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ORIGINAL RESEARCH

Terpenoid, Benzenoid, and Phenylpropanoid Compounds in the Floral Scent of *Vanda* Mimi Palmer

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Abstract *Vanda* Mimi Palmer is the product of a cross between *Vanda* Tan Chay Yan and *Vanda tessellata*. The flower of this hybrid produces a sweet-smelling fragrance during day time at the open-flower stage. This study aimed to investigate the floral scent constituents in *Vanda* Mimi Palmer. Scent emission analysis of this orchid was carried out at different time points in a 24-h cycle and also at different floral developmental stages. A comparison was also made on the volatiles emitted by *Vanda* Mimi Palmer and both of its parents. Gas chromatography-mass spectrometry (GC-MS) analysis showed that the scent of *Vanda* Mimi Palmer was dominated by terpenoid, benzenoid, and phenylpropanoid compounds. The identified terpenoids were ocimene, linalool oxide, linalool, and nerolidol; while the benzenoid and phenylpropanoid compounds were methylbenzoate, benzyl acetate, phenylethanol, and phenylethyl acetate. The emission of terpenoid, benzenoid, and phenylpropanoid compounds was developmentally and temporally regulated. Comparison of the volatiles emitted by both of its parents showed that the scent of *Vanda* Mimi Palmer is dissimilar to that of its fragrant parent, *V. tessellata*.

Keywords *Vanda* Mimi Palmer · Scent emission · Gas chromatography mass-spectrometry (GC-MS) · Terpenoids · Benzenoid and phenylpropanoid compounds

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Introduction

Volatiles from a flower attract pollinators such as birds and insects to visit flowering plants and help in pollination (Knudsen et al. 1993; Schiestl et al. 1997; Miyake et al. 1998; Odell et al. 1999; Jurgens et al. 2000). More than 1,700 floral scent compounds covering 990 taxa have been identified using the floral headspace method (Knudsen and Gershenzon 2006). The scent of flowers varies between species due to the combination of different compositions and levels of each molecule of low molecular mass such as monoterpenes, seisquiterpenes, benzenoids, phenylpropanoids, and fatty acid derivatives (Knudsen et al. 1993; Dudareva and Pichersky 2000). The entire floral organs are involved in scent emission but the petal is the main source of floral scent in most flowers (Pichersky et al. 1994). Some floral scent compounds are stored in special oil glands such as trichome prior to release into the air as volatiles (Effmert et al. 2006).

In floral scent studies, more than 500 terpenoid compounds have been identified including monoterpenes (C_{10}), seisquiterpenes (C_{15}), diterpenes (C_{20}), and irregular terpenes (Knudsen and Gershenzon 2006). Monoterpenoid compounds such as linalool, ocimene, mycrene, nerol, and geraniol have been identified in *Antirrhinum majus* (Dudareva et al. 2003; Nagegowda et al. 2008), *Clarkia breweri* (Raguso and Pichersky 1995), and *Arabidopsis thaliana* (Chen et al. 2003). While sesquiterpenes such as

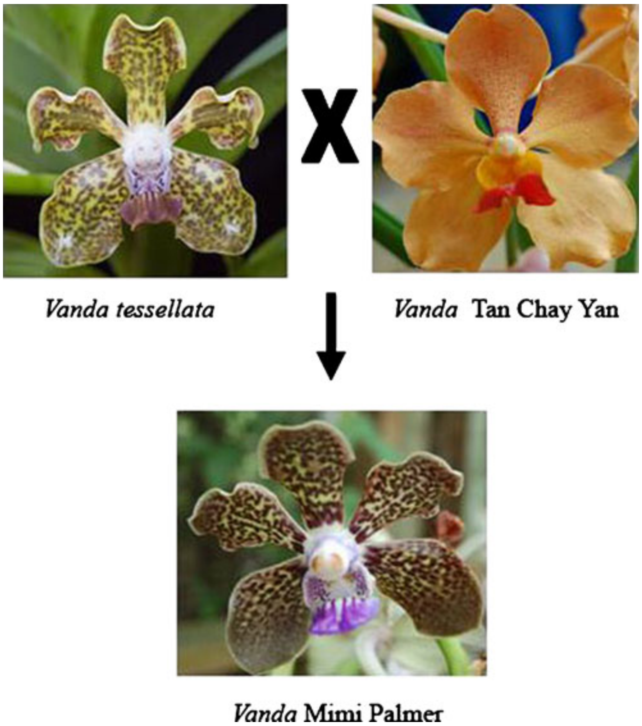

Fig. 1 *Vanda* Mimi Palmer and its parents. *Vanda* Mimi Palmer is a hybrid of *V. tessellata* (adapted from Hamdan 2008) and *Vanda* Tan Chay Yan

germacrene D, caryophyllene, and nerolidol were detected in *Rosa hybrida* (Hendel-Rahmanim et al. 2007), *Petunia hybrida* (Verdonk et al. 2003), *A. thaliana* (Chen et al. 2003), carnation (*Dianthus caryophyllus*) (Schade et al. 2001), and *A. majus* (Nagegowda et al. 2008). Another class that is highly distributed among scented flowers is benzenoid/phenylpropanoid compounds. More than 300 compounds of this class have been identified which includes methylbenzoate, methylsalicylate, phenylacetaldehyde, phenylethyl acetate, benzyl acetate, phenylethanol, eugenol, and isoeugenol (Knudsen and Gershenzon 2006).

In orchids, volatile compounds encompassing terpenoids, benzenoid/phenylpropanoid compounds, and also fatty acid derivatives have been reported from *Aerangis confusa*, *Cattleya lawrenceana*, *Dendrobium trigonopus*, *Dendrochilum cobbianum*, *Platanthera chlorantha*, *Polystachya cultriformis*, and *Zygopetalum crinitum* (Kaiser 1993). More recently, linalool, mycrene, nerol and 2-hexanol were detected in *Phalaenopsis bellina* using gas chromatography mass-spectrometry (GC-MS; Hsiao et al. 2006).

In this study, we attempted to investigate the scent constituents of *Vanda* Mimi Palmer, an award winning hybrid of *Vanda* Tan Chay Yan and *Vanda tessellata* (Fig. 1). This orchid has a strong sweet-smelling fragrance during the day at the open flower stage (Janna et al. 2005) and has won the Champion Award for Fragrant Orchid organized by the Royal Horticultural Society of Thailand in 1993 and the Best Orchid Fragrance in the 17th World Orchid Conference in 2002 (Nair and Arditti 2002). In Malaysia, this orchid is one of the most famous hybrids sought after by local cosmetic and beauty industries due to its sweet fragrance. Despite its economic importance, no work on identification of the floral scent constituents from this hybrid has been reported so far. In this study, we analyzed the scent profiles at different floral developmental stages and at different time points in a 24-h cycle. In addition, we also compared the volatiles emitted with those from its parents.

Materials and Methods

Plant Materials

Orchid plants (*Vanda* Mimi Palmer and *Vanda* Tan Chay Yan) used in this study were purchased and maintained by the United Malaysian Orchids Sdn. Bhd., a nursery located in Rawang, Selangor, Malaysia. Both *Vanda* Mimi Palmer and *Vanda* Tan Chay Yan used in this study were grown separately in pots with charcoal under tropical climate (12 h in light followed by 12 h in dark). Fully open flowers used for this study were between 5 and 7 days old. Floral buds of 1.5 cm in length and 2 days old half-open flowers were used for the scent emission study at different flower developmental stages.

Volatiles Captured from Single Flower for Analysis

A single flower of *Vanda* Mimi Palmer was trapped in a modified funnel without detaching the flower from its stalk

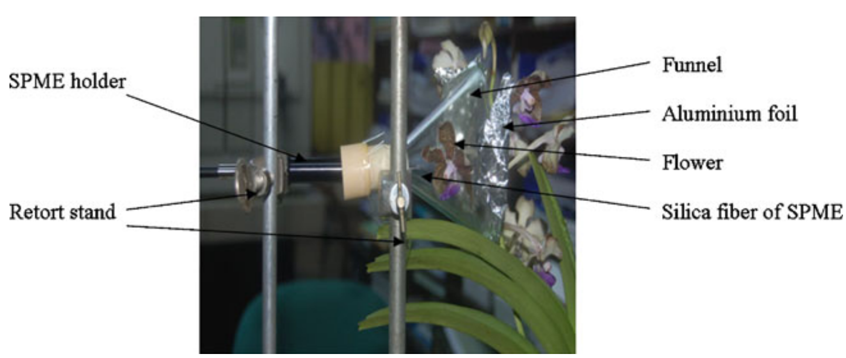

Fig. 2 Solid phase micro-extraction (SPME) used to capture volatile compounds emitted by fully open flower of *Vanda* Mimi Palmer. Flowers at other developmental stages of *Vanda* Mimi Palmer including bud and half-open flower as well as the fully open flower of *Vanda* Tan Chay Yan were captured by SPME in the same manner

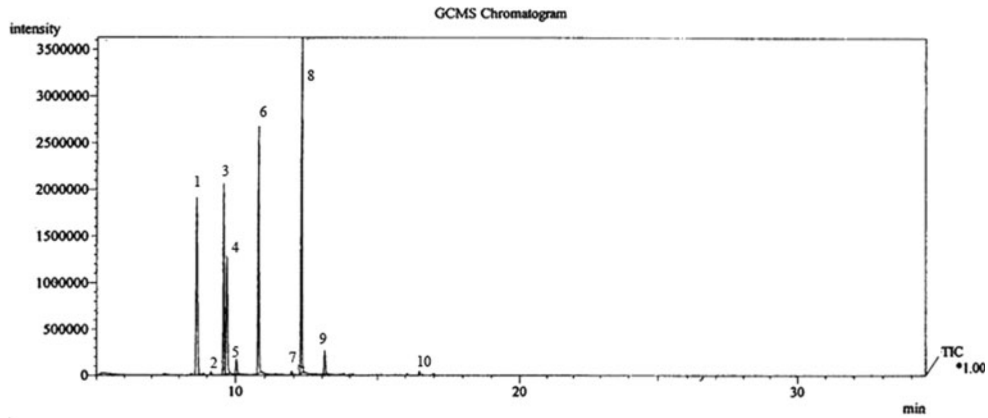

Fig. 3 Gas chromatogram of volatile compounds emitted by fully open flower of *Vanda* Mimi Palmer during the highest peak at 2:00 pm: *1* ocimene, *2* linalool oxide, *3* linalool, *4* methylbenzoate, *5* phenylethanol, *6* benzyl acetate, *7* formanilide, *8* phenylethyl acetate, *9* indole, and *10* nerolidol

(Fig. 2). Solid phase micro-extraction (SPME) (Supelco, USA) containing fused silica fiber coated with 100 µm poly (dimetylsiloxane) was used to capture the scent emitted by the flower for 15 min. The volatiles emitted were captured and analyzed from three different flower developmental stages: bud, half-open flower and fully open flower, taken at 12:00 noon. Temporal emission of fully open flower was analyzed at 2-h intervals in a 24-h cycle. Volatiles emitted by fully open flower of *Vanda* Tan Chay Yan were also captured at 12:00 noon and analyzed in the same manner. Volatile emission analysis for the three flower developmental stages and temporal emission in a 24-hour cycle were carried out in three replicates. Averages of the three replicates were used o plot two graphs (terpenoids and benzenoids/phenylpropanoids) with the error bar showing the standard error for the three replicates.

Analysis of Volatiles by GC-MS

The volatile compounds captured by SPME fiber was injected into the injector port of a Shimadzu Gas Chromatography-Mass Spectrometry (GC-17A/GCMS-QP5050) with a splitless injection mode and thermally desorbed for 1 min at 250°C. The volatile compounds were separated using a capillary HP-5 column (50 m×0.32 mm, film thickness 1.05 µm) with helium (21 kPa) as a carrier gas. The GC oven was programmed at 45°C for 1 min followed by an increase of 10°C per minute to 280°C and a final extension at 280°C for 10 min. The mass spectra of eluted compounds were recorded for the m/z of 30–300. The spectrum of each compound was compared to the 2002 National Institute of Standards and Technology library (Scientific Instrument Services, USA).

Comparison of Volatiles Emitted by *Vanda* Mimi Palmer and Its Parents

A comparison was carried out between the volatiles emitted by *Vanda* Mimi Palmer and its parents (*Vanda* Tan Chay Yan and *V. tessellata*). Volatiles emitted by fully open flower of both *Vanda* Mimi Palmer and *Vanda* Tan Chay Yan were captured at 12:00 noon and analyzed by GC-MS as described above while the result of headspace analysis of

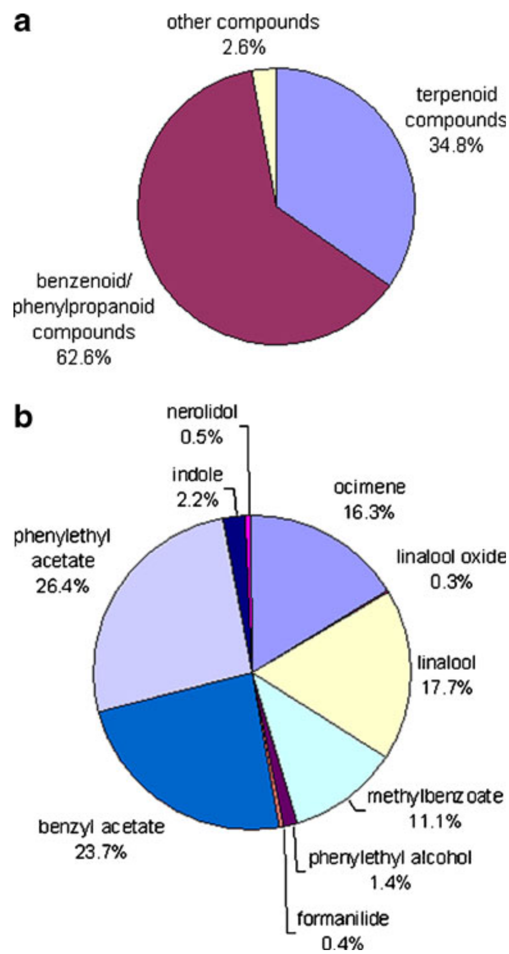

Fig. 4 Percentage of **a** terpenoid, benzenoid/phenylpropanoid and other compounds and **b** each compound in the scent of fully open flower of *Vanda* Mimi Palmer. The pie charts show the percentage of each individual compounds and class of compounds detected in the scent of *Vanda* Mimi Palmer during the highest peak of scent emission at 2:00 pm

Table 1 Volatile compounds emitted by fully open flower of *Vanda* Mimi Palmer with their relative retention time and fragments

Peak	Retention time (min)	Main fragments (m/z)	Compound name
Monoterpene			
1	8.636	93, 41, 79, 53, 105, 67, 121, 36	Ocimene
2	9.147	43, 59, 41, 93, 81, 112	Linalool oxide
3	9.592	71, 41, 43, 93, 69, 121, 136, 107	Linalool
Sesquiterpene			
10	16.492	41, 69, 43, 93, 71, 107, 136, 162, 123	Nerolidol
Benzenoid compounds			
4	9.702	105, 77, 136, 51	Methylbenzoate
5	10.03	91, 122, 65, 39, 51, 78, 105	Benzyl acetate
Phenylpropanoid compounds			
6	10.783	108, 43, 91, 150, 79, 65, 39	Phenylethanol
8	11.926	104, 43, 91, 65, 78, 39	Phenylethyl acetate
Indoles			
9	13.084	117, 90, 63, 39, 50, 74	Indole
Formanilide			
7	12.26	93, 161, 65, 39, 52, 76	Formanilide

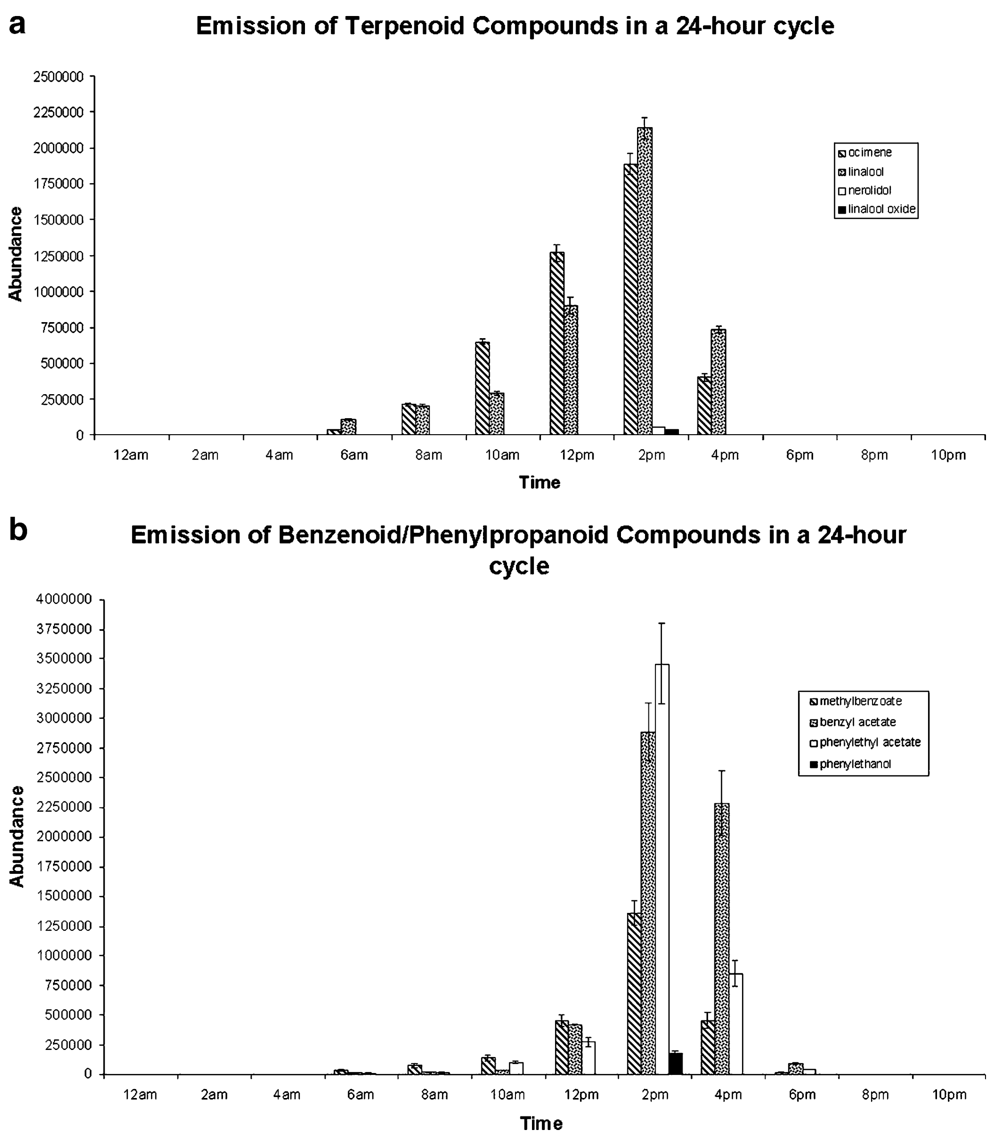

Fig. 5 Emission of volatile compounds by fully open flower of *Vanda* Mimi Palmer in a 24-h cycle: **a** terpenoids (ocimene, linalool oxide, linalool, and nerolidol) and **b** benzenoid/phenylpropanoid compounds (methylbenzoate, benzyl acetate, phenylethyl acetate, and phenylethanol (phenylethyl alcohol)). The volatile compounds of fully open flower of *Vanda* Mimi Palmer were captured by solid phase micro-extraction (SPME) before injecting into GC-MS injector port. The experiment was carried out in Malaysia's tropical climate (12 h daylight and 12 h darkness)

volatiles emitted by *V. tessellata* reported by Kaiser (1993) was used in the comparison.

Results

Floral Scent Constituents of *Vanda* Mimi Palmer

GC-MS analysis (Fig. 3) detected ten compounds in the floral scent of *Vanda* Mimi Palmer which were ocimene, linalool oxide, linalool, methybenzoate, phenylethyl alcohol (phenyl ethanol), formanilide, indole, and nerolidol. The scent of *Vanda* Mimi Palmer was detected at the highest peak in the early afternoon (at 2:00 pm) and was represented by 34.8% of terpenoid compounds, 62.6% of benzenoid/phenylpropanoid compounds and 2.6% traces of other compounds including indole and formanilide (Fig. 4a). The major terpenoid compounds detected in the scent of *Vanda* Mimi Palmer were ocimene and linalool, representing 98% of the terpenoid compounds (data not shown). There were traces of two terpenoid compounds including linalool oxide (monoterpene) and nerolidol (seisquiterpene) which represent 0.3% and 0.5%, respectively, of the total scent (Fig. 4b). While for benzenoid/phenylpropanoid compounds, phenylethyl acetate was detected at the highest level representing 26.4% of the total scent of *Vanda* Mimi Palmer, followed by benzylacetate (23.7%), methylbenzoate (11.1%) and phenylethyl alcohol (phenylethanol; 1.4%). All the

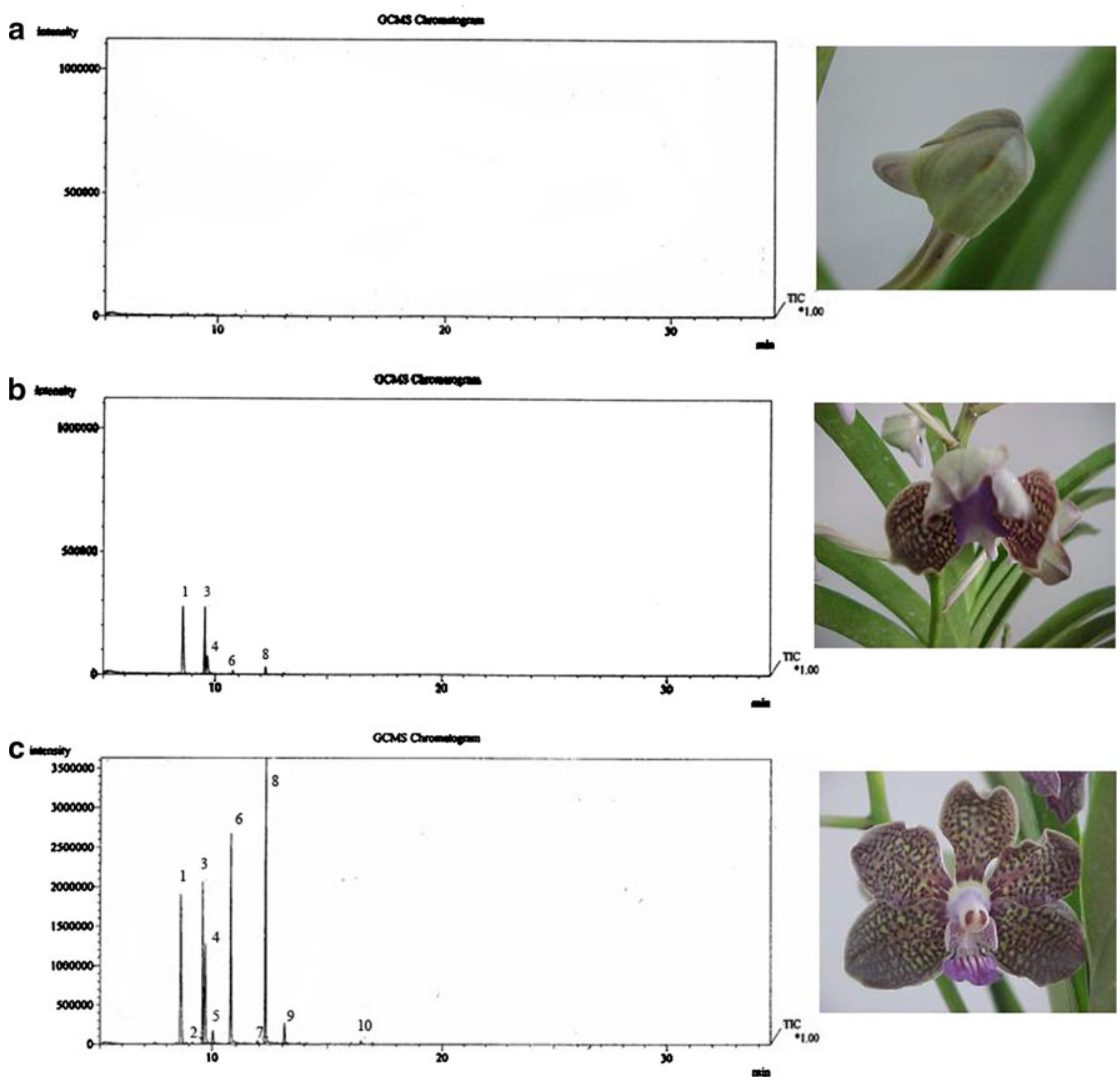

Fig. 6 Comparison of volatiles emitted by *Vanda* Mimi Palmer at three different flower developmental stages: **a** bud, **b** half-open flower, and **c** fully open flower. The compounds are: *1* ocimene, *2* linalool oxide, *3* linalool, *4* methylbenzoate, *5* phenylethanol, *6* benzyl acetate, *7* formanilide, *8* phenyletyl acetate, *9* indole, and *10* nerolidol

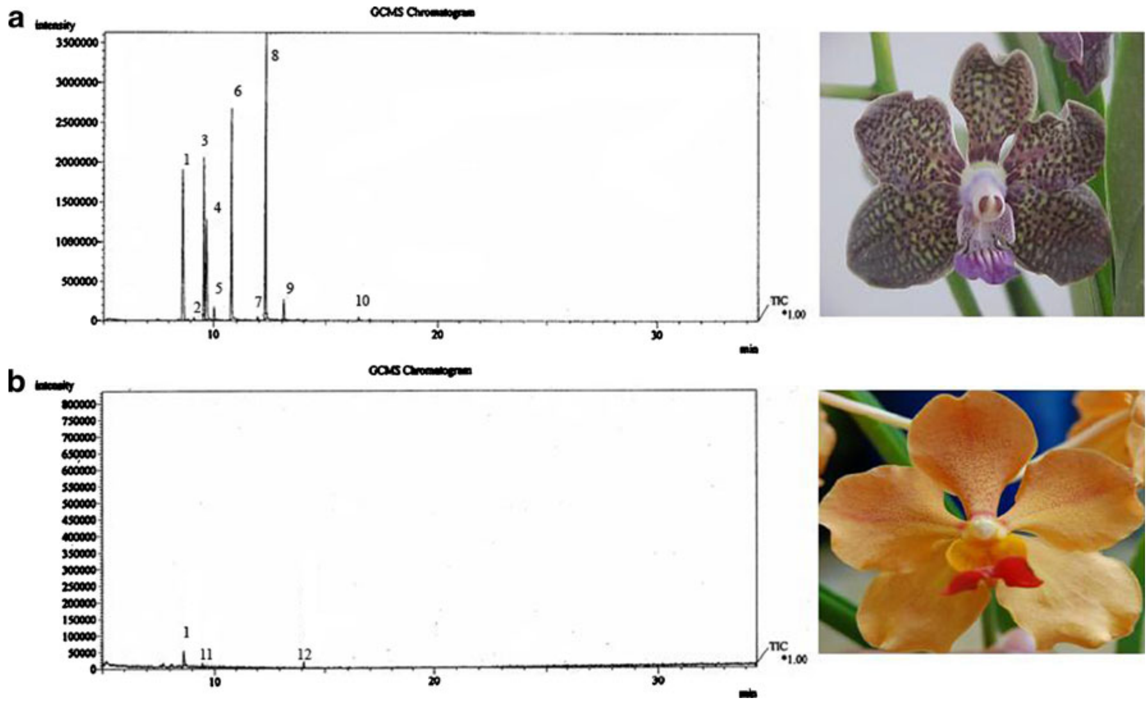

Fig. 7 Comparison of volatiles emitted by fully open flower of **a** *Vanda* Mimi Palmer and **b** *Vanda* Tan Chay Yan. The compounds are: *1* ocimene, *2* linalool oxide, *3* linalool, *4* methylbenzoate, *5* phenylethanol, *6* benzyl acetate, *7* formanilide, *8* phenyletyl acetate, *9* indole, *10* nerolidol, *11* decane, and *12* copaene

compounds with their relative retention times and the main fragments are listed in Table 1.

Profiles of *Vanda* Mimi Palmer's Scent Emission

Floral scent analyses in a 24-h cycle as summarized in Fig. 5a and b show that the emission of terpenoids as well as benzenoid/phenylpropanoid compounds were detected as early as 6:00 am (dawn). The emissions of the compounds were detected to increase gradually until the highest peak in the early afternoon (at 2:00 pm) followed by a gradual decrease towards the evening. Among the terpenoid compounds, two monoterpenes (ocimene and linalool) were dominant throughout the day while linalool oxide (monoterpene) and nerolidol (sesquiterpene) were only detected in trace amounts at 2:00 pm (see Fig. 5a). The

Table 2 Comparison of terpenoids and benzenoid/phenylpropanoid compounds emitted by *Vanda* Mimi Palmer, *Vanda* Tan Chay Yan, and *Vanda tessellata*

Compound	*Vanda* Mimi Palmer	*Vanda* Tan Chay Yan	*V. tessellata* (Kaiser 1993)
α-pinene			√
Benzaldehyde			√
Benzyl acetate	√		√
Benzyl alcohol			√
Cinnamyl alcohol			√
Copaene		√	
Linalool	√		√
Linalool oxide			
Methylbenzoate	√		√
Methyl cinnamate			√
Methyl salicylate			√
Mycrene			√
Nerolidol	√		
Ocimene	√	√	√
Phenylethanol	√		
Phenylethyl acetate	√		

The "√" indicates the presence of the compound in the volatiles emitted by the flowers

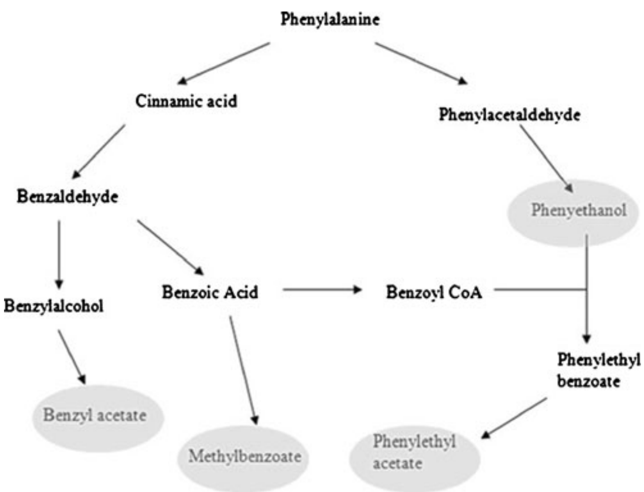

Fig. 8 Postulation of benzenoid/phenylpropanoid pathway of *Vanda* Mimi Palmer. This elucidation was based on benzenoid/phenylpropanoid metabolism of *P. hybrida* (Boatright et al. 2004; Pichersky and Dudareva 2007)

emission pattern of benzenoid/phenylpropanoid compounds (methylbenzoate, benzyl acetate, and phenylethyl acetate) were detected to be similar to the emission pattern of terpenoid compounds, detected early at dawn, increased gradually and peaking in the early afternoon, and followed by a gradual decline until late evening. Another compound classified in benzenoid/phenylpropanoid class which is phenylethyl alcohol (phenylethanol) was only detected in trace during the highest peak at 2:00 pm. After 6:00 pm, neither terpenoid nor benzenoid/phenylpropanoid compounds was detected from the flowers throughout the night until pre-dawn. Scent analyses at three developmental stages (bud, half-open flower, and fully open flower) in Fig. 6 reveals no detectable volatile compounds emitted from the bud stage. In the half-open flower stage, only five compounds were found to be emitted by the flower including ocimene, linalool, methylbenzoate, benzyl acetate, and phenylethyl acetate. At this blooming stage, two monoterpene compounds (ocimene and linalool) were detected at very high levels compared to other compounds. While benzenoid/phenylpropanoid compounds such as methylbenzoate, benzyl acetate, and phenylethyl acetate were detected at a very low level compared to the terpenoid compounds in half-open flower stage. In fully open flower stage, all the ten volatile compounds were detected in the scent of *Vanda* Mimi Palmer. The benzenoid/phenylpropanoid compounds (benzyl acetate and phenylethyl acetate) were detected at the highest level in the total scent of this developmental stage.

Comparison of Volatiles of *Vanda* Mimi Palmer with Its Parents

The volatile compounds detected from *Vanda* Tan Chay Yan were ocimene, decane, and copaene (Fig. 7). However, GC-MS analysis was not carried out on *V. tessellata* due to inavailability of the sample source. Thus, a previously reported result by Kaiser (1993) on the scent of *V. tessellata* was used for comparison. The profiles of *Vanda* Mimi Palmer's volatiles and its parents are shown in Table 2. From the table, only ocimene was found to be emitted by *Vanda* Mimi Palmer and both its parents. While three compounds (benzyl acetate, methylbenzoate, and linalool) were detected in the scent of *Vanda* Mimi Palmer and its fragrant parent, *V. tessellata* (Kaiser 1993). Interestingly, three compounds which were nerolidol, phenylethanol, and phenylethyl acetate were unique to *Vanda* Mimi Palmer.

Discussion

The GC-MS analyses of the volatile compounds of *Vanda* Mimi Palmer showed there were four candidates, ocimene, linalool oxide, linalool, and nerolidol, potentially derived from the terpenoid pathway. Ocimene, linalool oxide and linalool are classified as monoterpenes (Croteau and Karp 1991; Knudsen and Gershenzon 2006) while nerolidol is a sesquiterpene (Knudsen and Gershenzon 2006; Nagegowda et al. 2008). Monoterpenes and sesquiterpenes are common volatile compounds detected in scented orchids including *P. bellina* (Hsiao et al. 2006), *Dendrobium beckleri*, and *Phalaenopsis violacea* (Kaiser 1993). The terpenoid compounds emitted by *Vanda* Mimi Palmer flowers were also reported to be present in other flowers such as *Anthirrhinum majus* (linalool, ocimene and nerolidol) (Dudareva et al. 2003; Nagegowda et al. 2008) and *C. breweri* (linalool) (Pichersky et al. 1994). This implies that the terpenoid pathway in *Vanda* Mimi Palmer is possibly involved in the biosynthesis of linalool, ocimene, and nerolidol compounds, and similar to the terpenoid pathway reported in other well studied scented flowers.

Comparison of the volatiles emitted by *Vanda* Mimi Palmer and its parents, *Vanda* Tan Chay Yan (non-fragrant orchid) and *V. tessellata* (fragrant orchid; see Table 2) showed ocimene is the only common compound detected in all three orchids. An ocimene synthase from *Vanda* Mimi Palmer which has yet to be identified might be involved in the final step catalyzing the formation of ocimene from geranyl diphosphate, a precursor for monoterpenoids biosynthesis. For another monoterpene compound which is linalool, a linalool synthase which has been identified in the floral ESTs of *Vanda* Mimi Palmer (unpublished data) might be involved in catalyzing the formation of linalool from geranyl diphosphate. The linalool synthase gene might have been derived from *V. tessellata* since linalool compound was also reported in the scent of *V. tessellata* previously by Kaiser (1993) in his GC-MS analysis. Besides that, formation of nerolidol (a sesquiterpene compound) might be catalyzed by a sesquiterpene synthase. Since no sesquiterpene compound was identified in *V. tessellata* (Kaiser 1993), we assume that the level is too low to be detectable or the sesquiterpene synthase gene is not present in this orchid. The sesquiterpene synthase gene in *Vanda* Mimi Palmer might be derived from *Vanda* Tan Chay Yan since copaene (a sesquiterpene) was identified in its scent (see Fig. 7).

Based on the comparison between the volatiles of *Vanda* Mimi Palmer and its parents (see Table 2), both benzyl acetate and methylbenzoate compounds were identified in the scent of *Vanda* Mimi Palmer and *V. tessellata* (Kaiser 1993). These compounds could have possibly been derived from the benzenoid/phenylpropanoid pathway. Interestingly, many benzenoid/phenylpropanoid compounds identified in *V. tessellata* (Kaiser 1993) were not detected in *Vanda* Mimi Palmer such as benzaldehyde, benzylalcohol, cinnamyl alcohol, methyl cinnamate, and methyl salicylate. Likewise, some compounds were only detected in the scent of *Vanda* Mimi Palmer such as phenylethanol and phenylethyl acetate. Based on the differences, it was postulated that some modifications might have occurred in the benzenoid/phenylpropanoid pathway of *Vanda* Mimi Palmer compared to its fragrant parent (*V. tessellata*) which has shown emission of benzenoid and phenylpropanoid compounds too (Kaiser 1993). Benzaldehyde, benzyl alcohol and cinnamyl alcohol, which were detected in the scent of *V. tessellata* as final products, might be used as intermediates or precursors for methylbenzoate, benzylacetate and phenylethyl acetate biosynthesis in *Vanda* Mimi Palmer. The benzenoid/phenylpropanoid pathway is well studied in *P. hybrida*, *R. hybrida*, and *C. breweri* (Boatright et al. 2004; Pichersky and Dudareva 2007). The benzenoid compounds (methylbenzoate and benzyl acetate) identified in *Vanda* Mimi Palmer might be derived from cinnamic acid while the phenylpropanoid compounds (phenylethanol and phenylethyl acetate) might be derived from phenylacetaldehyde based on the floral scent studies of *P. hybrida* and *C. breweri* (Boatright et al. 2004; Kaminaga et al. 2006; Pichersky and Dudareva 2007; Fig. 8). The findings in this study suggest that the fragrance-related genes of *Vanda* Mimi Palmer that are involved in the benzenoid/phenylpropanoid pathway might be inherited from *V. tessellata*, a native orchid of South Asia especially in Sri Lanka (Motes 1997).

In summary, the scent emission of *Vanda* Mimi Palmer, which is dominated by terpenoids as well as benzenoid/phenylpropanoid compounds, is developmentally and temporally regulated and might be contributed by the genes pool from both parents, *V. tessellata* and *Vanda* Tan Chay Yan.

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