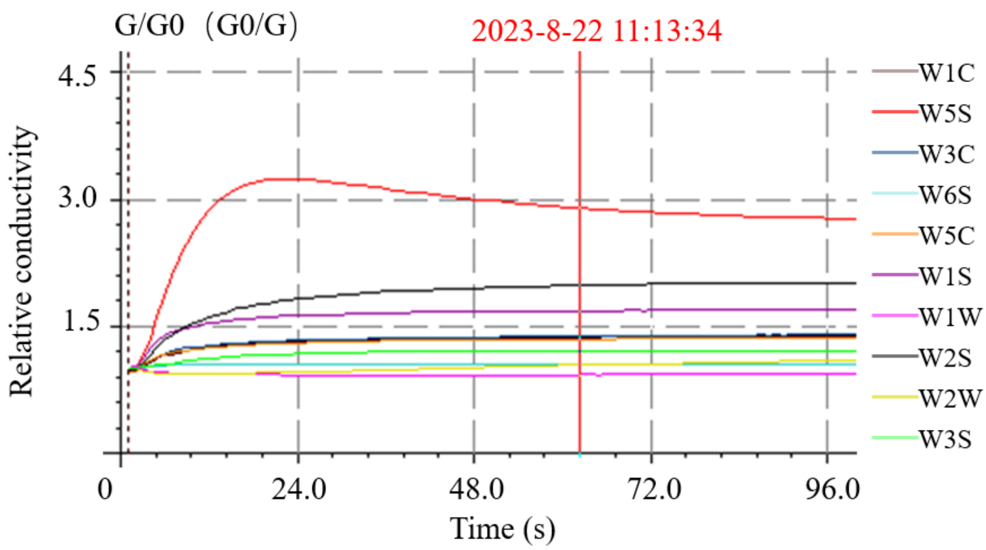

Figure 1. Sensor response to aroma of "cardinal" table grape variety.

3.2. Evaluation of Grape Aroma Response Intensity by Electronic Nose Sensor

Descriptive statistics were performed on the response values detected by sensors in 182 samples of tested grapes (54 samples of *V. vinifera* × *V. labrusca* and 128 samples of *V. vinifera*). According to the analysis results of grape berry aroma by GC-MS technology applied by Xia et al, the main volatile substances in grape berries can be roughly divided into alcohols, aldehydes, esters, ketones, alkanes, and olefins, etc. [13]. However, the volatile substances in berries of different grape germplasm differ greatly. Electronic nose detection (Figure 2A,B) found that the sensors W5S, W2S, W1S, and W2W showed obvious response intensity to the aroma of *V. vinifera* × *V. labrusca* and *V. vinifera* varieties. These results indicate that volatile contributions in grape germplasm are sensitive to W5S, W2S, W1S, and W2W sensors, such as nitrogen oxides, methane, sulfur compounds, alcohols and some aromatic compounds, and these substances have extensive genetic variation between germplasm, and may be the main volatile substances in grape aroma. The response values of W1C, W3C, W6S, W5C, W1W, W3S, and other sensors hardly change.

The comparison of three indicators (amplitude of change, max–minimum value and coefficient of variation) showed that the aroma produced by different substances is different (Table 2). The response values of W5S, W2S, and W1S sensors are higher than other sensors, with coefficients of variation reaching 57.6%, 54.4%, and 48.7%, respectively. However, among the three aroma sensors W2W, W3S, and W1C, the aroma response values of grapes are generally low. The coefficients of variation were 31.2%, 3.4%, and 15.7%, respectively. The content of aromatic substances in the grapes was low. In summary, aroma differences between grape germplasm were mainly caused by aromatic compounds and non-aromatic compounds, among which aromatic compounds were mainly aromatic and sulfur compounds, but the difference was smaller than that of non-substances.

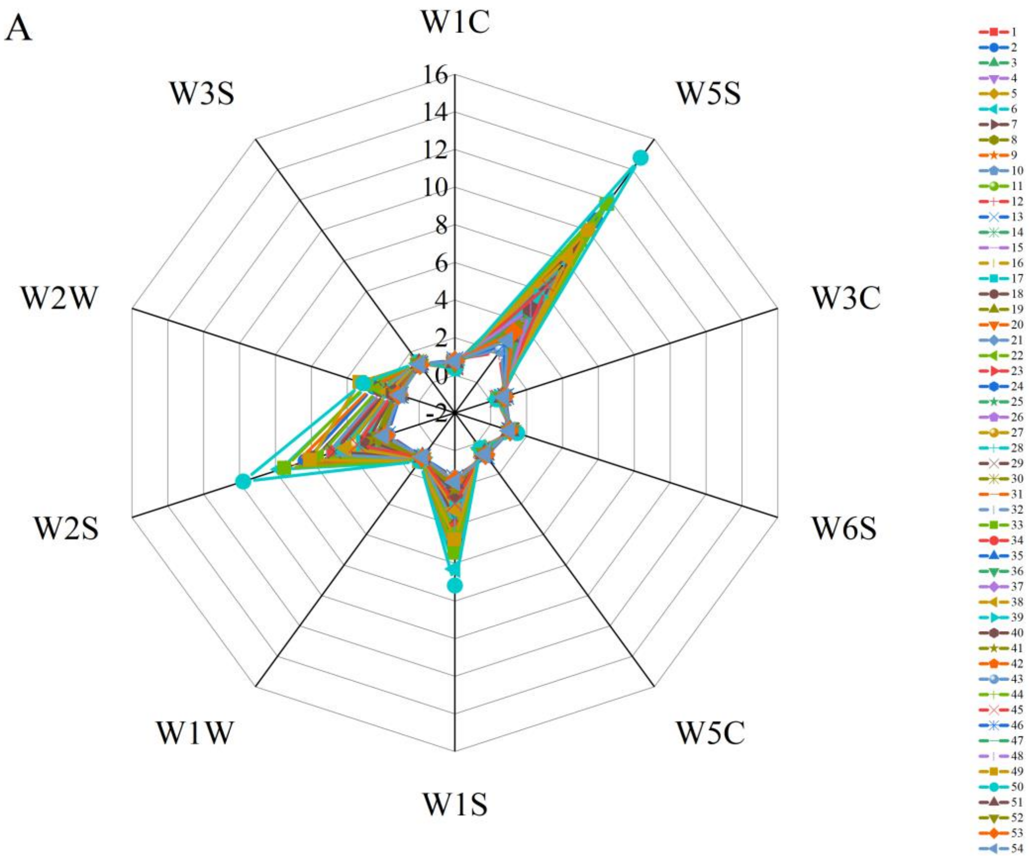

Figure 2. *Cont.*

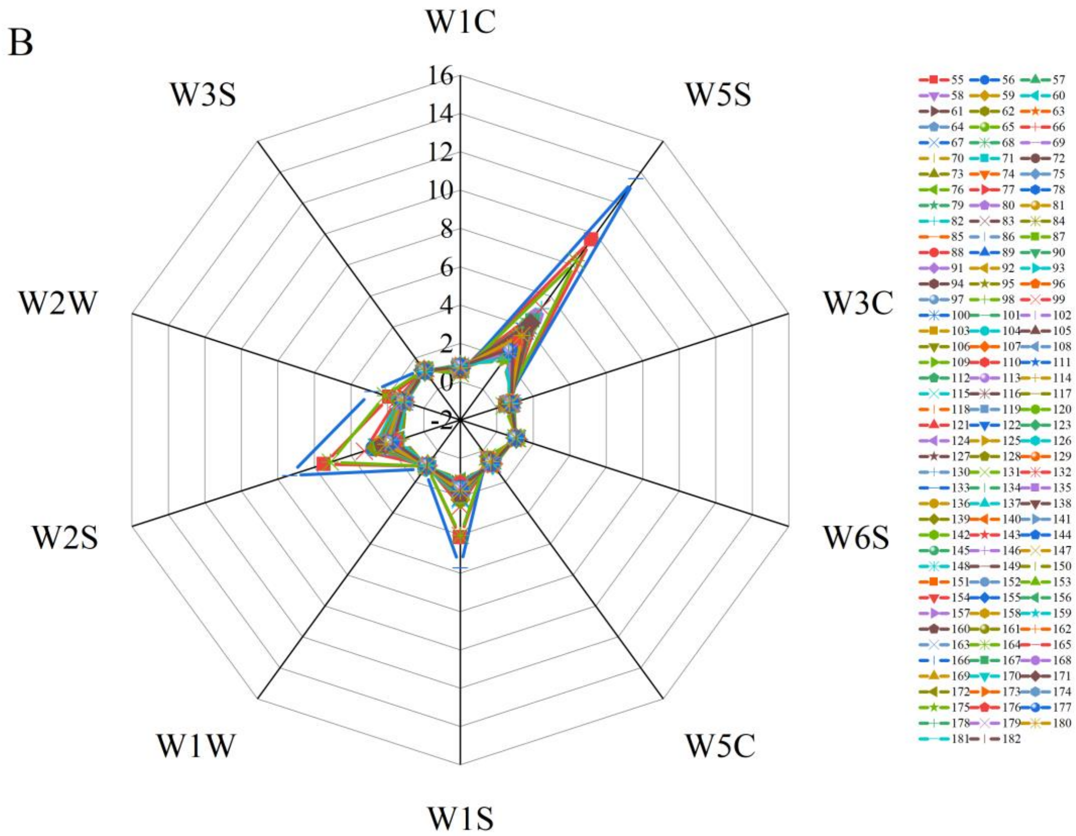

Figure 2. Radar map of electronic nose response values of different grape varieties. Note: (**A**): *V. vinifera* × *V. labrusca*; (**B**): *V. vinifera*.

Table 2. Comparison of response values of different grape aroma sensors.

Index	W1C	W5S	W3C	W6S	W5C	W1S	W1W	W2S	W2W	W3S
Mean	0.70	3.89	0.70	1.08	0.70	1.97	0.97	2.39	1.25	1.19
Standard deviation	0.11	2.24	0.13	0.05	0.13	0.96	0.05	1.30	0.39	0.04
Max	0.94	14.76	0.96	1.47	0.98	7.18	1.19	9.80	3.30	1.33
Min	0.35	1.80	0.32	1.03	0.30	1.08	0.89	1.18	0.98	1.10
Xmax–Xmin	0.59	12.96	0.64	0.44	0.68	6.10	0.30	8.62	2.32	0.23
Variable coefficient (%)	15.7	57.6	18.6	4.6	18.6	48.7	5.2	54.4	31.2	3.4

3.3. Aroma Cluster Analysis of Different Experimental Grape Germplasm

According to the sensor response values, 182 grape germplasm were divided into two categories (Figure 3). The first group (I) contained 165 samples of 'Mill' 'Hongxiangjiao' and 'Horigon', accounting for 90.66% of the sample germplasm, which mainly contained nitrogen oxides; the second group (II) was further divided into two categories, one of which contained 13 germplasm such as 'Spabang', 'Neijingxiang', and 'Niagara', accounting for 7.14% of the germplasm of the test sample, while the other group only contained 4 germplasm of 'Jinmeigui', 'Zhengguo 6', and 'Spabang', accounting for 2.20% of the germplasm of the test sample. The sensor response values of the germplasm resources of this group were mainly nitrogen oxides, alcohols, and alkanes, but the contents of the latter four germplasm were higher than that of the former.

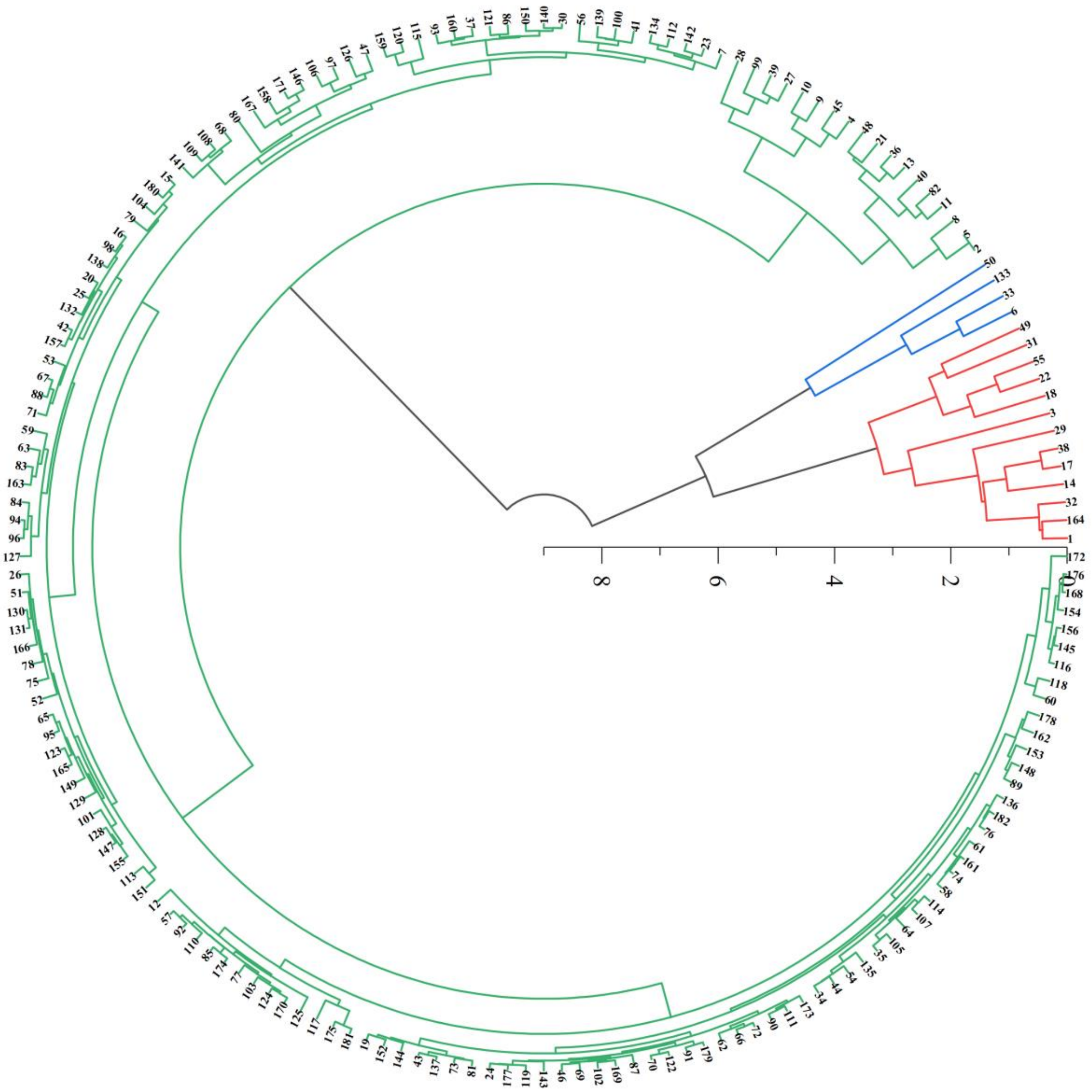

Figure 3. The cluster analysis of 182 table grape germplasm was carried out based on 10 sensor response values. Note: green is the first class (I); red and blue are the second class (II).

3.4. Analysis of Grape Aroma Components and Screening of Special Grape Germplasm

It can be seen from Figure 2 that aroma differences among grape germplasm are mainly caused by the response values of four sensors: W5S, W2S, W1S, and W2W, among which W5S, W2S, and W1S are aromatic sensors. W2W is an aromatic sensor. In order to screen out the table grape germplasm with special fragrance, the response values of three main sensors (W5S, W2S, and W1S) and three aromatic sensors (W3S, W2W, and W1C) were selected, aroma components of 182 table grape germplasm were analyzed. Three stable signal time points of each table grape germplasm were selected to take the average value of the sensors for PCA (principal component analysis) (Figures 4 and 5), and the difference in response values between the three main sensors and the three aromatic sensors was compared (Figures 6 and 7). In the PCA of the response values of the three main sensors, the contribution rate of the first principal component PC1 and the second principal component PC2 was 97.6% and 2.3%, respectively, and the total contribution rate was 99.9%. In the PCA of the response values of the three aromatic sensors, the contribution rate of the first principal component PC1 and the second principal component PC2 was 79.5% and 15.9%, respectively, and the total contribution rate was 95.4%, which was mainly the first principal component that played a role in the variety differentiation. Although the varieties tested were diverse, from the overall point of view of the two main axes of the principal components PC1 and PC2, some grape varieties overlapped with each other and could not be completely distinguished, but some varieties with specific aromas could be better distinguished.

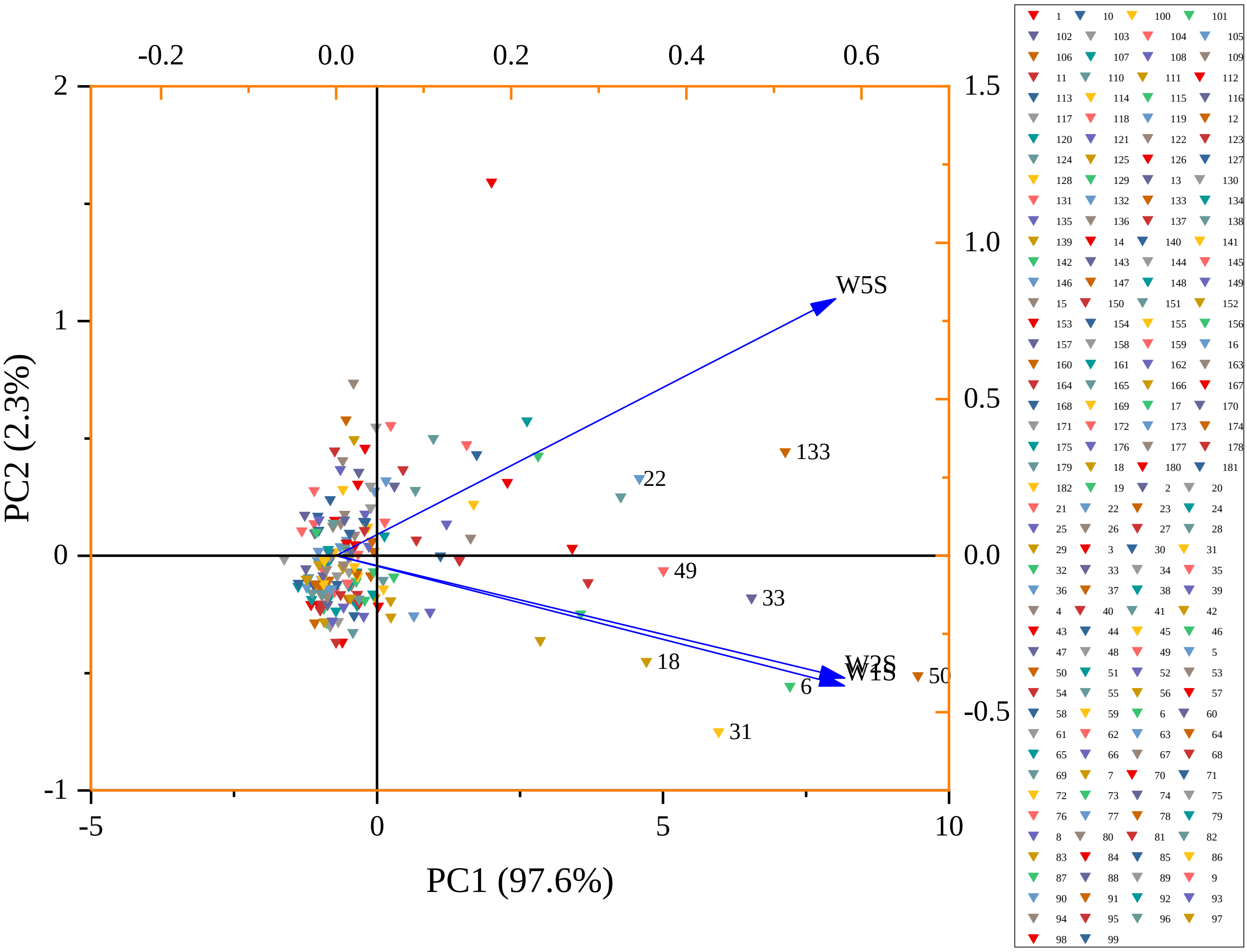

Figure 4. PCA of response values of three main sensors.

The significance difference analysis (Figures 6 and 7) further indicated that eight varieties, including ‘Spabang’, ‘Neijingxiang’, ‘Zaotian Muscat’, ‘Jinmeigui’, ‘Zhengguo 6’, ‘Muscat Angel’, ‘Zizao’, and ‘Qiumi’ had a strong and special berry fragrance. In terms of the first and second principal components, there are significant differences between them and other germplasm. The response values of eight cultivars in W3S and W1C aromatics sensors were not significantly different from those of other germplasm, but the response values of eith cultivars in three main sensors and W2W aromatics sensors were different from most germplasm (Figures 6 and 7). A comparison of the response values was recorded by the four sensors W5S, W2S, W1S (alkanes), and W2W (Figures 6A–C and 7C). Among them, ‘Spabang’, ‘Neijingxiang’, ‘Zaotian, Muscat’, ‘Jinmeigui’, ‘Zhengguo, 6’, ‘Muscat, Angel’, ‘Zizao’, and ‘Qiumi’ had a stronger aroma in these four sensors.

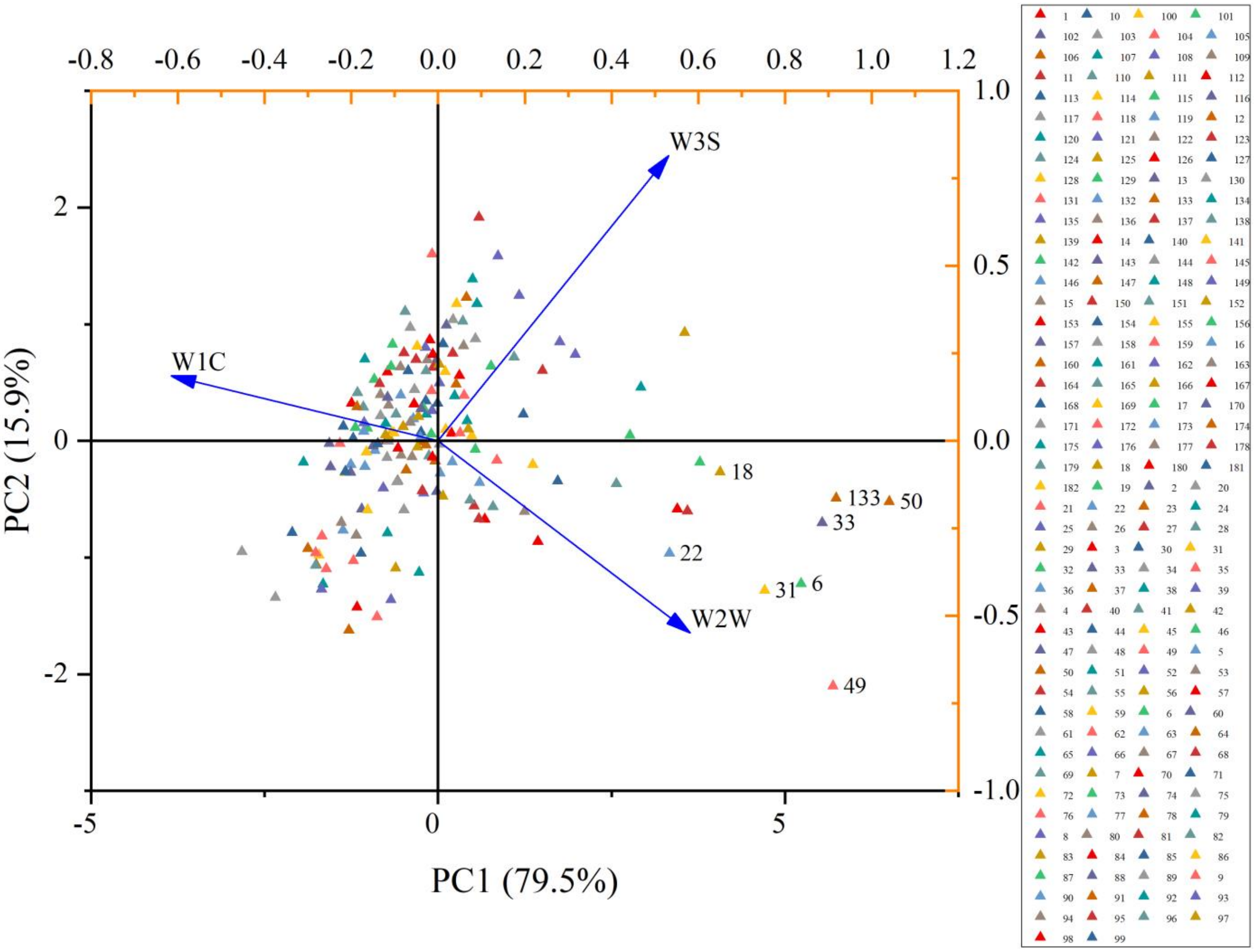

Figure 5. PCA of response values of three aromatic sensors.

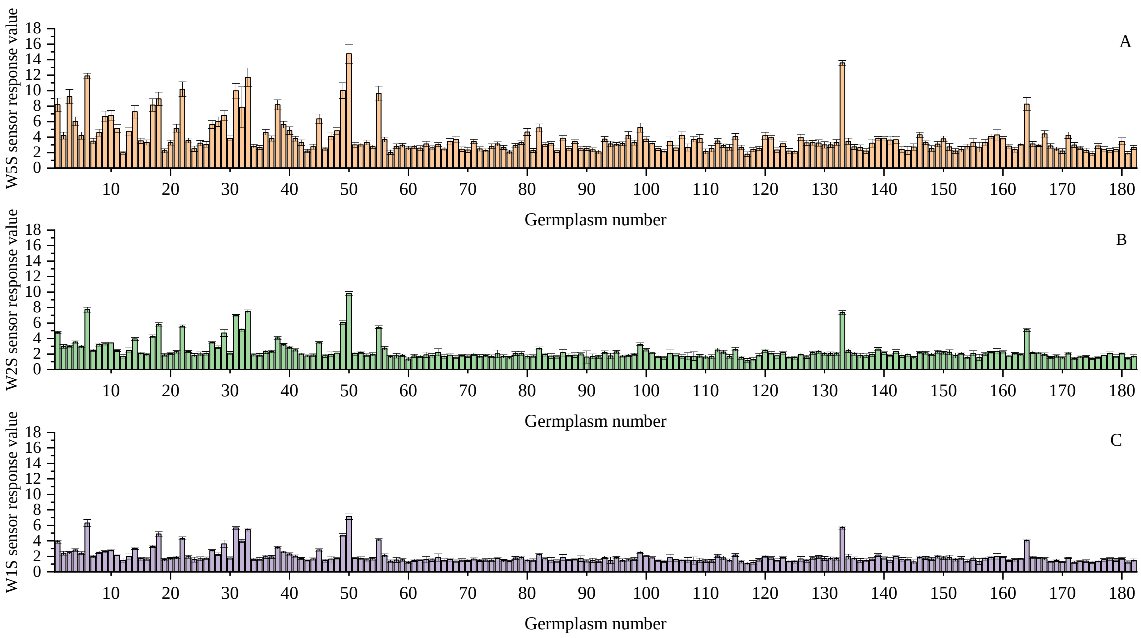

Figure 6. Comparison of response values of the three main sensors. Note: (**A**): W5S sensor response value; (**B**): W2S sensor response value; (**C**): W1S sensor response value.

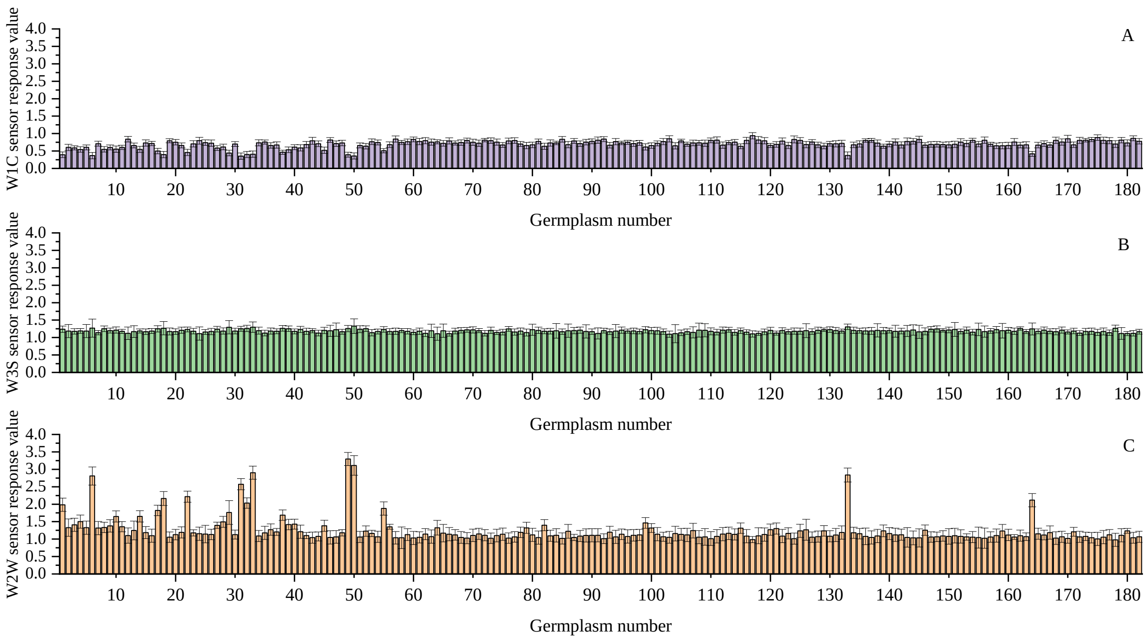

Figure 7. Comparison of response values of three aromatic sensors. Note: (**A**): W1C sensor response value; (**B**): W3S sensor response value; (**C**): W2W Sensor response value.

The W5S, W2S, and W1S sensor of 'Spabang' has the highest response value, and the W2W sensor is second only to 'Neijingxiang'. The W2W sensor response value of 'Neijingxiang' ranked first, and its W5S, W2S, and W1S sensor response values were significantly higher than those of the other 97% of germplasm ($p < 0.05$, Figure 6A–C). The response value of the 'Muscat Angel' W5S sensor was second only to 'Spabang', and the response value of its W2S, W1S, and W2W sensors was significantly higher than that of the other 98% of germplasm ($p < 0.05$, Figures 6B,C and 7C). The response value of the 'Jinmeigui' W2S sensor was second only to 'Spabang', and the response value of its W5S, W1S, and W2W sensors was significantly higher than that of the other 98% of germplasm ($p < 0.05$, Figures 6A,C and 7C). The W5S, W2S, W1S, and W2W sensor response values of 'Zhengguo, 6', 'Muscat, Angel', 'Zizao', and 'Qiumi' were significantly higher in all germplasm than in the other 95% of germplasm ($p < 0.05$, Figures 6A–C and 7C). Among the eight varieties with a strong and special berry flavor, there were five *V. vinifera* × *V. labrusca* grapes, accounting for 9.26% of the measured *V. vinifera* × *V. labrusca*, and three *V. vinifera* germplasm, accounting for 2.34% of *V. vinifera* × *V. labrusca*, and the flavor of *V. vinifera* × *V. labrusca* was stronger than that of *V. vinifera*.

4. Discussion

As a new analytical technique, the electronic nose has attracted wide attention due to its broad application in aroma analysis of agricultural products and beverages, as well as in the detection of the ripe and rotten states of berries [21]. Giovana et al. employed an electronic nose equipped with an array of gas sensors featuring cross-electrodes coated with polyaniline-based nanocomposites, in conjunction with carboxylated multi-walled carbon nanotubes doped with various acids, to differentiate artificial strawberry fragrances. Utilizing principal component analysis (PCA) and linear discriminant analysis (LDA), they investigated the electronic nose's capability to discern distinct strawberry aromas, with findings that confirmed its effectiveness [22]. Du et al. took kiwi fruit as the research object, collected data for different maturity stages of kiwi fruits with an electronic nose, and analyzed the maturity of kiwi fruits according to volatile odor. The study demonstrated an impeccable identification accuracy of 100 percent, underscoring the electronic nose's proficiency in determining kiwi maturity through volatile compounds [23]. Building on these precedents, our study employed the electronic nose technique to appraise the aromatic constituents of berries from diverse table grape cultivars. Leveraging radar charts and principal component analysis (PCA), we discerned variations in the content and composition of aromatic substances across grape varieties. These findings underscore the electronic nose's utility in the preliminary assessment of aromatic profiles within grape germplasm resources, offering a valuable tool for grape aroma analysis and variety differentiation.

The content of volatile substances in grape berries is a key factor affecting berry quality, and variety resource diversity is the core of breeding work. Identifying the composition and content of volatile substances in ripe berries of grape germplasm is of great significance for the development, utilization, and breeding of grape resources [24]. Genetic diversity was related to the coefficient of variation in the germplasm population. Among the 182 germplasm resources, the composition and content of aroma compounds were larger, and the coefficient of variation was higher, indicating that the genetic abundance of the 182 table grape germplasm was higher. The composition and content of aroma compounds of different germplasm resources were also different.

Grape berries have attracted much attention due to their rich aromatic substances, and many domestic and foreign researchers have successfully identified the diversity of aroma components in grapes, including alcohols, aldehydes, esters, ketones, alkanes, and olefins [25]. So far, more than 100 kinds of aroma components in grape berries have been identified, and scholars have different opinions on the classification of these aroma components. There are many kinds of volatile substances in grape berries, among which the content of nitrogen oxides, alcohols, alkanes, and other substances is higher. Aroma compounds include sulfur compounds and alcohols. Some germplasms, such as Rekord, Rizamat, and Longyan, were rich only in nitrogen oxides. Some germplasm are rich in nitrogen oxides, alcohols, alkanes, and other substances, such as Spabang, Neijingxiang, Zaotian Muscat, etc.

In an earlier study, Liu et al. analyzed the volatile compounds in cabernet Sauvignon grape berries and detected 55 kinds of volatile compounds, among which ketones, alcohols, aldehydes, and a small amount of ester compounds were mainly detected [8]. Shi et al. used HPLC-QqQ-MS/MS and GC-MS to detect the volatile compounds of five grape varieties, among which the volatile compounds mainly included hexal, (E)-2-hexenal, (E, Z) -2, 6-nonadienal, β-hemalone, and (E))-2-nonenal gives the grape a more floral, fruity, and earthy flavor [26]. The results of this study show that there are significant differences in berry aromas between the 182 germplasm, which also means that some varieties have special aromas due to the high genetic abundance of grapes. The aroma of grape berries is different, mainly due to nitrogen oxides, hydrogen sulfide, methane, and so on. The scents of 'Spabang', 'Neijingxiang', 'Zaotian, Muscat', 'Jinmeigui', 'Zhengguo, 6', 'Muscat, Angel', 'Zizao', and 'Qiumi' are considered special. The eight materials showed significant differences not only in non-aromatic substances but also in aromatic components and organic sulfides. Therefore, 'Spabang' and the other eight grape germplasm can be used as the parent material for breeding grape fragrant varieties. This study further confirmed that the content of aroma substances in table grapes at maturity was significant, especially the content of nitrogen oxides, alkanes, alcohols, and some aromatic compounds. Surface electronic nose technology can effectively distinguish different grape varieties and identify and evaluate their berry aroma.

As one of the important characteristics of grapes, aroma has always been the focus of consumers and grape breeders [16]. Aroma compounds are usually present in free or bound form in the skin and flesh of grape berries. Feng et al. reported that the main characteristic aroma compounds of the 'Gold Finger' grape fruit are aldehydes and esters, and these substances make it rich in a special aroma [27]. Relevant studies have shown that differences in grape fruit aroma may be related to flesh color [28]. Manuel et al. used the E-nose system to analyze the aroma differences in eight grape varieties. Red grapes generally produce more intense aromas than white varieties [29]. In the context of this study, red grape varieties such as 'Spabang', 'Zaotian Muscat', 'Zhengguo 6', 'Zizao', 'Qiumi', and 'Compell' were selected for analysis. Notably, 'Spabang', 'Zaotian Muscat', 'Zhengguo 6', 'Zizao', and 'Qiumi' were found to possess unique aromatic signatures. Collectively, these red varieties are characterized by a robust fragrance, corroborating the findings of Manuel et al. [29]. This study thus contributes to the understanding of the aromatic diversity within red grape varieties and offers insights into the potential for enhancing grape breeding programs with an emphasis on aroma.

There are many factors affecting the production of fruit aroma substances, among which environmental factors such as altitude, temperature, and drought are important and will affect the production of fruit aroma. As the surrounding environment of the fruit changes, the type and content of aroma substances also change significantly; Mayobre et al. have shown that the volatile content changes during storage, although the effect depends on the season. Although storage at room temperature generally increases the production of volatiles, during cooling, downregulation of ADH and AAT reduces ester production, loses fruity and sweet flavors, and increases grassy flavors [30]. Nicola et al. selected 'Glera' grapes from two vineyards with different elevations and soil climates for study. Genome-wide gene expression analysis of berries revealed significant differences in ripening transcriptome programs, reflecting differences in water conditions, light, and temperature experienced by grapes growing at two sites, which in turn affected the different substance content of grapes, and the aroma content of 'Glera' grapes was affected by different environmental conditions [31]. Giacomo et al. compared fully irrigated control vines with two different levels of water scarcity from berry and pea size to the transition stage, different levels of water scarcity in the lag stage, and two different levels of water scarcity from the transition stage to harvest. At harvest, the total VOC concentrations were higher in water-stressed grapevine berries from berry pea size to transition stage or lag stage, and water deficits after transition determined concentrations similar to the controls. This pattern was more pronounced in the glycosylation portion and was also observed in single compounds, mainly monoterpenes and C13-norisoprene. On the other hand, the content of free VOC was higher in berries that stressed the vines after lagging or color transformation. Significant glycoylation and free VOC increments measured after transient water stress confined to the lagging stage highlight the critical role played by this stage in the regulation of berry aroma compound biosynthesis, thereby suggesting that droughts affect berry aroma production content [32]. The ripening time of grape samples in this study ranged from early August to late October. The 'Neijingxiang', 'Jinmeigui' and 'Muscat Angel' of cluster II matured in early August, when the rainfall quantity was large before picking. However, 'Tuoketuo', 'Sudani', and 'Kaiotome' in cluster I matured in early October, and the rainfall amount was small. Most other germplasm matured between late August and mid-September, after the rainy season. Therefore, differences between grape aroma clusters may be related not only to intrinsic genotype differences, but also to differences in their external environmental factors.

By using appropriate identification methods to accurately analyze the aroma components of grape fruits, the differences in aroma components of table grapes can be further clarified. In this study, three biological replicates and three technical replicates were used to evaluate the aroma of table grape berries, and the results showed higher reproducibility. By controlling the environmental conditions detected by the sensor, the detection time and the sample processing method are consistent, and the influence of the sensor response on the detection of aroma characteristics is minimized. In the future, existing aroma extraction methods such as steam distillation, supercritical CO_2 extraction, headspace, thermal desorption, and solid phase microextraction should be optimized in order to more comprehensively evaluate, extract, and utilize grape berry aroma substances. Electronic nose has complementary advantages with gas chromatography and gas chromatography-mass spectrometry and will become an important technical guarantee for experimental results.

5. Conclusions

In this research, an evaluation of the aroma of 182 fresh table grape berries was conducted. The electronic nose demonstrated sensitivity to the aroma components present in the tested varieties of fresh table grapes, and the contribution rate of the sensor was W5S (nitrogen oxides), W2S (alcohols and some aromatic compounds), W1S (alkanes), and W2W (sensor of organic sulfide). Cluster analysis revealed that the aroma profile of table grapes is relatively straightforward. Principal component analysis (PCA) highlighted significant variations in the content and composition of aroma substances across different grape varieties. From this analysis, eight distinctive germplasm with notably strong aromas were identified: 'Spabang', 'Neijingxiang', 'Zaotian Muscat', 'Jinmeigui', 'Zhengguo 6', 'Muscat Angel', 'Zizao', and 'Qiumi'. The outcomes of this study offer a scientific foundation for the selection of grape varieties in the table grape processing industry and contribute significant data resources for the breeding of table grapes.

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Appendix A

Table A1. Table grape variety resource characteristic.

Number	Germplasm	Species	Berry of Color	With or Without Aroma
1	Hongshuangwei	*V. vinifera* × *V. labrusca*	Rose	With
2	Hongxiangjiao	*V. vinifera* × *V. labrusca*	Red-violet	With
3	Hongxing	*V. vinifera* × *V. labrusca*	Red	With
4	Amber	*V. vinifera* × *V. labrusca*	Red	With
5	Horigon	*V. vinifera* × *V. labrusca*	Green-yellow	Without
6	Jinmeigui	*V. vinifera* × *V. labrusca*	Green-yellow	With
7	Compell	*V. vinifera* × *V. labrusca*	Red-violet	With
8	New YorK Muscat	*V. vinifera* × *V. labrusca*	Blue black	With
9	Luode Berry	*V. vinifera* × *V. labrusca*	Green-yellow	With
10	Rommel	*V. vinifera* × *V. labrusca*	Green-yellow	Without

Table A1. *Cont.*

Number	Germplasm	Species	Berry of Color	With or Without Aroma
11	Royal Rose	*V. vinifera* × *V. labrusca*	Green-yellow	With
12	Rose Gueen	*V. vinifera* × *V. labrusca*	Green-yellow	Without
13	Meiguiyi	*V. vinifera* × *V. labrusca*	Red-violet	With
14	Meizhoubai	*V. vinifera* × *V. labrusca*	Green-yellow	With
15	Mill	*V. vinifera* × *V. labrusca*	Red-violet	Without
16	Moldova	*V. vinifera* × *V. labrusca*	Blue black	Without
17	Niagara	*V. vinifera* × *V. labrusca*	Green-yellow	With
18	Autumn Royal	*V. vinifera* × *V. labrusca*	Rose	With
19	Steuben	*V. vinifera* × *V. labrusca*	Red	Without
20	Slenuben	*V. vinifera* × *V. labrusca*	Red-violet	Without
21	Tample	*V. vinifera* × *V. labrusca*	Red-violet	With
22	Muscat Angel	*V. vinifera* × *V. labrusca*	Green-yellow	With
23	Wanxia	*V. vinifera* × *V. labrusca*	Red-violet	Without
24	Vergennes	*V. vinifera* × *V. labrusca*	Green-yellow	With
25	Xiangyue	*V. vinifera* × *V. labrusca*	Red-violet	With
26	Rose cioutat	*V. vinifera* × *V. labrusca*	Green-yellow	With
27	Millennium	*V. vinifera* × *V. labrusca*	Blue black	With
28	Zaoshuheihuxiang	*V. vinifera* × *V. labrusca*	Blue black	With
29	Zhengkang 1	*V. vinifera* × *V. labrusca*	Red-violet	With
30	Zhuosexaing	*V. vinifera* × *V. labrusca*	Green-yellow	With
31	Zizao	*V. vinifera* × *V. labrusca*	Blue black	With
32	Meiyehei	*V. vinifera* × *V. labrusca*	Blue black	With
33	Zhengguo 6	*V. vinifera* × *V. labrusca*	Blue black	With
34	Hanazawa1	*V. vinifera* × *V. labrusca*	Green-yellow	Without
35	Canada Muscat	*V. vinifera* × *V. labrusca*	Green-yellow	With
36	Tebieheidali	*V. vinifera* × *V. labrusca*	Red-violet	With
37	ZIFENG	*V. vinifera* × *V. labrusca*	Red-violet	With
38	Mars Seedless	*V. vinifera* × *V. labrusca*	Red-violet	With
39	Canadice	*V. vinifera* × *V. labrusca*	Rose	Without
40	Leikemangte	*V. vinifera* × *V. labrusca*	Green-yellow	With
41	Honey Seedless	*V. vinifera* × *V. labrusca*	Green-yellow	With
42	Hongsiweisen	*V. vinifera* × *V. labrusca*	Green-yellow	With
43	Juwang	*V. vinifera* × *V. labrusca*	Red-violet	Without
44	TriumpH	*V. vinifera* × *V. labrusca*	Green-yellow	Without
45	Tiankangmeigui	*V. vinifera* × *V. labrusca*	Red-violet	With
46	Yuantian 314	*V. vinifera* × *V. labrusca*	Red	Without
47	Ziguang	*V. vinifera* × *V. labrusca*	Red-violet	Without
48	Huafuputao	*V. vinifera* × *V. labrusca*	Red-violet	With
49	Neijingxiang	*V. vinifera* × *V. labrusca*	Green-yellow	With
50	Spabang	*V. vinifera* × *V. labrusca*	Blue black	With
51	Golden Finger	*V. vinifera* × *V. labrusca*	Green-yellow	Without
52	Jinsuiputao	*V. vinifera* × *V. labrusca*	Green-yellow	With
53	Governor Rose	*V. vinifera* × *V. labrusca*	Green-yellow	With
54	Zaomoli	*V. vinifera* × *V. labrusca*	Green-yellow	Without
55	Zhengguo 21	*V. vinifera*	Red	With
56	Zhengguo 8	*V. vinifera*	Rose	With
57	Skenderg	*V. vinifera*	Green-yellow	Without
58	Rosario Rosso	*V. vinifera*	Red	Without
59	Flame Muscat	*V. vinifera*	Red	Without
60	Huangmisi	*V. vinifera*	Green-yellow	Without
61	Jilaer	*V. vinifera*	Red	Without
62	Kaiotome	*V. vinifera*	Green-yellow	Without
63	Jingxiu	*V. vinifera*	Red	With
64	Kashimeigui	*V. vinifera*	Red-violet	With
65	Chasselas napaleon	*V. vinifera*	Green-yellow	With
66	Kelimukaonisong	*V. vinifera*	Green-yellow	Without
67	Khoussaine khelime barmak	*V. vinifera*	Green-yellow	Without
68	Kutesaita	*V. vinifera*	Green-yellow	Without
69	Rekord	*V. vinifera*	Green-yellow	Without
70	Rizamat	*V. vinifera*	Red	Without

Table A1. *Cont.*

Number	Germplasm	Species	Berry of Color	With or Without Aroma
71	Longyan	*V. vinifera*	Green-yellow	Without
72	Lushaji	*V. vinifera*	Green-yellow	Without
73	Lvnai	*V. vinifera*	Green-yellow	Without
74	Lvputao	*V. vinifera*	Green-yellow	Without
75	Muscat Violet Commmon	*V. vinifera*	Red	With
76	Manai	*V. vinifera*	Green-yellow	Without
77	Mascat hamburg	*V. vinifera*	Red-violet	With
78	Zhengguo 4	*V. vinifera*	Red-violet	With
79	Zhengguo 5	*V. vinifera*	Red-violet	With
80	Manicure Finger	*V. vinifera*	Green-yellow	Without
81	Mihaer	*V. vinifera*	Green-yellow	Without
82	Mudanhong	*V. vinifera*	Red	With
83	Jingyu	*V. vinifera*	Green-yellow	Without
84	Nimrang	*V. vinifera*	Green-yellow	Without
85	Niuxin	*V. vinifera*	Green-yellow	Without
86	Paikaer	*V. vinifera*	Green-yellow	Without
87	Aromatic of pecs	*V. vinifera*	Green-yellow	With
88	Pannoniavin	*V. vinifera*	Red	Without
89	Pinger	*V. vinifera*	Red-violet	Without
90	Mascat plevenski	*V. vinifera*	Red	With
91	Qichakapulie	*V. vinifera*	Green-yellow	Without
92	Qiaqiwahe	*V. vinifera*	Green-yellow	Without
93	Qiaobao 2	*V. vinifera*	Green-yellow	Without
94	Joanne Charnice	*V. vinifera*	Green-yellow	Without
95	Qiuhongbao	*V. vinifera*	Green-yellow	Without
96	Rilujiewei	*V. vinifera*	Green-yellow	Without
97	Ribier	*V. vinifera*	Red-violet	Without
98	Ciotat Chasselas	*V. vinifera*	Green-yellow	Without
99	Shasibadaer	*V. vinifera*	Green-yellow	With
100	Pearl of csaba	*V. vinifera*	Green-yellow	Without
101	Shaengli	*V. vinifera*	Red-violet	Without
102	Su 46	*V. vinifera*	Red-violet	Without
103	Sudani	*V. vinifera*	Green-yellow	Without
104	Madeleine solomon	*V. vinifera*	Green-yellow	Without
105	Tuoketuo	*V. vinifera*	Red-violet	Without
106	Victoria	*V. vinifera*	Green-yellow	With
107	Weilameigui	*V. vinifera*	Red-violet	Without
108	Weike	*V. vinifera*	Rose	Without
109	Woyijinuo	*V. vinifera*	Green-yellow	Without
110	Wuzibiekemeigui	*V. vinifera*	Red-violet	Without
111	Tompsons seedless 1	*V. vinifera*	Green-yellow	Without
112	Xinong 20	*V. vinifera*	Green-yellow	Without
113	Xiabai	*V. vinifera*	Green-yellow	Without
114	Xiangfei	*V. vinifera*	Green-yellow	With
115	Muscat Mathiasz Janosne	*V. vinifera*	Green-yellow	With
116	Yalian	*V. vinifera*	Green-yellow	Without
117	Mascat of alexandria	*V. vinifera*	Green-yellow	Without
118	Yanhong	*V. vinifera*	Green-yellow	With
119	Yipinxiang	*V. vinifera*	Green-yellow	Without
120	Yangputao	*V. vinifera*	Green-yellow	Without
121	Kocsias Irma	*V. vinifera*	Green-yellow	With
122	Yiliputao	*V. vinifera*	Green-yellow	Without
123	Yilixiangputao	*V. vinifera*	Green-yellow	With
124	Elizabeth grape	*V. vinifera*	Green-yellow	Without
125	Itchkimar	*V. vinifera*	Green-yellow	Without
126	Yisibishali	*V. vinifera*	Green-yellow	Without
127	Ltalia	*V. vinifera*	Green-yellow	Without
128	Rose Ltalia	*V. vinifera*	Red-violet	With
129	Yuanliqiaowushen	*V. vinifera*	Green-yellow	Without
130	cardinal	*V. vinifera*	Red-violet	Without

Table A1. *Cont.*

Number	Germplasm	Species	Berry of Color	With or Without Aroma
131	Zaomeigui	*V. vinifera*	Red-violet	Without
132	Zaoshu Muscat	*V. vinifera*	Red-violet	With
133	Zaotian Muscat	*V. vinifera*	Red-violet	With
134	Zexiang	*V. vinifera*	Green-yellow	With
135	Zeyu	*V. vinifera*	Green-yellow	With
136	Zhengfuputao	*V. vinifera*	Green-yellow	Without
137	Zhengguo 28	*V. vinifera*	Red-violet	Without
138	Zhengguo 3	*V. vinifera*	Red	Without
139	Zhengzhouzaohong	*V. vinifera*	Red-violet	Without
140	Zifeng	*V. vinifera*	Red-violet	Without
141	Zijixin	*V. vinifera*	Red-violet	Without
142	Ziputao	*V. vinifera*	Green-yellow	Without
143	Zitao	*V. vinifera*	Red-violet	Without
144	Zizhenzhu	*V. vinifera*	Red-violet	With
145	Blush Seedless	*V. vinifera*	Red	Without
146	Black Monukka	*V. vinifera*	Red	Without
147	Jinsuiwuhelu	*V. vinifera*	Green-yellow	With
148	Jingfengwuhe	*V. vinifera*	Green-yellow	With
149	Jingzijing	*V. vinifera*	Rose	With
150	Dawn Seedless	*V. vinifera*	Green-yellow	Without
151	Beauty seedless	*V. vinifera*	Red-violet	Without
152	Nasaili	*V. vinifera*	Green-yellow	Without
153	Ningxiawuhebai	*V. vinifera*	Green-yellow	Without
154	Autumn Seedless	*V. vinifera*	Green-yellow	Without
155	Sando khani	*V. vinifera*	Green-yellow	Without
156	Watekangseedless	*V. vinifera*	Red	Without
157	Tompsons seedless	*V. vinifera*	Green-yellow	Without
158	Centennial Seedless	*V. vinifera*	Green-yellow	With
159	Wuhemeigui	*V. vinifera*	Green-yellow	Without
160	Wuhezi	*V. vinifera*	Red-violet	With
161	Xiying	*V. vinifera*	Green-yellow	Without
162	Yanggeer	*V. vinifera*	Green-yellow	Without
163	Flame seedless	*V. vinifera*	Red	Without
164	Hongze	*V. vinifera*	Rose	With
165	Kelina	*V. vinifera*	Green-yellow	Without
166	Qingzi	*V. vinifera*	Blue black	Without
167	Shiliuhong	*V. vinifera*	Red-violet	Without
168	Waerse	*V. vinifera*	Green-yellow	Without
169	Lival	*V. vinifera*	Red-violet	With
170	Hongsidi	*V. vinifera*	Red-violet	Without
171	Cinsaut	*V. vinifera*	Red-violet	Without
172	Zaokangbao	*V. vinifera*	Red-violet	Without
173	Qiumi	*V. vinifera*	Red-violet	Without
174	Jintian0608	*V. vinifera*	Red-violet	Without
175	Jintianmeigui	*V. vinifera*	Red	Without
176	Jingxiangyu	*V. vinifera*	Green-yellow	Without
177	Jintianfeicui	*V. vinifera*	Green-yellow	Without
178	Jintianhong	*V. vinifera*	Red	Without
179	Zidiqiu	*V. vinifera*	Red-violet	Without
180	Taotailang	*V. vinifera*	Green-yellow	With
181	Shennongjinhuanghou	*V. vinifera*	Green-yellow	Without
182	Qiaowushen	*V. vinifera*	Green-yellow	Without

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