



UNIVERSITI PUTRA MALAYSIA

**IDENTIFICATION, CLONING AND CHARACTERIZATION OF
SELECTED FULL-LENGTH FRAGRANCE-RELATED TRANSCRIPTS
FROM ORCHID (*VANDA MIMI PALMER*)**

CHAN WAI SUN

FBSB 2009 22



**IDENTIFICATION, CLONING AND CHARACTERIZATION OF SELECTED
FULL-LENGTH FRAGRANCE-RELATED TRANSCRIPTS FROM ORCHID
(VANDA MIMI PALMER)**

CHAN WAI SUN

**MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA**

2009



**IDENTIFICATION, CLONING AND CHARACTERIZATION OF SELECTED
FULL-LENGTH FRAGRANCE-RELATED TRANSCRIPTS FROM ORCHID
(VANDA MIMI PALMER)**

By

CHAN WAI SUN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfilment of the Requirements for the Degree of Master of Science**

August 2009



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

IDENTIFICATION, CLONING AND CHARACTERIZATION OF SELECTED FULL-LENGTH FRAGRANCE-RELATED TRANSCRIPTS FROM ORCHID (VANDA MIMI PALMER)

By

CHAN WAI SUN

August 2009

Chairman: Janna Ong Abdullah, PhD

Faculty: Biotechnology and Biomolecular Sciences

Floral fragrance has important economical value in ornamental plants, crops and industries related to essential oils. However, the understanding of the molecular mechanisms underlying the biosynthesis of floral fragrance in monocotyledonous plants; in particular orchids, is still in its infancy. This study aimed to isolate and characterize fragrance-related genes from *Vanda* Mimi Palmer in order to enhance understanding of the molecular biology of fragrance in vandaceous orchid. *Vanda* Mimi Palmer is a tropical scented orchid with high economical value. In the effort to identify potential fragrance-related genes in *Vanda* Mimi Palmer, a floral cDNA library and a subtracted cDNA library were constructed. A total of 100 clones were selected from the cDNA library and their nucleotide sequences were determined, of which 83 clones showed homology to known amino acid sequences, comprising 6 contigs and 62 singletons, which were further assigned into 9 categories based on their functional roles. Two ESTs were identified as potential fragrance-related transcripts and they were 1-deoxy-D-xylulose 5-phosphate reductoisomerase (DXR) and lipoxygenase. From the Suppression



Subtractive Hybridization (SSH) library, 107 clones were up-regulated in the full bloom flowers of *Vanda Mimi Palmer* where 33 clones (3 singletons and 30 contigs) showed similarities to known sequences in the public database and were classified based on their putative functional roles as secondary metabolism (97%) and hypothetical proteins (3%), and 32 of the clones were transcripts encoding fragrance-related transcripts. The fragrance-related transcripts code for sesquiterpene synthase, tyrosine decarboxylase and putative alcohol acyltransferase. However, only three ESTs were selected for full-length gene isolation and characterization and they are putative alcohol acyltransferase (VMPAAT), sesquiterpene synthase (VMPSTS) and DXR (VMPDXR). Southern analyses showed that each of the isolated transcripts belongs to a large gene family, containing more than one copy in the *Vanda Mimi Palmer* genome. Real time RT-PCR indicated that VMPAAT and VMPSTS transcripts were expressed preferentially in floral tissues whereas VMPDXR was expressed differentially in different types of tissues (root, leaf, petal, sepal and column). All three clones showed higher transcript expressions in blooming and full bloom flowers compared to flower bud. VMPAAT and VMPDXR transcripts expressions showed no fluctuations whereas VMPSTS showed otherwise. In conclusion, the findings in this study have contributed to the GeneBank database resources for orchids and have opened some insights on molecular biology of fragrance in vandaceous orchids.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMENCILAN, PENGKLONAN DAN PENCIRIAN TRANSKRIP-TRANSKRIP LENGKAP BERKAITAN BAU WANGI YANG DIPILIH DARIPADA ORKID (VANDA MIMI PALMER)

Oleh

CHAN WAI SUN

Ogos 2009

Pengerusi: Janna Ong Abdullah, PhD

Fakulti: Bioteknologi dan Sains Biomolekul

Bunga wangi mempunyai nilai ekonomi yang penting dalam tumbuh-tumbuhan hiasan, pertanian dan perindustrian berkaitan minyak wangi. Akan tetapi, kefahaman tentang mekanisme di peringkat molekular penghasilan bau wangi baru berkembang dalam tumbuhan monokot terutamanya orkid. Penyelidikan ini bertujuan untuk memencilkan dan mencirikan gen yang terlibat dalam penghasilan bau wangi untuk menambahkan kefahaman biologi molekul berkenaan bau wangi dalam orkid vandaceous. *Vanda Mimi Palmer* ialah sejenis orkid tropika yang berbau wangi, dikenalpasti mempunyai potensi untuk menjadi tumbuhan hiasan penting yang mempunyai nilai ekonomi yang tinggi. Untuk mengenalpasti gen yang terlibat dalam penghasilan bau wangi daripada *Vanda Mimi Palmer*, suatu perpustakaan cDNA (cDNA library) untuk bunga dan satu perpustakaan yang telah disaring (subtracted cDNA library) telah dihasilkan. Sebanyak 100 klon telah dipilih daripada bunga perpustakaan cDNA dan jujukan nukleotide ditetapkan, di mana 83 klon menunjukkan padanan yang sah dengan jujukan-jujukan



asid amino yang diketahui. Mereka terdiri daripada 6 ‘contigs’ dan 62 ‘singletons’ di mana selanjutnya dibahagikan kepada 9 kategori berdasarkan fungsi masing-masing. Dua ESTs dikenalpasti sebagai transkrip yang terlibat dalam penghasilan bau wangi dan mereka ialah 1-deoxy-D-xylulose 5-phosphate reductoisomerase (DXR) dan lipoxygenase. Daripada perpustakaan ‘Suppression Subtractive Hybridization’ (SSH), sebanyak 107 klon yang ‘up-regulated’ dalam bunga yang telah berkembang penuh di mana 33 klon (3 ‘singletons’ dan 30 ‘contig’) menunjukkan padanan yang sah dengan jujukan yang diketahui dalam pengkalan data umum dan dikelaskan mengikut fungsi di mana metabolisme sekunder (97%) dan protein hipotetik (3%), dan 32 klon ialah transkrip yang terlibat penghasilan bau wangi. Transkrip-transkrip ini ialah 3 ‘ESTs’ yang mengekodkan sesquiterpene synthase, putatif acyltransferase dan tyrosine decarboxylase. Akan tetapi, hanya tiga ‘ESTs’ dipilih daripada dua perpustakaan cDNA ini untuk pemencilan gen lengkap dan pencirian dan mereka ialah putatif acyltransferase (VMPAAT), sesquiterpene synthase (VMPSTS) dan DXR (VMPDXR). Analisa penghibridan ‘Southern’ menunjukkan setiap transkrip yang terpilih mungkin berasal dari famili gen besar dan mengandungi lebih daripada satu salinan dalam *Vanda Mimi Palmer* genom. ‘Real time reverse transcriptase-polymerase chain reaction’ menunjukkan transkript-transkript VMPAAT dan VMPSTS diekspres secara predomnan di dalam tisu bunga manakala pengekspresan VMPDXR adalah berlainan di dalam tisu yang berbeza (akar, daun, petal, sepal, kolum, bibir). Ketiga-tiga klon menunjukkan ekspresi yang lebih tinggi di dalam bunga yang sedang berkembang dan telah berkembang penuh berbanding dengan bunga kudup. Ekspresi bagi transkrip-transkrip VMPAAT dan VMPDXR menunjukkan pergerakan tidak menentu sementara

VMPSTS menunjukkan corak yang sebaliknya. Secara kesimpulan, data yang diperolehi dalam penyelidikan ini telah memberi sumbangan kepada pangkalan data 'GeneBank' terutamanya orkid dan menambahkan kefahaman di peringkat biologi molekul berkenaan bau wangi secara lebih terperinci di dalam orkid vandaceous.



ACKNOWLEDGEMENTS

I would like to express my utmost gratitude to my supervisor, Dr. Janna Ong Abdullah, for her patient, encouragement, time as well as precious advice and guidance, leading me throughout this research project. My sincere appreciation is also extended to my co-supervisors, Professor Dr. Maziah Mahmood and Dr. Parameswari, for their guidance, support and technical guidance. Besides, they kindly provided good lab facilities and equipments needed for completing my studies in their laboratories.

Special thanks due to Professor Dr. Rasedee Abdullah, Professor Dr. Raja Noor Zaliha, Associate Professor Dr. Ho Chai Ling, Associate Professor Dr. Suhaimi and Professor Dr. Tan Wen Siang for giving me permissions to use the instruments in their laboratories. Speechless thankful is given to United Malaysia Plantation for their valuable assistance in maintaining the plant material, orchid (*Vanda Mimi Palmer*), in good conditions and providing orchid with blooms throughout this research project.

I would like to thank all my ex- and present lab mates in plant biotechnology laboratory, 002 laboratory and plant molecular biology laboratory as well as friends from LIFE for their technical guidance, support, care, forgiveness, valuable ideas and experience. My deepest appreciation extended to my parents, sister, cousins and friends for their endless support, care and love, accompanying me to go through all the happiness and sadness in my study.



I certify that an Examination Committee met on 26 August 2009 to conduct the final examination of Chan Wai Sun on her Master of Science thesis entitled “Isolation and Characterization of Selected Full-length Fragrance-related Transcripts from Orchid (*Vanda Mimi Palmer*)” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee are as follows:

Chairman

Associate Professor Dr. Ho Chai Ling
Faculty Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Chairman)

Internal I

Associate Professor Datin Dr. Siti Nor Akmar Abdullah
Faculty Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Internal Examiner)

Internal II

Professor Dr. Tan Wen Siang
Faculty Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Internal Examiner)

External

Associate Professor Dr. Jennifer Ann Harikrishna
Faculty Science
Universiti Malaya
(External Examiner)

BUJANG KIM HUAT, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:



This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Janna Ong Abdullah, PhD

Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Chairman)

Maziah Mahmood, PhD

Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Parameswari a/p Namasivayam, PhD

Lecturer
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

HASANAH MOHD. GHAZALI, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10 December 2009



DECLARATION

I hereby declare that the thesis is based on my original work except for equations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

CHAN WAI SUN

Date:



TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xviii
CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	4
2.1 The Orchid Plant	4
2.1.1 Genus: <i>Vanda</i>	5
2.1.2 <i>Vanda</i> Mimi Palmer	6
2.2 Plant volatiles	9
2.2.1 Roles of Plant Volatiles	9
2.2.2 Release Sites of Plant Volatiles	12
2.2.3 Composition of Floral Volatiles	13
2.2.4 Biosynthesis of Floral Volatiles	13
2.2.5 2-C-Methyl-D-Erythritol 4-phosphate (MEP), Mevalonate (MVA) and Terpenes Biosynthesis Pathway	16
2.2.6 Benzenoids Biosynthesis Pathway	19
2.2.7 Lipoxygenase Pathway	23
2.3 Regulation of Floral Volatiles and Fragrance-related Transcripts	26
2.4 Molecular Studies on Orchid Fragrance	30
2.5 Molecular Approaches	31
2.5.1 cDNA Library	31
2.5.2 Suppression Subtractive Hybridization (SSH)	33
2.5.3 Gene Expression Measurement	35
3 MATERIALS AND METHODS	
3.1 Plant Materials	37
3.2 Total RNA Extraction from <i>Vanda</i> Mimi Palmer Flowers	37
3.3 Formaldehyde Denaturing Agarose Gel Electrophoresis	38
3.4 Poly-A ⁺ RNA Isolation	39
3.4.1 Quantification of Poly-A ⁺ RNA Using Ethidium Bromide Plate Assay	40



3.5	Construction of <i>Vanda</i> Mimi Palmer Floral cDNA Library	40
3.5.1	First-strand cDNA Synthesis	41
3.5.2	Second-strand cDNA Synthesis	41
3.5.3	Blunting cDNA Termini	42
3.5.4	Ligation of Double-stranded cDNA with <i>Eco</i> RI Adaptors	42
3.5.5	Phosphorylating <i>Eco</i> RI Ends	43
3.5.6	Digestion with <i>Xho</i> I	43
3.5.7	Size Fractionation of Double-stranded cDNA	44
3.5.8	Purification of DNA from Agarose Gel	44
3.6	Ligation of cDNA into Uni-ZAP XR Vector	45
3.7	Packaging of Bacteriophages	45
3.8	Preparation of Host Bacteria	46
3.9	Plating and Titering of Primary cDNA Library	46
3.10	Amplification of Primary cDNA Library	47
3.11	Plating and Titering of Amplified cDNA Library	48
3.12	<i>In Vivo</i> Excision	48
3.13	Purification of Plasmid DNA	49
3.14	Restriction Enzyme Digestion of Plasmid DNA	50
3.15	DNA Sequencing and Sequence Analysis	50
3.16	Construction of Two Subtractive cDNA Libraries of <i>Vanda</i> Mimi Palmer Flowers by Subtractive Suppression Hybridization (SSH) Technique	51
3.16.1	First-strand cDNA Synthesis	52
3.16.2	Second-strand cDNA Synthesis	52
3.16.3	Double-stranded cDNA Digestion with <i>Rsa</i> I	53
3.16.4	Ligation of Double-stranded cDNA with Adaptor 1 and Adaptor 2R	55
3.16.5	First Hybridization	56
3.16.6	Second Hybridization	57
3.16.7	Polymerase Chain Reaction (PCR) Amplification	57
3.16.8	PCR Analysis of Subtraction Efficiency	59
3.17	Cloning of Subtracted PCR Mixture of Forward Subtracted cDNA Library	60
3.18	Growth of Bacteria in Suspension Culture	61
3.19	Reverse Northern Analysis	61
3.19.1	Preparation of Probes for Hybridization	63
3.20	Purification of Plasmid DNA	64
3.21	DNA Sequencing and Sequence Analysis	64
3.22	Isolation of Full-length Sequence of Fragrance-related cDNA from <i>Vanda</i> Mimi Palmer	64
3.22.1	Synthesizing 5'- and 3'-RACE-ready cDNAs	65
3.22.2	Primer Design	66
3.22.3	Full-length Isolation of VMPAAT Transcript	66
3.22.4	Full-length Isolation of VMPSTS Transcript	70
3.22.5	Full-length Isolation of VMPD XR Transcript	70
3.22.6	Sequence Analysis of the Full-length Transcript	71



3.23	Genomic DNA Extraction of <i>Vanda Mimi Palmer</i>	72
3.23.1	Quantification and Qualification of Genomic DNA	73
3.24	Southern Analysis	74
3.24.1	Hybridization Probes	76
3.25	Real-time RT-PCR (Reverse Transcriptase-PCR)	79
3.25.1	First-strand cDNA Synthesis	79
3.25.2	Endogenous Control Selection	80
3.25.3	Primers and Fluorogenic TaqMan® Probes Design	80
3.25.4	Optimization of Real-time RT-PCR Run Conditions	82
3.25.5	Relative Quantification (Comparative C _T Method)	84
4	RESULTS AND DISCUSSION	
4.1	Floral cDNA Library Construction	86
4.1.1	Characterization of cDNA Library	89
4.1.2	Fragrance-related Transcripts	101
4.2	Floral Subtracted cDNA Library of <i>Vanda Mimi Palmer</i>	102
4.2.1	Characterization of Subtracted cDNA Library	105
4.2.2	Classification of ESTs Based on Functional Roles	110
4.3	Isolation of Full-length Fragrance-related Transcripts	116
4.3.1	Sequence Analysis of VMPAAT Transcript	117
4.3.2	Sequence Analysis of VMPSTS Transcript	124
4.3.3	Sequence Analysis of VMPDXR Transcript	131
4.4	Southern Analysis	139
4.4.1	VMPAAT	140
4.4.2	VMPSTS	140
4.4.3	VMPDXR	140
4.5	Gene Expression Study of Fragrance-related Transcripts	142
4.5.1	Real-time PCR Validation Using the Comparative C _T Method	142
4.5.2	Expressions Profiles of VMPAAT, VMPSTS and VMPDXR in Different Tissues	146
4.5.3	Expressions Profiles of VMPAAT, VMPSTS and VMPDXR at Different Floral Developmental Stages	149
4.5.4	Expressions Profiles of VMPAAT, VMPSTS and VMPDXR at Different Times	152
4.6	General Conclusion	155
5	CONCLUSION	157
	BIBLIOGRAPHY	159
	APPENDIXES	175
	BIODATA OF STUDENT	205



LIST OF TABLES

Table		Page
1	Fragrance Emissions in <i>Vanda</i> Mimi Palmer	8
2	Primers Sequences for the Isolation of Full-length Transcripts	67
3	Thermal Cycling Conditions to Isolate ORF, 3'- and 5'-end cDNAs	69
4	Primers Used in Probes Preparation for Southern Analyses	77
5	Thermal Cycling Conditions Used in Probes Preparation for Southern Analyses	78
6	Primers and Probes Used in Real-Time RT-PCR	81
7	Classification of Acquired ESTs	92
8	Abundances of Acquired ESTs	94
9	Abundances of <i>Vanda</i> Mimi Palmer's Floral ESTs	111
10	Examples of ESTs Encoded Known or Putative Fragrance-related Transcripts	109
11	Different Combination of Probe and Primer Concentrations	175
12	BLASTX Results of ESTs from Floral cDNA Library from <i>Vanda</i> Mimi Palmer (CD)	178
13	BLASTX Results of ESTs from Floral subtracted cDNA Library from <i>Vanda</i> Mimi Palmer (CD)	181



LIST OF FIGURES

Figure		Page
1	<i>Vanda</i> Mimi Palmer and Its Parents	7
2	Examples of Plant Volatiles	14
3	Overview of MEP and MVA Pathways	17
4A	Proposed Benzenoids Biosynthesis Pathway	21
4B	Proposed Benzenoids Biosynthesis Pathway	22
5	Lipoxygenase/ Octadecanoid Pathway	25
6	Overview of the First and Second Hybridization in SSH	34
7	Developmental Stages of <i>Vanda</i> Mimi Palmer Flower	88
8	Total RNA Isolated from <i>Vanda</i> Mimi Palmer Flower in Subtracted cDNA Library Construction	88
9	Floral cDNA Library Construction	95
10	Functional Categorization of ESTs into 9 Categories	93
11	Total RNA Isolated from <i>Vanda</i> Mimi Palmer Flower at Different Developmental Stages (A and B) Corresponding to Different Time Points	104
12	Analysis of PCR Products of First and Second Rounds of Hybridizations	106
13	PCR Analyses of Subtraction Efficiencies of the Forward Subtracted cDNA Libraries	108
14	Reverse Northern Analyses of Clones from Forward Subtracted cDNA Library	108
15	Insert Size of Clones from Forward Subtracted cDNA Library	109
16	Classification of ESTs from <i>Vanda</i> Mimi Palmer's Forward-subtracted Floral cDNA Library as According to Their Functional Roles	113
17	ORF of VMPEAT Isolated Using SMART-RACE PCR	118



18	The Nucleotide and Deduced Amino Acid Sequences of VMPAAT	120
19	Alignment of Deduced Amino Acid Sequences of VMPAAT with <i>Cucumis melo</i> , <i>Verbena x hybrida</i> , <i>Clitonia ternatea</i> , <i>Petunia x hybrida</i> , and <i>Clarkia breweri</i> Sequences	122
20	Phylogenetic Relationship of VMPAAT and Different Plant Species Based on the Deduced Amino Acid Sequences	123
21	ORF of VMPSTS Isolated Using SMART-RACE PCR	125
22	The Nucleotide and Deduced Amino Acid Sequences of VMPSTS	128
23	Alignment of Deduced Amino Acid Sequences of VMPSTS with <i>Zinger zerumbet</i> , <i>Elaeis oleifera</i> , <i>Zinger officinale</i> and <i>Vitis vinifera</i> Sequences	129
24	Phylogenetic Relationship of VMPSTS and Different Plant Species Based on the Deduced Amino Acid Sequences	130
25	ORF of VMPDXR Isolated Using SMART-RACE PCR	132
26	The Nucleotide and Deduced Amino Acid Sequences of VMPDXR	135
27	Alignment of Deduced Amino Acid Sequences of VMPDXR with <i>Hevea brasiliensis</i> , <i>Lycopersicon esculentum</i> , <i>Oryza sativa</i> (japonica-cultivar group), <i>Zea mays</i> and <i>Artemisia annua</i> Sequences	136
28	Phylogenetic Relationship of VMPDXR and Different Plant Species Based on the Deduced Amino Acid Sequences removing transit peptide	138
29	Southern Analysis	141
30	Selection of Endogenous Controls Using GeNorm	144
31	PCR Efficiencies of Targets and Endogenous Controls	145
32	Expression Profiles of VMPAAT, VMPSTS and VMPDXR Transcripts in Different Tissues	147
33	Expression Profiles of VMPAAT, VMPSTS and VMPDXR Transcripts at Different Floral Developmental Stages	150
34	Expression Profiles of VMPAAT, VMPSTS and VMPDXR Transcripts at Different Times	153



35	Quantification of Poly-A ⁺ RNA Using an Ethidium-bromide Agarose Plate	177
36	Nucleotide Sequences of ESTs from Floral cDNA Library and Floral Subtracted cDNA Library from <i>Vanda</i> Mimi Palmer	184



LIST OF ABBREVIATIONS

AFLP	amplified fragment length polymorphism
AHCT	anthocyanin O-hydroxycinnamoyltransferase
AMV	Avian Myeloblastosis Virus
AOC	allene oxide cyclase
AOS	allene oxide synthase
bp	base pair
BAHD	first letter of first four characterized family members
BAMT	S-adenosyl-L-methionine:benzoic acid carboxyl methyltransferase
BEAT	benzylalcohol <i>O</i> -acetyltransferase
BEBT	benzoyl-coenzyme A (CoA):benzyl alcohol benzoyl transferase
BPBT	benzoyl CoA: benzyl alcohol/ phenylethanol benzoyltransferase
BSA	bovine serum albumin
BSMT	benzoic acid/ salicylic acid methyltransferase
cDNA	complementary deoxyribonucleic acid
cDNA-RDA	cDNA-representational difference analysis
CHAT	acetyl CoA:(<i>Z</i>)-3-hexen-1-ol acetyltransferase
C _T	threshold cycle
CTAB	hexadecyltrimethyl-ammonium bromide
DAT	deacetylvindoline 4- <i>O</i> -acetyltransferase
DEPC	diethylpyrocarbonate
DMAPP	dimethylallyl diphosphate
DMSO	dimethyl sulphoxide



DNA	deoxyribonucleic acid
DXR	1-deoxy-D-xylulose 5-phosphate reductoisomerase
DXS	1-deoxy-D-xylulose 5-phosphate synthase
dNTP	deoxynucleoside triphosphates
EDTA	ethylenediaminetetraacetic acid
EF	elongation factor
EST	expressed sequence tag
EtBr	ethidium bromide
FA	formaldehyde agarose
FGP	Floral Genome Project
FRET	Fluorescent Resonance Energy Transfer
GSPs	gene specific primers
HbDXR1	<i>Hevea basiliensis</i> DXR
HCBT	anthranilate N-hydroxycinnamoyl/ benzoyltransferase
13(S)-HPLA	13(S)-hydroperoxylinolenic acid
IAA	indole acetic acid
IPP	isopentenyl diphosphate
IPTG	isopropylthio- β -D-galactoside
ISSR	intersimple sequence repeats
JA	jasmonic acid
JMT	jasmonate carboxyl methyltransferase
kb	kilo base pair
LB	Luria-Bertani



LiCl	lithium chloride
LOX	lipoxygenase
M	molarity
M	gene stability measure
MADS	MCM1-AGAMOUS-DEFICIENS-SRF
MeJA	methyl jasmonic acid
MEP	2-C-methyl-D-erythritol 4-phosphate
MgCl ₂	magnesium chloride
MgSO ₄	magnesium sulphate
MOPS	3-N-morpholino propanesulfonic acid
MTHFR	5, 10-methylene-tetrahydrofolate reductase
MVA	mevalonate
NaCl	sodium chloride
NaH ₂ PO ₄	sodium dihydrogen phosphate
Na ₂ HPO ₄	sodium hydrogen phosphate
NaOAc	sodium acetate
NaOH	sodium hydroxide
NCBI	National Center for Biotechnology Information
NH ₄ OAc	ammonium acetate
OD	optical density
ODO1	ODORANT1
OPDA	(9S, 13S)-oxophytodienoic acid
OPR	12-oxo-PDA reductase



ORF	open reading frame
PAL	phenylalanine ammonia-lyase
PAAS	phenylacetaldehyde synthase
PbDXR	<i>Phalaenopsis bellina</i> DXR
PbGDPS	<i>Phalaenopsis bellina</i> geranyl diphosphate synthase
PcDXR	grey poplar DXR
PCR	polymerase chain reaction
PdLOX	<i>Populus deltoids</i> lipoxygenase
PhCFAT	Petunia's acetyl CoA: coniferyl alcohol acyltransferase
PhPAAS	Petunia's phenylacetaldehyde synthase
PhBPBT	Petunia's benzoylCoA: benzyl alcohol/ phenylethanol benzoyltransferase
PhBSMT	Petunia's benzoic acid/salicylic acid carboxyl methyltransferase
PhCFAT	petunia's coniferyl alcohol acyltransferase
PhIGS1	isoeugenol synthase 1
Pfu	plaque forming unit
PVP	polyvinyl pyrrolidone
R ²	correlation coefficient
RACE	rapid amplification of cDNA ends
RAPD	random amplified polymorphic DNA
RcOMT1	rose orcinol methyltransferase 1
RcOMT2	rose orcinol methyltransferase 2
RFLP	restriction fragment length polymorphism
RhAAT	rose alcohol acetyltransferase



RhGP1	rose geranylgeranylated protein 1
RNA	ribonucleic acid
RNase	ribonuclease
rRNA	ribosomal RNA
RT-PCR	reverse transcription-polymerase chain reaction
SA	salicylic acid
SAM	S-adenosyl methionine
SDS	sodium dodecyl sulfate
SKP1	S-phase kinase-associated protein 1
SSC	standard saline citrate
SSH	subtractive suppression hybridization
SSR	simple sequence repeats
TAE	tris-acetate-EDTA
TE	tris-EDTA
T _m	melting temperature
Tris-HCl	tris-hydrochloric acid
TUC	tentative unique contig
TUG	tentative unique gene
TUS	tentative unique singleton
U	unit
Ubi	ubiquitin
UPM	universal primer A mix
UTR	untranslated region



UV	ultraviolet
V	volts
VMPAAT	alcohol acyltransferase from <i>Vanda</i> Mimi Palmer
VMPDXR	DXR from <i>Vanda</i> Mimi Palmer
VMPSTS	sesquiterpene synthase from <i>Vanda</i> Mimi Palmer
X-gal	5-bromo-4-chloro-3-indolyl- β -D-galactoside

