UNIVERSITI PUTRA MALAYSIA

OLFACTORY DETECTION OF METHYL EUGENOL BY MALE ORIENTAL FRUIT FLY, BACTROCERA DORSALIS (HENDEL) (DIPTERA: TEPHRITIDAE)

ANNA CHIENG CHUI TING

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By

ANNA CHIENG CHUI TING

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Chair : Alvin Hee Kah Wei, PhD
Faculty : Science

Oriental fruit fly, *Bactrocera dorsalis* (Hendel) is one of the world's most destructive pests of fruits and vegetables. Methyl eugenol (ME), a potent male attractant that is also found as a plant volatile compound, when mixed with insecticides is widely used to manage and control those pestiferous flies. Upon detection of ME, *B. dorsalis* male will respond rapidly by flying in zig-zag pattern to, landing and subsequent feeding on ME. Hitherto, with tremendous progress in molecular biology, there is now improved understanding in the molecular basis of insect detection of odourants such as ME by the antennae (ANT) of male *B. dorsalis*. However, little is known about the role of the maxillary palp (MP) in odourant detection. The general aim of this study was to evaluate the role of olfactory organs, ANT and MP in male *B. dorsalis* detection of ME. Therefore, the specific objectives of this study were to: 1) ascertain the function of MP in detection of ME by male *B. dorsalis*; 2) evaluate electrophoretic protein pattern in both MP and ANT, and following male attraction to ME, 3) evaluate associated proteome changes, 4) evaluate transcriptome changes followed by 5) an integrated proteo-transcriptome analysis. First, it has been demonstrated in those males from wind tunnel and cage behavioural assays that both olfactory organs were functionally complementary in detecting ME. The ANT was involved in long-range detection of ME while the MP at close range, manoeuvres the male towards the ME source for feeding. Second, exposure to ME appeared to have increased the protein concentration of both olfactory organs compared to those non-ME-exposed. When protein profiles of the male olfactory organs were obtained using gradient PAGE, a number of proteins present were below 66 kDa. Similarly, SDS-PAGE analyses showed most protein bands were between 20-100 kDa with 2 major bands below 20 kDa. No marked differences were seen in the protein patterns of both organs when compared between before, and

after exposure to ME. Finally, a complementary approach using shotgun proteomics followed by transcriptomics (reference-based alignment) revealed the existence of 30 genes/ proteins having tissue specific expression with 7 being odourant binding proteins and 1 belonging to alcohol dehydrogenase. Six genes were significantly expressed in those organs with 5 up-regulated and 1 down-regulated. Of those 5 genes, *Bdor*OBP69a was induced in both olfactory organs following the exposure to ME. Whilst *Bdor*OBP69a was not detected in the proteome of both organs, another OBP *Bdor*OBP84a-2 was significantly up-regulated in the MP only following exposure to ME. The presence of those different genes and proteins that were induced in different organs following exposure to ME suggests that the proteo-transcriptomic basis of gene-protein is an intricate pattern of operation. In genes that were involved in detoxification of xenobiotics including ME i.e., P450 members, two different types of those annotated genes were up-regulated at proteome level in both olfactory organs following exposure to ME. This suggests the role of MP in detecting and feeding on ME.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGESANAN BAU METIL EUGENOL OLEH LALAT BUAH ORIENTAL, *BACTROCERA DORSALIS* (HENDEL) (DIPTERA: TEPHRITIDAE)

Oleh

ANNA CHIENG CHUI TING

April 2019

Pengerusi : Alvin Hee Kah Wei, PhD
Fakulti : Sains

Lalat buah Oriental, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) adalah salah satu serangga perosak buah-buahan dan sayur-sayuran yang paling serius di dunia. Metil eugenol (ME), sejenis bahan penarik poten lalat buah jantan yang juga ditemui sebagai sebatian tumbuhan yang mudah meruap, apabila dicampur dengan racun serangga perosak telah digunakan secara meluas dalam pengurusan dan pengawalan serangga perosak tersebut. Apabila ME dikesan oleh lalat jantan *B. dorsalis*, lalat tersebut akan bergerak balas dengan pantas melalui penerbangan secara zig-zag yang diikuti dengan pendaratan dan pemakanan sebatian ME itu. Kini, berikutan perkembangan yang pantas dalam biologi molekul, pemahaman yang berasaskan molekul mengenai pengesanan bau seperti ME oleh organ antena (ANT) lalat buah jantan *B. dorsalis* adalah lebih baik. Walau bagaimanapun, pemahaman mengenai peranan palpa maksilari (MP) dalam pengesanan bau sebatian meruap masih lagi kurang. Oleh itu, matlamat umum kajian ini adalah untuk menilai peranan ANT dan MP dalam pengesanan ME oleh lalat jantan *B. dorsalis*. Sehubungan itu, maka objektif khusus kajian ini adalah untuk: 1) menentu fungsi MP dalam pengesanan ME oleh jantan *B. dorsalis*; 2) menilai corak protein elektroforetik dalam kedua-dua MP dan ANT; 3) menilai perubahan proteome; 4) menilai perubahan transcriptome diikuti dengan 5) perubahan proteo-transkriptome yang berkaitan berikutan penarikan jantan *B. dorsalis* ke ME. Pertama, melalui kajian kelakuan dengan menggunakan asai terowong angin dan sangkar, organ ANT dan MP telah ditunjukkan berfungsi secara saling melengkapi dalam pengesanan ME. ANT adalah terlibat dalam pengesanan jarak jauh ME manakala MP adalah untuk pengesanan ME secara jarak dekat dengan memimpin lalat jantan ke arah sumber ME untuk dimakan. Kedua, pendedahan lalat jantan kepada ME telah menghasilkan peningkatan dalam kepekatan protein kedua-dua organ ANT dan MP lalat jantan *B. dorsalis* berbanding dengan lalat jantan yang tidak terdedah kepada ME. Apabila profil protein ANT dan MP jantan diperolehi melalui kaedah elektroforesis gel

poliakrilamida (PAGE) tak nyahasli (native), beberapa protein yang dijumpai adalah di bawah 66 kDa. Begitu juga dengan SDS-PAGE yang menunjukkan kebanyakan jalur protein berada di antara 20-100 kDa dengan 2 jalur utama di bawah 20 kDa. Tiada perbezaan ketara didapati dalam kedua-dua corak protein ANT dan MP apabila perbandingan dibuat di antara corak protein sebelum dan selepas pendedahan kepada ME. Akhirnya, pendekatan pelengkap dengan menggunakan kaedah proteomik rawak ("shotgun proteomics") diikuti dengan transkriptomik penyejajaran berasaskan rujukan mendedahkan kewujudan pengekspresan 30 gen/ protein berasaskan tisu dengan 7 protein pengikat pembau ("odourant") dan 1 alkohol dehidrogenase. Pengekpresan gen berlaku dengan ketara dalam 6 gen dalam ANT dan MP dengan peningkatan dalam 5 gen dan penurunan dalam 1 gen. Daripada 5 gen tesebut, *Bdor*OBP69a telah didorong dalam kedua-dua ANT dan MP selepas pendedahan kepada ME. Walaupun *Bdor*OBP69a tidak dikesan dalam proteome kedua-dua organ, satu lagi OBP *Bdor*OBP84a-2 telah menujukan kenaikan yang ketara dalam MP sahaja selepas pendedahan kepada ME. Kemunculan gen-gen dan protein yang berlainan yang diinduksi dalam organ-organ yang berlainan berikut pendedahan kepada ME menunjukkan asas proteo-transkriptomik gen-protein adalah corak operasi yang rumit dan penilaian terhadap kesan temporal pada ANT dan MP berikut pendedahan jantan *B. dorsalis* kepada ME adalah diperlukan. Analisis lanjut juga menunjukkan bahawa dalam gen yang terlibat dalam detoksifikasi xenobiotik termasuk ME i.e., ahli P450, dua jenis gen yang dianotasi telah menujukkan kenaikan di tahap proteome dalam ANT dan MP masing-masing berikutan pendedahan kepada ME. Ini turut mencadangkan peranan MP dalam pengesanan dan pemakanan ME.

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Alvin Hee Kah Wei, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Christina Yong Seok Yien, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

Tan Wen Siang, PhD
Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Wee Suk Ling, PhD
Associate Professor
School of Environmental and Natural Resource Sciences
Universiti Kebangsaan Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature: ______________________
Name of Member of Supervisory Committee: ______________________

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LIST OF ABBREVIATIONS

7TM	7-transmembrane domain
ADH	alcohol dehydrogenase
ANT	antenna/ antennea
APS	ammonium persulfate
BSA	Bovine serum albumin
cDNA	complementary DNA
CF	(*E*)-coniferyl alcohol
CL	cuelure
CSP	chemosensory protein
CYPs	cytochromes P450
DAE	day of emergence
DAP	differentially abundant protein
DEG	differentially expressed gene
DMC	(*Z*)-3,4-dimethoxycinnamyl alcohol
DMP	2-ally-4,5-dimethoxyphenol
GPCR	G-protein coupled receptor
GR	gustatory receptor
GST	glutathione S-transferases
iGluR	ionotropic ‘glutamate’ receptor
IR	ionotropic receptor
kDA	kilodalton
LC-MS	liquid chromatography mass spectometry
m/z	mass/ ion
MAT	male annihilation techniques
ME	methyl eugenol
ME-exp	methyl eugenol exposed
ME-unexp	methyl eugenol unexposed (control)
MP	maxillary palp(s)
mRNA	messengers RNA
NADH	reduced nicotinamide adenine dinucleotide
NADPH	reduced nicotinamide adenine dinucleotide phosphate
OBP	Odourant binding protein
OR	Odourant receptor
ORCO	Odourant receptor co-receptor
ORN	olfactory receptor neurone
ODE	Odourant degradation enzyme
PBP	pheromone binding protein
PBPRP	pheromone binding protein related protein
PCB	polychlorinated biphenyls
R_f	relative front
RK	raspberry ketone
RKF	raspberry ketone formate
rpm	revolutions per minute
SDS-PAGE	sodium dodecyl sulphate-polyacrylamide gel electrophoresis
SIT	sterile insect techniques
SNMP	sensory neurone membrane protein
TCA	trichloroacetic acid

TEMED	tetramethylethylenediamine
TML	tridmedlure
UGT	UDP-glucuronosyltranferases

CHAPTER 1

INTRODUCTION

True fruit flies (Diptera: Tephritidae) consist of some of the world's most serious insect pests of horticultural production throughout the subtropical and tropical regions (Drew, 1989). Within the past decades, there has been an increase in economic loss towards the production of commercial fruits and vegetables due to severe fruit fly infestations and invasion (Allwood *et al.,* 2002).Thus, with certain species of Tephritidae such as the Oriental fruit fly and Mediterranean fruit fly possesing high mobility, dispersal and high degress of polyphagy, they have been documented as major invaders in a list of quarantine targets (Clarke *et al.*, 2005; Vayssières *et al.*, 2014; Wan *et al.*, 2017). Hitherto, global losses attributed to fruit fly damage have been estimated to be over US$ 2 billion annually (Shelly *et al.*, 2014).

As one of the largest genera in the fruit fly family of Tephritidae (subfamily: Dacinae), the genus *Bactrocera* includes around 500 described species (Drew, 1989; Drew and Hancock, 2000). Within the genus *Bactrocera*, there exists the *B. dorsalis* complex that consists of 85 morphologically similar species such as the highly invasive and damaging *B. dorsalis*, *B. dorsalis* (Hendel) (Clarke *et al.*, 2005; Drew and Romig, 2013). However, the close similarities between the *B. dorsalis* and its siblings species such as *B. invadens* Drew, Tsuruta & White, *B. papayae* Drew & Hancock and *B. philippinensis* Drew & Hancock that are all major fruit pests have created much confusion over their identities (Lux *et al.*, 2003; Schutze *et al.*, 2012) that impacts global quarantine fruit restrictions. However, with the synonymization of *B. dorsalis* with the threreafore mentioned species recently as a single *B. dorsalis* species (Schutze *et al.*, 2015), this allows the improvement of pest management tools which is restricted previously due to the species limits (Schutze *et al.*, 2015).

The detection and control of *B. dorsalis* relies heavily on methyl eugenol (ME), 1,2-dimethoxy-4-(2-propenyl) benzene (phenylpropanoid) that is a unique and potent attractant for male tephritid fruit flies (Metcalf *et al.*, 1975) since its discovery over a century ago (Howlett, 1915). As a component of plant compound, ME is known to occur in over 480 plant species (Tan and Nishida, 2012). Following *B. dorsalis* male consumption of ME, the heightened during courtship period at dusk attraction of female towards those conspecific males has been attributed to production of attractive chemical cues in the form of sex pheromone, (*E*)-coniferyl alcohol (CF), along with 2-ally-4,5-dimethoxyphenol (DMP) and (*Z*)-3,4-dimethoxycinnamyl alcohol (DMC) from ME that were emitted from the rectal gland during wing fanning at dusk (Nishida *et al.*, 1988a, 1988b).

In managing the *B. dorsalis*, multiple tactics with the aim to achieve low pest prevalence or pest free status have been developed by using of ME as attractant. The tactics which are used to manage and control these pestiferous tephritid fruit flies through the manipulation of certain facets of the biology of these flies that include the sterile insect technique (SIT), male annihilation technique (MAT), protein bait sprays and biological control (Piñero *et al.,* 2009b; Vargas *et al.*, 2015). The application of ME as a supplement in feeding the sterile males which are released in SIT programmes can aid in male signalling and thus increasing the mating competitiveness of the ME-fed male over non-ME-fed wild male (Hee and Tan, 1998; McInnis *et al.*, 2011; Tan *et al.*, 2014) with conspecific feral females (Pereira *et al.*, 2013). As millions of sterile males are released in SIT in order to suppress the reproduction of the feral female pests, the efficacy of SIT is further enhanced when MAT which uses insecticide intoxicated ME in attracting, killing and eventually reducing the number of wild males is implemented prior to the commencement of SIT.

As most tactics for monitoring and controlling of *B. dorsalis* involve the continuous use of ME as male attractant, there have been concerns that lines of non-ME-attracted males may be generated (Ito and Iwahashi, 1974; Shelly, 1997). Further, sequential MAT releases of insecticide baited ME followed by releases of SIT irradiated males may result in those sterile males themselves attracted and killed by those ME baits (Barclay *et al.*, 2014). This underscores the need for enhanced understanding on mechanisms of male detection of ME at the behavioural, physiological and molecular levels. Therefore, the understanding of the olfactory system provides the basis designing novel tephritid pest control approaches such as silencing of sequence-specific gene using RNA interference (RNAi) (Mamta and Rajam, 2017) through the manipulation of olfactory mechanism of *B. dorsalis*.

The *B. dorsalis,* like other insects, owns two bilateral symmetrical pairs of olfactory organs on its head, namely, antenna (ANT) and maxillary palp (MP). Although there has been significant important development in elucidating the molecular basis of antennal function of *B. dorsalis* in recent years (Zheng *et al.*, 2013; Wu *et al.*, 2015; Wu *et al.*, 2016; Liu *et al.*, 2016; Liu *et al.,* 2017; Liu *et al.*, 2018), there has been no information on the function of *B. dorsalis* MP in detecting ME. The MP is also another pair of olfactory organs which have been shown to house specific receptors in responding to behaviourally important odourants in *D. melanogaster* (Dweck *et al.,* 2016) and *B. tryoni* (Verschutt *et al.*, 2018). Therefore, it is believed that specific odourant receptors which respond selectively to ME might also present on the MP of *B. dorsalis* since both olfactory organs contain similar types of olfactory sensilla (Dickens *et al.*, 1988; Lee *et al.*, 1994) that may accommodate receptors tuned to ME.

Thus, in this study, my first objective (Chapter 3) was to evaluate if the MP is also involved in the male *B. dorsalis* attraction to ME. Cage behavioural assays and wind tunnel assays involving response of *B. dorsalis* to ME with ANT and/ or MP ablation were conducted. My second objective (Chapter 4) was to examine for any changes in the electrophoretic protein pattern in both ANT and

MP of the *B. dorsalis* following exposure to ME. This is due to the fact that in olfactory organs, a number of proteins have been implicated to be involved in detection of volatile compounds such as odourants. Changes in the electrophoretic patterns of protein expression in the ANT and MP were observed. Finally, an integrated analysis of generated proteomic and transcriptomic profiles of both ANT and MP of *B. dorsalis* male was performed in order to understand mechanism(s) of olfactory processing (perireceptor events) in those organs following attraction to ME which still remain largely unclear to date (i.e., proteome analysis [Chapter 5], transcriptome analysis [Chapter 6] and integrated proteo-transcriptome analysis [chapter 7]). It was expected that result from this research will shed new light on the role of the MP of *B. dorsalis* in detection of ME and the associated changes in the proteome and transcriptome level of the MP and ANT following attraction to ME. This information will be beneficial for development of novel proteo-transcriptome based strategies to control those pests.

REFERENCES

Abdel-latief, M., Garbe, L. A., Koch, M., & Ruther, J. (2008). An epoxide hydrolase involved in the insect sex attractant and its use to localize the production site. *Proceedings of the National Academy of Sciences of the United States of America, 105*, 8914-8919.

Abuin, L., Bargeton, B., Ulbrich, M. H., Isacoff, E. Y., Kellenberger, S., & Benton, R. (2011). Functional architecture of olfactory ionotropic glutamate receptors. *Neuron*, *69*, 44-60.

Ahn, S. J., Vogel, H., & Heckel, D. G. (2012). Comparative analysis of the UDP-glycosyltransferase multigene family in insects. *Insect Biochemistry and Molecular Biology*, *42*, 133-147.

Ai, M., Min, S., Grosjean, Y., Leblanc, C., Bell, R., Benton, R., & Suh, G. S. (2010). acid sensing by the *Drosophila* olfactory system. *Nature*, *468*, 691-696.

Al-Attar, A. M. (2010). Physiological and histopathological investigations on the effects of ***α***-lipoic acid in rats exposed to malathion. *Journal of Biomedicine and Biotechnology, 2010*, 1-8.

AlJabr, A. M., Hussain, A., Rizwan-ul-Haq, M., & Al-Ayedh, H. (2017). Toxicity of plant secondary metabolites modulating detoxification genes expression for natural red palm weevil pesticide development. *Molecules*, *22*, 169.

Allwood, A. J. (1996a). Biology and ecology: Prerequisites for understanding and managing fruit flies (Diptera: Tephritidae). In Allwood, A. J. & Drew, R. A. I. (Eds.), *Management of Fruit Flies in the Pacific: A Regional Symposium* (The Australian Centre for International Agricultural Research Proceeding No. 76., pp. 95-101). Nadi, Fiji: The Australian Centre for International Agricultural Research.

Allwood, A. J. (1996b). Control strategies for fruit flies (Family Tephritidae) in the South Pacific. In Allwood, A. J., & Drew, R. A. I. (Eds.), *Management of Fruit Flies in the Pacific: A Regional Symposium* (The Australian Centre for International Agricultural Research Proceeding No. 76., pp. 171-178). Nadi, Fiji. The Australian Centre for International Agricultural Research.

Allwood, A. J., Vueti, E. T., Leblanc, L., & Bull, R. (2002). Eradication of introduced *Bactrocera* species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques. In Veitch C. R. & Clout, M. N. (Eds.), *Turning the tide: The eradication of island invasive species* (Proceedings of the International Conference on Eradication of Island Invasives No. 27, pp. 19-25). IUCN.

Andersson, M. (1994). *Sexual selection*. Princeton, NJ: Princeton University Press.

Anton, S., van Loon, J. J. A., Meijerink, J., Smid, H. M., Takken, W., & Rospars, J. (2003). Central projections of olfactory receptor neurons from single antennal and palpal sensilla in mosquitoes. *Arthropod Structure & Development, 32*, 319-327.

Arakaki, N., Kuba, H., & Soemori, H. (1984). Mating behavior of the Oriental fruit fly, *Dacus dorsalis* Hendel (Diptera: Tephritidae). *Applied Entomology and Zoology*, *19*, 42-51.

Asahina, K., Pavlenkovich, V., & Vosshall, L. B. (2008) .The survival advantage of olfaction in a competitive environment. *Current Biology, 18*, 1153–1155.

Ashburner, M. (1989). *Drosophila. A laboratory handbook*. Cold Spring Harbor, New York: Cold Spring Harbor Laboratory Press.

Ayer, W. A. & Singer, P. P. (1980). Phenolic metabolites of the bird's nest fungus *Nidula niveo tomentosa. Phytochemistry, 19*, 2717-2721.

Back, E. A. & Pemberton, C. E. (1918). *The Mediterranean fruit fly in Hawaii* (No. 536). US Department of Agriculture.

Baggerman, G., Vierstraete, E., De Loof, A., & Schoofs, L. (2005). Gel-based versus gel-free proteomics: a review. *Combinatorial Chemistry & High Throughput Screening*, *8*, 669-677.

Barclay, H. J. & Hendrichs, J. (2014). Modeling trapping of fruit flies for detection, suppression or eradication. In Shelly, T. E., Epsky, N., Jang, E. B., Flores-Reyes, J., & Vargas, R. I. (Eds.), *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies* (pp. 379-420). New York, NY: Springer.

Bateman, M. A., Insungza, V., & Arreta, P. (1973). The eradication of Queensland fruit fly from Easter Island. *FAO Plant Protection Bulletin 21*, 114.

Benton, R., Vannice, K. S., Gomez-Diaz, C., & Vosshall, L. B. (2009). Variant ionotropic glutamate receptors as chemosensory receptors in *Drosophila*. *Cell, 136*, 149-162.

Beroza, M., Alexander, B. H., Steiner, L. F., Mitchell, W. C., & Miyashita, D. H. (1960). New synthetic lures for the male melon fly. *Science, 131*, 1044–1045.

Beroza, M., Inscoe, M. N., Schwartz Jr, P. H., Keplinger, M. L., & Mastri, C. W. (1975). Acute toxicity studies with insect attractants. *Toxicology and Applied Pharmacology*, *31*, 421-429.

Bohbot, J. D., Lu, T., & Zwiebel, L. J. (2010). Molecular Regulation of Olfaction in Mosquitoes. In Takken, W. & Knols, B. G. (Eds.), *Ecology and Control of Vector-Borne Diseases. Olfaction in Vector Host Interactions* (Vol. 2, pp. 17-38). Wageningen, Netherlands: Wageningen Academic Publishers.

Bollag, D. M., Rozycki, M. D. & Edelstein, S. J. (1996). *Protein methods*, 2nd Edition. New York, NY: Wiley.

Bradford, M. M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry, 72*, 248-254.

Brito, N. F., Moreira, M. F., & Melo, A. C. (2016). A look inside odourant-binding proteins in insect chemoreception. *Journal of Insect Physiology*, *95*, 51-65.

Brouwer, A., Longnecker, M. P., Birnbaum, L. S., Cogliano, J., Kostyniak, P., Moore, J., Schantz, S., & Winneke, G. (1999). Characterization of potential endocrine related health effects at lowdose levels of exposure to PCBs. *Environmental Health Perspectives, 107*, 639-649.

Caers, J., Verlinden, H., Zels, S., Vandersmissen, H. P., Vuerinckx, K., & Schoofs, L. (2012). More than two decades of research on insect neuropeptide GPCRs: an overview. *Frontiers in Endocrinology*, *3*, 151.

Caldas, E. D. & Jardim, A. N. O. (2012). Exposure to toxic chemicals in the diet: is the Brazilian population at risk? *Journal Exposure Science and Environmental. Epidemiology, 22*, 1-15.

Cantrell, B., Chadwick, B., & Cahill, A. (2002). *Fruit fly fighters: eradication of the papaya fruit fly*. Collingwood, VIS, Australia: Commonwealth Scientific and Industrial Research Organization Publishing.

Carmichael, A., Wharton, R., & Clarke, A. (2005). Opiine parasitoids (Hymenoptera: Braconidae) of tropical fruit flies (Diptera: Tephritidae) of the Australian and South Pacific region. *Bulletin of Entomological Research, 95*, 545-569.

Cayol, J. P. (2000). Changes in sexual behaviour and life history traits of tephritid species caused by mass-rearing processes. In Aluja, M. & Norrbom, A. L. (Eds.) *Fruit Flies (Tephritidae): Phylogeny and Evolution of Behaviour* (pp. 843-860). Boca Raton, FL: CRC Press.

Chapman, R. F. (1998). *The insects: structure and function*. Cambridge, UK: Cambridge University Press.

Chapman, R. F., Simpson, S. J., & Douglas, A. E. (2013). *The insect: structure and function*. Cambridge, UK: Cambridge University Press.

Chase, J., Touhara, K., Prestwich, G. D., Schal, C, & Blomquist, G. J. (1992). Biosynthesis and endocrine control of the production of the German cockroach sex pheromone 3,11-dimethylnonacosane-2-one. *Proceedings of the National Academy of Sciences of the United States of America, 89*, 6050-6054.

Chesler, A., & Firestein, S. (2008). Neuroscience: Current views on odour receptors. *Nature*, *452*, 944.

Chieng, A. C. T., Hee, A. K. W., & Wee, S. L. (2018). Involvement of the antennal and maxillary palp structures in detection and response to methyl eugenol by male *Bactrocera dorsalis* (Diptera: Tephritidae). *Journal of Insect Science*, *18*, 19.

Chinajariyawong, A., Clark, A. R., Jirasurat, M., Kritsaneepiboon, S., Labey, H. A., Vijaysegaran, S., & Walter, G. H. (2000). Survey of Opiine parasitoids of fruit flies (Diptera: Tephritidae) in Thailand and Malaysia. *The Raffles Bulletin of Zoology, 48*, 71-101.

Cho, W. C. (2007). Proteomics technologies and challenges. *Genomics, Proteomics & Bioinformatics*, *5,* 77-85.

Christenson, L. D., & Foote, R. H. (1960). Biology of fruit flies. *Annual Review of Entomology*, *5*, 171-192.

Chua, T. H. & Khoo, S. G. (1995). Variations in carambola infestation rates by *Bactrocera carambolae* Drew and Hancock (Diptera: Tephritidae) with fruit availability in Carambola orchard. *Researches on Population Ecology, 37*, 151-157.

Clarke, A. R., Armstrong, K. F., Carmichael, A. E., Milne, J. R., Raghu, S., Roderick, G. K., & Yeates, D. K. (2005). Invasive phytophagus pests arising through a recent tropical evolutionary radiation: The *Bactrocera dorsalis* complex of fruit flies. *Annual Review of Entomo*logy*, 50*, 293-319.

Clyne, P., Warr, C., Freeman, M., Lessing, D., Kim, J., & Carlson, J. (1999). A novel family of divergent seven-transmembrane proteins: candidate odourant receptors in *Drosophila*. *Neuron, 22*, 327-338.

Corey, E. J., & Watt, D. S. (1973). Total synthesis of (+-)-. alpha.-and (+-)-. beta.-copaenes and ylangenes. *Journal of the American Chemical Society*, *95*, 2303-2311.

Cornelius, M. L., Duan, J. J., & Messing, R. H. (2000a). Volatile host fruit odours as attractants for the Oriental fruit fly (Diptera: Tephritidae). *Journal Economic Entomology, 93*, 93-100.

Cornelius, M. L., Nergel, L., Duan, J. J., & Messing, R. H. (2000b). Responses of female Oriental fruit flies (Diptera: Tephritidae) to protein and host fruit odours in field cage and open field tests. *Environmental Entomology, 29*, 14-19.

Cribb, B. W. & Merritt, D. J. (2013). Chemoreception. In Chapman, R. F., Simpson, S. J., & Douglas, A. E. (Eds.), *The Insects: Structure and Function* (5th ed., pp. 771-792). Cambridge, U.K.: Cambridge University Press.

Croset, V., Rytz, R., Cummins, S. F., Budd, A., Brawand, D., Kaessmann, H., Gibson, T. J., & Benton, R. (2010). Ancient protostome origin of chemosensory ionotropic glutamate receptors and the evolution of insect taste and olfaction. *PLOS Genetics, 6*, e1001064.

Cunningham, R. T. (1989) Parapheromones. In Robinson, A. S. & Hooper, G. (Eds.) Fruit flies: their biology, natural enemies and control, vol 3A (pp. 221-230). Amsterdam, The Netherlands: Elsevier.

de Bruyne, M., Clyne, O. J., & Carlson, J. R. (1999). Odour coding in a model olfactory organ: the *Drosophila* maxillary palp. *The Journal of Neuroscience, 19*, 4520-4532.

de Meyer, M., Robertson, M. P., Mansell, M. W., Ekesi, S., Tsuruta, K., Mwaiko, W., Vayssières, J-F., & Peterson, A. T. (2010). Ecological niche and potential geographic distribution of invasive fruit fly *Bactrocera invadens* (Diptera, Tephritidae). *Bulletin of Entomological Research, 100*, 35-48.

DeGennaro, M., McBride, C. S., Seeholzer, L., Nakagawa, T., Dennis, E. J., Goldman, C., Jasinskiene, N., James, A. A., & Vosshall, L. B. (2013). Orco mutant mosquitoes lose strong preference for humans and are not repelled by volatile DEET. *Nature, 498*, 487-491.

Dickens, J. C., Hart, W. G., Ligth, D. M., & Jang, E. B. (1988). Tephritid olfaction: morphology of the antenna of four tropical species of economic importance (Diptera: Tephritidae). *Annals of Entomological Society of America, 81*, 325-331.

Ding, X., & Kaminsky, L. S. (2003). Human extrahepatic cytochromes P450: function in xenobiotic metabolism and tissue-selective chemical toxicity in the respiratory and gastrointestinal tracts. *Annual Review of Pharmacology and Toxicology*, *43*, 149-173.

Ding, P. & Syakirah, M. N. (2009). Influence of fruit bagging on postharvest quality of 'harumanis' mango (*Mangifera indica* L.). In Erkan, M. & Aksoy, U. (Eds.), *Proceeding 6th International Postharvest Symposium 877*. (Acta horticulturae, no. 877, pp. 169-174). Leuven, Belgium: International Society for Horticultural Science.

Dobin, A., Davis, C. A., Schlesinger, F., Drenkow, J., Zaleski, C., Jha, S., ... & Gingeras, T. R. (2013). STAR: ultrafast universal RNA-seq aligner. *Bioinformatics*, *29*, 15-21.

Draz, K. A., El-Aw, M. A., Hashem, A. G., & El-Gendy, I. R. (2008). Influence of radiation dose on some biological aspects of the peach fruit fly, *Bactrocera zonata* (Saunders)(Diptera: Tephritidae). *Au*stralian *Journal of Basic and Applied Sciences, 2*, 815-822.

Draz, K. A., Tabikha, R. M., El-Aw, M. A., & Darwish, H. F. (2016). Impact of gamma radiation doses on sperm competitiveness, fecundity and morphometric characters of peach fruit fly, *Bactrocera zonata* (Saunders)(Diptera: Tephritidae). *Journal of Radiation Research and Applied Science, 9*, 352-362.

Drew, R. A. I. (1974). The responses of fruit fly species (Diptera: Tephritidae) in the South Pacific area to male attractants. *Journal of the Australian Entomological Society, 13*, 267-270.

Drew, R. A. I. (1989). The taxonomy and distribution of tropical and subtropical Dacinae (Diptera: Tephritidae). In Robinson, A. S., & Hopper, G. (Eds.), *Fruit Flies, Their Biology, Natural Enemies and Control* (pp. 9-14). Amsterdam, Netherland: Elsevier Science Publishers.

Drew, R. A. I. (1997). The economic and social impact of the *Bactrocera papayae* Drew and Hancock (Asian papaya fruit fly) outbreak in Australia. In Allwood, A. J., & Drew, R. A. I. (Eds.), *Management of Fruit Flies in the Pacific: A Regional Symposium* (pp. 205-207). Canberra, Australia: Australian Centre for International Agricultural Research.

Drew, R. A. I. & Hancock, D. L. (1994) The *Bactrocera dorsalis* complex of fruit flies in Asia. *Bulletin of Entomological Research (*Supplement No.2, 68p). Wallingford, United Kingdom: CAB International.

Drew, R. A. I. & Hancock, D. L. (2000). Phylogeny of the tribe Dacini (Dacinae) based on morphologicak, distributional, and biological data. In Aluja, M. & Norrbom, A. L. (Eds.), *Fruit Flies (Tephritidae): Phylogeny and Evolution of Behaviour* (pp. 491-533). Boca Raton, FL: CRC Press.

Drew, R. A. I. & Romig, M. C. (1997). Overview: Tephritidae in the Pacific and South-East Asia. In Allwood, A. J. & Drew, R. A. I. (Eds.), *Management of fruit flies in the Pacific: A Regional Symposium* (pp. 46-53). Canberra, Australia: Australian Centre for International Agricultural Research.

Drew, R. A. I. & Romig, M. C. (2013). *Tropical fruit flies of South-East Asia: (Tephritidae: Dacinae)*. Wallingford, United Kingdom: CAB International.

Drew, R. A. I, Tsuruta, K., & White, I. M. (2005). A new species of pest fruit fly (Diptera: Tephritidae: Dacinae) from Sri Lanka and Africa. *African Entomology, 13*, 149-154.

Dweck, H. K. M., Ebrahim, S. A. M., Khallaf, M. A., Koenig, C., Farhan, A., Stieber, R., Weiβflog, J., Svatoš, A., Grosse-Wilde, E., Knaden, M., & Hansson, B. S. (2016). Olfactory channels associated with the *Drosophila* maxillary palp mediate short-and long-range attraction. *eLife, 5*, e14925.

Dyck, V. A., Hendrichs, J., & Robinson, A. S. (2005). *Sterile insect technique: principles and practice in area-wide integrated pest management*. Dordrecht, The Netherlands: Springer.

El-Akhdar, E. A. H. & Afia, Y. E. (2009). Functional ultrastructure of antenna, wings and their associated sensory receptors of peach fruit fly, *Bactrocera zonata* (Saunders) as influenced by the sterilizing dose of gamma irradiation. *Journal of Radiation Research and Applied Sciences, 2*, 797-817.

Elfekih, S., Chen, C. Y., Hsu, J. C., Belcaid, M., & Haymer, D. (2016). Identification and preliminary characterization of chemosensory perception-associated proteins in the melon fly *Bactrocera cucurbitae* using RNA-seq. *Scientific Reports*, *6*, 19112.

Ernst, K. D. (1969). *Die Feinstruktur von Riechsensillen auf der Antenne des Aaskäfers Necrophorus (Coleoptera*). *Zeitschrift für Zellforschung und mikroskopische Anatomie, 94*, 72-102.

Fantke, P. & Jolliet, O. (2016). Life cycle human health impacts of 875 pesticides. *The International Journal of Life Cycle Assessment, 21*, 722-733.

Farhadian, S. F., Suárez-Fariñas, M., Cho, C. E., Pellegrino, M., & Vosshall, L. B. (2012). Post-fasting olfactory, transcriptional, and feeding responses in *Drosophila*. *Physiology & Behaviour*, *105*, 544-553.

Fay, H. A. C. (1989). Multi-host species of fruit fly. In Robinson, A. S. & Hooper, G. H. S. (Eds.), *World Crop Pests: Fruit flies: their biology, natural enemies and control* (pp. 129-140). Amsterdam, The Netherlands: Elsevier Science Publishers.

Feeny, P. A. U. L., Rosenthal, G. A., & Berenbaum, M. R. (1992). The evolution of chemical ecology: contributions from the study of herbivorous insects. In Rosenthal, G. A. & Berenbaum, M. R. (Eds.), *Herbivores: Their Interaction with Secondary Plant Metabolites: Evolutionary and Ecological Processes* (Vol.2, pp. 1-44). New York, NY: Academic Press.

Felsenstein J. (1985). Confidence limits on phylogenies: An approach using the bootstrap. *Evolution,* 39, 783-791

Feyereisen, R. (2012). 8-Insect CYP genes and P450 enzymes. In: Gilbert, L.I. (Ed.), *Insect Molecular Biology and Biochemistry* (pp. 236-316). San Diego: Academic Press.

Fletcher, B. S. (1987). The biology of dacine fruit flies. *Annual Review of Entomology, 32*, 115-144.

Fornasiero, U., Guitto, A., Caporale, G., Baccichetti, R. & Musajo, L. (1969) Identification of the attractant of *Ceratitis capitata* males contained in the *Angelica archangelica* seed oil. *Gazzetta Chimica Italiana, 99*, 700-710.

Franco, T. A., Oliveira, D. S., Moreira, M. F., Leal, W. S., & Melo, A. C. A. (2015). Silencing the odourant receptor co-receptor *RproOrco* affects the physiology and behaviour of the Chagas disease vector *Rhodnius prolixus*. *Insect Biochemistry and Molecular Biology, 69*, 82-90.

Frazier, J. L. (1985). Nervous system: Sensory system. In Blum, M. S. (Eds.), *Fundamentals of insect physiology* (pp. 287-356). New York, NY: John Wiley and Sons.

Frazier, J. L. (1992). How animals perceive secondary plant compounds, 2nd edition. In Rosenthal, G. A. & Berenbaum, M. R. (Eds.), *Herbivores: Their Interaction with Secondary Plant Metabolites: Evolutionary and Ecological Processes* (Vol.2, pp. 89-97). New York, NY: Academic Press.

Galizia, C. G. & Sachse, S. (2010). Odour coding in insects. In Menini, A. (Eds.), *The neurobiology of olfaction* (PP 35-70). Boca Raton, FL: CRC Press.

Gao, Q. & Chess, A. (1999). Identification of candidate *Drosophila* olfactory receptors from genomic DNA sequences. *Genomics, 60*, 31-39.

Garfin, D. E. (1990). Chapter 29 one-dimensional gel Electrophoresis. In Burgess, R. R. and Deutscher, M. P. (Eds.), *Methods in Enzymology* (2^{nd} ed.,. Vol. 463, pp 498-513). USA: Elsevier.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., ... Eggers, S. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology, 11*, 97-105.

Getahun, M. N., Olsson, S. B., Lavista-Llanos, S., Hansson, B. S., & Wicher, D. (2013). Insect odourant response sensitivity is tuned by metabotropically autoregulated olfactory receptors. *PLoS One*, *8*, e58889.

Getchell, T. V., Margolis, F.L., & Getchell, M. L. (1984). Perireceptor and receptor events in vertebrate olfaction. *Progress in Neurobiology, 23*, 317–345.

Giannakakis, A. & Fletcher, B. S. (1985). Morphology and distribution of antennal sensilla of *Dacus tryoni* (Froggatt) (Diptera: Tephritidae). *Journal of Australian Entomological Society, 24*, 31-35.

Gilmore, J. E. (1989). Control: sterile insect technique (SIT): overview. In Robinson, A. S. & Hooper, G. *World Crop Pests 3(B). Fruit flies: their natural enemies and control* (pp. 353-363). Amsterdam, The Netherlands: Elsevier Science Publishers.

Grabe, V., Baschwitz, A., Dweck, H. K., Lavista-Llanos, S., Hansson, B. S., & Sachse, S. (2016). Elucidating the neuronal architecture of olfactory glomeruli in the *Drosophila* antennal lobe. *Cell Reports, 16*, 3401-341.

Green, J. G. (1987). Carambola production in Malaysia and Taiwan. *Proceedings of the Florida State Horticultural Society, 100*, 275-278.

Gu, X., Cai, P., Yang, Y., Yang, Q., Yao, M., Idrees, A., ... & Chen, J. (2018). The response of four braconid parasitoid species to methyl eugenol: Optimization of a biocontrol tactic to suppress *Bactrocera dorsalis*. *Biological Control*, *122*, 101-108.

Gui, S. H., Pei, Y. X., Xu, L., Wang, W. P., Jiang, H. B., Nachman, R. J., ... & Wang, J. J. (2018). Function of the natalisin receptor in mating of the oriental fruit fly, *Bactrocera dorsalis* (Hendel) and testing of peptidomimetics. *PLoS one*, *13*, e0193058.

Guiotto, A., Fornasiero, U., & Baccichetti, F. (1972). Investigations on attractants for males of *Ceratitis capitata*. *Il Farmaco; Edizione Scientifica*, *27*, 663.

Hallberg, E. & Hansson, B. S. (1999). Arthropod sensilla: morphology and phylogenetic considerations. *Microscopy Research and Technique, 47*, 428-439.

Hallem, E. A., Dahanukar, A., & Carlson, J. R. (2006). Insect odour and taste receptors. *Annual Review Entomology, 51*, 113-135.

Hansson, B. S. (1999). *Insect Olfaction*. Berlin, Germany: Springer.

Hansson, B. S., & Stensmyr, M. C. (2011). Evolution of insect olfaction. *Neuron*, *72*, 698-711.

Happ, G. M. (1969). Multiple sex pheromones of the mealworm beetle, *Tenebrio molitor* L. *Nature, 222*, 180-181.

Haq, I., Vreysen, M. J., Cacéres, C., Shelly, T. E., & Hendrichs, J. (2014). Methyl eugenol aromatherapy enhances the mating competitiveness of male *Bactrocera carambolae* Drew & Hancock (Diptera: Tephritidae). *Journal of Insect Physiology, 68*, 1-6.

Haq, I., Cáceres, C., Meza, J. S., Hendrichs, J., & Vreysen, M. J. (2018). Different methods of methyl eugenol application enhance the mating success of male Oriental fruit fly (Dipera: Tephritidae). *Scientific Reports*, *8*, 6033.

Hardy, D. E. (1949). Studies in Hawaiian Fruit flies (Diptera, Tephritidae). *Proceedings of the Entomology Society of Washington, 51*, 181-205.

Hardy, D. E. (1979). Review of economic fruit flies of the South Pacific Region. *Pacific Insects, 20*, 429-432.

Haverkamp, A., Hansson, B. S., & Knaden, M. (2018). Combinatorial Codes and Labeled Lines: How Insects Use Olfactory Cues to Find and Judge Food, Mates, and Oviposition Sites in Complex Environments. *Frontiers in Physiology*, *9*, 49.

Hee, A. K. W. (2003). Transportation of methyl eugenol metabolites as sex pheromonal components in male fruit fly, *Bactrocera papayae* (Drew & Hancock) (Diptera: Tephritidae), PhD thesis, Universiti Sains Malaysia.

Hee, A. K. W., Ooi, Y. S., Wee, S. L., & Tan, K. H. (2015). Comparative sensitivity to methyl eugenol of four putative *Bactrocera dorsalis* complex sibling species–further evidence that they belong to one and the same species *B. dorsalis*. *ZooKeys*, 2015, 313.

Hee, A. K. W. & Tan, K. H. (1998). Attraction of female and male *Bactrocera papayae* to conspecific males fed with methyl eugenol and attraction of females to male sex pheromone components. *Journal of Chemical Ecology, 24*, 753-764.

Hee, A. K. W. & Tan, K. H. (2004). Male sex pheromonal components derived from methyl eugenol in the hemolymph of the fruit fly *Bactrocera papayae*. *Journal of Chemical Ecology, 30*, 2127-2138.

Hee, A. K. W. & Tan, K. H. (2005). Bioactive fractions containing methyl eugenol-derived sex pheromonal components in haemolymph of the male fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae). *Bulletin of Entomological Research*, *95*, 615-620.

Hee, A. K. W., & Tan, K. H. (2006). Transport of methyl eugenol-derived sex pheromonal components in the male fruit fly, *Bactrocera dorsalis*. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *143*, 422-428.

Hibino, Y. & Iwahashi, O. (1996). Appearance of wild females unreceptive to sterilized males on Okinawa Is. in the eradication program of the melon fly, *Dacus cucurbitae* Coquillett (Diptera: Tephritidae). *Applied Entomology and Zoology,* 26, 265-270.

Hodgson, E., & Levi, P. E. (1998). Interactions of piperonyl butoxide with cytochrome P450. In Jones, D. G. *The Insecticide Synergist* (pp. 41-53). San Diego, California: Academic Press Ltd.

Hooper, G. H. S. (1971). Gamma sterilization of the Mediterranean fruit fly. In sterility principle for insect control of fruit flies. In *Sterility principle for insect control or eradication* (pp. 87-95). Vienna, Austria: Proceedings of Symposium International Atomic Energy Agency 1970.

Howlett, F. M. (1912). The effect of oil of citronella on two species of *Dacus. Transactions of the Royal Entomological Society of London, 60*, 412-418.

Howlett, F. M. (1915). Chemical reactions of fruit flies. *Bulletin of Entomological Research, 6*, 297-305.

Hu, F., Zhang, G. N., Jia, F. X., Dou, W., & Wang, J. J. (2010). Morphological characterization and distribution of antennal sensilla of six fruit flies (Diptera: Tephritidae). *Annals of the Entomological Society of America, 103*, 2661-2670.

Huang, Y., Lu, X. P., Wang, L. L., Wei, D., Feng, Z. J., Zhang, Q., ... & Wang, J. J. (2015). Functional characterization of NADPH-cytochrome P450 reductase from *Bactrocera dorsalis*: Possible involvement in susceptibility to malathion. *Scientific Reports*, *5*, 18394.

IAEA (International Atomic Energy Agency) (2003). *Trapping guidelines for area-wide fruit fly programmes*. Vienna, Austria: IAEA.

Ishida, Y., Chiang, V. P., Haverty, M. I., & Leal, W. S. (2002a). Odourant-binding roteins from a primitive termite. *Journal of Chemical Ecology, 28,* 1887- 1893.

Ishida, Y., Cornel, A. J., & Leal, W. S. (2002b). Identification and cloning of a female antenna-specific odourant-binding protein in the mosquito *Culex quinquefasciatus*. *Journal of Chemical Ecology, 28*, 867-871.

Ishida, Y. & Leal, W. S. (2005). Rapid inactivation of a moth pheromone. *Proceedings of the National Academy of Sciences of the United States of America, 102*, 14075-14079.

Isnadi, S. (1991). The distribution of *Dacus* spp. in the Indonesian Archipelagos. In Vijaysegaran, S. & Ibrahim, A. G. (Eds.), *Proceedings of the First International Symposium on Fruit Flies in the Tropics* (pp.99-107). Kuala Lumpur, Malaysia. The Malaysian Agricultural Research and Development Institute.

Jacquin-Joly, E., Vogt, R. G., Francois, M. C., & Nagnan-Le, M. P. (2001). Functional and expression pattern analysis of chemosensory proteins expressed in antenna and pheromonal gland of *Mamestra brassicae*. *Chemical Senses, 26*, 833-844.

Jallon, J. M. & Wicker-Thomas, C. (2003). Genetic studies on pheromone production in Drosophila. In Blomquist, G. & Vogt, R. (Eds.), *Insect Pheromone Biochemistry and Molecular Biology* (pp. 253-282). London, United Kingdom: Elsevier.

Jang, E. B., Khrimian, A., & Siderhurst, M. S. (2011). Di-and tri-fluorinated analogs of methyl eugenol: attraction to and metabolism in the Oriental fruit fly, *Bactrocera dorsalis* (Hendel). *Journal of Chemical Ecology*, *37*, 553-564.

Jang, E. B., Raw, A. S., & Carvalho, L. A. (2001). Field attraction of Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) to synthetic stereoselective enantiomers of the ceralure B1 isomer. *Journal of Chemical Ecology*, *27*, 235-242.

Jayanthi, K. P., Kempraj, V., Aurade, R. M., Roy, T. K., Shivashankara, K. S., & Verghese, A. (2014). Computational reverse chemical ecology: virtual screening and predicting behaviourally active semiochemicals for *Bactrocera dorsalis*. *BMC Genomics, 15*, 209.

Jensen, O. N. (2006). Interpreting the protein language using proteomics. *Nature Reviews Molecular Cell Biology, 7*, 391.

Jiang, H. B., Gui, S. H., Xu, L., Pei, Y. X., Smagghe, G., & Wang, J. J. (2017). The short neuropeptide F modulates olfactory sensitivity of *Bactrocera dorsalis* upon starvation. *Journal of Insect Physiology*, *99*, 78-85.

Jiang, H., Wei, Z., Nachman, R. J., & Park, Y. (2014). Molecular cloning and functional characterization of the diapause hormone receptor in the corn earworm *Helicoverpa zea. Peptides*, *53*, 243-249.

Jiang, X., Pregitzer, P., Grosse-Wilde, E., Breer, H., & Krieger, J. (2016). Identification and characterization of two “sensory neuron membrane proteins” (SNMPs) of the desert locust, *Schistocerca gregaria* (Orthoptera: Acrididae). *Journal of Insect Science, 16*, 33.

Jin, X., Ha, T. S., & Smith, D. P. (2008). SNMP is a signaling component required for pheromone sensitivity in *Drosophila. Proceedings of the National Academy of Sciences of the United States of America,* 105, 10996-11001.

Jin, S., Zhou, X., Gu, F., Zhong, G., & Yi, X. (2017). Olfactory plasticity: variation in the expression of chemosensory receptors in *Bactrocera dorsalis* in different physiological states. *Frontiers in Physiology*, *8*, 672.

Jones, D. T., Taylor, W. R., & Thornton, J. M. (1992). The rapid generation of mutation data matrices from protein sequences. *Computer Applications in the Biosciences,* 8, 275-282.

Jones, W. D., Cayirlioglu, P., Kadow, I. G., & Vosshall, L. B. (2007). Two chemosensory receptors together mediate carbon dioxide detection in *Drosophila. Nature*, *445*, 86-90.

José, L., Cugala, D., & Santos, L. (2013). Assessment of invasive fruit fly fruit infestation and damage in Cabo Delgado Province, Northern Mozambique. *African Crop Science Journal*, *21*, 21-28.

Jurenka, R. A. (2003). Biochemistry of female moth sex pheromones. In Blomquist, G. and Vogt, R. (Eds.), *Insect Pheromone Biochemistry and Molecular Biology* (pp. 53-80). London, United Kingdom: Elsevier.

Jurenka, R. A. (2004). Insect pheromone biosynthesis. *Topics in Current Chemistry, 239*, 97-132.

Kandel, S. E., & Lampe, J. N. (2014). Role of protein–protein interactions in cytochrome P450-mediated drug metabolism and toxicity. *Chemical Research in Toxicology*, *27*, 1474-1486.

Kaufman, T. S. (2015). The multiple faces of Eugenol. A versatile starting material and building block for organic and bio-organic synthesis and a convenient precursor toward bio-based fine chemicals. *Journal of the Brazilian Chemical Society*, *26*, 1055-1085.

Kaupp, U. B. (2010). Olfactory signalling in vertebrates and insects: differences and commanalities. *Nature Reviews Neuroscience, 11*, 188-200.

Keiser, I., Nakagawa, S., Kobayashi, R. M., Chambers, D. L., Urago, T., & Doolittle, R. E. (1973). Attractiveness of cue-lure and the degradation product 4-(*p*-hydroxyphenyl)-2-butanone to male melon flies in the field in Hawaii. *Journal of Economic Entomology, 66*, 112-114.

Kelm, M. A., Nair, M. G., & Schutzki, R. A. (1997). Mosquitocidal compounds from *Magnolia salicifolia. International Journal of Pharmacognosy. 35*, 84-90.

Kennedy, J. S., & Marsh, D. (1974). Pheromone-regulated anemotaxis in flying moths. *Science*, *184*, 999-1001.

Khamis, F. M., Karam, N., Ekesi, S., De Meyer, M., Bonomi, A., Gomulski, L. M., ... & Kenya, E. U. (2009). Uncovering the tracks of a recent and rapid invasion: the case of the fruit fly pest *Bactrocera invadens* (Diptera: Tephritidae) in Africa. *Molecular Ecology*, *18*, 4798-4810.

Kim, D., Langmead, B., & Salzberg, S. L. (2015). HISAT: a fast spliced aligner with low memory requirements. *Nature Methods*. *12*, 357-360.

Kim, D., Pertea, G., Trapnell, C., Pimentel, H., Kelley, R., & Salzberg, S. L. (2013). TopHat2: accurate alignment of transcriptomes in the presence of insertions, deletions and gene fusions. *Genome Biology*, *14*, R36.

Kim, M. S., Repp, A., & Smith, D. P. (1998). LUSH odourant-binding protein mediates chemosensory responses to alcohols in *Drosophila melanogaster*. *Genetics*. *150*, 711-721.

Kivanc, M. (1988). Antimicrobial activity of “Çörtük” (*Echinophora sibthorpiana* Guss.) spice, its essential oil and methyl eugenol. *Molecular Nutrition and Food Research, 32*, 635-637.

Kogan, M. & Bajwa, W. I. (1999). Integrated pest management: A global reality? *Anais da Sociedade Entomológica do Brasil, 28*, 1-25.

Koyama, J., Teruya, T., & Tanaka, K. (1984). Eradication of the Oriental fruit fly (Diptera: Tephritidae) from the Okinawa Islands by a male annihilation method. *Journal of Economic Entomology, 77*, 468-472.

Kramer, V. J., Helferich, W. G., Bergman, Å., Klasson-Wehler, E., & Giesy, J. P. (1997). Hydroxylated polychlorinated biphenyl metabolites are anti-estrogenic in a stably transfected human breast adenocarcinoma (MCF7) cell line. *Toxicology and Applied Pharmacology, 144*, 363-376.

Kuhbandner, B. (1984). Ultrastructure and ontogeny of the hair sensilla on the funicle of *Calliphora erythrocephala* (Insexta, Diptera). *Zoomorphology. 104*, 373-385.

Kumar, S., Stecher, G., Li, M., Knyaz, C., & Tamura, K. (2018). MEGA X: Molecular Evolutionary Genetics Analysis across computing platforms. *Molecular Biology and Evolution,* 35, 1547-1549.

Låås, T. (1989). Chapter 12: Electrophoresis in gels. In Janson, J and Rydén, L. (Eds.), *Protein purification: Principles, high resolution methods and applications* (pp. 360). Weinheim, Germany: VCH Publlishers.

Laissue, P. P. & Vosshall, L. B. (2008). The olfactory sensory map in *Drosophilla*. *Advances in Experimental Medicine and Biology, 628*, 102-114.

Lance, D. R. & McInnis, D. O. (2005). Biological basis of the sterile insect technique. In Dyck V. A., Hendrichs J., & Robinson A. S. (Eds.), *Sterile insect technique: Principles and practice in area-wide integrated pest management* (pp. 69-94). Dordrecht, The Netherlands. Springer.

Larsson, M. C., Domingos, A. I., Jones, W. D., Chiappe, M. E., Amrein, H., & Vosshall, L. B. (2004). Or83b encodes a broadly expressed odourant receptor essential for *Drosophila* olfaction. *Neuron, 43*, 703-714.

Larter, N. K., Sun, J. S., & Carlson, J. R. (2016). Organization and function of *Drosophila o*dourant binding protein. *eLife,5*, e20242.

Law, C. W., Chen, Y., Shi, W., & Smyth, G. K. (2014). Voom: precision weights unlock linear model analysis tools for RNA-seq read counts. *Genome Biology. 15,* R29.

Leal, W. S. (2013). odourant reception in insects: roles of receptors, binding proteins, and degrading enzymes. *Annual Review of Entomology, 58*, 373-391.

Lee, W. Y., Chang, J. C., Hwang, Y. B., & Lin, T. L. (1994). Morphology of the antennal sensilla of the Oriental fruit fly, *Dacus dorsalis* Hendel (Diptera: Tephritidae). *Zoological Studies, 33*, 65-71.

Lee, W. Y., Chang, J. C., Lin, T. L., & Hwang, Y. B. (1995). Ultrastructure of the antennal sensilla of the Oriental fruit fly, *Bactrocera* (Dacus) *dorsalis* (Hendel) (Diptera: Tephritidae). *Zoological Studies*, *34*, 21-28.

Lei, H. & Vickers, N. (2008). Central processing of natural odour mixtures in insects. *Journal of Chemical Ecology, 34*, 915-927.

Le S. Q. & Gascuel O. (2008). An improved general amino acid replacement matrix. *Moleculer Biology and Evolution,* 25, 1307-1320.

Li, S., Picimbon, J. F., Ji, S., Kan, Y., & Chuanling Q. (2008). Multiple functions of an odourant-binding protein in the mosquito *Aedes aegypti*. *Biochemical and Biophysical Research Communications, 372*, 464-468.

Li, Y., Wu, Y., Chen, H., Wu, J., & Li, Z. (2012). Population structure and colonization of *Bactrocera dorsalis* (Diptera: Tephritidae) in China, inferred from mtDNA COI sequences. *Journal of Applied Entomology, 136*, 241-251.

Li, Z., Ni, J. D., Huang, J., & Montell, C. (2014). Requirement for *Drosophila* SNMP1 for rapid activation and termination of pheromone-up-regulated activity. *PLoS Genetics, 10*, e1004600.

Liang, G. H., Fu, L. Q., Zheng, J. X., Lin, H. Y., Lin, J. H., Sim, S. B., ... & Geib, S. M. (2018). Molecular characterization of interspecific competition of *Diachasmimorpha longicaudata* (Ashmead) and *Fopius arisanus* (Sonan) parasitizing the Oriental fruit fly, *Bactrocera dorsalis* (Hendel). *Biological Control*, *118*, 10-15.

Lim, C. L. (1999). Genetic variability and molecular biology of sexual behaviour of local fruit flies, *Bactrocera dorsalis* complex Hendel (Diptera: Tephritidae). Msc thesis (in Malay), Universiti Sains Malaysia, Penang, Malaysia.

Lin, Y. L. & Chow, C. J. (1984). Studies on the constituents of aerial parts of *Scutellaria rivularis* wall. *Kuo Li Chung-Kuo I Yao Yen Chiu Pao Kao, 1984*, 141-165.

Liu, Z., Smagghe, G., Lei, Z., & Wang, J. J. (2016). Identification of male-and female-specific olfaction genes in antenna of the Oriental fruit fly (*Bactrocera dorsalis*). *PLoS one, 11,* e0147783.

Liu, H., Chen, Z. S., Zhang, D. J., & Lu, Y. Y. (2018). *Bdor*OR88a modulates the responsiveness to methyl eugenol in mature males of *Bactrocera dorsalis* (Hendel). *Frontiers in Physiology*, *9*, 987.

Liu, H., Zhao, W., Fu, L., Han, Y., Chen, J., & Lu, Y. (2017) *Bdor*OBP2 plays an indispensable role in the perception of methyl eugenol by mature males of *Bactrocera dorsalis* (Hendel). *Scientific Reports, 7*, 15894.

Loke, W. H., Tan, K. H., & Vijaysegaran, S. (1992). Semiochemicals and related compounds in insect pest management-Malaysian experiences. In Aziz, A., Kadir, S. A., & Barlow, H. S. (Eds.), *Pest Management and the Environment in 2000* (pp. 111-126). Wallingford, United Kingdom: CAB International.

Lu, Q., Huang, L. Y., Chen, P., Yu, J. F., Xu, J., Deng, J. Y., & Ye, H. (2015). Identification and RNA interference of the Pheromone Biosynthesis Activating Neuropeptide (PBAN) in the common cutworm moth *Spodoptera litura* (Lepidoptera: Noctuidae). *Journal of Economic Entomology, 108*, 1344-1353.

Lundin, C., Käll, L., Kreher, S. A., Kapp, K., Sonnhammer, E. L., Carlson, J. R., Heijne, G. V., & Nilsson, I. (2007). Membrane topology of the *Drosophila* OR83b odourant receptor. *Federation of European Biochemical Societies Letters, 581*, 5601-5604.

Lux, S. A., Copeland, R. S., White I. M., Manrakhan A., & Billah M. K. (2003). A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Africa. *International Journal of Tropical Insect Science, 23*, 355-361.

Maksimović, M. (1971). Effect of cobalt-60 irradiation of male pupae of the gypsy moth, *Lymantria dispar* L., on biological functions of male moths. In studies in radiation sterilization of insects. In *Sterility principle for insect control or eradication* (pp. 15-23). Vienna, Austria: Proceedings of Symposium International Atomic Energy Agency 1970.

Mamta, B. & Rajam, M. V. (2017). RNAi technology: a new platform for crop pest control. *Physiology and Molecular Biology of Plants*, *23*, 487-501.

Martin, F. & Alcorta, E. (2011). Regulation of olfactory transduction in the Orco channel. *Frontiers in Cellular Neuroscience, 5*, 21.

Martin, J. A., & Wang, Z. (2011). Next-generation transcriptome assembly. *Nature Reviews Genetics*, *12*, 671.

McInnis, D., Kurashima, R., Shelly, T., Komatsu, J., Edu, J., & Pahio, E. (2011). Prerelease exposure to methyl eugenol increases the mating competitiveness of sterile males of the Oriental fruit fly (Diptera: Tephritidae) in a Hawaiian orchard. *Journal of Economic Entomology, 104*, 1969-1978.

McKenna, M. P., Hekmat-Scafe, D. S., Gaines, P., & Carlson, J. R. (1994). Putative *Drosophila* pheromone-binding proteins expressed in a subregion of the olfactory system. *The Journal of Biological Chemistry*, *269*, 16340-16347.

Mei, T., Fu, W. B., Li, B., He, Z. B., & Chen, B. (2018). Comparative genomics of chemosensory protein genes (CSPs) in twenty-two mosquito species (Diptera: Culicidae): Identification, characterization, and evolution. *PLoS one*, *13*, e0190412.

Metcalf, R. L. (1990). Chemical ecology of *Dacine* fruit flies (Diptera: Tephritidae). *Annals of the Entomological Society of America, 83*, 1017-1030.

Metcalf, R. L. & Kogan, M. (1987). Plant volatiles as insect attractants. *CRC Critical Reviews in Plant Science, 5*, 251-301.

Metcalf, R. L. & Metcalf, E. R. (1992). Fruit flies of the family Tephritidae. In Metcalf, R. L. & Metcalf, E. R. (Eds.), *Plant kairomones in insect ecology and control* (pp. 109-152). New York, NY: Chapman and Hall.

Metcalf, R. L., Mitchell, W. C., Fukuto, T. R., & Metcalf, E. R. (1975). Attraction of the Oriental fruit fly, *Dacus dorsalis*, to methyl eugenol and related olfactory stimulants. *Proceedings of the National Academy of Sciences of the United States of America, 72*, 2501-2505.

Meyer, A., & Galizia, C. G. (2012). Elemental and configural olfactory coding by antennal lobe neurons of the honeybee (*Apis mellifera*). *Journal of Comparative Physiology A, 198*, 159-171.

Miele, M., Domdero, R., Ciarallo, G., & Mazzei, M. (2001). Methyl eugenol in *Ocimum basilicum* L. Cv. Genovese Gigante. *Journal of Agricultural and Food Chemistry, 49*, 517-521.

Miller, A. J., Roman, B., & Norstrom, E. (2016). A method for easily customizable gradient gel electrophoresis. *Analytical biochemistry*, *509*, 12-14.

Missbach, C., Dweck, H. K. M., Vogel, H., Vilcinskas, A., Stensmyr, M. C., Hansson, B. S., & Grosse-Wilde, E. (2014). Evolution of insect olfactory receptors. *eLife*. *3*, e02115.

Miyazaki, H., Otake, J., Mitsuno, H., Ozaki, K., Kanzaki, R., Chieng, A. C. T., ... & Ono, H. (2018). Functional characterization of olfactory receptors in the Oriental fruit fly *Bactrocera dorsalis* that respond to plant volatiles. *Insect Biochemistry and Molecular Biology*, *101*, 32-46.

Mohr, S. E., Hu, Y., Kim, K., Housden, B. E., & Perrimon, N. (2014). Resources for functional genomics studies in *Drosophila melanogaster*. *Genetics*, *197*, 1-18.

Mudavanhu, P., Addison, P., & Conlong, D. E. (2017). Effect of mass rearing and gamma irradiation on the mating behaviour of *Eldana saccharina*. *Entomologia Experimentalis et Applicata*, *162*, 159-167.

Nagaharshitha, D., Vimala, B., & Haldankar, P. (2014). Effect of bagging on growth and development of mango (*Mangifera indica* L.) cv. Alphonso. *Trends Biosciences, 7*, 1647-1649.

Nakagawa, T., Sakurai, T., Nishioka, T., & Touhara, K. (2005). Insect sex-pheromone signals mediated by specific combinations of olfactory receptors. *Science, 307*, 1638-1642.

Nakahira, M., Ono, H., Wee, S. L., Tan, K. H., & Nishida, R. (2018). Floral synomone diversification of *Bulbophyllum* sibling species (Orchidaceae) in attracting fruit fly pollinators. *Biochemical Systematics and Ecology*, *81*, 86-95.

Nichols, Z. & Vogt, R. G. (2008). The SNMP/CD36 gene family in Diptera, Hymenoptera and Coleoptera: *Drosophila melanogaster*, *D. pseudoobscura*, *Anopheles gambiae*, *Aedes aegypti*, *Apis mellifera*, and *Tribolium castaneum*. *Insect Biochemistry and Molecular Biology, 38*, 398-415.

Nishida, R., & Tan, K. H. (2016). Search for new fruit fly attractants from plants: A review. In *Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance*, *12-16 May 2014* (pp. 249-262). Bangkok, Thailand: International Fruit Fly Steering Committee.

Nishida, R., Tan, K. H., & Fukami, H. (1988a). Cis-3,4-dimethoxycinnamyl alcohol from the rectal glands of the Oriental fruit fly, *Dacus dorsalis*. *Chemistry Express, 3*, 207-210.

Nishida, R., Tan, K. H., Serit, M., Lajis, N. H., Sukari, A. M., Takahashi, S., & Fukami, H. (1988b). Accumulation of phenylpropanoids in the rectal glands of males of the Oriental fruit fly, *Dacus dorsalis*. *Experientia, 44*, 534-536.

Nugnes, F., Russo, E., Viggiani, G., & Bernardo, U. (2018). First Record of an Invasive Fruit Fly Belonging to *Bactrocera dorsalis* Complex (Diptera: Tephritidae) in Europe. *Insects*, *9*, 182.

Nurdijati, S., Tan, K. H., & Toong, Y. C. (1996). Basil plants (*Ocimum* spp.) and their prospects in the management of fruit flies. In Chua, T. H. & Khoo, S. G., (Eds.), *Problems and Management of Tropical Fruit Flies* (pp. 47-51). Kuala Lumpur, Malaysia: Kai Wah Press.

Ohnishi, A., Hull, J. J., & Matsumoto, S. (2006). Targeted disruption of genes in the *Bombys mori* sex pheromone biosynthetic pathway. *Proceedings of the National Academy of Science of the United States of America, 103*, 4398-4403.

Olafson, P. U. (2013). Molecular characterization and immunolocalization of the olfactory co-receptor Orco from two blood-feeding muscid flies, the stable fly (*Stomoxys calcitrans*, L.) and the horn fly (*Haematobia irritans irritans*, L.). *Insect Molecular Biology*, *22*, 131-142.

Oshlack, A., & Wakefield, M. J. (2009). Transcript length bias in RNA-seq data confounds systems biology. *Biology Direct*, *4*, 14.

Peck, S. L. & McQuate, G. T. (2000). Field tests of environmentally friendly malathion replacements to suppress wild Mediterranean fruit fly (Diptera: Tephritidae) populations. *Journal of Economic Entomology, 93*, 280-289.

Pelosi, P., Iovinella, I., Felicioli, A., & Dani, F. R. (2014). Soluble proteins of chemical communication: an overview across arthropods. *Frontiers in Physiology, 5*, 320.

Pelosi, P. & Maida, R. (1990). Odourant-binding proteins in vertebrates and insects: similarities and possible common function. *Chemical Senses, 15*, 205-215.

Pelosi, P. & Maida, R. (1995). Odourant-binding proteins in insects. *Comparative Biochemistry and Physiology, 111B*, 503-514.

Peñalva-Arana, D. C., Lynch, M., & Robertson, H. M. (2009). The chemoreceptor genes of the waterflea *Daphnia pulex*: many Grs but no Ors. *BMC Evolutionary Biology* 9: 79.

Pereira, R., Yuval, B., Liedo, P., Teal, P. E. A., Shelly, T. E., McInnis, D. O., & Hendrichs, J. (2013). Improving sterile male performance in support of programmes integrating the sterile insect technique against fruit flies. *Journal of Applied Entomology,* 137, 178-190.

Perry, T., Batterham, P., & Daborn, P. J. (2011). The biology of insecticidal activity and resistance. *Insect Biochemistry and Molecular Biology*, *41*, 411-422.

Persoons, C. J., Verwiel, P. E. J., Talman, E., & Ritter, F. J. (1979). Sex pheromone of the American cockroach, *Periplaneta americana*. *Journal of Chemical Ecology, 5*, 221-236.

Pertea, M., Pertea, G. M., Antonescu, C. M., Chang, T. C., Mendell, J. T., & Salzberg, S. L. (2015). StringTie enables improved reconstruction of a transcriptome from RNA-seq reads *Nature Biotechnology. 33, 290-295.*

Pertea, M., Kim, D., Pertea, G. M., Leek, J. T., & Salzberg, S. L. (2016). Transcript-level expression analysis of RNA-seq experiments with HISAT, StringTie and Ballgown. *Nature Protocols*, *11*, 1650.

Pevsner, J. (2015). *Bioinformatics and functional genomics, third edition*. Singapore: John Wiley & Sons.

Pfaffmann, C. (1969). *Olfaction and taste: Proceedings of the third international symposium*. New York, NY: Rockefeller University Press.

Picimbon, J. F. (2003). Biochemistry and Evolution of OBP and CSP proteins. In Blomquist, G. J. & Vogt, R. G. (Eds.), *Insect Pheromone Biochemistry and Molecular Biology* (pp. 539-566). London, United Kingdom: Elsevier Academic Press.

Pike, E. A., & Corcoran, R. J. (1998). *Bactrocera papayae* (Diptera: Tephritidae) incursion-Cairns, Australia. *Acta Horticulturae, 464*, 321-326.

Piñero, J. C., Mau, R. F. L., & Vargas, R. I. (2009a). Managing Oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae), with spinosad-based protein bait sprays and sanitation in papaya orchards in Hawaii. *Journal of Economic Entomology, 102*, 1123-1132.

Piñero, J. C., Mau, R. F. L., McQuate, G. T., & Vargas, R. I. (2009b). Novel bait stations for attract-and kill of pestiferous fruit flies. *Entomologia Experimentalis et Applicata, 133*, 208-216.

Pino, J. A., Mesa, J., Muñoz, Y., Marti, M. P., & Marbot, R. (2005) Volatile components from mango (*Mangifera indica* L.) cultivars. *Journal of Agricultural and Food Chemistry, 53*, 2213-2223.

Priya, G. L., Rameshkumar, P., Ponmanickam, P., Eswaran, R., Sudarmani, D. N. P., & Rajagopal, T. (2013). Identification of volatile and protein profiles in the sting and mandibular glands of the worker honey bee (*Apis cerana indica*). *Biochemistry and Physiology, 2*, 108.

Prokopy, R. J., Papaj, D. R., Hendrichs, J., & Wong, T. T. Y. (1992). Behavioural responses of *Ceratitis capitata* flies to bait spray droplets and natural food. *Entomologia Experimentalis et Applicata, 64*, 247-257.

Rać, M. E., Safranow, K., & Poncyljusz, W. (2007). Molecular basis of human CD36 gene mutations. *Molecular Medicine, 13*, 288.

Rafaeli, A. & Jurenka, R. A. (2003). PBAN regulation of pheromone biosynthesis in female moth. In Blomquist, G. & Vogt, R. (Eds.), *Insect*

Pheromone Biochemistry and Molecular Biology (pp. 107-136). London, United Kingdom: Elsevier.

Regnier, F. E. & Law, J. H. (1968). Insect pheromones. *Journal of Lipid. Research, 9*, 541-551.

Reisenman, C. E., Lee, Y., Gregory, T., & Guerenstein, P. G. (2013). Effects of starvation on the olfactory responses of the blood-sucking bug *Rhodnius prolixus*. *Journal of Insect Physiology*, *59*, 717-721.

Reisenman, C. E., Lei, H., & Guerenstein, P. G. (2016). Neuroethology of olfactory-guided behavior and its potential application in the control of harmful insects. *Frontiers in Physiology*, *7*, 271.

Rejesus, R. S., Baltazar, C. R., & Manoto, E. C. (1991). Fruit flies in the Philippines: Current status and future prospects. In Vijaysegaran, S. & Ibrahim, A. G. (Eds.), *Proceedings of First International Symposium on Fruit Flies in the Tropics* (pp. 108-124). Kuala Lumpur, Malaysia. Malaysian Agricultural Research and Development Institute.

Resilva S., Obra G., Zamora N., & Gaitan E. (2007). Development of quality control procedures for mass produced and released *Bactrocera philippinensis* (Diptera: Tephritidae) for sterile insect technique programs. *Florida Entomologist, 90*, 58-63.

Riffell, J. A., Lei, H., Christensen, T. A., & Hildebrand, J. G. (2009). Characterization and coding of behaviourally significant odour mixtures. *Current Biology, 19*, 335-340.

Ripley, L. B. & Hepburn, G. A. (1935). Olfactory attractants for male fruit flies. *Entomology. Memoirs, Department of Agriculture, South Africa, 9,* 3-17

Roan, C. C., Flitters, N. E., & Davis, C. J. (1954). Light intensity and temperature as factors limiting the mating of the Oriental fruit fly. *Annals of the Entomological Society of America*, *47*, 593-594.

Robinson, M. D. & Oshlack, A. (2010). A scaling normalization method for differential expression analysis of RNA-seq data. *Genome Biology, 11,* R25.

Roelofs, W. L. & Rooney, A. P. (2003). Molecular genetics and evolution of pheromone biosynthesis in Lepidoptera. *Proceedings of the National Academy of Sciences of the United States of America, 100*, 9179-9184.

Roessler, Y. (1989). Insecticidal bait and cover spray. In Robinson, A.S. & Hooper, G. (Eds.), *Volume 3A: Fruit Flies, their Biology, Natural Enemies and Control* (pp. 329-335). Amsterdam, The Netherlands: Elsevier.

Rogers, S. (2013). Nervous system. In Chapman, R. F., Stephen J. Simpson, & Angela E. Douglas (Eds.), *The Insects: Structure and Function.* (5th ed., pp. 625-669). Cambridge, United Kingdom: Cambridge University Press.

Rogers, M. E., Sun, M., Lerner, M. R., & Vogt, R. G. (1997). Snmp-1, a novel membrane protein of olfactory neurons of the silk moth *Antheraea polyphemus* with homology to the CD36 family of membrane proteins. *Journal of Biological Chemistry, 272*, 14792-14799.

Rohland, N. & Reich, D. (2012). Cost-effective, high-throughput DNA sequencing libraries for multiplexed target capture. *Genome Resesarch, 22*, 939-946.

Rossi, P., Bao, L., Luciani, A., Panighi, J., Desjobert, J., Costa, J., Casanova, J., Bolla, J., & Berti, L. (2007). (E)-Methylisoeugenol and elemicin: Antibacterial components of *Daucus carota* L. essential oil against *Campylobacter jejuni*. *Journal of Agricultural and Food Chemistry, 55*, 7332-7336.

Rungrojwanich, K. & Walter, G. H. (2000). The Australian fruit fly parasitoid *Diachasmimorpha kraussii* (Fullaway): Life history, ovipositional patterns, distribution and hosts (Hymenoptera: Braconidae: Opiinae). *Pan-Pacific Entomologist, 76*, 1-11.

Ryan, M. (2002). *Insect chemoreception: fundamental and applied*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Rybczynski, R. G. V. R., Vogt, R. G., & Lerner, M. R. (1990). Antennal-specific pheromone-degrading aldehyde oxidases from the moths *Antheraea polyphemus* and *Bombyx mori*. *Journal of Biological Chemistry*, *265*, 19712-19715.

Sabatier, L., Jouanguy, E., Dostert, C., Zachary, D., Dimarcq, J. L., Bulet, P., & Imler, J. L. (2003). Pherokine-2 and -3. *European Journal of Biochemistry, 270*, 3398-3407.

Sabine, B. N. E. (1992). *Pre-harvest control methods. International Training Course Fruit Flies.* Kuala Lumpur, Malaysia: Malaysian Agricultural Research and Development Institute.

Sagrero-Nieves, L. & Bartley, J. P. (1995). Volatile components of avocado leaves (*Persea Americana* Mill) from the Mexican race. *Journal of the Science of Food and Agriculture, 67*, 49-51.

Sarwar, M. (2015). Cultural measures as management option against fruit flies pest (Tephritidae: Diptera) in garden or farm and territories. *International Journal of Animal Biology, 1*, 165-171.

Sato, K., Pellegrino, M., Nakagawa, T., Nakagawa, T., Vosshall, L. B., & Touhara, K. (2008). Insect olfactory receptors are heteromeric ligand-gated ion channels. *Nature*. *452*, 1002-1006.

Scopes, R. K. (1987). *Protein Purification: Principles and Practice, 2nd Edition*. New York, NY: Springer-Verlag.

Scherkenbeck, J., & Zdobinsky, T. (2009). Insect neuropeptides: structures, chemical modifications and potential for insect control. *Bioorganic and Medicinal Chemistry*, *17*, 4071-4084.

Schulten, G. G. M. (1996). Food security. Pre- and post- harvest food losses and integrated pest management. In Allwood, A. J. & Drew, R. A. I. (Eds.), *Management of Fruit Flies in the Pacific: A Regional Symposium* (The Australian Centre for International Agricultural Research Proceeding No. 76., pp. 10-14). Nadi, Fiji: The Australian Centre for International Agricultural Research.

Schutze, M. K., Aketarawong, N., Amornsak, W., Armstrong, K. F., Augustinos, A. A., Barr, N., ... Clarke, A. R. (2015). Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): Taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. *Systematic Entomology, 40*, 456-471.

Schutze, M. K., Jessup, A., & Clarke, A. R. (2012). Wing shape as a potential discriminator of morphologically similar pest taxa within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae). *Bulletin of Entomological Research*, *102*(1), 103-111.

Schutze, M. K., Mahmood, K., Pavasovic, A. N. A., Bo, W., Newman, J., Clarke, A. R., ... & Cameron, S. L. (2015). One and the same: integrative taxonomic evidence that *Bactrocera invadens* (Diptera: Tephritidae) is the same species as the Oriental fruit fly *Bactrocera dorsalis*. *Systematic Entomology*, *40*, 472-486.

Schwanhäusser, B., Busse, D., Li, N., Dittmar, G., Schuchhardt, J., Wolf, J., ... & Selbach, M. (2011). Global quantification of mammalian gene expression control. *Nature*, *473*, 337.

Serizawa, S., Miyamichi, K., & Sakano, H. (2004). One neuron-one receptor rule in the mouse olfactory system. *Trends in Genetics*, *20*, 648-653.

Seyednasrollah, F., Laiho, A., & Elo, L. L. (2013). Comparison of software packages for detecting differential expression in RNA-seq studies. *Briefings in Bioinformatics*, *16*, 59-70.

Sharma, R. R., Reddy, S. V. R., & Jhalegar, M. J. (2014). Pre-harvest fruit bagging: A useful approach for plant protection and improved post-harvest fruit quality - a review. *Journal of Horticultural Science and Biotechnology, 89*, 101-113.

Shanbhag, S. R., Müller, B., & Steinbrecht, R. A. (1999). Atlas of olfactory organs of *Drosophila melanogaster*: 1. Types, external organization, innervation and distribution of olfactory sensilla. *International Journal of Insect Morphology and Embryology, 28*, 377-397.

Shanbhag, S. R., Müller, B., & Steinbrecht, R. A. (2000). Atlas of olfactory organs of *Drosophila melanogaster*: 2. Internal organization and cellular architecture of olfactory sensilla. *Arthropod Structure and Development*, *29*, 211-229.

Shelly, T. E. (1994). Consumption of methyl eugenol by male *Bactrocera dorsalis* (Diptera: Tephritidae): low incidence of repeat feeding. *Florida Entomologist*, *77*, 201-201.

Shelly, T. E. (2001). Feeding on methyl eugenol and *Fagraea berteriana* flowers increases long-range female attraction by males of the Oriental fruit fly (Diptera: Tephritidae). *Florida Entomologist, 84*, 634-640.

Shelly, T. E. (2010). Effects of methyl eugenol and raspberry ketone/cue lure on the sexual behaviour of *Bactrocera* species (Diptera: Tephritidae). *Applied Entomology and Zoology, 45*, 349-361.

Shelly, T. E. & Dewire, A. L. M. (1994). Chemically mediated mating success in male Oriental fruit flies (Diptera: Tephritidae). *Annals of the Entomological Society of America, 87*, 375-382.

Shelly, T. E., Edu, J., & Pahio, E. (2005). Influence of diet and methyl eugenol on the mating success of males of the Oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae). *Florida Entomologist*, *88*, 307-313.

Shelly, T. E., Epsky, N., Jang, E. B., Reyes-Flores, J., & Vargas, R. I. (2014). *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies.* Dordrecht, The Netherlands: Springer.

Shelly, T. E., Resilva, S., Reyes, M. and Bignayan, H. (1996). Methyl eugenol and mating competitiveness of irradiated male *Bactrocera philippinensis* (Diptera: Tephritidae). *Florida Entomologist, 79*, 481-488.

Shiga, M. (1989). Control: sterile insect technique (SIT): current program in Japan. In Robinson, A. S. & Hooper, G. *World Crop Pests 3(B). Fruit Flies: their Natural Enemies and Control* (pp. 365-374). Amsterdam, The Netherlands: Elsevier Science Publishers.

Siciliano, P., Scolari, F., Gomulski, L. M., Falchetto, M., Manni, M., Gabrieli, P., ... & Malacrida, A. R. (2014). Sniffing out chemosensory genes from the Mediterranean fruit fly, *Ceratitis capitata*. *PLoS One*, *9*, e85523.

Singh, R. B. (1988). Significance of fruit flies in fruit and vegetable production in the Asia-Pacific region. In Vijaysegaran, S. & Ibrahim, A. G. (Eds.), *First International Symposium on Fruit Flies in the Tropics* (pp. 11-29). Kuala Lumpur, Malaysia. Malaysian Agricultural Research and Development Institute.

Singh, R. K., Shah, N. I., & Solanki, P. D. (2017). Influence of fruit bagging on chemical quality of mango (*Mangifera indica* L.) Varieties. *International Journal of Plant and Soil Science, 18*, 1-7.

Sivinski, J. M. & Calkins, C. (1986). Pheromones and parapheromones in the control of tephritids. *Florida Entomologist, 69*, 157-168.

Sivinski, J. & Webb, J. C. (1985). The form and function of acoustic courtship signals of the papaya fruit fly, *Toxotrypana curvicauda* (Tephritidae). *Florida Entomologist, 68*, 634-641.

Slifer, E. H. 1967. The thin-walled olfactory sense organs on insect antenna. In Beament, J. W. I. & Treherne, J. E. (Eds.), *Insect and Physiology* (pp. 233-245). Edinburgh and London, United Kingdom: Oliver and Boyd Ltd.

Smid, M., van den Braak, R. R. C., van de Werken, H. J., van Riet, J., van Galen, A., de Weerd, V., ... & Wilting, S. M. (2018). Gene length corrected trimmed mean of M-values (GeTMM) processing of RNA-seq data performs similarly in intersample analyses while improving intrasample comparisons. *BMC Bioinformatics*, *19*, 236.

Song, Y. Q., Sun, H. Z., & Du, J. (2018). Identification and tissue distribution of chemosensory protein and odourant binding protein genes in *Tropidothorax elegans* Distant (Hemiptera: Lygaeidae). *Scientific Reports*, *8*, 7803.

Srikachar, S., Plodkornburee, W., & Jumroenma, K. (2016). Integrated pest management of fruit flies on rose apple in Thailand. In Sabater-Muñoz, B., Vera, T., Pereira, R., & Orankanok, W. (Eds.), *Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance* (pp. 184-201). Bangkok, Thailand: International Fruit Fly Steering Committee.

Steinbrecht, R. A., & Gnatzy, W. (1984). Pheromone receptors in *Bombyx mori* and *Antheraea pernyi*. I. Reconstruction of the cellular organization of the sensilla trichodea. *Cell and Tissue Research, 235*, 25-34.

Steinbrecht, R. A., Ozaki, M., & Ziegelberger, G. (1992). Immunocytochemical localization of pheromone-binding protein in moth antenna. *Cell and Tissue Research, 270*, 287-302.

Steiner, L. F. (1952a). Methyl eugenol as an attractant for Oriental fruit fly. *Journal of Economic Entomology, 45*, 241-248.

Steiner, L. F. (1952b). Fruit fly control in Hawaii with poison-bait sprays containing protein hydrolysates. *Journal of Economic Entomology, 45*, 838-843.

Steiner, L. F., Hart, W. G., Harris, E. J., Cunningham, R. T., Ohinata, K., & Kamakahi, D. C. (1970). Eradication of the Oriental fruit fly from the Mariana Islands by the methods of male annihilation and sterile insect release. *Journal of Economic Entomology*, *63*, 131-135.

Steiner, L. F., & Lee, R. K. S. (1955). Large-area tests of a male-annihilation method for Oriental fruit fly control. *Journal of Economic Entomology*, *48*, 311-317.

Steiner, L. F., Mitchell, W. C., Harris, E. J., Kozuma, T. T., & Fujimoto, M. S. (1965). Oriental fruit fly eradication by male annihilation. *Journal of Economic Entomology, 58*, 961-964.

Stengl, M. & Funk, N. W. (2013). The role of the coreceptor Orco in insect olfactory transduction. *Journal of Comparative Physiology A, 199*, 897-909.

Stephens, A. E. A., Kriticos, D. J., & Leriche, A. (2007). The current and future potential geographical distribution of the Oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae). *Bulletin of Entomological Research, 97*, 369-378.

Stocker, R. F. (1994). The organization of the chemosensory system in *Drosophila melanogaster*: a review. *Cell Tissue Research, 275*, 3-26.

Strauch, M., Lüdke, A., Münch, D., Laudes, T., Galizia, C. G., Martinelli, E., Lavra, L., Paolesse, R., Ulivieri, A., Catini, A., Capuano, R., & Natale, C. D. (2014). More than apples and oranges- detecting cancer with a fruit fly's antenna. *Scientific Reports, 4*, 1-9.

Strehler, E. E., Filoteo, A. G., Penniston, J. T., & Caride, A. J. (2007). Plasma membrane Ca (2+) pumps: structural diversity as the basis for functional versatility. *Biochemal Society Transactions, 30*, 919-922.

Suh, E., Bohbot, J. D., & Zwiebel, L. J. (2014). Peripheral olfactory signaling in insects. *Current Opinion in Insect Science, 6*, 86-92.

Sukontason, K., Sukontason, K. L., Piangjai, S., Boonchu, N., Chaiwong, T., Ngern-klun, R., ... & Olson, J. K. (2004). Antennal sensilla of some forensically important flies in families Calliphoridae, Sarcophagidae and Muscidae. *Micron*, *35*, 671-679.

Sun, Y. L., Huang, L. Q., Pelosi, P., & Wang, C. Z. (2012). Expression in antenna and reproductive organs suggests a dual role of an odourant-binding protein in two sibling *Helicoverpa species. PLoS One, 7*, e30040.

Syed, Z. & Leal, W. S. (2007). Maxillary palp are broad spectrum odourant detectors in *Culex quinquefasciatus*. *Chemical Senses, 32*, 727-738.

Tan, K. H. (1983) Response of Dacus (Diptera: Tephitidae) to *Ocimum sanctum* extracts and different synthetic attractants in Penang, Malaysia. In Cavalloro, R. (Eds.), *Fruit Flies of Economic Importance* (pp. 513-515). Rotterdam, The Netherlands: A.A. Balkema Publishers.

Tan, K. H. (1984). Description of a new attractant trap and the effect of placement height on catches of two *Dacus* species (Diptera: Tephritidae). *Journal of Plant Protection in the Tropics, 1*, 117-120.

Tan, K. H. (1985). Estimation of native populations of male *Dacus* spp. by using Jolly's stochastic method using a new designed attractant trap in a village ecosystem. *Journal of Plant Protection, 2*, 87-95.

Tan, K. H. (1993). Ecohormones for the management of fruit fly pests-Understanding plant fruit fly predator interrelationships. In International Atomic Energy Agency (IAEA) (Eds.), *Management of Insect Pests: Nuclear and Related Molecular and Genetic Techniques. Proceedings of a symposium*. Vienna, Austria: International Atomic Energy Agency.

Tan, K. H. (1996). Chemical ecology of fruit flies, *Bactrocera* species- an update. In Chua, T. H. & Khoo, S. G. (Eds.). *Problems and Management of Tropical Fruit Flies* (pp. 36-46). Kuala Lumpur, Malaysia: The Working Group on Malaysia Fruit Flies.

Tan, K. H. (2000). Behaviour and chemical ecology of *Bactrocera* flies. In Tan, K. H. (Eds.), *Area-wide Control Of Fruit Flies and Other Insect Pests* (pp. 647-656). Penang, Malaysia: Penerbit Universiti Sains Malaysia.

Tan, K. H. (2009). Fruit fly pests as pollinators of wild orchids. *Orchid Digest*, *73*, 180-187.

Tan, K. H., Kirton, L. G., & Serit, M. (1987). Age response of *Dacus dorsalis* (Hendel) to methyl eugenol in (a) a wind tunnel and (b) traps set in a village, and its implication in population estimation. In Economopoulos, A. P. (Eds.), *Proceedings of the Second International Symposium on Fruit Flies*. Colymbari, Crete, Greece: Elsevier Science Publishers.

Tan, K. H., & Nishida, R. (1995). Incorporation of raspberry ketone in the rectal glands of males of the Queensland fruit fly, *Bactrocera tryoni* Froggatt (Diptera: Tephritidae). *Applied Entomology and Zoology*, *30*, 494-497.

Tan, K. H. & Nishida, R. (1996). Sex pheromone and mating competition after methyl eugenol consumption in the *Bactrocera dorsalis* complex. In Mcpheron, B. A. & Steck, G. J. (Eds.), *Fruit Fly Pests: A World Asessment of Their Biology and Management* (pp. 147-153). Delray Beach, FL: St. Lucie Press.

Tan, K. H. & Nishida, R. (1998). Ecological significance of male attractant in the defence and mating strategies of the fruit fly, *Bactrocera papayae*. *Entomologia Experimentalis et Applicata*, *89*, 155-158.

Tan, K. H., & Nishida, R. (2000). Mutual reproductive benefits between a wild orchid, *Bulbophyllum patens*, and *Bactrocera* fruit flies via a floral synomone. *Journal of Chemical Ecology*, *26*, 533-546.

Tan, K. H. & Nishida, R. (2012). Methyl eugenol: Its occurrence, distribution, and role in nature, especially in relation to insect behaviour and pollination. *Journal of Insect Science, 12*, 1-74.

Tan, K. H., Nishida, R., Jang, E. B., & Shelly, T. E. (2014). Pheromones, male lures, and trapping of tephritid fruit flies. In Shelly, T. E., Epsky, N., Jang, E. B., Flores-Reyes, J., & Vargas, R. I. (Eds.), *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies* (pp. 15-74). Berlin, Germany: Springer.

Tan, K. H., Nishida, R., & Toong, Y. C. (2002) Floral synomone of a wild orchid, *Bulbophyllum cheiri*, lures *Bactrocera* fruit flies for pollination. *Journal of Chemical Ecology, 28*, 1161-1172.

Tan, K. H. & Serit, M. (1994). Adult population dynamics of *Bactrocera dorsalis* (Diptera: Tephritidae) in relation to host phenology and weather in two villages of Penang Island, Malaysia. *Environmental Entomology, 23*, 267-275.

Tan, K. H., Tan, L. T., & Nishida, R. (2006). Floral phenylpropanoid cocktail and architecture of *Bulbophyllum vinaceum* orchid in attracting fruit flies for pollination. *Journal of Chemical Ecology*, *32*, 2429-2441.

Tan K. H., Tokushima I., Ono H., & Nishida R. (2011) Comparison of phenylpropanoid volatiles in male rectal pheromone gland after methyl eugenol consumption, and molecular phylogenetic relationship of four global pest fruit fly species – *Bactrocera invadens, B. dorsalis, B. correcta and B. zonata. Chemoecology, 21*, 25-33.

Tegoni, M., Campanacci, V., & Cambillau, C. (2004). Structural aspects of sexual attraction and chemical communication in insects. *Trends in Biochemical Sciences, 29*, 257-264.

Tillman, J. A., Seybold, S. J., Jurenka, R. A., & Blomquist, G. J. (1999). Insect pheromone- an overview of biosynthesis and endocrine regulation. *Insect Biochemistry and Molecular Biology,* 29, 481-514.

Tittiger, C. (2003). Molecular biology of bark beetle pheromone production and endocrine regulation. In Blomquist, G. J. & Vogt, R. G. (Eds.), *Insect pheromone biochemistry and molecular biology* (pp. 201-230). London, United Kingdom: Elsevier.

Torres-Vila, L. M., & Jennions, M. D. (2005). Male mating history and female fecundity in the Lepidoptera: do male virgins make better partners?. *Behavioural Ecology and Sociobiology*, *57*, 318-326.

UniProt Consortium. (2018). *General odourant-binding protein lush*. Retrieved from https://www.uniprot.org/uniprot/O02372

Van den Berg, M. J. & Ziegelberger, G. (1991). On the function of the pheromone binding protein in the olfactory hairs of *Antheraea polyphemus*. *Journal of Insect Physiology, 37*, 79-85.

Vargas, R. I., Leblanc, L., Piñero, J. C., & Hoffman, K.M (2014). Male annihilation, past, present, and future. In Shelly, T., Epsky, N., Jang, E. B., Reyes-Flores, J., & Vargas, R.. (Eds.), *Trapping Tephritid Fruit Flies. Lures, Area-Wide Programs, and Trade Implications* (pp. 493-511). Berlin, Germany: Springer.

Vargas, R. I., Piñero, J. C., & Leblanc, L. (2015). An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the pacific region. *Insects, 6*, 297-318.

Vargas, R. I., Souder, S. K., Nkomo, E., Cook, P. J., Mackey, B., & Stark, J. D. (2015). Weathering and chemical degradation of methyl eugenol and raspberry ketone solid dispensers for detection, monitoring, and male annihilation of *Bactrocera dorsalis* and *Bactrocera cucurbitae* (Diptera: tephritidae) in Hawaii. *Journal of Economic Entomology, 108*, 1612-1623.

Vargas, R. I., Shelly, T. E., Leblanc, L. & Piñero, J. C. (2010). Recent advances in methyl eugenol and cue-lure technologies for fruit fly detection, monitoring, and control in Hawaii. *Vitamins and Hormones, 83*, 575-595.

Vayssières, J. F., Sinzogan, A., Adandonon, A., Rey, J. Y., Dieng, E. O., Camara, K., ... & Gogovor, G. (2014). Annual population dynamics of mango fruit flies (Diptera: Tephritidae) in West Africa: socio-economic aspects, host phenology and implications for management. *Fruits*, *69*, 207-222.

Verheij, E. W. M. & Coronel, R. E. (1992). Introduction. In: Verheij, E. W. M., and Coronel, R. E. (Eds.), *Plant Resources of South-East Asia No. 2. Edible Fruits and Nuts* (pp. 15-56). Bogor, Indonesia: PROSEA Fround.

Verschut, T. A., Farnier, K., Cunningham, J. P., & Carlsson, M. A. (2018). Behavioural and physiological evidence for palp detection of the male-specific attractant cuelure in the Queensland fruit fly (*Bactrocera tryoni*). *Frontiers in Physiology*, *9*.

Vijaysegaran, S. (1988). The current situation on frut flies in Peninsular Malaysia. In: Vijaysegaran, S. and Ibrahim, A. G. (Eds.), *First International Symposium on Fruit Flies in the Tropics* (pp. 125-139). Kuala Lumpur, Malaysia: The Malaysian Agricultural Research and Development Institute.

Vijaysegaran, S. (1989). An improved technique for fruit fly control in carambola cultivation using spot sprays of protein baits. *National Seminar on Carambola: Developments and Prospects*. Kuala Lumpur, Malaysia.

Vijaysegaran, S. (1996). Fruit flies of economic importance to the fruit industry and methods for their control in Malaysia. In Chua, T. H. & Khoo, S. G. (Eds.), *Problems and Management of Tropical Fruit Flies: Proceedings of the Second Symposium on Tropical Fruit Flies* (pp.61-79). Kuala Lumpur, Malaysia.

Vijaysegaran, S. (1993). Control of fruit flies in the tropical regions of Asia. In Aluja, M. & Liedo, P. (Eds.), *Fruit Flies*: *Biology and Management* (pp. 455-463). New York, NY: Springer.

Visser, J. H. (1986). Host odor perception in phytophagous insects. *Annual Review of Entomology*, *31*, 121-144.

Vogt, R. G. (1987). The molecular basis of pheromone reception: its influence on behaviour. In Prestwich, G. D. & Blomquis, G. J. (Eds.), *Pheromone Biochemistry* (pp. 385-431). New York, NY: Academic Press.

Vogt, R. G. (2005). Molecular Basis of Pheromone Detection in Insects. In Gilbert, L. I., Latro, K., & Gill, S. (Eds.), *Comprehensive Insect Physiology, Biochemistry, Pharmacology and Molecular Biology* (Vol. 3, pp. 753-804). London, United Kingdom: Elsevier.

Vogt, R. G., & L. M. Riddiford (1981). Pheromone binding and inactivation by moth antenna. *Nature, 293*, 161-163.

Vosshall, L. B., Amrein, H., Morozov, P. S., Rzhetsky, A., & Axel, R. (1999). A spatial map of olfactory receptor expression in the *Drosophila* antenna. *Cell, 96*, 725-736.

Vosshall, L. B. & Hansson, B. S. (2011). A unified nomenclature system for the insect olfactory coreceptor. *Chemical Senses,* 36, 497-498.

Vreysen, M. J., Robinson, A. S., & Hendrichs, J. (Eds.). (2007). *Area-wide control of insect pests: from research to field implementation*. Springer Science & Business Media.

Wagner, G. P., Kin, K., & Lynch, V. J. (2012). Measurement of mRNA abundance using RNA-seq data: RPKM measure is inconsistent among samples. *Theory in Biosciences*, *131*, 281-285.

Walsh, C. T., Garneau-Tsodikova, S.,& Gatto, G. J. (2005). Protein posttranslational modifications: the chemistry of proteome diversifications. *Angewandte Chemie International Edition*, *44*, 7342-7372.

Wan, F., Jiang, M., & Zhan, A. (2017). *Biological invasions and its management in china* (Vol. 1). Dordrecht, The Neherlands: Springer.

Wang, Q., Hasan, G., & Pikielny, C. W. (1999). Preferential expression of biotransformation enzymes in the olfactory organs of *Drosophila melanogaster*, the antenna. *Journal of Biological Chemistry*, *274*, 10309-10315.

Wang, T., Joshi, S. B., Kumru, O. S., Telikepalli, S., Middaugh, C. R., & Volkin, D. B. (2013). Case studies applying biophysical techniques to better characterize protein aggregates and particulates of varying size. In Narhi, L. O. (Eds.), *Biophysics for Therapeutic Protein Development* (pp. 205-243). New York, NY: Springer- Verlag New York.

Wasserman, S. L. & Itagaki, H. (2003). The olfactory responses of the antenna and maxillary palp of the fleshfly, *Neobellieria bullata* (Diptera: Sarcophagidae), and their sensitivity to blockage of nitric oxide synthase. *Journal of Insect Physiology, 49,* 271-280.

Wee, S. L. & Hee, A. K. W. (2018). Diurnal attraction of fruit flies (Diptera: Tephritidae) to methyl eugenol in a village ecosystem in Tanjung Bungah, Penang, Malaysia. *Serangga, 23*, 83-91.

Wee, S. L., Hee, A. K. W., & Tan, K. H. (2002). Comparative sensitivity to and consumption of methyl eugenol in three *Bactrocera dorsalis* (Diptera: Tephritidae) complex sibling species. *Chemoecology, 12*, 193-197.

Wee, S. L., Munir, M. A., & Hee, A. K. W. (2018). Attraction and consumption of methyl eugenol by male *Bactrocera umbrosa* Fabricius (Diptera: Tephritidae) promotes conspecific sexual communication and mating performance. *Bulletin of Entomological Research*, *108*, 116-124.

Wee, S. L. & Tan, K. H. (2000). Sexual maturity and intraspecific mating success of two sibling species of the *Bactrocera dorsalis* complex. *Entomologia Experimentalis et Applicata, 94*, 133-139.

Wee, S. L. & Tan, K. H. (2001). Allomonal and hepatotoxic effects following methyl eugenol consumption in *Bactrocera papayae* male against *Gekko monarchus*. *Journal of Chemical Ecology, 27*, 953-964.

Wee, S. L., Tan K. H., & Nishida, R. (2007). Pharmacophagy of methyl eugenol by males enhances sexual selection of *Bactrocera carambola. Journal of Chemical Ecology, 33*, 1272-1282.

Wei, D., Dou, W., Jiang, M., & Wang, J. (2017). Oriental fruit fly *Bactrocera dorsalis* (Hendel). In *Biological Invasions and Its Management in China* (pp. 267-283). Springer, Dordrecht.

Wicher, D. (2015). Olfactory signaling in insects. In Glatz, R. (Eds.), *Progress in Molecular Biology and Translational Science, Molecular Basis of Olfaction* (Vol. 130, pp. 37-54). Burlington, NJ. Academic Press.

Wicher, D., Schäfer, R., Bauernfeind, R., Stensmyr, M. C., Heller, R., Heinemann, S. H., & Hasson, B. S. (2008). *Drosophila* odourant receptors are both ligand-gated and cyclic-nucleotide-activated cation channels. *Nature*. 452: 1007-1012

White, I. M. & Elson-Harris, M. M. (1992). *Fruit Flies of Economic Significance: their Identification and Bionomics.* Wallingford, United Kingdom: CAB International.

Wigglesworth, V. B. (1953). *The origin of sensory neurons in an insect, Rhodnius prolixus* (*Hemiptera*). *Quarterly Journal of Microscopical Science, 94*, 93-112.

Wortman-Wunder, E. & Vivanco, J. M. (2011). Chemical ecology: definition and famous examples. In Vivanco, J. M. & Weir, T. (Eds.), *Chemical Biology of the Tropics: An interdisciplinary Approach* (pp. 15-26). Berlin, Germany: Springer-Verlag Berlin Heidelberg.

Wu, Z., Lin, J., Zhang, H., & Zeng, X. (2016). *Bdor*OBP83a-2 mediates responses of Oriental fruit fly to semiochemicals. *Frontiers in Physiology, 7*, 452.

Wu, Z., Zhang, H., Wang, Z., Bin, S., He, H., & Lin, J. (2015). Discovery of chemosensory genes in the Oriental fruit fly, *Bactrocera dorsalis*. *PLOS ONE, 10*, 1-21.

Yamashita, O. (1996). Diapause hormone of the silkworm, *Bombyx mori*: structure, gene expression and function. *Journal of Insect Physiology*, *42*, 669-679.

Yano, K. (1987). Minor components from growing buds of *Artemisia capillaris* that acts as insect antifeedants. *Journal of Agricultural and Food Chemistry, 35*, 889-891.

Zacharuk, R. Y. (1985). Antenna and sensilla. In Kerkut, G. A. & Gilbert, L. I. (Eds.). *Comparative Insect Physiology, Biochemistry and Pharmacology* (Vol. 6, pp. 1-60). Oxford, United Kingdom: Pergamon Press.

Zhang, R., Gao, G., & Chen, H. (2016). Silencing of the olfactory co-receptor gene in *Dendroctonus armandi* leads to EAG response declining to major host volatiles. *Scientific Reports, 6*, 23136.

Zhang, G., Hull-Sanders, H., Hu, F., Dou, W., Niu, J., & Wang, J. (2011). Morphological characterization and distribution of sensilla on maxillary palp of six *Bactrocera* fruit flies (Diptera: tephritidae). *Florida Entomologist, 94*, 379-388.

Zhang, Q., Nachman, R. J., Kaczmarek, K., Zabrocki, J., & Denlinger, D. L. (2011). Disruption of insect diapause using agonists and an antagonist of diapause hormone. *Proceedings of the National Academy of Sciences*, *108*, 16922-16926.

Zhang, T. Y., Sun, J. S., Zhang, Q. R., Xu, J., Jiang, R. J., & Xu, W. H. (2004). The diapause hormone-pheromone biosynthesis activating neuropeptide gene of *Helicoverpa armigera* encodes multiple peptides that break, rather than induce, diapause. *Journal of Insect Physiology*, *50*, 547-554.

Zheng, W., Peng, W., Zhu C., Zhang, Q., Saccone, G., & Zhang, H. (2013). Identification and expression profile analysis of odourant binding proteins in the Oriental fruit fly *Bactrocera dorsalis*. *International Journal of Molecular Science, 14*, 14936-14949.

Zheng, W., Zhu, C., Peng, T., & Zhang, H. (2012). Odourant receptor co-receptor Orco is upregulated by methyl eugenol in male *Bactrocera dorsalis* (Diptera: Tephritidae). *Journal of Insect Physiology, 58*, 1122-1127.

Zhou, Y. L., Zhu, X. Q., Gu, S. H., Cui, H. H., Guo, Y. Y., Zhou, J. J., & Zhang, Y. J. (2014). Silencing in *Apolygus lucorum* of the olfactory coreceptor Orco gene by RNA interference induces EAG response declining to two putative semiochemicals. *Journal of Insect Physiology, 60*, 31-39.

Zvelebil, M. & Baum, J. O. (2007). *Understanding Bioinformatics*. New York, NY: Garland Science, Taylor & Francis Group, LLC.

BIODATA OF STUDENT

Anna Chieng Chui Ting was born on 10th March 1990 in Kuching, Sarawak, Malaysia. After completing her secondary school education and obtaining the Sijil Pelajaran Malaysia (SPM) certificate from SMK Jalan Arang, she continued to attain the higher school certificate, Sijil Tinggi Persekolahan Malaysia (STPM) from SMK Batu Lintang, Kuching. In July 2010, she was enrolled for tertiary education in Universiti Putra Malaysia (UPM) and received her B.Sc. (First Class Hons.) degree, majoring in Biology from Faculty of Science, Universiti Putra Malaysia in 2014. With an excellent track record, she was accepted as a PhD student in Entomology under that tutelage of Dr Alvin KW Hee in the same faculty of her alma mater. Over the course of her doctoral candidature, she has successfully published two key papers in Insect Biochemistry and Molecular Biology as well as Journal of Insect Science.

LIST OF PUBLICATIONS

Chieng, A. C. T., Hee, A. K. W., & Wee, S. L. (2018). Involvement of the antennal and maxillary palp structures in detection and response to methyl eugenol by male *Bactrocera dorsalis* (Diptera: Tephritidae). *Journal of Insect Science*, *18*, 19.

Miyazaki, H., Otake, J., Mitsuno, H., Ozaki, K., Kanzaki, R., **Chieng, A. C. T**., ... & Ono, H. (2018). Functional characterization of olfactory receptors in the Oriental fruit fly *Bactrocera dorsalis* that respond to plant volatiles. *Insect Biochemistry and Molecular Biology*, *101*, 32-46.

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