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ARTICLE

Correlation between Floral Color Attributes and Volatile Components among 10 Fragrant *Phalaenopsis* Cultivars

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ABSTRACT: To study the main aroma components of *Phalaenopsis* orchid and their relationship with colors, 10 fragrant cultivars with different colors, like pink, rose, yellow, and purple, were used as samples in this experiment. Headspace-gas chromatography-mass spectrometry was used to determine the main components of floral fragrance and analyze the correlation between floral color and fragrance. The results showed that the main aroma components of the 10 fragrant cultivars of *Phalaenopsis* were alcohols, alkenes, esters, and benzene ring compounds, and the main aroma components of different cultivars were diverse. The main aroma components of yellow fragrant flowers were esters, alcohols, and alkenes. The purple and pink series were alcohols and phenyl rings. There was a certain correlation between flower color and floral fragrance. There was a significant positive correlation between esters and flower color C* value, and a significant negative correlation between alkenes and flower color h value. There was a significant negative correlation between alcohol and flower color C* value, and a significant positive correlation between alcohol and L* value. The content of benzene compounds was negatively correlated with L* and positively correlated with h value. This may be related to the synthesizing of anthocyanins and benzene ring compounds through the phenylpropanoid metabolic pathway. In this paper, the correlation between *Phalaenopsis* floral color and fragrance was studied, and the synthetic pathway of floral color and fragrance components was analyzed. The proposed method and research data can provide a theoretical basis for floral color breeding and fragrance synthesis.

KEYWORDS: *Phalaenopsis*; flower color; flower fragrance; correlation analysis

1 Introduction

Phalaenopsis is the general term for plants of *Phalaenopsis* genus within the Orchidaceae family. These plants are admired for their elegant flower shapes and rich colors, making them important potted flowers both domestically and internationally. The flowers display a wide range of colors, such as white, yellow, orange, pink, rose-red, and purple, and the color patterns include solid and variegated colors with striped petals [1]. However, one significant drawback of *Phalaenopsis* is its lack of fragrance. Even though a few fragrant cultivars have been cultivated [2,3], they still suffer from weak fragrance, fewer flowers, smaller flower sizes, and poor reproductive traits. The floral fragrance of plants is primarily composed of terpenes, phenylpropanoids/benzenoids, and aliphatic compounds [4–7]. The dominant fragrance components of different fragrant *Phalaenopsis* cultivars vary. Current research on scent compounds of *Phalaenopsis* mainly focuses on terpenes, such as myrcene, sabinene, ocimene, eucalyptol, linalool, geraniol, and 1,8-cineole [8–11]. For instance, the primary aromatic compounds family of *P. bellina* are monoterpenes, benzenoids, and phenylpropanoids, and the geraniol; linalool [11], and their derivatives being the key contributors to its fragrance. In contrast, there are no detectable releases of monoterpene derivatives in *P. equestris*, however, its volatile compounds are mainly fatty acid derivatives and phenylpropanoids, these fragrant compounds are barely detectable by the human nose [12]. The main scent compounds of *P. violacea* are monoterpenes and sesquiterpenes, including elemicin, santol, and linalool [10]. A study by Tong et al. on eight newly hybridized fragrant *Phalaenopsis* cultivars found that terpenes such as 1,8-cineole, α-pinene, and linalool were the primary scent components [13]. Despite these findings, the relationship between different fragrance components and the flower colors or fragrance pattern of *Phalaenopsis* has not yet been reported. In *Paeonia delavayi* [14], the main volatile components of the green cultivar 'Gesang Lv' were linalool, caryophyllene, oxidized linalool, and pinene. The main volatile components of the red cultivar 'Gesang Hong' were macrophyllene D, methyl decanoate, hexol, and pinene. The main volatile components of the yellow cultivar 'Gesang Huang' were linalool, caryophyllene, methyl decanoate, and germacrene. In roses [15], three groups of ten cultivars were divided in the coordinate system of a* and b* hue, including red, yellow-white, and purplish red. A significant positive correlation between the total emission of floral volatile compounds in the aromatic hydrocarbon metabolic pathway and the b* value of petals ($p < 0.01$) was found, which indicated that the more yellow the flower was, the higher contents of volatile compounds in the aromatic hydrocarbons metabolic pathway were released. In this paper, the correlation between *Phalaenopsis* flower color and floral fragrance was analyzed for the first time.

Phalaenopsis breeding at fragrant traits poses technical challenges, such as hybrid incompatibility and poor reproductive capacity. Traditional hybridization remains the most common method for breeding new orchid varieties. This study aims to measure the fragrance components of ten fragrant *Phalaenopsis* cultivars and analyze the correlation between flower color and fragrance, providing a theoretical foundation for hybrid breeding, laws of inheritance of *Phalaenopsis*, and the synthesis of *Phalaenopsis* fragrances.

2 Materials and Methods

2.1 Experiment Materials

The study focused on ten fragrant *Phalaenopsis* orchids (see Fig. 1) selected from about 500 most popular *Phalaenopsis* varieties in the Chinese flower market, including three pink varieties: *Phalaenopsis schilleriana* (S), 'Orange Beauty' (O), and 'SX098' (SX); two rose-red varieties: 'H026' (H) and 'SK16' (SK); two orange varieties: 'Brother Sara Gold' (B) and 'SH51' (SH); two yellow varieties: 'Zhi Duo Xing' (Z) and 'Yan Die Huang Fei' (Y); and one purple variety: 'Purple Martin' (P). All were sourced from Xiamen HEMING Flower Technology Co., Ltd. (China) and cultivated for two years in a greenhouse equipped with a fan water curtain cooling system, internal and external sunshade system, and heating system at the Yantai Academy of Agricultural Sciences (Shandong Province, China). The temperature was 25°C–30°C, the light intensity was 10,000 lx, and the humidity was 70%~85%. The growing medium was Chilean-imported sphagnum moss, with fertilizer for 2000 to 3000 times the concentration of N, P, and K content of 20-20-20. Watering was carried out on sunny days to ensure that the leaves did not collect water at night. Yellow and blue armyworm boards were used to control pests. 4-leaves\1-heart 2a newly matured seedlings with healthy, pest-free, and similar growing conditions were selected for the experiment.

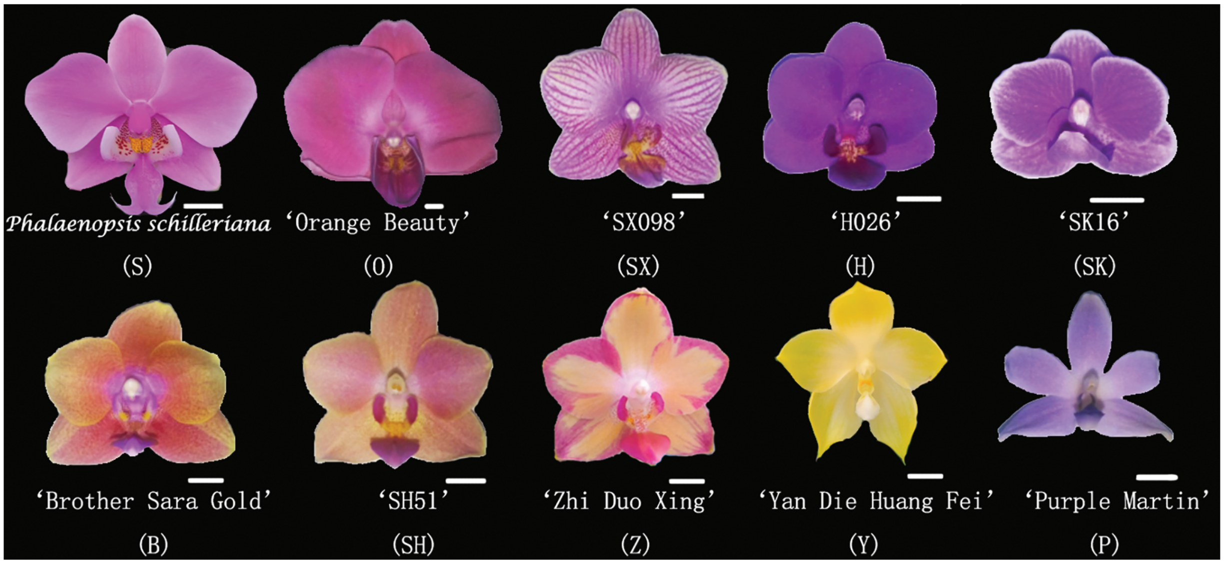

Figure 1: Experiment materials. Abbreviations: *Phalaenopsis schilleriana* (S), 'Orange Beauty' (O), 'SX098' (SX), 'H026' (H), 'SK16' (SK), 'Brother Sara Gold' (B), 'SH51' (SH), 'Zhi Duo Xing' (Z), 'Yan Die Huang Fei' (Y), 'Purple Martin' (P)

2.2 Flower Color Parameters Measurement

Flowers were collected on the second day in full opening and placed against a white background under the same lighting conditions. The color parameters of the flowers were then measured using a colorimeter (NF555, Nippon Denshoku Industries Co. Ltd., Tokyo, Japan) to obtain the values for L* (lightness, ranging from black to white, 0–100), C* (saturation, calculated as C* = (a*2 + b*2)1/2) and h (hue angle, calculated as $h = \tan^{-1}(b^*/a^*)$) were also determined [15].

2.3 Olfactory Sensory Evaluation of Fragrance

After the experimental materials bloomed, ten plants were sampled and placed in a room with the same environmental conditions (room temperature at 25°C). The flower colors were measured using the Royal Horticultural Society (RHS) color chart, and the floral fragrance was assessed through olfactory sensory evaluation. The *Phalaenopsis* flowers were selected on the second after they bloomed. A group of 20 people (10 males and 10 females) evaluated and scored the fragrance of each cultivar. Scoring ranges from 0 for no fragrance, 1 for a light scent, 2 for a moderate fragrance, and 3 for a strong scent. The average score was calculated, and the fragrance characteristics were described after scoring [16,17].

2.4 Analysis of Fragrance Components

Flower samples, including sepals, petals, and one gynandrium, were taken for analysis. A 2 g samples were weighed and placed in a sampling vial, then sealed and allowed to equilibrate for 10 min. The solid-phase microextraction method was employed, placing the sampling vial on a ceramic heating plate at 45°C (Corning PC-4200, Corning Inc., Corning, NY, USA) for extraction by using a 100 μm polydimethylsiloxane (PDMS) extraction fiber (Beijing Huayi Instrument Technology Co., Ltd., Beijing, China) for 30 min. The fragrance components were measured using Headspace Gas Chromatography-Mass Spectrometry (GC-MS) [18]. A Shimadzu GCMS-QP2010 plus gas chromatography-mass spectrometry system (Shimadzu Corporation, Kyoto, Japan) was used. The chromatographic conditions were as follows: the chromatography column was Rtx-5MS (60 m × 0.25 mm × 0.25 mm); the injection volume was 1 μL; helium was used as the carrier gas, pressure at 112.0 kPa; the total flow rate was 8.0 mL/min, with a column flow rate of 1 mL/min and a split ratio of 5:1. The temperature program was as follows: the injector temperature was set to 250°C, the initial column temperature was 40°C (held for 2 min), then increased to 180°C at a speed of 8°C/min, followed by a further increase to 250°C at a rate of 15°C/min, held for 5 min. The mass spectrometry conditions include an interface temperature of 230°C; the ionization method was electron ionization (EI) source; the ion source temperature was set to 200°C; and the detector voltage was 0.8 kV. The fiber head was inserted into the injector for analysis over 2 min. Each experiment was repeated three times parallelly. The sampled mass spectra were analyzed using the NIST library and WILEY library in series for compound identification, combined with manual spectral analysis to confirm the chemical constituents of the volatiles. The relative percentage of each component in the sample gas was calculated by using normalized peak area, with the formula: Content (%) = (the peak area of the specific substance/sum of all gas peak areas in the sample) × 100 [19]. By referring to the characteristics of chemical compounds and relevant literature, the volatile components of each cultivar were analyzed, allowing for the selection of non-fragrant and fragrant gas components, ultimately identifying the main fragrant components responsible for the *Phalaenopsis* floral scent.

2.5 Data Analysis

The data was analyzed, and charts were created using Microsoft Excel 2016, while the correlation coefficients between flower color and fragrance were calculated using IBM SPSS Statistics 24 software.

3 Results and Discussion

3.1 Flower Color Measurement

The petal colors of 10 *Phalaenopsis* orchids were measured (lightness L*, chroma C*, and hue angle h), as shown in Fig. 2. L* indicates the brightness and the value range is 0 to 100. The higher the value is, the lighter the color is. The C* value represents the saturation of the color. The higher the value is, the brighter the color is. h is the hue angle and the way colors are positioned in the color system, ranging from 0 to 360°. The closer the h value is to 0° (360°), the redder the color is; Closer to 90°, the more yellow the color is; Closer to 180°, the greener the color is; Closer to 270 degrees, the bluer the color is. The results indicated that pink and yellow *Phalaenopsis* series had higher L* values, lower C* values, and lower h values, while magenta and purple *Phalaenopsis* cultivars had lower L* values, higher C* values, and higher h values. The L* value of flower color was negatively correlated with C* and h values. The color distribution of these 10 *Phalaenopsis* cultivars is quite broad, with h values ranging from 25° to 325°. The flower colors are diverse but lack blue-green hues class. In China, red represents festivity and is used for festivals, and white and yellow represent grief and are used for funerals, so the magenta and orange cultivars with higher C* and h values are much more popular than other colors in the market.

The red color in plant petals primarily originates from anthocyanins, while yellow is mainly synthesized by carotenoids; The mix of these two pigments creates an orange color. *Phalaenopsis* orchids exhibits a rich variety of flower colors, encompassing nearly all color spectra except for blue-green, and the flower color pattern exhibit multiple complex models such as spots-shape, stripes-shape, and halo-shape. Wang et al. used the ISCC-NBS color nomenclature system to categorize the flower colors of *Phalaenopsis* orchids into seven major color groups: yellow, brown, red, violet, pink, purple, and white [20]. A negative correlation between the brightness and chroma of flower colors they observed. The results of our experiment were confirmed and consistent with those of previous studies [21], indicating that the brightness (L* value) of *Phalaenopsis* orchid flower colors is significantly negatively correlated with chroma (C* value) and hue angle (h). Specifically, as the depth of flower color increases, the L* value decreases, while the C* value increases.

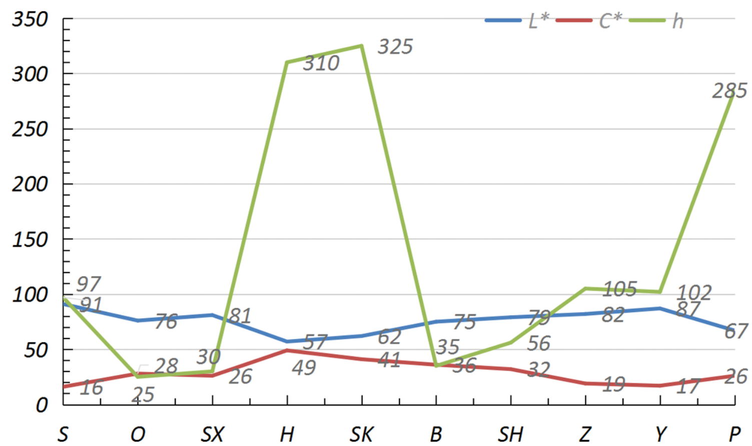

Figure 2: Color comparison of 10 fragrant *Phalaenopsis* petals. Abbreviations: L* (lightness), C*(saturation), h (Hue Angle, the unit is degree)

3.2 *Measurement of Phalaenopsis Fragrance*

The sensory evaluation was conducted on the fragrance of 10 *Phalaenopsis* orchid cultivars, and the results are shown in Table 1. The cultivars 'Sara Golden', 'Purple Martin', 'SK16', 'SX098', 'SH51', 'Zhiduoxing', and 'Yandie Huangfei' had relatively strong fragrances. Among them, 'SH16' had the strongest and most pungent smell. The yellow and orange cultivars, including 'Sara Golden', 'SH51', 'Zhiduoxing', and 'Yandie Huangfei', were characterized by a fruity sweet fragrance.

Table 1: Sensory evaluation of floral scent and color of 10 *Phaleanopsis* cultivars

Abbreviation	Name	Color of flower	Serial Num. of color chart	Diameters of flower (cm)	Intensity of fragrance	Type of fragrance
S	*Phalaenopsis schilleriana*	Pink	N74D	6.5 ± 0.2	2.05	Floral scent
O	'Orange beauty'	Pink	55B	11.5 ± 0.2	1.05	Subtle floral scent
SX	'SX098'	Light rose-red	75B	5.5 ± 0.2	2.85	Rose scent, sweet scent
H	'H026'	Rose-red	N78B	3.5 ± 0.1	1.95	Herbaceous scent
SK	'SK16'	Rose-red	N78A	3.5 ± 0.1	2.95	Sweet scent, pungent strong scent
B	'Brother sara gold'	Orange-yellow	25A	5.5 ± 0.2	2.7	Floral scent, sweet scent
SH	'SH51'	Orange-yellow	47C	4.4 ± 0.1	2.85	Fruity sweet scent
Z	'Zhi Duo Xing'	Yellow	72D	4.5 ± 0.1	2.85	Fruity sweet scent
Y	'Yan Die Huang Fei'	Yellow	2D	4.5 ± 0.2	2.75	Sweet scent
P	'Purple martin'	Purple	N87C	3.9 ± 0.1	2.45	Floral scent

In total, over 60 gas components were identified in 10 fragrant *Phalaenopsis* orchids, which were mainly classified by their chemical structure into alcohols, esters, alkenes, and benzenoid compounds. Among them, 'SK098' and 'Yandie Huangfei' were primarily composed of alcohol, reaching 53.62% and 89.60%, respectively. 'SK16' and 'Zhidaoxing' had the highest proportions of ester components, at 58.05% and 49.22%. 'Sara Huangjin' and 'SH51' were dominated by alkenes, at 54.22% and 45.04%, respectively. 'H026' was primarily composed of esters and alkenes, accounting for 31.15% and 32.25%. 'Zima Ding' had 36.70% aromatic compounds and 24.76% alcohols, while the Tiger-striped *Phalaenopsis* orchid was mainly comprised of aromatic compounds, esters, and alcohols, accounting for 29.79%, 25.62%, and 18.88%, respectively. 'Xiang Cheng Mei Ren' was primarily made up of esters and alkenes, at 32.73% and 35.59%.

According to Table 2, the volatile components of 10 fragrant *Phalaenopsis* orchids were classified and analyzed. The results, categorized in descending order, showed that the components ranked as follows: alcohols, alkenes, esters, and aromatic compounds. Within each category, the contribution rates of components, ordered from highest to lowest, are as follows. Alcohols: linalool, citronellol, eucalyptol, n-hexanol, nerol, dodecanol. Alkenes: ocimene, cedrene, β-laurolene, α-pinene, γ-terpinene, pinene. Esters: hexyl acetate, neryl acetate, di-n-butylphthalate, geranyl acetate, isopropyl myristate, diisobutyl phthalate. Benzenoid: fluorenes, 1,4-dimethylbenzene, dibenzofuran, indole.

From the perspective of flower color classification, the main fragrance components of yellow *Phalaenopsis* orchids are dominated by esters (hexyl acetate), alcohols (linalool and eucalyptol), and alkenes (cedrene and basilene). In contrast, the purple-red and pink orchids primarily contain alcohols (geraniol, n-hexanol, and nerol) and aromatic compounds (1,4-dimethylbenzene and fluorenes).

Different fragrant types of *Phalaenopsis* orchid cultivars have distinct dominant floral scent components. Current research indicates that the fragrance components of fragrant *Phalaenopsis* orchids are mainly terpenes, such as linalool in *P*. 'Tsuei You Beauty' [9]. *P. bellina* contains nerolidol, geraniol, and linalool [11,12], while *P. violacea* has elaeagnol, agarol, and linalool [10]. Other flower species also exhibit different dominant aromatic components among various cultivars. For instance, the fragrance components of peonies, such as *Paeonia ostii* and *Pa. rockii*, have the highest terpenes content, whereas *Pa. delavayi and Pa.lutea* have a relatively higher content of benzenoid compounds [22]. The results of these experiments indicate that the main determined components of floral scent in different *Phalaenopsis* orchid varieties differ, and the primary compounds are alcohols, alkenes, esters, and benzenoids.

3.3 Correlation between Color and Fragrance of Phalaenopsis Orchids

A two-factor correlation analysis was conducted to examine the relationship between flower color parameters (L^*, C^*, h) and the contents of alcohols, alkenes, esters, and benzenoid compounds in the fragrances of 10 fragrant *Phalaenopsis* orchids. The Pearson correlation coefficient was calculated for each value (Table 3). The results showed that the ester content in the fragrance components depicted a highly significant positive correlation with the C^* value of flower color, while the alkene content displayed a highly significant negative correlation with the h value of flower color. The saturation of flower color increased, and the content of esters in the fragrance also increased. Furthermore, a greater inclination towards the yellow color spectrum correlates with a higher content of alkenes in the fragrance.

Additionally, the alcohol content in the fragrance had a significant negative correlation with the C^* value of flower color and a significant positive correlation with the L^* value. This indicates that as the saturation of flower color decreases and brightness increases, the content of alcohol in the fragrance rises.

Table 2: Floral scent components of 10 *Phaleanopsis* cultivars (percentage)

Compounds	Sensory evaluation	*Phalaenopsis schilleriana*	'Orange beauty'	SK098	H026	SK16	'Brother sara gold'	SH51	'Zhi Duo Xing'	'Yan Die Huang Fei'	'Purple martin'
Alcohols											
Citronellol	Lemongrass and citronella scent	3.01	—	39.50	—	—	—	—	—	27.02	—
Eucalyptol	The cool scent of camphor	—	—	—	—	—	—	10.92	15.45	—	—
n-hexanol	Unique fragrance	—	5.06	5.05	3.79	2.80	1.60	2.14	—	—	—
Linalool	Floral scent, woody scent, and fruity scent	—	—	1.20	—	—	—	3.48	8.85	59.59	16.84
Octanol	Herbal scent, and leafy scent	—	—	0.99	—	—	—	0.85	—	—	—
4-hexen-1-ol acetate	Flower scent	—	—		—	—	—	—	—	2.29	—
1-undecanol	Lemon fragrance	—	—	2.01	—	—	—	—	—	—	—
dodecanol	Flower scent	—	—	—	1.64	1.99	—	0.92	—	—	3.61
3,6-nonanediol	Fruity scent	—	—	—	—	—	—	—	—	—	2.24
cis-3-nonen-1-ol	Fatty and cantaloupe scent	—	—	—	2.81	—	—	—	—	—	2.07
trans-nerolidol	Citrus scent	—	—	1.67	—	2.81	—	—	—	—	—
trans-*α*-santalol	Lily of the valley scent	1.30	—		—	—	—	—	—	—	—
Nerol	The fragrance of rose and orange blossom	12.36	—	3.20	—	—	—	—	—	—	—
Geraniol	Fragrance of rose	2.21	—	—	—	—	—	—	—	0.70	—
α-pinene	The scent of pine wood, needle leaves, and resin	—	—	—	—	—	—	—	0.87	—	—
Sum		18.88	5.06	53.62	8.24	7.60	1.60	18.31	25.17	89.60	24.76
Esters											
dibutyl phthalate	Aromatic scent	—	—	—	—	—	—	1.98	—	—	—
diisobutyl phthalate.	Aromatic scent	—	—	—	—	—	—	1.62	—	—	7.51
Hexyl acetate	Fruity scent	—	23.94	9.16	13.68	32.81	14.00	5.45	—	0.80	—
Butyl butyrate	Fruity scent	—	—	—	—	—	—		—	0.59	—
Geranyl acetate	Banana fragrance	—	5.77	—	—	8.16	4.74	1.00	—	—	—
Hexyl butyrate	Sweet fruit fragrance	—	—	—	—	—	—	4.45	—	—	—
di-n-butylphthalate	Aromatic scent	—	3.02	2.24	6.79	4.53	—	—	—	—	5.87
Isopropyl myristate	The scent of nutmeg.	—	—	3.63	6.79	8.17	—	—	—	—	—
Diisobutyl phthalate	Aromatic scent	—	—		3.89	4.38	—	—	—	—	—
Neryl acetate	Fruit fragrance	25.62	—	1.29	—	—	—	—	—	—	—
Sum		25.62	32.73	16.32	31.15	58.05	18.74	14.50	0.00	1.39	13.38
Alkenes											

(Continued)

Table 2 (continued)

Compounds	Sensory evaluation	*Phalaenopsis schilleriana*	'Orange beauty'	SK098	H026	SK16	'Brother sara gold'	SH51	'Zhi Duo Xing'	'Yan Die Huang Fei'	'Purple martin'
Sabinene	Juniper fragrance	—	—	2.14	—	—	—	30.71	25.21	—	—
β-myrcene	Light balsamic scent	9.01	—	—	—	—	—	—	4.62	3.90	—
Limonene	Orange scent	—	—	—	—	—	—	—	—	1.26	—
γ-terpinene	The fresh scent of young tree leaves	—	—	—	—	—	—	—	7.86	—	—
Ocimene	A grassy and floral scent combined with a litter orange flower oil scent	—	31.40	—	—	2.98	52.82	1.83	—	1.12	—
Terpinenes	The scent of pine wood, needle leaves, and resin	—	—	—	—	—	—	—	7.76	—	—
Myrcene	Subtle balsamic scent	—	—	—	—	—	—	1.45	—	—	—
delta-3-carene	Pine scent	—	—	—	—	—	—	—	1.56	—	—
Pinene	The scent of pine wood, needle leaves, and resin	—	4.19	—	—	—	1.40	1.83	1.56	—	—
Limonene	Orange scent	—	—	—	—	—	—	1.67	—	—	—
β-pinene	The scent of turpentine, dry wood, and pine resin	—	—	—	—	—	—	5.82	—	—	—
Farnesene	The scent of fresh petals and apples	—	—	—	—	—	—	—	0.65	—	—
3,7,11-Trimethyl-1,3,6,10-dodecatetraene	Fruity aroma	—	—	—	—	—	—	1.73	—	—	5.51
2,6-dimethyl-1,3-octadiene.		—	—	5.11	—	—	—	—	—	—	—
Sum		9.01	35.59	7.25	0.00	2.98	54.22	45.04	49.22	6.28	5.51
Benzenoid											
Benzonitrile	Almond scent	—	—	—	—	—	—	—	1.57	—	—
Biphenylene	Special scent	—	—	2.90	—	4.83	—	1.76	—	—	6.83
p-Xylene	Sweet fragrance	29.79	—	—	—	—	—	—	0.92	—	—
Indole	Intense fecal odor, highly diluted fragrance that can be used as a flavoring	—	7.76	—	—	—	16.51	—	—	—	—
Acenaphthylene	Pungent smell	—	1.74	—	6.88	—	—	—	—	—	4.73
Dibenzofuran	Aromatic scent	—	—	5.63	—	5.05	—	3.46	—	—	10.67

(Continued)

Table 2 (continued)

Compounds	Sensory evaluation	*Phalaenopsis schilleriana*	'Orange beauty'	SK098	H026	SK16	'Brother sara gold'	SH51	'Zhi Duo Xing'	'Yan Die Huang Fei'	'Purple martin'
Fluorene	Fragrance like naphthalene and camphor wood	—	3.70	6.31	9.97	10.23	—	4.23	—	—	14.47
1-acenaphthenone	smoky odor	—	3.96	—	15.40	—	1.09	—	—	—	—
Sum		29.79	17.16	14.84	32.25	20.11	17.60	9.45	2.49	0.00	36.70
Other type											
Geranylacetone	Green sweet scent and a slight rose fragrance	—	—	—	2.52	—	—	—	—	—	
3-hexen-1-yl butanoate	Green scent, fruity aroma, and the fragrances of unripe apple and black pepper	—	—	—	—	—	—	5.26	—	—	—
p-cymene	Fresh, aromatic, slightly spicy, with a camphor scent	—	—	—	—	—	—	—	14.90	—	—
Decanal	Citrus scent, waxy fragrance, and floral aroma	—	1.89	—	2.57	—	—	—	—	—	—
Other non-fragrant components	—	16.70	7.57	7.97	23.27	11.26	7.84	7.44	8.21	2.73	19.65

Table 3: Correlation between flower color and floral scent components

	C*	h	Alcohols	Alkenes	Esters	Benzenoids
L*	−0.88218**	−0.77185**	0.504663*	0.278913	−0.57856*	−0.52398*
C*		0.514291*	−0.57044*	−0.09935	0.625278**	0.385019
h			−0.2076	−0.622**	0.471411*	0.559241*
Alcohols				−0.34528	−0.57672*	−0.51175*
Alkenes					−0.33771	−0.47259*
Esters						0.469032

Note: **$p < 0.01$, *$p < 0.05$.

Moreover, the content of benzenoid compounds was significantly negatively correlated with L* and positively correlated with h, which meant that the darker the flower colors were, the more it leaned towards the blue-purple spectrum, the higher levels of benzenoid compounds in the fragrance were. Therefore, it is likely that there exists some correlation between the color and fragrance of *Phalaenopsis* orchids.

The fragrance of *Phalaenopsis* orchids has some correlation with their color. The main fragment components of yellow-fragrant *Phalaenopsis* orchids are primarily alcohols, alkenes, and esters, while the purple and pink cultivars mainly contain alcohols and benzenoid compounds. As the saturation of the flower color increases, the content of esters in the fragrance also increases synergistically. Additionally, the more the flower color leans towards the yellow spectrum, the higher the content of alkenes in the fragrance. Conversely, lower saturation and higher brightness correspond to an increased content of alcohol in the floral scent. Furthermore, darker flower colors that lean towards the blue-purple spectrum are associated with higher levels of benzenoid compounds in the fragrance.

These relationships may be linked to the synthesis of anthocyanins and benzenoid compounds in the red cultivars of *Phalaenopsis* orchids, both of which are produced via the phenylpropanoid metabolic pathway. The synthesis pathways of floral fragrance components (such as terpenes and phenyl/phenylpropanoids) are somewhat related to the pathways of secondary metabolites, such as pigments (anthocyanins, carotenoids, etc.) [23,24]. The mevalonate pathway is an upstream pathway for the synthesis of benzenoid compounds and anthocyanins, while phenylpropanoids serve as precursors for the synthesis of benzenoid compounds and anthocyanins. The floral fragrance and color can be regulated through the mevalonate pathway simultaneously [23,25].

The flower color and fragrance are complex traits controlled by multiple genes. Based on previous studies [5,26,27], the synthesis pathways diagram for flower color and flower fragrance were depicted (Fig. 3). The diagram illustrates that the synthesis of flower color and fragrance components is closely related. For example, the synthesis of pigments such as carotenoids, and lycopene shares the methylerythritol phosphate (MEP) pathway with fragment molecules such as alcohols like linalool, citronellol, and geraniol and alkenes such as ocimene. The synthesis of blue-purple pigments from delphinidin and cornflower blue shares the Shikimate pathway with benzenoid compounds. These reveal the reasons behind the differences in the main aromatic components between yellow and purple *Phalaenopsis* orchids.

Phalaenopsis orchids had varied phenotypic diversity, particularly in the variation of flower color [28]. Previous research has indicated that purple-red coloration in *Phalaenopsis* flowers may be controlled by a single gene [29], and floral fragrance is a heritable trait. Tong et al. conducted experiments on the fragrance components in eight newly hybridized fragrant *Phalaenopsis* cultivars, categorizing the scents into woody, minty, and fruity types, and identified fragrance compounds as candidate marker traits to distinguish between different fragrant flower groups [13].

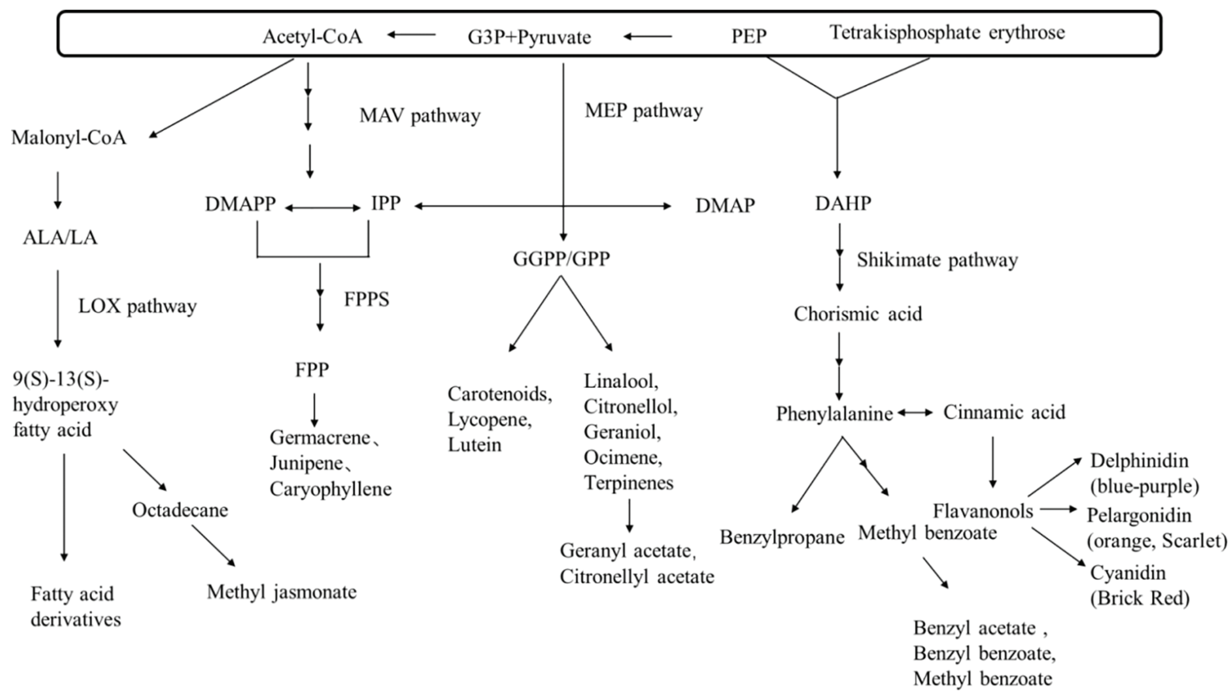

Figure 3: Synthetic pathways of floral color and aroma. ALA: alpha-linolenic acid; LA: linoleic acid; DMAPP: Dimethylallyl pyrophosphate; IPP: Isopentenyl pyrophosphate; FPPS: Farnesyl pyrophosphate synthase; FPP: Farnesyl pyrophosphate; PEP: Phosphoenolpyruvate; DMAP: Dimethylallyl phosphate; GGPP: Geranylgeranyl pyrophosphate; GPP: Geranyl pyrophosphate; DAHP: 3-Deoxy-D-arabino-heptulosonic acid 7-phosphate

4 Conclusions

The main components of the fragrance of *Phalaenopsis* are diverse in different color types. The fragrance of *Phalaenopsis* flowers has some correlation with their color. There was a significant positive correlation between esters and flower color C* value, and also between alcohol and L* value, and a significant negative correlation between alkenes and flower color h value, and also between alcohol and flower color C* value. This study measured both the flower color and fragrance components of *Phalaenopsis* orchids and analyzed the correlation between them, suggesting that flower color and flower fragrance may follow a pattern of genetic linkage. Phalaenopsis cultivars *Phalaenopsis schilleriana*, 'SK16', 'Brother Sara Gold', 'SH51', 'Zhi Duo Xing', 'Yan Die Huang Fei' and 'Purple Martin' with high C* and h values and strong aroma were selected as important parents for future cross-breeding. In the *Phalaenopsis* breeding study, if the mother was pure yellow, and the father was magenta, the base color of the first cross-generation was yellow 57.7% and purple 42.3%. At the same time, 87.2% of the first cross-generation inherited paternal magenta stripes [30]. Moreover, floral scents tend to be inherited maternally. Therefore, according to the breeding goal, the color and fragrance type of the parents should be analyzed and the combination of parents should be precisely designed in advance. In this study, the proposed methods and research data presented provide a theoretical foundation for future breeding on flower color and fragrance. The future study will focus on developing a flower evaluation system including a comprehensive index synthesizing C*, L*, and h, and identifying the necessary volatile compounds, to provide a more reliable framework for assessing *Phalaenopsis* quality.

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Ethics Approval: Not applicable.

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