UNIVERSITI PUTRA MALAYSIA

RESISTANCE AGAINTS SPINOSAD IN Plutella xylostella Linnaeus (DIAMONDBACK MOTH) AND ITS CROSS RESISTANCE TO OTHER INSECTICIDES

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BERILMU BERBAKTI

RESISTANCE AGAINST SPINOSAD IN *Plutella xylostella* Linnaeus (DIAMONDBACK MOTH) AND ITS CROSS RESISTANCE TO OTHER INSECTICIDES

By

NUR ADIBAH BINTI MOHD ISHADI

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RESISTANCE AGAINST SPINOSAD IN *Plutella xylostella* Linnaeus (DIAMONDBACK MOTH) AND ITS CROSS RESISTANCE TO OTHER INSECTICIDES

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February 2020

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Plutella xylostella (Diamondback moth, DBM) has developed resistance to different classes of insecticides over the years in Malaysia. This study aimed at establishing the resistance development and mechanism of DBM towards spinosad resistance. The parameters assessed were the role of specific enzymes (P450, GST and esterases), the fitness cost in resistant strain, mode of resistance inheritance, resistance stability and cross resistance potential with other selected insecticides. DBM was obtained from Ladybird Organic Farm, Selangor. Bioassay conducted on spinosad-selected (Spi-Sel) from parent (P) generation to the 15^{th} generation (G15) showed approximately 42.81-fold increase in the resistance. P450 had significantly 4-fold higher activity ($p<0.05$) in the Spi-Sel strain than in susceptible (SS) strain. Spi-Sel strain experienced high fitness cost during resistance development (relative fitness: 0.25). The larva of SS strain had significantly higher survival rate while larva of Spi-Sel strain required significantly shorter time to complete the stage. Spinosad resistance in Spi-Sel strain was governed by a single major autosomal factor that was inherited recessively. The recessiveness of the resistance was represented by the value of degree of dominance (D_{LC}) of F1 and F1', -0.6062 and 0.0311 respectively. The overlapping fiducial limit between the F1 and F1' concluding the autosomal inheritance. No significant deviation ($P>0.05$) between the expected and observed mortality of the backcross (BC2) population implied monofactorial resistance. Spinosad-decaying (Spi-Dec) strain was produced by terminating the selection at G27 to study the resistance stability. The LC_{50} ranging from 547.33 to 132.57 ppm from G1 until G5 implying the unstable resistance. Moderate cross resistance was recorded towards emamectin and deltamethrin (RR = 3.8 and RR = 3.49, respectively) and low cross resistance recorded towards chlorantraniliprole (RR = 1.16). Unstable resistance accompanied by moderate to low cross resistance to other insecticides in the present finding suggested that resistance to spinosad in DBM can be reversed to susceptible status again and that resistance can be delayed by alternating the spinosad with insecticides of different classes and mode of action.

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

KERINTANGAN TERHADAP SPINOSAD DALAM *Plutella xylostella* Linnaeus (KUPU-KUPU INTAN) DAN RINTANG SILANGNYA KEPADA RACUN SERANGGA PEROSAK LAIN

Oleh

NUR ADIBAH BINTI MOHD ISHADI

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Plutella xylostella (Kupu-kupu intan; DBM) telah menunjukkan kerintangan kepada kelas racun serangga perosak yang berbeza setelah sekian lama di Malaysia. Kajian ini bertujuan untuk membina perkembangan kerintangan dan mekanisma DBM terhadap spinosad. Parameter yang dinilai termasuklah fungsi enzim spesifik (P450, GST and esterases), 'fitness cost' dalam 'strain' rintang, mod pewarisan kerintangan, kestabilan kerintangan dan potensi silang rintang dengan racun serangga perosak yang lain. DBM telah diperolehi daripada Ladang Organik Ladybird di Selangor. Bioesei telah dijalankan ke atas generasi P sehingga generasi ke-15 (G15) menunjukkan nilai kerintangan sebanyak 42.81 kali ganda. Enzim P450 mempunyai 4 kali ganda aktiviti yang signifikan pada 'strain Spi-Sel' berbanding 'strain SS' Kadar penerusan hidup bagi larva 'strain SS' lebih tinggi secara signifikan berbanding dengan 'strain Spi-Sel' namun larva 'Spi-Sel' mengambil masa yang signifikan lebih singkat untuk melengkapkan kitaran tersebut. Kerintangan spinosad dalam kajian ini melibatkan satu faktor autosomal yang diwarisi secara resesif. Tahap kedominanan (D_{LC}) melambangkan keresesifan tersebut dengan nilai -0.6062 dan 0.0311 bagi setiap satu F1 dan F1'. Had fidusial yang bertindih antara F1 dan F1' melambangkan pewarisan secara autosomal yang tidak melibatkan pengaruh induk dalam kes ini. Tiada diviasi yang signifikan ($P>0.05$) antara kematian dijangka dan kematian direkod bagi populasi silang balik (BC2), menunjukkan bahawa kerintangan spinosad melibatkan hanya satu faktor (major). 'Strain spinosad-decaying' (Spi-Dec) telah dihasilkan melalui pemberhentian proses pemilihan pada G27 bagi tujuan kajian kestabilan kerintangan. Nilai LC_{50} mempunyai julat antara 547.33 ke 132.57 ppm daripada generasi pertama (G1) sehingga generasi kelima (G5), menunjukkan kerintangan yang tidak stabil. Silang rintang sederhana telah direkodkan terhadap emamectin dan deltamethrin (RR = 3.8 dan RR = 3.49, masing-masing) serta silang rendah rendah direkodkan terhadap chlorantraniliprole (RR = 1.16). Penurunan yang cepat dalam kerintangan spinosad berserta silang rintang sederhana dan rendah terhadap serangga perosak lain mencadangkan bahawa kerintangan spinosad dalam

DBM boleh dikembalikan kepada status lemah semula dan dilambatkan dengan menggilirkan spinosad dengan racun perosak yang berlainan kelas dan mod tindakan.

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This thesis was submitted to the Senate of University Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

P450	Cytochrome P450
GST	Glutathione-S-Transferase
ppm	Part per million
mm	millimetre
nAChRs	Nicotinic acetylcholine receptors
GABA	Gamma-aminobutyric acid
IRAC	Insecticide Resistance Action Committee
DCNB	2-dichloro-4-nitrobenzene
ld-pm	Log dose-probit mortality
LC	Lethal concentration
RR	Resistance ratio
FL	Fiducial limit
SE	Standard Error
mM	micromol
EDTA	Editic acid
PMSF	Phenylmethyl sulfonylfluoride
DTT	1,4-dithiothreitol
PTU	Phenylthiourea
BSA	Bovine serum albumin
D_{ML}	Effective dominance
SS	Susceptible
Spi-Sel	Spinosad-selected
Spi-Dec	Spinosad-decaying

CHAPTER 1

INTRODUCTION

Diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae) is a well-known pest of Brassicacea. It is an oligophagous species, feed exclusively on the *Brassica* crops, primarily because of glucosinolate, a secondary metabolite that presence in the crops to enhance the feeding and oviposition in DBM. Zalucki et al. (2012) presented a detailed basis for estimating the worldwide control cost of diamondback moth, valued approximately US$4 billion-US$5 billion.

DBM multivoltine nature allows it to reproduce year-round; it can complete four generations in temperate areas per year while in tropical countries, it is capable to reach up to 20 generations (Lima-Neto et al., 2016; Knodel & Ganehiarachchi, 2008). Practically, when more generations are produced and all life stages are available throughout year, it has resulted an increase in frequency of insecticide application. Therefore, DBM in tropical countries are subjected to more insecticides than the temperate countries.

In tropical countries, intensive planting of host plants has provided a convenient environment for DBM to sustain, however the production of the host plants on the other hand are largely threatened by the pest (Regupathy, 1996). In the Southeast Asia, the countries depended primarily on the agriculture and as they are seeking to enter the global market by providing fresh fruits and vegetables, it is crucial to produce high cosmetic standards fresh produce (Thuy et al., 2012). In order to meet this demand, insecticides are used intensively to control the pests. However, frequent and malpractice of insecticides application leads to resistance development of DBM to a wider range of insecticides.

Earlier, studies have proven DBM resistance to the early generations of insecticides such as organophosphates, pyrethroids and organochlorines as well as newer generations with novel mode of actions including spinosad, neonicotinoids and juvenile hormone disruptor (Meghana et al., 2018; Zhang et al., 2017; Park et al., 2004) Acknowledged as one the few insect species resistant to majority of the insecticide classes (Furlong et al., 2012), DBM is ranked second in the insecticide resistance list by Arthropod Pesticide Resistance Database (APRD,2018). Entailing resistance, DBM has also confers cross resistance to several groups of insecticides, either the insecticides are within the same or different groups. Studies have shown the DBM ability to confer cross resistance towards insecticides via different mechanisms such as by sharing of similar target sites, augmentation of detoxification enzymes and sharing of the midgut binding site (Chen et al., 2011; Gong et al., 2014; Wang et al., 2013).

Spinosad is an insecticide derived from soil actinomycete *Saccharopolyspora spinosa* that was firstly commercialized in 1997. Primarily it activates the nicotinic acetylcholine receptor and have gamma amino butyric acid (GABA) receptor as the secondary target site (Salgado, 1998). In Asia, it was initially introduced to control the DBM and was firstly introduced in Malaysia in 1998 (Samsuddin et al., 2004). However, in 2002, the first resistance case towards spinosad was recorded in DBM field population in the USA (Zhao et al., 2002) and subsequently, several other cases were recorded (Shono & Scott, 2003; Ferguson, 2004; Sayyed et al., 2004).

In Malaysia, up until today, DBM is the major pest to the crucifers' production since 1941 (Syed et al., 1997). Although chemical control is the most common mean of controlling DBM in crucifers' production areas in Malaysia, up until now, there are a dearth of information on this topic in the country, specifically ones that emphasize on the effects of insecticides on DBM resistance. The latest study focusing on DBM resistance in Malaysia were conducted in 2016 (Nabihah, 2016). Realizing the importance of recent knowledge in this aspects, this study was conducted to fill the gap. In addition to that, it is crucial to understand current DBM resistance status in Malaysia to be shared with farmers and suggest appropriate solution to them.

Therefore, the objectives of this study were:

1. To study the spinosad resistance in laboratory selected (Spi-Sel) DBM strain
2. To investigate the resistance development of spinosad in Spi-Sel strain.
3. To study the activity of detoxification enzymes involved in the development of resistance.
4. To examine the effect of the resistance on the fitness of Spi-Sel strain.
5. To characterized the mode of inheritance of the spinosad resistance in the Spi-Sel strain.
6. To investigate the stability of spinosad resistance and cross resistance potential to other insecticides.

REFERENCES

Abbas, N., Khan, H. A. A., & Shad, S. A. (2014). Resistance of the house fly *Musca domestica* (Diptera: Muscidae) to lambda-cyhalothrin: Mode of inheritance, realized heritability, and cross-resistance to other insecticides. *Ecotoxicology*, *23*(5): 791–801.

Abbas, N., Khan, H., & Shad, S. A. (2015). Cross-resistance, stability, and fitness cost of resistance to imidacloprid in *Musca domestica* L., (Diptera: Muscidae). *Parasitology Research*, *114*(1): 247–255.

Abbas, N., Shad, S. A., & Razaq, M. (2012). Fitness cost, cross resistance and realized heritability of resistance to imidacloprid in *Spodoptera litura* (Lepidoptera: Noctuidae). *Pesticide Biochemistry and Physiology*, *103*(3), 181-188.

Abhilash, P. C., & Singh, N. (2009). Pesticide use and application: An Indian scenario. *Journal of Hazardous Materials*, *165*(1-3): 1–12.

Abro, G. H., Syed, T. S., Kalhoro, A. N., Sheikh, G. H., Awan, M. S., Jessar, R. D., & Shelton, A. M. (2013). Insecticides for control of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) in Pakistan and factors that affect their toxicity. *Crop Protection*, *52*: 91–96.

Acharya, B. (2017). Fitness costs and inheritance of *Bt* CryAB2 resistance in fall armyworm, *Spodoptera frugiperda* (J.E. Smith), *149*(May), 73. Retrieved from https://digitalcommons.lsu.edu/gradschool_theses.

Afzal, M. B. S., & Shad, S. A. (2017). Spinosad resistance in an invasive cotton mealybug, *Phenacoccus solenopsis*: cross-resistance, stability and relative fitness. *Journal of Asia-Pacific Entomology*, *20*(2), 457-462.

Afzal, M. B. S., Shad, S. A., Basoalto, E., Ejaz, M., & Serrao, J. E. (2015). Characterization of indoxacarb resistance in *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae): Cross-resistance, stability and fitness cost. *Journal of Asia-Pacific Entomology*, *18*(4): 779–785.

Ahmad, M., Arif, M. I., & Ahmad, M. (2007). Occurrence of insecticide resistance in field populations of *Spodoptera litura* (Lepidoptera: Noctuidae) in Pakistan. *Crop Protection*, *26*(6): 809-817.

Ahmad, M., & Iqbal Arif, M. (2009). Resistance of Pakistani field populations of spotted bollworm Earias vittella (Lepidoptera: Noctuidae) to pyrethroid, organophosphorus and new chemical insecticides. *Pest Management Science: formerly Pesticide Science*, *65*(4), 433-439.

Alon, M., Alon, F., Nauen, R., & Morin, S. (2008). Organophosphates' resistance in the B-biotype of *Bemisia tabaci* (Hemiptera: Aleyrodidae) is associated with a point mutation in an ace1-type acetylcholinesterase and overexpression of carboxylesterase. *Insect Biochemistry and Molecular Biology*, *38*(10): 940–949.

Alphey, N., Bonsall, M. B., & Alphey, L. (2011). Modeling resistance to genetic control of insects. *Journal of Theoretical Biology*, *270*(1): 42–55.

Aldridge, W. N. (1993). The esterases: perspectives and problems. *Chemico-biological interactions*, *87*(1-3), 5-13.

Ankersmit, G. W. (1953). DDT-resistance in *Plutella maculipennis* (Curt.)(Lep.) in Java. *Bulletin of Entomological Research*, *44*(3): 421-425.

Arthropod Pesticide Resistance Database (APRD), Retrieved 22 December 2018 from https://www.pesticideresistance.org/search.php

Askari-Saryazdi, G., Hejazi, M. J., Ferguson, J. S., & Rashidi, M. R. (2015). Selection for chlorpyrifos resistance in *Liriomyza sativae* Blanchard: Cross-resistance patterns, stability and biochemical mechanisms. *Pesticide Biochemistry and Physiology*, *124*, 86–92.

Asser-Kaiser, S., Fritsch, E., Undorf-Spahn, K., Kienzle, J., Eberle, K. E., Gund, N. A., Reineke,A., Zebitz, C. P. W., Heckel, D. G., Huber, J. & Jehle, J. A. (2007). Rapid emergence of baculovirus resistance in codling moth due to dominant, sex-linked inheritance. *Science*, *317*(5846): 1916-1918.

Attique, M. N. R., Khaliq, A., & Sayyed, A. H. (2006). Could resistance to insecticides in *Plutella xylostella* (Lep., Plutellidae) be overcome by insecticide mixtures? *Journal of Applied Entomology*, *130*(2): 122–127.

Atumurirava, F., Furlong, M. J., Srinivasan, R., Shelton, A. M., & Collinsm, H. L. (2011, March). Diamondback moth resistance to commonly used insecticides in Fiji. In *Proceedings of the Sixth International Workshop on Management of the Diamondback Moth and Other Crucifer Insect Pests* (pp. 21-25).

Ay, R., & Kara, F. E. (2011). Toxicity, inheritance of fenpyroximate resistance, and detoxification-enzyme levels in a laboratory-selected fenpyroximate-resistant strain of *Tetranychus urticae* Koch (Acari: Tetranychidae). *Crop Protection*, *30*(6): 605–610.

Khan, A., H., Akram, A., W., & Ali, S. (2014). Genetics, cross-resistance and mechanism of resistance to spinosad in a field strain of *Musca domestica* L. (Diptera: Muscidae). *Acta Tropica*, *130*: 148–154.

Balabaskaran, S., Chuen, S. S., & Muniandy, S. (1989). Glutathione S-transferase from the diamondback moth (*Plutella xylostella* Linnaeus). *Insect Biochemistry*, *19*(4): 435–443.

Basit, M., Saleem, M. A., Saeed, S., & Sayyed, A. H. (2012). Cross resistance, genetic analysis and stability of resistance to buprofezin in cotton whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae). *Crop Protection*, *40*: 16–21.

Basit, M., Sayyed, A. H., Saleem, M. A., & Saeed, S. (2011). Cross-resistance, inheritance and stability of resistance to acetamiprid in cotton whitefly, *Bemisia* *tabaci* Genn (Hemiptera: Aleyrodidae). *Crop Protection*, *30*(6): 705–712.

Bass, C., Carvalho, R. A., Oliphant, L., Puinean, A. M., Field, L. M., Nauen, R., Williamson, M.S., Moores, G., Gorman, K. (2011). Overexpression of a cytochrome P450 monooxygenase, CYP6ER1, is associated with resistance to imidacloprid in the brown planthopper, *Nilaparvata lugens*. *Insect Molecular Biology*, *20*(6): 763–773.

Bautista, M. A. M., Miyata, T., Miura, K., & Tanaka, T. (2009). RNA interference-mediated knockdown of a cytochrome P450, CYP6BG1, from the diamondback moth, *Plutella xylostella*, reduces larval resistance to permethrin. *Insect Biochemistry and Molecular Biology*, *39*(1): 38–46.

Belinato, T. A., Martins, A. J., & Stanislav, T. (2016). Insecticide resistance and fitness cost. *Insecticides Resistance: InTech*, 243-61.

Berglund, A. (1994). The operational sex ratio influences choosiness in a pipefish. *Behavioral Ecology*, *5*(3): 254–258.

Bielza, P., Quinto, V., Grávalos, C., Abellán, J., & Fernández, E. (2008). Lack of fitness costs of insecticide resistance in the western flower thrips (Thysanoptera: Thripidae). *Journal of Economic Entomology*, *101*(2): 499–503.

Bourguet, D., Genissel, A., & Raymond, M. (2000). Insecticide resistance and dominance levels. *Journal of Economic Entomology*, *93*(6): 1588–95.

Bouvier, J. C., Buès, R., Boivin, T., Boudinhon, L., Beslay, D., & Sauphanor, B. (2001). Deltamethrin resistance in the codling moth (Lepidoptera: Tortricidae): Inheritance and number of genes involved. *Heredity*, *87*(4): 456–462.

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*(1-2): 248–254.

Campos, M. R., Rodrigues, A. R. S., Silva, W. M., Silva, T. B. M., Silva, V. R. F., Guedes, R. N. C., & Siqueira, H. A. A. (2014). Spinosad and the tomato borer *Tuta absoluta*: a bioinsecticide, an invasive pest threat, and high insecticide resistance. *PloS one*, *9*(8).

Cárcamo, J. G., Aguilar, M. N., Barrientos, C. A., Carreño, C. F., & Yañez, A. J. (2014). Emamectin benzoate treatment alters the expression and activity of CYP1A, FMO and GST in different tissues of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, *434*: 188–200.

Cardozo, R. M., Panzera, F., Gentile, A. G., Segura, M. A., Pérez, R., Díaz, R. A., & Basombrío, M. A. (2010). Inheritance of resistance to pyrethroids in *Triatoma infestans*, the main Chagas disease vector in South America. *Infection, Genetics and Evolution*, *10*(8): 1174–1178.

Carrière, Y., & Tabashnik, B. E. (2001). Reversing insect adaptation to transgenic insecticidal plants. *Proceedings of the Royal Society B: Biological Sciences*, *268*(1475): 1475–1480.

Carrillo, J., Danielson-François, A., Siemann, E., & Meffert, L. (2012). Male-biased sex ratio increases female egg laying and fitness in the housefly, *Musca domestica*. *Journal of Ethology*, *30*(2): 247–254.

Castaneda, L. E., Figueroa, C. C., Fuentes-Contreras, E., Niemeyer, H. M., & Nespolo, R. F. (2009). Energetic costs of detoxification systems in herbivores feeding on chemically defended host plants: a correlational study in the grain aphid, *Sitobion avenae. Journal of Experimental Biology*, *212*(8): 1185–1190.

Cao, G., & Han, Z. (2006). Tebufenozide resistance selected in *Plutella xylostella* and its cross- resistance and fitness cost. *Pest Management Science: formerly Pesticide Science*, *62*(8): 746-751.

Chang, C., Huang, X., Chang, P., Wu, H., & Dai, S. (2012). Inheritance and stability of sodium channel mutations associated with permethrin knockdown resistance in *Aedes aegypti. Pesticide Biochemistry and Physiology 104*:136–142.

Che, W., Huang, J., Guan, F., Wu, Y., & Yang, Y. (2015). Cross-resistance and inheritance of resistance to emamectin benzoate in *Spodoptera exigua* (Lepidoptera: Noctuidae). *Journal of Economic Entomology*, *108*(4): 2015-2020.

Chen, X., Yuan, L., Du, Y., Zhang, Y., & Wang, J. (2011a). Cross-resistance and biochemical mechanisms of abamectin resistance in the western flower thrips, *Frankliniella occidentalis. Pesticide Biochemistry and Physiology*, *101*(1): 34–38.

Chiang and Sun, 1993. Glutathione transferase isozymes of diamondback moth larvae and their role in the degradation of some organophosphorus insecticides. P*esticides Biochemistry and Physiology*, 45: 7-14.

Corrales, N., & Campos, M. (2004). Populations, longevity, mortality and fecundity of *Chrysoperla carnea* (Neuroptera, Chrysopidae) from olive-orchards with different agricultural management systems. *Chemosphere*, *57*(11): 1613–1619.

Coustau, C., & Chevillon, C. (2000). Resistance to xenobiotics and parasites: can we count the cost?. *Trends in Ecology & Evolution*, *15*(9): 378-383.

Crow, J. F. (1957). Genetics of insect resistance to chemicals. *Annual Review of Entomology*, *2*(1): 227-246.

Cui, F., Weill, M., Berthomieu, A., Raymond, M., & Qiao, C. L. (2007). Characterization of novel esterases in insecticide-resistant mosquitoes. *Insect Biochemistry and Molecular Biology*, *37*(11): 1131–1137.

D'Ávila, V. A., Barbosa, W. F., Reis, L. C., Gallardo, B. S. A., Torres, J. B., & Guedes, R. N. C. (2018). Lambda-cyhalothrin exposure, mating behavior and reproductive output of pyrethroid-susceptible and resistant lady beetles (*Eriopis connexa*). *Crop Protection*, *107:* 41–47.

Da Silva, J. E., De Siqueira, H. A. A., Silva, T. B. M., De Campos, M. R., & Barros, R. (2012). Baseline susceptibility to chlorantraniliprole of Brazilian populations of *Plutella xylostella*. *Crop Protection*, *35:* 97–101.

Daglish, G. J., Nayak, M. K., & Pavic, H. (2014). Phosphine resistance in *Sitophilus oryzae* (L.) from eastern Australia: Inheritance, fitness and prevalence. *Journal of Stored Products Research*, *59*: 237-244.

Daly, J. C., & Fisk, J. H. (1998). Sex-linked inheritance of endosulphan resistance in *Helicoverpa armigera*. *Heredity*, *81*(1): 55–62.

Dangal, V., & Huang, F. (2015). Fitness costs of Cry1F resistance in two populations of fall armyworm, *Spodoptera frugiperda* (J.E. Smith), collected from Puerto Rico and Florida. *Journal of Invertebrate Pathology*, *127*: 81–86.

David, J. P., Ismail, H. M., Chandor-Proust, A., & Paine, M. J. I. (2013). Role of cytochrome P450s in insecticide resistance: Impact on the control of mosquito-borne diseases and use of insecticides on earth. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*: 20120429.

Dawkar, V. V., Chikate, Y. R., Lomate, P. R., Dholakia, B. B., Gupta, V. S., & Giri, A. P. (2013). Molecular insights into resistance mechanisms of lepidopteran insect pests against toxicants. *Journal of Proteome Research*, *12*(11): 4727–4737.

Devonshire, A. L., & Moores, G. D. (1982). A carboxylesterase with broad substrate specificity causes organophosphorus, carbamate and pyrethroid resistance in peach-potato aphids (*Myzus persicae*). *Pesticide Biochemistry and Physiology*, *18*(2): 235-246.

dos Santos Dias, L., da Graca Macoris, M. D. L., Andrighetti, M. T. M., Otrera, V. C. G., dos Santos Dias, A., da Rocha Bauzer, L. G. S., Rodovalho, C.D.M, Martins, A.J. & Lima, J. B. P. (2017). Toxicity of spinosad to temephos-resistant *Aedes aegypti* populations in Brazil. *PloS one*, *12*(3), e0173689.

Dosdall, L. M., Soroka, J. J., & Olfert, O. (2011). The Diamondback Moth in Canola and Mustard : Current Pest Status and Future Prospects. *Prairie Soils & Crops Journal*, *4:* 66–76.

Ducharme, J., & Auclair, K. (2018). BBA - Proteins and proteomics use of bioconjugation with cytochrome P450 enzymes. *BBA - Proteins and Proteomics*, *1866*(1): 32–51.

Dusfour, I., Zorrilla, P., Guidez, A., Issaly, J., Girod, R., Guillaumot, L., Robert, C. & Strode, C. (2015). Deltamethrin resistance mechanisms in *Aedes aegypti* populations from three French overseas territories worldwide. *PLoS Neglected Tropical Diseases*, *9*(11): 1–17.

Ejaz, M., Afzal, M. B. S., Shabbir, G., Serrão, J. E., Shad, S. A., & Muhammad, W. (2017). Laboratory selection of chlorpyrifos resistance in an invasive pest, *Phenacoccus solenopsis* (Homoptera: Pseudococcidae): Cross-resistance, stability and fitness cost. *Pesticide Biochemistry and Physiology*, *137:* 8–14.

El-Latif, A. O. A., & Subrahmanyam, B. (2010). Pyrethroid resistance and esterase activity in three strains of the cotton bollworm, *Helicoverpa armigera* (Hübner). *Pesticide biochemistry and physiology*, *96*(3), 155-159.

Elghar, G. E. A., Elbermawy, Z. A., Yousef, A. G., & Elhady, H. K. A. (2005). Monitoring and characterization of insecticide resistance in the cotton leafworm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *Journal of Asia-Pacific Entomology*, *8*(4): 397–410.

Enayati, A. A., Ranson, H., & Hemingway, J. (2005). Insect glutathione transferases and insecticide resistance. *Insect Molecular Biology*, *14*(1): 3–8.

FAOSTAT 2012. FAOSTAT .Food and Agriculture Organization of the United Nations, Rome, Italy. (http://faostat.fao.org).

Fatma, W., Sumayyah, A., & Dieng, H. (2019). Susceptibility and fitness cost of *Aedes albopictus* on their survivability after the exposure to the insecticide. *Journal of Asia-Pacific Entomology 22*: 553–560.

Fauziah, I., Mohd Norazam, M. T., & Mohd, R. Z. (2012). Toxicity of selected insecticides (spinosad, indoxacarb and abamectin) against the diamondback moth (*Plutella xylostella* L.) on cabbage. *Asian Journal of Agriculture and Rural Development*, *2* (393-2016-23894):17-26.

Ferguson, J. S. (2004). Development and stability of insecticide resistance in the leafminer *Liriomyza trifolii* (Diptera: Agromyzidae) to cyromazine, abamectin, and spinosad. *Journal of Economic Entomology*, *97*(1): 112–9.

Ferreira, C. B. S., Andrade, F. H. N., Rodrigues, A. R. S., Siqueira, H. A. A., & Gondim, M. G. C. (2015). Resistance in field populations of *Tetranychus urticae* to acaricides and characterization of the inheritance of abamectin resistance. *Crop Protection*, *67*: 77–83.

Ffrench-Constant, R. H., Daborn, P. J., & Le Goff, G. (2004). The genetics and genomics of insecticide resistance. *Trends in Genetics*, *20*(3): 163–170.

Flores, A. E., Albeldaño-Vázquez, W., Salas, I. F., Badii, M. H., Becerra, H. L., Garcia, G. P., Fuentesa, S.L., Brogdonb, W. G., Black W. C. IV & Beaty, B. (2005). Elevated α-esterase levels associated with permethrin tolerance in *Aedes aegypti* (L.) from Baja California, Mexico. *Pesticide Biochemistry and Physiology*, *82*(1): 66–78.

Furlong, M. J., Wright, D. J., & Dosdall, L. M. (2012). Diamondback Moth Ecology and Management: Problems, Progress, and Prospects. *Annual Review of Entomology*, *58*(1): 517–541.

Cueto, M.G. & Picollo, M.I. (2015). Insecticide resistance in vector Chagas disease: Evolution, mechanisms and management. *Acta Tropica*, *149*: 70–85.

Gao, C., Ma, S., Shan, C., & Wu, S. (2014). Thiamethoxam resistance selected in the western flower thrips *Frankliniella occidentalis* (Thysanoptera : Thripidae): Cross-resistance. *Pesticide Biochemistry and Physiology*, *114*: 90–96.

Gao, J. R., Yoon, K. S., Frisbie, R. K., Coles, G. C., & Clark, J. M. (2006). Esterase-mediated malathion resistance in the human head louse, *Pediculus capitis* (Anoplura: Pediculidae). *Pesticide Biochemistry and Physiology*, *85*(1): 28–37.

Gassmann, A. J., Carrière, Y., & Tabashnik, B. E. (2008). Fitness costs of insect resistance to *Bacillus thuringiensis*. *Annual Review of Entomology*, *54*(1): 147–163.

Germano, M. D., Vassena, C. V., & Picollo, M. I. (2010). Autosomal inheritance of deltamethrin resistance in field populations of *Triatoma infestans* (Heteroptera: Reduviidae) from Argentina. *Pest Management Science*, *66*(7): 705–708.

Girón-Pérez, K., Oliveira, A. L., Teixeira, A. F., Guedes, R. N. C., & Pereira, E. J. G. (2014). Susceptibility of Brazilian populations of *Diatraea saccharalis* to Cry1Ab and response to selection for resistance. *Crop Protection*, *62*: 124–128.

Golizadeh, A., Kamali, K., Fathipour, Y., & Abbasipour, H. (2009). Life table of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) on five cultivated brassicaceous host plants. *Jornal of Agricultural Science and Technology* 11: 115-124.

Gomez, M. B., Pessoa, G. D. A. C., Rosa, A. C. L., Echeverria, J. E., & Diotaiuti, L. G. (2015). Inheritance and heritability of deltamethrin resistance under laboratory conditions of *Triatoma infestans* from Bolivia. *Parasites & Vectors*, *8*: 595.

Gong, Y.J., Wang, Z.H., Shi, B.C., Kang, Z.J., Zhu, L., Jin, G.H., & Weig, S.J. (2014). Correlation between pesticide resistance and enzyme activity in the diamondback moth, *Plutella xylostella* . *Journal of Insect Science*, *13*(135): 1–13.

Gould, F., Anderson, A., Jones, A., Sumerford, D., Heckel, D. G., Lopez, J., Micinski, S., Leonard, R. & Laster, M. (1997). Initial frequency of alleles for resistance to *Bacillus thuringiensis* toxins in field populations of *Heliothis virescens*. *Proceedings of the National Academy of Sciences of the United States of America*, *94*(8): 3519–23.

Groeters, F. R., & Tabashnik, B. E. (2000). Roles of selection intensity, major genes, and minor genes in evolution of insecticide resistance. *Journal of Economic Entomology*, *93*(6): 1580-1587.

Gu, H., Fitt, G. P., & Baker, G. H. (2007). Invertebrate pests of canola and their management in Australia: A review. *Australian Journal of Entomology*, *46*(3): 231–243.

Guengerich, P.F. (2004). Cytochrome P450: What have we Learned and what are the future issues? *Drug Metabolism Reviews*, *36*(2): 159–197.

Guo-Min, A. I., Qing-Min, W. A. N. G., Dong-Yun, Z. O. U., Xi-Wu, G. A. O., & Fu-Gen, L. I. (2009). High performance liquid chromatography assay for p-nitroanisole o-demethylation by cytochrome P450 enzymes in *Musca domestica* L. *Chinese Journal of Analytical Chemistry*, *37*(8): 1157-1160.

Gulzar, A., & Wright, D. J. (2015). Sub-lethal effects of Vip3A toxin on survival, development and fecundity of *Heliothis virescens* and *Plutella xylostella*. *Ecotoxicology*, *24*(9): 1815–1822.

Gunning, R. V., Moores, G. D., & Devonshire, A. L. (1996). Esterases and esfenvalerate resistance in Australian *Helicoverpa armigera* (Hübner) Lepidoptera: Noctuidae. *Pesticide Biochemistry and Physiology*, *54*(1): 12-23.

Guo, L., Liang, P., Zhou, X., & Gao, X. (2014). Novel mutations and mutation combinations of ryanodine receptor in a chlorantraniliprole resistant population of *Plutella xylostella* (L.). *Scientific Reports*, *4*: 1–7.

Hackett, S. C., & Bonsall, M. B. (2016). Type of fitness cost influences the rate of evolution of resistance to transgenic Bt crops. *Journal of Applied Ecology*, *53*(5): 1391–1401.

Halimatunsadiah, A. B., Norida, M., Omar, D., & Kamarulzaman, N. H. (2016). Application of pesticide in pest management: The case of lowland vegetable growers. *International Food Research Journal*, *23*(1): 85-94.

Hansen, L. G., & Hodgson, E. (1971). Biochemical characteristics of insect microsomes: N-and O-demethylation. *Biochemical Pharmacology*, *20*(7): 1569-1578.

Haridas, C. V., & Tenhumberg, B. (2018). Modeling effects of ecological factors on evolution of polygenic pesticide resistance. *Journal of Theoretical Biology*, *456*: 224–232.

Harold, J. A., & Ottea, J. A. (1997). Toxicological significance of enzyme activities in profenofos-resistant tobacco budworms, *Heliothis virescens* (F.). *Pesticide Biochemistry and Physiology*, *58*(1): 23-33.

Haseeb, M., Liu, T. X., & Jones, W. A. (2004). Effects of selected insecticides on *Cotesia plutellae*, endoparasitoid of *Plutella xylostella*. *BioControl*, *49*(1): 33–46.

Hayes, J. D., & Strange, R. C. (2000). Glutathione S-transferase polymorphisms and their biological consequences. *Pharmacology*, *61*(3): 154–166.

Helps, J. C., Paveley, N. D., & van den Bosch, F. (2017). Identifying circumstances under which high insecticide dose increases or decreases resistance selection. *Journal of Theoretical Biology*, *428*: 153–167.

Hemingway, J., Hawkes, N. J., McCarroll, L., & Ranson, H. (2004). The molecular basis of insecticide resistance in mosquitoes. *Insect Biochemistry and Molecular Biology*, *34*(7): 653–665.

Henderson, M. 1957. Insecticidal control of the diamondback moth, *Plutella maclipennis* on cabbage at Cameron Highlands. *Malay. Agric*. J. 40: 275-279.

Henry, K. & Baker, G. (2008) Diamondback moth in canola. *Reports* South Australian Research and Development Institute.

Herron, G. A., Gunning, R. V., Cottage, E. L. A., Borzatta, V., & Gobbi, C. (2014). Spinosad resistance, esterase isoenzymes and temporal synergism in *Frankliniella occidentalis* (Pergande) in Australia. *Pesticide Biochemistry and Physiology*, *114*(1): 32–37.

Højland, D. H., Jensen, K. M. V., & Kristensen, M. (2014). Expression of xenobiotic metabolizing cytochrome P450 genes in a spinosad-resistant *Musca domestica* L. strain. *PLoS ONE*, *9*(8).

Hsu, J. C., & Feng, H. T. (2006). Development of resistance to spinosad in oriental fruit fly (Diptera: Tephritidae) in laboratory selection and cross-resistance. *Journal of Economic Entomology*, *99*(3): 931–936.

Hu, Z.D., Xia, F., Qing-sheng, L., Huan-yu, C., Zhen-yu, L., Fei, Y., Pei, L., Xi-wu, G. (2014). Biochemical mechanism of clorantraniliprole resistance in the diamondback moth, *Plutella xylostella* Linnaeus. *Journal of Integrative Agriculture*, *13*(11): 2452–2459.

Huang, F., Buschman, L. L., & Higgins, R. A. (2005). Larval survival and development of susceptible and resistant *Ostrinia nubilalis* (Lepidoptera: Pyralidae) on diet containing *Bacillus thuringiensis*. *Agricultural and Forest Entomology*, *7*(1): 45–52.

Ibrahim, S. A., & Ali, A. M. Enzyme activities in susceptible and emamectin benzoate selected cotton leafworm (*Spodoptera littoralis*) larvae. 3rd International Conference on Biotechnology Applications in Agriculture (ICBAA), Benha University, Moshtohor and Sharm El-Sheikh, 5-9 April 2016 , Egypt.

İşci, M., & Ay, R. (2017). Determination of resistance and resistance mechanisms to thiacloprid in *Cydia pomonella* L. (Lepidoptera: Tortricidae) populations collected from apple orchards in Isparta Province, Turkey. *Crop Protection*, *91*: 82–88.

Insecticide Resistance and Action Committee, (2012). IRAC MoA Classification Scheme Prepared by : IRAC International MoA Working Group Contents : *Text*, (February), 1–23.

Ishtiaq, M., Razaq, M., Saleem, M. A., Anjum, F., Noor ul Ane, M., Raza, A. M., & Wright, D. J. (2014). Stability, cross-resistance and fitness costs of resistance to emamectin benzoate in a re-selected field population of the beet armyworm, *Spodoptera exigua* (Lepidoptera: Noctuidae). *Crop Protection*, *65:* 227–231.

Janmaat, A. F., & Myers, J. H. (2005). The cost of resistance to *Bacillus thuringiensis* varies with the host plant of *Trichoplusia ni*. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1567): 1031-1038.

Jarošík, V., & Honek, A. (2007). Sexual differences in insect development time in relation to sexual size dimorphism. *Sex, Size and Gender Roles: Evolutionary Studies of Sexual Size Dimorphism*, (Godfray): 205–212.

Jia, B., Liu, Y., Zhu, Y. C., Liu, X., Gao, C., & Shen, J. (2009). Inheritance, fitness cost and mechanism of resistance to tebufenozide in *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). *Pest Management Science*, *65*(9): 996–1002.

Jipanin, J., Rahman, A. A., Jaimi, J. R., & Phua, P. K. (2001, September). Management of pesticide use on vegetable production: Role of Department of Agriculture Sabah. In *6th SITE Research Seminar* (pp. 1-21).

Kang, W. J., Koo, H. N., Jeong, D. H., Kim, H. K., Kim, J., & Kim, G. H. (2017). Functional and genetic characteristics of Chlorantraniliprole resistance in the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Entomological Research*, *47*(6): 394-403.

Kao, C. H., & Sun, C. N. (1991). In vitro degradation of some organophosphorus insecticides by susceptible and resistant diamondback moth. *Pesticide Biochemistry and Physiology*, *41*(2): 132–141.

Karunaratne, S. H. P. P., Hemingway, J., Jayawardena, K. G. I., Dassanayaka, V., & Vaughan, A. (1995). Kinetic and molecular differences in the amplified and non-amplified esterases from insecticide-resistant and susceptible mosquitoes. *Journal of Biological Chemistry*, *270*(52): 31124–31128.

Karunker, I., Benting, J., Lueke, B., Ponge, T., Nauen, R., Roditakis, E., Vontas, J., Gorman, K., Denholm, I. & Morin, S. (2008). Over-expression of cytochrome P450 CYP6CM1 is associated with high resistance to imidacloprid in the B and Q biotypes of *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Insect Biochemistry and Molecular Biology*, *38*(6): 634–644.

Kaur, R., Schlipalius, D. I., Collins, P. J., Swain, A. J., & Ebert, P. R. (2012). Inheritance and relative dominance, expressed as toxicity response and delayed development, of phosphine resistance in immature stages of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). *Journal of Stored Products Research*, *51*: 74–80.

Kaur, P. & Kang, B.K. (2015) Baseline data for insecticide resistance monitoring in tobacco caterpillar, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) on cole crops in Punjab, India. *International Journal of Scientific Research 4*(4): 4-7.

Kayani, H. N., & Ahmad, M. (2016). Cross resistance pattern for emamectin benzoate and synthetic pyrethroids in diamondback moth, *Plutella xylostella* (l.)(Lepidoptera: Plutellidae). *Asian Journal of Agriculture and Biology 4*(3): 65-72.

Kliot, A., & Ghanim, M. (2012). Fitness costs associated with insecticide resistance. *Pest Management Science*, *68*(11): 1431–1437.

Knodel, J. J., & Ganehiarachchi, M. (2008). Diamondback Moth in canola: Biology and integrated pest management. *North Dakota State University*, (January).

Kruger, M. (2010). An investigation into the development and status of resistance of *Busseola fusca* (Lepidoptera: Noctuidae) to *Bt* maize (Doctoral dissertation, North-West University).

Kruger, M., Van Rensburg, J. B. J., & Van den Berg, J. (2011). Resistance to *Bt* maize in *Busseola fusca* (Lepidoptera: Noctuidae) from Vaalharts, South Africa. *Environmental Entomology*, *40*(2): 477-483.

Kruger, M., Van Rensburg, J. B. J., & Van den Berg, J. (2014). No fitness costs associated with resistance of *Busseola fusca* (Lepidoptera: Noctuidae) to genetically modified Bt maize. *Crop Protection*, *55*: 1–6.

Kwon, M., Lee, S. H., & Lin, M. Y. (2006). An evidence to use *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae) as a field control agent against diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae). *Journal of Asia-Pacific Entomology*, *9*(1): 55–59.

Lande, R. (1981). The minimum number of genes contributing to quantitative variation between and within populations. *Genetics*, *99*(3-4): 541–553.

Lester, H. A., Dibas, M. I., Dahan, D. S., Leite, J. F., & Dougherty, D. A. (2004). Cys-loop receptors: New twists and turns. *Trends in Neurosciences*, *27*(6): 329–336.

Lewontin, R. C. 1965. Selection for colonizing species. Pages 77-94 in H. G. Baker and G. L. Stebbins, eds. The genetics of colonizing species. Academic Press, New York.

Li, D. G., Shang, X. Y., Reitz, S., Nauen, R., Lei, Z. R., Lee, S. H., & Gao, Y. L. (2016). Field resistance to spinosad in western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Journal of Integrative Agriculture*, *15*(12): 2803-2808.

Li, X., Schuler, M. A., & Berenbaum, M. R. (2007). Molecular mechanisms of metabolic resistance to synthetic and natural xenobiotics. *Annual Review of Entomology*, *52*(1): 231–253.

Liang, P., Gao, X. W., & Zheng, B. Z. (2003). Genetic basis of resistance and studies on cross-resistance in a population of diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Pest Management Science*, *59*(11): 1232–1236.

Lima Neto, J. E., Amaral, M. H. P., Siqueira, H. A. A., Barros, R., & Silva, P. A. F. (2016). Resistance monitoring of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) to risk-reduced insecticides and cross resistance to spinetoram. *Phytoparasitica*, *44*(5): 631–640.

Lima Neto, J. E., & Siqueira, H. Á. A. D. (2017). Selection of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) to chlorfenapyr resistance: Heritability and the number of genes involved. *Revista Caatinga*, *30*(4): 1067–1072.

Lin, C. L., Yeh, S. C., Feng, H. T., & Dai, S. M. (2017). Inheritance and stability of mevinphos-resistance in *Plutella xylostella* (L.), with special reference to mutations of acetylcholinesterase 1. *Pesticide Biochemistry and Physiology*, *141*: 65–70.

Ling, S., Zhang, H., & Zhang, R. (2011). Effect of fenvalerate on the reproduction and fitness costs of the brown planthopper, *Nilaparvata lugens* and its resistance mechanism. *Pesticide Biochemistry and Physiology*, *101*(3): 148–153.

Liu and Tabashnik (1997). Visual determination of sex of diamondback moth larvae.*The Canadian Entomologist:* 585-586.

Liu, F., Xu, Z., Chang, J., Hen, J., Meng, F., Zhu, Y. C., & Shen, J. (2008). Resistance allele frequency to Bt cotton in field populations of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in China. *Journal of Economic Entomology*, *101*(3): 933–943.

Liu, X., Wang, H. Y., Ning, Y. B., Qiao, K., & Wang, K. Y. (2015). Resistance selection and characterization of chlorantraniliprole resistance in *Plutella xylostella* (Lepidoptera: Plutellidae). *Journal of Economic Entomology*, *108*(4): 1978–1985.

Liu, Y. B., Tabashnik, B. E., Meyer, S. K., & Crickmore, N. (2001). Cross-resistance and stability of resistance to *Bacillus thuringiensis* toxin Cry1C in diamondback moth. *Applied and Environmental Microbiology*, *67*(7): 3216–3219.

Lu, X. P., Wang, L. L., Huang, Y., Dou, W., Chen, C. T., Wei, D., & Wang, J. J. (2016). The epsilon glutathione S-transferases contribute to the malathion resistance in the oriental fruit fly, *Bactrocera dorsalis* (Hendel). *Comparative Biochemistry and Physiology Part - C: Toxicology and Pharmacology*, *180*: 40–48.

Maa, W. C. J., & Liao, S. C. (2000). Culture-dependent variation in esterase isozymes and malathion susceptibility of diamondback moth, *Plutella xylostella* L. *Zoological Studies-Taipei-*, *39*(4), 375-386.

Magoc, L., Yen, J. L., Hill-Williams, A., McKenzie, J. A., Batterham, P., & Daborn, P. J. (2005). Cross-resistance to dicyclanil in cyromazine-resistant mutants of *Drosophila melanogaster* and *Lucilia cuprina*. *Pesticide Biochemistry and Physiology*, *81*(2), 129–135.

Mansoor, M. M., Afzal, M. B. S., Basoalto, E., Raza, A. B. M., & Banazeer, A. (2016). Selection of bifenthrin resistance in cotton mealybug *Phenacoccus solenopsis*

Tinsley (Homoptera: Pseudococcidae): Cross-resistance, realized heritability and possible resistance mechanism. *Crop Protection*, *87*: 55–59.

Marchioro, C. A., & Foerster, L. A. (2012). Modelling reproduction of *Plutella xylostella* L. (Lepidoptera: Plutellidae): climate change may modify pest incidence levels. *Bulletin of Entomological Research*, *102*(4): 489–496.

Markussen, M. D. K., & Kristensen, M. (2012). Spinosad resistance in female *Musca domestica* L. from a field-derived population. *Pest Management Science*, *68*(1): 75–82.

Martins, A. J., Ribeiro, C. D. e. M., Bellinato, D. F., Peixoto, A. A., Valle, D., & Lima, J. B. P. (2012). Effect of insecticide resistance on development, longevity and reproduction of field or laboratory selected *Aedes aegypti* populations. *PLoS ONE*, *7*(3): 1–9.

Mazlan, N., & Mumford, J. (2005). Insecticide use in cabbage pest management in the Cameron Highlands, Malaysia. *Crop Protection*, *24*(1): 31–39.

McKenzie, J.A. (1996) Ecological and evolutionary aspects of insecticide resistance. Austin, Texas, R.G. Landes–Academic Press.

Medina, P., Budia, F., Del Estal, P., & Viñuela, E. (2003). Effects of three modern insecticides, pyriproxyfen, spinosad and tebufenozide, on survival and reproduction of *Chrysoperla carnea* adults. *Annals of Applied Biology*, *142*(1): 55–61.

Meghana, C., Jayappa, J., Reddy, N. A., & Devappa, V. (2018). Assessing susceptibility of diamondback moth , *Plutella xylostella* (Lepidoptera : Plutellidae) population of different geographic region to selected newer insecticides, *6*(1): 320–327.

Melo-Santos, M. A. V., Varjal-Melo, J. J. M., Araújo, A. P., Gomes, T. C. S., Paiva, M. H. S., Regis, L. N., Furtado, A.F., Magalhaes, T., Macoris, M.L.G., Andrighetti, M.T.M. & Ayres, C. F. J. (2010). Resistance to the organophosphate temephos: Mechanisms, evolution and reversion in an *Aedes aegypti* laboratory strain from Brazil. *Acta Tropica*, *113*(2): 180–189.

Mohan, M., & Gujar, G. T. (2003). Local variation in susceptibility of the diamondback moth, *Plutella xylostella* (Linnaeus) to insecticides and role of detoxification enzymes. *Crop Protection*, *22*(3): 495–504.

Moreau, J., Martinaud, G., Troussard, J. P., Zanchi, C., & Moret, Y. (2012). Trans-generational immune priming is constrained by the maternal immune response in an insect. *Oikos*, *121*(11): 1828–1832.

Moser, R., Pertot, I., Elad, Y., & Raffaelli, R. (2008). Farmers' attitudes toward the use of biocontrol agents in IPM strawberry production in three countries. *Biological Control*, *47*(2): 125–132.

Moussa, S., Kamel, E., Ismail, I. M., & Mohammed, A. (2016). Inheritance of *Bacillus thuringiensis* Cry1C resistance in Egyptian cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Entomological Research*, *46*(1): 61–69.

Muriithi, B. W., Affognon, H., Diiro, G., Kingori, S., Chrysantus, M., Nderitu, P. W., Mohamed, S.A. & Ekesi, S. (2015). Impact assessment of integrated pest management (IPM) technology for suppression of mango-infesting fruit flies in Kenya, *Crop Protection 81*: 20–29.

Nabihah, N. H. (2016) Selection on spinosad and emamectin benzoate Insecticide resistance level in field-collected Diamondback moth. Final year project thesis, Universiti Putra Malaysia, Serdang, Selangor.

Nair, R., Kalia, V., Aggarwal, K. K., & Gujar, G. T. (2010). Inheritance of Cry1Ac resistance and associated biological traits in the cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Journal of Invertebrate Pathology*, *104*(1): 31–38.

Nehare, S., Moharil, M. P., Ghodki, B. S., Lande, G. K., Bisane, K. D., Thakare, A. S., & Barkhade, U. P. (2010). Biochemical analysis and synergistic suppression of indoxacarb resistance in *Plutella xylostella* L. *Journal of Asia-Pacific Entomology*, *13*(2): 91–95.

Oakeshott, J. G., Devonshire, A. L., Claudianos, C., Sutherland, T. D., Horne, I., Campbell, P. M., Ollis, D.L., & Russell, R. J. (2005). Comparing the organophosphorus and carbamate insecticide resistance mutations in cholin- and carboxyl-esterases. *Chemico-Biological Interactions*, *157-158*: 269–275.

Oftadeh, M., Sendi, J. J., & Khosravi, R. (2015). Life table parameters of *Glyphodes pyloalis* Walker (Lep .: Pyralidae) on four varieties of mulberry *Morus alba* L . (Moraceae), *Journal of Asia-Pacific Entomology 18:* 315–320.

Ooi, P. A. C. (1995). Bringing science to farmers : Experiences in integrated diamondback moth management. *The Management of Diamondback Moth and Other Crucifer Pests*, (61): 25–33.

Ooi, A.C.P & Sudderuddin, K.I. (1978). Control of diamondback moth in Cameron Highlands, Malaysia *In* Proceedings of Plant Protection Conference 1978. Rubber Research Institute of Malaysia, Kuala Lumpur.

Oppenoorth, F. J. (1984). Biochemistry of insecticide resistance. *Pesticide Biochemistry and Physiology*, *22*(2): 187-193.

Oppenoorth, F. J., van der Pas, L. J. T., & Houx, N. W. H. (1979). Glutathione S-transferase and hydrolytic activity in a tetrachlorvinphos-resistant strain of housefly and their influence on resistance. *Pesticide Biochemistry and Physiology*, *11*(1-3): 176–188.

Orr, N., Shaffner, A. J., Richey, K., & Crouse, G. D. (2009). Novel mode of action of spinosad: Receptor binding studies demonstrating lack of interaction with known insecticidal target sites. *Pesticide Biochemistry and Physiology*, *95*(1): 1–5.

Paris, M., David, J. P., & Despres, L. (2011). Fitness costs of resistance to *Bti* toxins in the dengue vector *Aedes aegypti*. *Ecotoxicology*, *20*(6): 1184–1194.

Park, N. J., Oh, S. C., Choi, Y. H., Choi, K. R., & Cho, K. Y. (2004). Inheritance and cross resistance of phenthoate-selected diamondback moth, *Plutella xylostella* (Lepidoptera: Yponomeutidae). *Journal of Asia-Pacific Entomology*, *7*(2): 233–237.

Patil, S. S., Ugale, T. B., Lande, G. K., & Barkhade, U. P. (2011). Resistance to emamamectin benzoate in *Plutella xylostella* collected from different geographic locations, *4*(1): 168–171.

Pavlidi, N., Tseliou, V., Riga, M., Nauen, R., Van Leeuwen, T., Labrou, N. E., & Vontas, J. (2015). Functional characterization of glutathione S-transferases associated with insecticide resistance in *Tetranychus urticae*. *Pesticide Biochemistry and Physiology*, *121*: 53–60.

Prasad, T. P. N. H., & Shetty, N. J. (2013). Autosomal inheritance of alphamethrin, a synthetic pyrethroid, resistance in *Anopheles stephensi* - Liston, a malaria mosquito. *Bulletin of Entomological Research*, *103*(5): 547–554.

Pridgeon, J. W., Zhang, L., & Liu, N. (2003). Overexpression of CYP4G19 associated with a pyrethroid-resistant strain of the German cockroach, *Blattella germanica* (L.). *Gene*, *314*(1-2): 157–163.

Pu, X., Yang, Y., Wu, S., & Wu, Y. (2010). Characterisation of abamectin resistance in a field-evolved multiresistant population of *Plutella xylostella*. *Pest Management Science*, *66*(4): 371–378.

Qian, L., Cao, G., Song, J., Yin, Q., & Han, Z. (2008). Biochemical mechanisms conferring cross-resistance between tebufenozide and abamectin in *Plutella xylostella*. *Pesticide Biochemistry and Physiology*, *91*(3): 175–179.

Ramachandran, S., Buntin, G. D., & All, J. N. (2011). Response of canola to simulated diamondback moth (Lepidoptera: Plutellidae) defoliation at different growth stages. *Canadian Journal of Plant Science*, *80*(3): 639–646.

Regupathy, A. (1996). Insecticide resistance in diamondback moth (DBM), *Plutella xylostella* (L.): status and prospects for its management in India. *The Management of Diamondback Moth and Other Crucifer Pests*, 233–239.

Rehan, A., & Freed, S. (2014). Selection, mechanism, cross resistance and stability of spinosad resistance in *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae). *Crop Protection*, *56*: 10–15.

Reyes, M., Rocha, K., Alarcón, L., Siegwart, M., & Sauphanor, B. (2012). Metabolic mechanisms involved in the resistance of field populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) to spinosad. *Pesticide Biochemistry and*

Physiology, *102*(1): 45–50.

Ribeiro, L. M. S., Wanderley-Teixeira, V., Ferreira, H. N., Teixeira, Á. A. C., & Siqueira, H. A. A. (2014). Fitness costs associated with field-evolved resistance to chlorantraniliprole in *Plutella xylostella* (Lepidoptera: Plutellidae). *Bulletin of Entomological Research*, *104*(1): 88–96.

Rodrigues, A. R. S., Ruberson, J. R., Torres, J. B., Siqueira, H. álvaro A., & Scott, J. G. (2013). Pyrethroid resistance and its inheritance in a field population of *Hippodamia convergens* (Guérin-Méneville) (Coleoptera: Coccinellidae). *Pesticide Biochemistry and Physiology*, *105*(2): 135–143.

Roush, R. (1997). Insecticide resistance management in diamondback moth: quo vadis. *Proc. Third Int. Workshop on the Management of Diamondback Moth and Other Crucifer Pests. Sivapragasam, A., WH Loke, AH Kadir, and GS Lim,(eds). MARDI, Ministry of Agriculture. Malaysia. Pp*, 21–24.

Roush, R. T., & Daly, J. C. (1990). The role of population genetics in resistance research and management. In *Pesticide Resistance in Arthropods* (pp. 97-152). Springer, Boston, MA.

Roush, R. T., & McKenzie, J. A. (1987). Ecological studies of insecticide and acaricide resistance. *Annual Review of Entomology*, *32*(21): 361–380.

Salgado, V. L. (1998). Studies on the mode of action of Spinosad: Insect symptoms and physiological correlates. *Pesticide Biochemistry and Physiology*, *60*(2): 91–102.

Samsudin, A., Thompson, G.D., Downard, P., (2004). Challenges in implementing spinosad diamondback moth resistance management strategies in intensive vegetable growing areas in Asia. *In*: Endersby, N.M., Ridland, P.M. (Eds.), Proceedings of the Fourth International Workshop on the Management of Diamondback moth and other Crucifer pests, 15–26 November 2001. Department of Natural Resources and Environment, Melbourne, Australia, pp. 313–318.

Salman, S.Y., Aydinli, F., & Ay, R. (2015). Etoxazole resistance in predatory mite *Phytoseiulus persimilis* A.-H. (Acari: Phytoseiidae): Cross-resistance, inheritance and biochemical resistance mechanisms. *Pesticide Biochemistry and Physiology*, *122*: 96–102.

Santos-Amaya, O. F., Tavares, C. S., Monteiro, H. M., Teixeira, T. P. M., Guedes, R. N. C., Alves, A. P., & Pereira, E. J. G. (2016). Genetic basis of Cry1F resistance in two Brazilian populations of fall armyworm, *Spodoptera frugiperda*. *Crop Protection*, *81*: 154–162.

Sarfraz, M., Dosdall, L. M., & Keddie, B. A. (2006). Diamondback moth-host plant interactions: Implications for pest management. *Crop Protection*, *25*(7): 625–639.

Sarfraz, M., Keddie, A. B., & Dosdall, L. M. (2005). Biological control of the diamondback moth, *Plutella xylostella*: A review. *Biocontrol Science and Technology*, *15*(8): 763–789.

Sarfraz, M., & Keddie, B. A. (2005). Conserving the efficacy of insecticides against *Plutella xylostella* (L.) (Lep., Plutellidae). *Journal of Applied Entomology*, *129*(3): 149–157.

Sayyed, A. H., & Wright, D. J. (2004). Fipronil resistance in the diamondback moth (Lepidoptera: Plutellidae): inheritance and number of genes involved. *Journal of Economic Entomology*, *97*(6): 2043-2050.

Sayyed, A. H., Attique, M. N. R., Khaliq, A., & Wright, D. J. (2005). Inheritance of resistance and cross-resistance to deltamethrin in *Plutella xylostella* (Lepidoptera: Plutellidae) from Pakistan. *Pest Management Science*, *61*(7): 636–642.

Sayyed, A. H., & Crickmore, N. (2007). Selection of a field population of diamondback moth (Lepidoptera: Plutellidae) with acetamiprid maintains, but does not increase, cross-resistance to pyrethroids. *Journal of Economic Entomology*, *100*(3): 932-938.

Sayyed, A. H., Omar, D., & Wright, D. J. (2004). Genetics of spinosad resistance in a multi-resistant field-selected population of *Plutella xylostella*. *Pest Management Science*, *60*(8): 827–832.

Sayyed, A. H., Pathan, A. K., & Faheem, U. (2010). Cross-resistance, genetics and stability of resistance to deltamethrin in a population of *Chrysoperla carnea* from Multan, Pakistan. *Pesticide Biochemistry and Physiology*, *98*(3): 325–332.

Sayyed, A. H., Saeed, S., Noor-ul-ane, M., & Crickmore, N. (2008). Genetic, biochemical, and physiological characterization of spinosad resistance in *Plutella xylostella* (Lepidoptera: Plutellidae). *Journal of Economic Entomology*, *101*(5): 1658–1666.

Sayyed, A. H., & Wright, D. J. (2001). Cross-resistance and inheritance of resistance to *Bacillus thuringiensis* toxin Cry1AC in diamondback moth (*Plutella xylostella* L.) from lowland Malaysia. *Pest Management Science*, *57*(5): 413–421.

Sayyed, A. H., & Wright, D. J. (2006). Genetics and evidence for an esterase- associated mechanism of resistance to indoxacarb in a field population of diamondback moth (Lepidoptera: Plutellidae). *Pest Management Science: formerly Pesticide Science*, *62*(11): 1045-1051.

Schwenke, R. A., Lazzaro, B. P., & Wolfner, M. F. (2017). Reproduction–immunity trade-offs in insects, *Annual Review of Entomology, 61*: 239–256.

Scott, M., Diwell, K., & McKenzie, J. A. (2000). Dieldrin resistance in *Lucilia cuprina* (the Australian sheep blowfly): chance, selection and response. *Heredity*, *84*(5): 599.

Scott, J. G., Leichter, C. A., Rinkevich, F. D., Harris, S. A., Su, C., Aberegg, L. C., Moon, R., Geden, C. J., Gerry, A. C., Taylor, D. B., Byford, R. L., Watson, W., Johnson, G., Boxler, D., & Zurek, L. (2013). Insecticide resistance in house flies from the United States: Resistance levels and frequency of pyrethroid resistance alleles. *Pesticide Biochemistry and Physiology*, *108*(1): 377-384.

Scott, J. G., Liu, N., & Wen, Z. (1998). Insect cytochromes P450: Diversity, insecticide resistance and tolerance to plant toxins. *Comparative Biochemistry and Physiology - C Pharmacology Toxicology and Endocrinology*, *121*(1-3): 147–155.

Sentinella, A. T., Crean, A. J., & Bonduriansky, R. (2013). Dietary protein mediates a trade-off between larval survival and the development of male secondary sexual traits. *Functional Ecology*, *27*(5): 1134–1144.

Seth, R. K., Kaur, J. J., Rao, D. K., & Reynolds, S. E. (2004). Effects of larval exposure to sublethal concentrations of the ecdysteroid agonists RH-5849 and tebufenozide (RH-5992) on male reproductive physiology in *Spodoptera litura*. *Journal of Insect Physiology*, *50*(6): 505-517.

Shad, S. A., Sayyed, A. H., & Saleem, M. A. (2010). Cross-resistance, mode of inheritance and stability of resistance to emamectin in *Spodoptera litura* (Lepidoptera: Noctuidae). *Pest Management Science*, *66*(8): 839–846.

Shah, R. M., Abbas, N., Shad, S. A., & Varloud, M. (2015). Inheritance mode, cross-resistance and realized heritability of pyriproxyfen resistance in a field strain of *Musca domestica* L. (Diptera: Muscidae). *Acta Tropica*, *142*: 149–155.

Shahzad Afzal, M. B., & Shad, S. A. (2015). Resistance inheritance and mechanism to emamectin benzoate in *Phenacoccus solenopsis* (Homoptera: Pseudococcidae). *Crop Protection*, *71*: 60–65.

Shang, Q., Pan, Y., Fang, K., Xi, J., & Brennan, J. A. (2012). Biochemical characterization of acetylcholinesterase, cytochrome P450 and cross-resistance in an omethoate-resistant strain of *Aphis gossypii* Glover. *Crop Protection*, *31*(1): 15–20.

Sharma, R., & Peshin, R. (2016). Impact of integrated pest management of vegetables on pesticide use in subtropical Jammu , India. *Crop Protection 84*: 105-112.

Shelton, A. M., Hatch, S. L., Zhao, J. Z., Chen, M., Earle, E. D., & Cao, J. (2008). Suppression of diamondback moth using Bt-transgenic plants as a trap crop. *Crop Protection*, *27*(3-5): 403–409.

Shelton, A. M., & Nault, B. A. (2004). Dead-end trap cropping: A technique to improve management of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Crop Protection*, *23*(6): 497–503.

Shelton, A. M., Tang, J. D., Roush, R. T., Metz, T. D., & Earle, E. D. (2000). Field tests on managing resistance to Bt-engineered plants. *Nature Biotechnology*, *18*(3): 339-342.

Shen, J., Li, D., Zhang, S., Zhu, X., Wan, H., & Li, J. (2017). Fitness and inheritance of metaflumizone resistance in *Plutella xylostella*. *Pesticide Biochemistry and Physiology*, *139*: 53–59.

Shi, H., Pei, L., Gu, S., Zhu, S., Wang, Y., Zhang, Y., & Li, B. (2012). Glutathione S-transferase (GST) genes in the red flour beetle, Tribolium castaneum, and comparative analysis with five additional insects. *Genomics*, *100*(5), 327-335.

Shi, J., Zhang, L., & Gao, X. (2011). Characterisation of spinosad resistance in the housefly *Musca domestica* (Diptera: Muscidae). *Pest Management Science*, *67*(3): 335–340.

Shikano, I., Hua, K. N., & Cory, J. S. (2016). Baculovirus-challenge and poor nutrition inflict within-generation fitness costs without triggering transgenerational immune priming. *Journal of Invertebrate Pathology*, *136*: 35-42.

Shono, T., & Scott, J. G. (2003). Spinosad resistance in the housefly, *Musca domestica*, is due to a recessive factor on autosome 1. *Pesticide Biochemistry and Physiology*, *75*(1-2): 1–7.

Sibanda, T., Dobson, H. M., Cooper, J. F., Manyangarirwa, W., & Chiimba, W. (2000). Pest management challenges for smallholder vegetable farmers in Zimbabwe. *Crop Protection*, *19*(8-10): 807–815.

Sokal, R, and Rohlf, F J. 1981. *Biometry*, W. H. Freeman and Co., New York.

Somers, J., Luong, H. N. B., Mitchell, J., Batterham, P., & Perry, T. (2017). Pleiotropic effects of loss of the Dα1 subunit in *Drosophila melanogaster*: Implications for insecticide resistance. *Genetics*, *205*(1): 263–271.

Sonoda, S., & Tsumuki, H. (2005). Studies on glutathione S-transferase gene involved in chlorfluazuron resistance of the diamondback moth, *Plutella xylostella* L. (Lepidoptera: Yponomeutidae). *Pesticide Biochemistry and Physiology*, *82*(1): 94–101.

Sparks, T. C., Dripps, J. E., Watson, G. B., & Paroonagian, D. (2012). Resistance and cross-resistance to the spinosyns - A review and analysis. *Pesticide Biochemistry and Physiology*, *102*(1): 1–10.

Sparks, T. C., G. D. Thompson, L. L. Larson, H. A. Kirst, O. K. Jantz, T. V. Worden, M. B. Hertlein, and J. D. Busacca. 1995. Biological characteristics of the spinosyns: a new and naturally derived insect control agent, pp. 903-907. *In* Proceedings of the Beltwide Cotton Conference. National Cotton Council, San Antonio, TX.

Srinivas, R., Jayalakshmi, S. K., Sreeramulu, K., Sherman, N. E., & Rao, J. (2006). Purification and characterization of an esterase isozyme involved in hydrolysis of organophosphorus compounds from an insecticide resistant pest, *Helicoverpa armigera* (Lepidoptera: Noctüidae). *Biochimica et Biophysica Acta (BBA)-General Subjects*, *1760*(3): 310-317.

Stanley, J., Chandrasekaran, S., & Regupathy, A. (2009). Baseline toxicity of emamectin and spinosad to *Helicoverpa armigera* (Lepidoptera: Noctuidae) for resistance monitoring. *Entomological Research*, *39*(5): 321–325.

Stone, B. F. (1968). A formula for determining degree of dominance in cases of monofactorial inheritance of resistance to chemicals. *Bulletin of the World Health Organization*, *38*(2): 325–326.

Sudderuddin, K.I. & Kok, P.F. (1978). Insecticide resistance in *Plutella xylostella* collected from the Cameron Highlands of Malaysia. FAO Plant Protection Bulletin 26: 53-57.

Sun, J., Liang, P., & Gao, X. (2010). Inheritance of resistance to a new non-steroidal ecdysone agonist, fufenozide, in the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Pest Management Science*, *66*(4): 406–411.

Sun, J., Liang, P., & Gao, X. (2012). Cross-resistance patterns and fitness in fufenozide-resistant diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Pest Management Science*, 68(2): 285–289.

Sunitha, V., Singh, T. V. K., & Satyanarayana, J. (2014). Cross-resistance variation among different populations of diamondback moth, *Plutella xylostella* (Linn.) to new insecticides . *International Journal of Bio-Resource and Stress Management*, *5*(4): 522-529.

Syed, A. R. (1992). Insecticide resistance in diamondback moth in Malaysia. *Diamondback moth and other crucifer pests*, 437-442.

Syed, A. R., Sivapragasam, A., Loke, W. H., & Fauziah, I. (1997). Classical biological control of diamondback moth: the Malaysian experience. *A. Sivapragasam, et al*, 71-77.

Tabashnik, B. E., Van Rensburg, J. B. J., & Carrière, Y. (2009). Field-evolved insect resistance to *Bt* crops: definition, theory, and data. *Journal of Economic Entomology*, *102*(6): 2011-2025.

Tabashnik, B. E., Malvar, Thomas., Liu, Y. B., Finson, Naomi., Borthakur, D. U. L. A. L., Shin, B. S., Park, S.H., Masson, L., de Maagd, R.A., Bosch, D. (1996). Cross-resistance of the diamondback moth indicates altered interactions with domain II of *Bacillus thuringiensis* toxins. *Applied and Environmental. Microbiology*, *62*(8): 2839-2844.

Talekar, N. S., Shelton, A. M., York, N., Agricultural, S., & Station, E. (1993). Biology, Ecology , and Management of the Diamondback Moth. *New York*, (92): 275–301.

Tang, L. De, Qiu, B. L., Cuthbertson, A. G. S., & Ren, S. X. (2015). Status of insecticide resistance and selection for imidacloprid resistance in the ladybird beetle *Propylaea japonic*a (Thunberg). *Pesticide Biochemistry and Physiology*, *123*: 87–92.

Tang, B., Sun, J., Zhou, X., Gao, X., & Liang, P. (2011). The stability and biochemical basis of fufenozide resistance in a laboratory-selected strain of *Plutella xylostella*. *Pesticide Biochemistry and Physiology*, *101*(2): 80–85.

Taylor, M., & Feyereisen, R. (1996). Molecular biology and evolution of resistance to toxicants. *Molecular Biology and Evolution*, *13*(6): 719–734.

Thompson, G. D., Dutton, R., & Sparks, T. C. (2000). Spinosad - A case study: An example from a natural products discovery programme. *Pest Management Science*, *56*(8): 696–702.

Thuy, P. T., van Geluwe, S., Nguyen, V. A., & van der Bruggen, B. (2012). Current pesticide practices and environmental issues in Vietnam: Management challenges for sustainable use of pesticides for tropical crops in (South-East) Asia to avoid environmental pollution. *Journal of Material Cycles and Waste Management*, *14*(4): 379–387.

Tian, L., Cao, C., He, L., Li, M., Zhang, L., Zhang, L., Liu, H. & Liu, N. (2011). Autosomal interactions and mechanisms of pyrethroid resistance in house flies, *Musca domestica*. *International Journal of Biological Sciences*, *7*(6): 902–911.

Tine, S., Tine-Djebbar, F., Aribi, N., & Boudjelida, H. (2015). Topical toxicity of spinosad and its impact on the enzymatic activities and reproduction in the cockroach *Blatta orientalis* (Dictyoptera: Blattellidae) . *African Entomology*, *23*(2): 387–396.

Tong, H., Su, Q., Zhou, X., & Bai, L. (2013). Field resistance of *Spodoptera litura* (Lepidoptera: Noctuidae) to organophosphates, pyrethroids, carbamates and four newer chemistry insecticides in Hunan, China. *Journal of Pest Science*, *86*(3): 599–609.

Troczka, B. J., Williamson, M. S., Field, L. M., & Davies, T. G. E. (2017). Rapid selection for resistance to diamide insecticides in *Plutella xylostella* via specific amino acid polymorphisms in the ryanodine receptor. *Neurotoxicology*, *60*(1): 224–233.

Ullah, S., & Shad, S. A. (2017). Toxicity of insecticides, cross-resistance and stability of chlorfenapyr resistance in different strains of *Oxycarenus hyalinipennis* Costa (Hemiptera: Lygaeidae). *Crop Protection*, *99*:132–136.

Ullah, S., Shah, R. M., & Shad, S. A. (2016). Genetics, realized heritability and possible mechanism of chlorfenapyr resistance in *Oxycarenus hyalinipennis* (Lygaeidae: Hemiptera). *Pesticide Biochemistry and Physiology*, *133*: 91–96.

Van Leeuwen, T., Tirry, L., & Nauen, R. (2006). Complete maternal inheritance of bifenazate resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae) and its implications in mode of action considerations. *Insect Biochemistry and Molecular Biology*, *36*(11): 869–877.

Verkerk, R. H. J., & Wright, D. J. (1996). Multitrophic interactions and the diamondback moth : implications for pest management. In *Proceedings of the Third*

International Workshop. Malaysian Agricultural Research and Development Institute, Kuala Lumpur., 243–248.

Voudouris, C. C., Sauphanor, B., Franck, P., Reyes, M., Mamuris, Z., Tsitsipis, J. A., Vontas, J., & Margaritopoulos, J. T. (2011). Insecticide resistance status of the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) from Greece. *Pesticide Biochemistry and Physiology*, *100*(3): 229–238.

Wang, D., Qiu, X., Ren, X., Niu, F., & Wang, K. (2009). Resistance selection and biochemical characterization of spinosad resistance in *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). *Pesticide Biochemistry and Physiology*, *95*(2): 90–94.

Wang, D., Wang, Y.M., Liu, H.Y., Xin, Z., & Xue, M. (2013). Lethal and sublethal effects of spinosad on *Spodoptera exigua* (Lepidoptera: Noctuidae). *Journal of Economic Entomology*, *106*(4): 1825–1831.

Wang, R., Tetreau, G., & Wang, P. (2016). Effect of crop plants on fitness costs associated with resistance to *Bacillus thuringiensis* toxins Cry1Ac and Cry2Ab in cabbage loopers. *Scientific Reports*, *6*(August 2015): 1–9.

Wang, R., & Wu, Y. (2014). Dominant fitness costs of abamectin resistance in *Plutella xylostella*. *Pest Management Science*, *70*(12): 1872–1876.

Wang, W., Mo, J., Cheng, J., Zhuang, P., & Tang, Z. (2006). Selection and characterization of spinosad resistance in *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). *Pesticide Biochemistry and Physiology*, *84*(3): 180–187.

Wang, X., Khakame, S. K., Ye, C., Yang, Y., & Wu, Y. (2012). Characterisation of field-evolved resistance to chlorantraniliprole in the diamondback moth, *Plutella xylostella,* from China. *Pest Management Science*, *69*(5): 661–665.

Wang, X. P., Fang, Y. L., & Zhang, Z. N. (2011). Effects of delayed mating on the fecundity, fertility and longevity of females of diamondback moth, *Plutella xylostella*. *Insect Science*, *18*(3): 305–310.

Wiesch, P. S. Z., Engelstädter, J., & Bonhoeffer, S. (2010). Compensation of fitness costs and reversibility of antibiotic resistance mutations. *Antimicrobial Agents and Chemotherapy*, *54*(5): 2085–2095.

Wilce, M. C., & Parker, M. W. (1994). Structure and function of glutathione S-transferases. *Biochimica et Biophysica Acta (BBA)-Protein Structure and Molecular Enzymology*, *1205*(1): 1-18.

Williams, J. L., Ellers-Kirk, C., Orth, R. G., Gassmann, A. J., Head, G., Tabashnik, B. E., & Carrière, Y. (2011). Fitness cost of resistance to *Bt* cotton linked with increased gossypol content in pink bollworm larvae. *PLoS One*, *6*(6): e21863.

Wirth, M. C., Walton, W. E., & Federici, B. A. (2010). Inheritance Patterns, Dominance, stability, and allelism of insecticide resistance and cross-resistance in two colonies of *Culex quinquefasciatus* (Diptera: Culicidae) selected with cry toxins from *Bacillus thuringiensis* subsp. *israelensis*. *Journal of Medical Entomology*, *47*(5): 814–822.

Wu, G., Jiang, S., & Miyata, T. (2004). Seasonal changes of methamidophos susceptibility and biochemical properties in *Plutella xylostella* (Lepidoptera: Yponomeutidae) and its parasitoid *Cotesia plutellae* (Hymenoptera: Braconidae). *Journal of economic entomology*, *97*(5), 1689-1698.

Wu, G., & Miyata, T. (2005). Susceptibilities to methamidophos and enzymatic characteristics in 18 species of pest insects and their natural enemies in crucifer vegetable crops. *Pesticide Biochemistry and Physiology*, *82*(1): 79–93.

Wu, H. H, Yang, M. L, Guo, Y. P, & Ma, E. B. (2009)a. The susceptibilities of *Oxya chinensis* (Orthoptera: Acridoidea) to malathion and comparison of the esterase properties from three collected populations in Tianjin area, China. *Agricultural Sciences in China*, *8*(1): 76–82.

Wu, S., Yang, Y., Yuan, G., Campbell, P. M., Teese, M. G., Russell, R. J., Oakeshott, J.G., & Wu, Y. (2011). Overexpressed esterases in a fenvalerate resistant strain of the cotton bollworm, *Helicoverpa armigera*. *Insect Biochemistry and Molecular Biology*, *41*(1): 14–21.

Wu, X., Huang, F., Rogers Leonard, B., & Ottea, J. (2009)b. Inheritance of resistance to *Bacillus thuringiensis* Cry1Ab protein in the sugarcane borer (Lepidoptera: Crambidae). *Journal of Invertebrate Pathology*, *102*(1): 44–49.

Xu, R., Kuang, R., Pay, E., Dou, H., & de Snoo, G. R. (2008). Factors contributing to overuse of pesticides in western China. *Environmental Sciences*, *5*(4): 235–249.

Yin, X. H., Wu, Q. J., Li, X. F., Zhang, Y. J., & Xu, B. Y. (2008). Sublethal effects of spinosad on *Plutella xylostella* (Lepidoptera: Yponomeutidae). *Crop Protection*, *27*(10): 1385–1391.

Young, H. P., Bailey, W. D., & Roe, R. M. (2003). Spinosad selection of a laboratory strain of the tobacco budworm, *Heliothis virescens* (Lepidoptera: Noctuidae), and characterization of resistance. *Crop Protection*, *22*(2): 265-273.

Yu, S. J., Nguyen, S. N., & Abo-Elghar, G. E. (2003). Biochemical characteristics of insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J.E. Smith). *Pesticide Biochemistry and Physiology*, *77*(1): 1–11.

Zaka, S. M., Abbas, N., Shad, S. A., & Shah, R. M. (2014). Effect of emamectin benzoate on life history traits and relative fitness of *Spodoptera litura* (Lepidoptera: Noctuidae). *Phytoparasitica*, *42*(4): 493–501.

Zalucki, M. P., & Furlong, M. J. (2011). Predicting outbreaks of a migratory pest: an analysis of DBM distribution and abundance revisited. In *International Workshop* *on Management of the Diamondback Moth and Other Crucifer Insect Pests (6th, 2011). AVRDC: The World Vegetable Centre* (pp. 8-14).

Zalucki, M. P., Shabbir, A., Silva, R., Adamson, D., Shu-Sheng, L., & Furlong, M. J. (2012). Estimating the economic cost of one of the world's major insect pests, *Plutella xylostella* (Lepidoptera: Plutellidae): Just how long is a piece of string? *Journal of Economic Entomology*, *105*(4): 1115–1129.

Zanchi, C., Troussard, J. P., Moreau, J., & Moret, Y. (2012). Relationship between maternal transfer of immunity and mother fecundity in an insect. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1741), 3223–3230.

Zhang, L., Leonard, B. R., Chen, M., Clark, T., Anilkumar, K., & Huang, F. (2014). Fitness costs and stability of Cry1Ab resistance in sugarcane borer, *Diatraea saccharalis* (F.). *Journal of Invertebrate Pathology*, *117*(1): 26–32.

Zhang, S. Y., Kono, S., Murai, T., & Miyata, T. (2008). Mechanisms of resistance to spinosad in the western flower thrip, *Frankliniella occidentalis* (pergande) (thysanoptera: thripidae). *Insect Science*, *15*(2): 125–132.

Zhang, S., Zhang, X., Shen, J., Li, D., Wan, H., You, H., & Li, J. (2017). Cross-resistance and biochemical mechanisms of resistance to indoxacarb in the diamondback moth, *Plutella xylostella*. *Pesticide Biochemistry and Physiology*, *140:* 85–89.

Zhao JZ, Li Y, Collins HL, Gusukuma-Minuto L, Mau RFL, Thompson GD & Shelton AM. 2002. Monitoring and characterization of diamondback moth resistance to spinosad. *Journal of Economic Entomology* 95: 430-436.

Zhao, J. Z., Collins, H. L., Li, Y. X., Mau, R. F. L., Thompson, G. D., Hertlein, J. T., Andaloro, M., Boykin, R., & Shelton, A. M. (2006). Monitoring of diamondback moth (Lepidoptera: Plutellidae) resistance to spinosad, indoxacarb, and emamectin benzoate. *Journal of Economic Entomology*, *99*(1): 176–81.

Zhou, J., & Jin, S. (2009). Safety of vegetables and the use of pesticides by farmers in China: Evidence from Zhejiang province. *Food Control*, *20*(11): 1043–1048.

Zhu, Y. C., & Luttrell, R. (2012). Variation of acephate susceptibility and correlation with esterase and glutathione S-transferase activities in field populations of the tarnished plant bug, *Lygus lineolaris*. *Pesticide Biochemistry and Physiology*, *103*(3): 202–209.

Zhu, Y. C., Snodgrass, G. L., & Chen, M. S. (2004). Enhanced esterase gene expression and activity in a malathion-resistant strain of the tarnished plant bug, *Lygus lineolaris. Insect Biochemistry and Molecular Biology*, *34*(11), 1175–1186.

Zyoud, S. H., Sawalha, A. F., Sweileh, W. M., Awang, R., Al-Khalil, S. I., Al-Jabi, S. W., & Bsharat, N. M. (2010). Knowledge and practices of pesticide use among farm workers in the West Bank, Palestine: Safety implications. *Environmental Health and Preventive Medicine*, *15*(4): 252–261.

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LIST OF PUBLICATIONS

Journal

Nur Adibah Mohd Ishadi, Norida Mazlan. Insecticide Use Impacts on Pest Resistance: An Evidence from Diamondback Moth. International Journal of Sciences: Basic and Applied Research (2015) 22(1): 131-150

Conference Proceedings

Nur Adibah, M.I., Norida, M., Dzolkhifli, O., Lau, W.H. 2019. High Resistance *Plutella xylostella* to Spinosad Exhibited Low Cross Resistance to Other Insecticides. 8th International Conference on Management of the Diamondback Moth and Other Crucifer Insect Pests. March 4-8, 2019, World Vegetable Centre, Shanhua, Taiwan. Oral Presenter.

Nur Adibah, M.I., Norida, M., Dzolkhifli, O. and Lau, W.H. 2018. The Development of Spinosad Resistance and its Stability in *Plutella xylostella* (Diamondback Moth, DBM). 10th International Conference on Plant Protection in the Tropics (ICPPT). August 6 - 8, 2019, Melaka International Trade Center (MTDC), Melaka, Malaysia. Oral Presenter.

Nur Adibah Mohd Ishadi, Norida Mazlan. 2016. Spinosad Resistance in *Plutella xylostella* and its Fitness Cost from Semenyih, Selangor. 9th International Conference on Plant Protection in the Tropics (ICPPT). August 3 – 5, 2016, Hilton Hotel, Kuching, Sarawak, Malaysia. Oral presenter.

Ishadi, N.A.M. and Norida, M. 2015. Spinosad resistance selected in field collected population of diamondback moth in Selangor, Malaysia. International Congress and General Meeting Agricultural Sciences for Sustainable Development (ISSAAS). November 7-9, 2015, Setagaya Campus, Tokyo University of Agriculture, Tokyo, Japan. Oral presenter.

Ishadi, N.A.M., Norida, M., Omar, D. and Lau, W.H. 2014. A Preliminary Study: Toxicity Level of Spinosad and Emamectin Benzoate on *Plutella xylostella* Population From Ulu Yam, Selangor. International Symposium on Insect: Harnessing the Power, Unlocking its Potential.December, 1 – 3, 2014, Bayview Hotel Melaka, Malaysia. Poster presenter.

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