UNIVERSITI PUTRA MALAYSIA

ECOBIOLOGICAL ASPECTS OF INVASIVE APPLE SNAILS (Pomacea spp.) IN RICE FIELDS, PENINSULAR MALAYSIA

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FP 2015 67

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By

GILAL ARFAN AHMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2015

DEDICATION

My Paradise

My Mother

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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June 2015

Chair: Professor Rita Muhamad Awang, PhD
Faculty: Agriculture

Alien invasive apple snails, *Pomacea canaliculata* Lamarck and *Pomacea maculata* Perry were introduced into Malaysia around 1991. Since their introduction, *Pomacea* spp. have damaged vast area under rice cultivation and are major threat to rice self sufficiency in Malaysia. However, no thorough research has been done on their ecobiological aspects in the country, especially in Peninsular Malaysia. Therefore, this study focused on understanding the different ecobiological aspects of these apple snails. Studies on the abundance of *Pomacea* spp. in twenty five rice fields of five states in Peninsular Malaysia, confirmed the presence of *P. maculata* and *P. canaliculata. Pomacea maculata* was more abundant and widely distributed. Population of *P. canaliculata* was not recorded in Penang. Rice fields in Perak showed the highest population of snails (10.13 snails / m^2). The lowest population was recorded from rice fields of Kelantan and Kedah during sowing and harvesting, respectively. Population of snails was significantly higher during sowing of rice as compared to harvesting due to the presence of plenty of water and young rice seedlings as their food. Population fluctuation of egg, juvenile and adult snails in a rice field over two rice growing seasons from August, 2013 to May, 2014 highlighted comparatively higher populations during off season in comparison to main season. Population of different stages of *P. maculata* increased during reproductive and ripening stages of rice. No population of juveniles, females and males was recorded at harvesting due to water drain out from rice field. Higher populations were significantly correlated to relative humidity, rainfall, and density of *Limnocharis flava* and *Ischaemum rugosum*. Different indices of population dispersion i.e., variance to mean ratio, Lloyd index and Green Co-efficient mostly confirmed regular or uniform dispersion pattern of various stages of *P. maculata*. However, Iwao's patchiness regression and Taylor's power law mostly confirmed aggregated dispersion pattern. Findings of the growth studies confirmed that size of one day hatchlings of *P. canaliculata* was significantly higher than *P. maculata.* Comparatively higher growth rate was observed in *P. canaliculata* than *P. maculata* with both species sexually matured during 27th and 32nd weeks, respectively. No significant difference was observed in shell length, height and width of the two species at maturity. Both *Pomacea* spp. started consuming rice during 4th week after hatching from eggs. Mating and oviposition behavior studies confirmed higher mating frequency, oviposition duration and higher number of eggs per clutch of smaller size along with more eggs per minute in *P. maculata.* Mating and oviposition in both species occurred mostly during

the night hours. No difference was recorded for mating duration, oviposition frequency, hatching success and hatching period between two species. Highly significant correlation between oviposition duration and total number of eggs was only observed in *P. canaliculata*. Feeding preference of 1, 2 and 3 cm sized snails of the two species on leaves and stems of rice and *L. flava* confirmed higher preference for *L. flava* in all three sizes based on higher consumption. *Limnocharis flava* also supported higher growth and weight gain in both *Pomacea* spp. Rice stems supported the least growth and weight gain. Study on damage potential of two *Pomacea* spp. to rice established by direct seeding and 14, 21 and 28 days old transplanted seedlings showed that both species caused 100% loss to direct seeded and 14 days transplanted rice. Damage decreased with older transplanted seedlings with the least damage recorded in 28 days old transplanted rice. No loss of seedlings by two *Pomacea* spp. was recorded in 21 and 28 days old transplanted rice after 5^{th} and 4^{th} weeks, respectively. Sowing methods and damage by *Pomacea* spp. caused considerable reduction in number of tillers, panicles and Leaf Area Index. Higher number of these parameters was recorded in 21 days old transplanted rice control treatment. Additional space in 28 days old transplanted rice snail infested plots due to missing seedlings compensated them by producing more spikelets per panicle, grain filling percentage and grain harvest index. Accordingly, yields in 28 days old transplanted rice treatments damaged by *Pomacea* spp. were comparable with control treatments of 28 and 21 days old transplanted rice. Studies on the effect of water levels of 5 and 2 cm, and densities of 1, 2 and 3 snails per plot of *Pomacea* spp. confirmed significantly higher damage by all the snail densities at 5 cm water level. Higher damage was recorded at a density of 3 snails / plot of either species. No significant difference between *P. maculata* and *P. canaliculata* was recorded in rice grown by different methods at two water levels, suggesting the same damage potential of the two species to rice.

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

ASPEK EKOBIOLOGI SIPUT GONDANG INVASIF (*Pomacea* spp.) DI SAWAH PADI, SEMENANJUNG MALAYSIA

Oleh

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Spesis invasif asing, *Pomacea canaliculata* Lamarck dan *Pomacea maculata* Perry telah diperkenalkan di Malaysia sekitar tahun 1991. Sejak diperkenalkan, *Pomacea* spp. telah menyebabkan kerugian yang besar pada kebanyakan kawasan penanaman padi dan menjadi ancaman kepada sistem sara diri di Malaysia. Akan tetapi, sehingga kini, masih tiada kajian mendalam dijalankan tentang aspek ekobiologi siput gondang terutama di Semenanjung Malaysia. Oleh itu, kajian tentang aspek ekobiologikal berbeza telah dijalankan. Kajian mengenai taburan *Pomacea* spp. di 25 kawasan sawah padi yang berbeza pada lima negeri di Semenanjung Malaysia mengesahkan kehadiran dua spesis siput gondang yang telah dikenal pasti iaitu *P. maculata* dan *P. canaliculata*. Populasi *Pomacea maculata* mempunyai taburan yang luas dan banyak. Populasi *P. canaliculata* tidak diperoleh di Pulau Pinang. Sawah padi di Perak telah merekodkan populasi tertinggi siput gondang iaitu 10.13 siput / m^2. Populasi siput gondang yang terendah telah dicatatkan di Kelantan dan Kedah semasa menyemai dan menuai hasil, masing-masing. Populasi siput gondang adalah lebih tinggi ketika menyemai berbanding semasa menuai disebabkan oleh faktor air yang lebih banyak dan umur padi yang muda yang menjadi makanan utama siput gondang. Kajian turun naik populasi siput gondang pada setiap peringkat; telur, juvana, siput betina dan jantan di sawah padi pada dua musim penanaman iaitu musim utama dan musim luar dari Ogos, 2013 sehingga Mei, 2014 menunjukkan perbandingan populasi yang lebih tinggi semasa musim luar berbanding semasa musim utama. Peningkatan populasi *P. maculata* bagi setiap peringkat yang berbeza telah diperhatikan ketika peringkat pembiakan dan matang. Tiada populasi juvana, siput jantan dan betina direkodkan ketika peringkat penuaian disebabkan oleh pengaliran keluar air dari sawah. Bagi faktor-faktor alam sekitar pula, populasi siput yang tinggi mempunyai hubungan korelasi yang signifikan dengan kelembapan, taburan hujan dan kepadatan *Limnocharis flava* dan *Ischaemum rugosum*. Indeks perbezaan bagi serakan populasi sebagai contoh varians kepada nisbah min, 'Lloyd index' dan 'Green Co-efficient' mengesahkan corak serakan tetap atau seragam pada setiap peringkat *Pomacea* spp. Bagaimanapun, teori regresi Iwao dan teori undang-undang kuasa Taylor kebanyakkanya mengesahkan corak serakan agregat. Hasil kajian pertumbuhan menunjukkan saiz bagi anak tetas yang berumur sehari bagi *P. canaliculata* adalah lebih cepat berbanding *P. maculata.* Secara perbandingannya, kadar pertumbuhan adalah lebih tinggi pada *P. canaliculata* berbanding *P. maculata* walaupun kedua-dua spesis matang dari segi seksual masing-masing pada minggu ke 27 dan 32. Akan tetapi, tiada

perbezaan ketara diperhatikan pada panjang, tinggi dan lebar cangkerang bagi kedua-dua spesis. *Pomacea* spp. mula memakan padi apabila mencecah umur empat minggu selepas tetas. Kajian tentang tingkah laku ketika mengawan dan oviposit mengesahkan bahawa semakin bertambah kekerapan mengawan, tempoh oviposit dan bilangan telur per kelompok lebih tinggi dan lebih telur dihasilkan dalam seminit bagi *P. maculata* berbanding *P. canaliculata.* Proses mengawan dan oviposit telur bagi kedua-dua spesis berlaku pada waktu malam dan tiada perbezaan dicatatkan bagi tempoh mengawan, kekerapan oviposit, kejayaan penetasan dan juga tempoh penetasan. Korelasi yang amat ketara antara tempoh oviposit dan jumlah bilangan telur telah diperhatikan pada *P. canaliculata*. Keutamaan pemakanan bagi siput berukuran 1, 2 dan 3 cm *P. maculata* dan *P. canaliculata* antara daun dan batang padi dan juga *L. flava* menunjukkan ketiga-tiga siput berlainan saiz itu lebih menggemari *L. flava*. *Limnocharis flava* juga membantu dalam meningkatkan pertumbuhan dan pertambahan berat pada *Pomacea* spp. manakala batang padi kurang menyumbang kepada pertumbuhan dan pertambahan berat siput. Kajian pada potensi kerosakan kedua-dua *Pomacea* spp. antara padi bagi kaedah penanaman terus dan anak padi berumur 14, 21 dan 28 hari selepas pemindahan menunjukkan bahawa kedua-dua spesis menyebabkan 100% kerosakan pada padi yang ditanam terus dan anak padi berumur 14 hari selepas dipindahkan. Bagaimanapun, kerosakan semakin berkurang apabila umur anak padi yang lebih tua digunakan dan anak padi berumur 28 hari menunjukkan tahap kerosakan paling rendah. Tiada kerugian disebabkan oleh *Pomacea* spp. dicatatkan bagi anak padi berumur 21 dan 28 hari selepas minggu kelima dan keempat. Kaedah semaian dan kerosakan oleh kedua-dua *Pomacea* spp. mengakibatkan pengurangan yang ketara pada bilangan anak padi, bilangan tangkai dan juga indeks keluasan daun bagi anak padi berumur 21 hari selepas dipindahkan berbanding kawalan. Jarak penanaman yang betul beserta ruang tambahan yang disebabkan oleh serangan siput gondang membolehkan anak padi berumur 28 hari untuk menghasilkan lebih spikelet pada setiap tangkai, peratusan bijirin dan indeks tuaian bijirin. Sewajarnya, hasil bagi rawatan anak pokok berumur 28 hari adalah setanding rawatan kawalan 28 dan 21 hari. Kajian tentang pengaruh paras air; 5 cm dan 2 cm terhadap kepadatan satu, dua dan tiga ekor siput bagi setiap plot dan setiap spesis Pomacea mengesahkan bahawa jumlah kerosakan yang lebih tinggi adalah pada paras air 5 cm berbanding 2 cm. Tahap kerosakan yang tinggi telah direkodkan pada plot yang berkepadatan tiga ekor siput berbanding yang lain. Tiada perbezaan yang ketara antara *P. maculata* dan *P. canaliculata* yang telah direkodkan pada kawasan penanaman padi dengan kaedah yang berbeza dan paras air yang berbeza kerana kedua- dua spesis mempunyai potensi kerosakan yang sama.

ACKNOWLEDGEMENTS

I bow before Almighty Allah and express my humblest and sincerest words of gratitude to Him, Who bestowed upon the feeble author the potential and ability to make material contribution to the already existing ocean of knowledge.

I would like to express my sincere thanks and appreciation to my supervisor, Prof. Dr. Rita Muhamad Awang for her kind assistance, readily available support, patience, encouragement, critical advice, suggestions, intellectual guidance and understanding throughout my study in Malaysia. I am also greatly indebted to my supervisory committee members, Prof. Dr. Dzolkhifli Omar and Dr. Nor Azwady Abdul Aziz, for their suggestions, enlightening comments, advice and help throughout my study and encouragement in the completion of this thesis.

My gratitude goes to the management of Sindh Agriculture University, Tandojam, Sindh, Pakistan for granting me scholarship to pursue a Ph.D. study at Universiti Putra Malaysia (UPM), Malaysia. I also acknowledge the Ministry of Education (MOE), Malaysia for the Long term Research Grant Scheme LRGS (5525001) (Food Security) and Universiti Putra, Malaysia for funding this research project and technical supports. My special thanks to Mr. Tamsil Shariff, Mr. Shamuddin, Mr. Manan Tikon, Mr. Rajan and all the staff of Department of Plant Protection, UPM for their support and assistance. Cooperation, patience and guidance from Dr. Manjeri Gnanasegaram during preparation of this thesis are also highly acknowledged. The technical support from Dr. Natrah Ikhsan for the identification of Algae is also highly appreciated.

I wish to express my deepest appreciation to numerous people who walked with me along the journey of this study and thesis preparations. I enjoyed my time spent at Malaysia thoroughly and I would cherish these memories for rest of my life.

Finally, I find no words to thank the patience and unconditional love and support of my family during my entire PhD studies especially to my angels Farah, Qubra and naughty Amber and Saqlain.

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

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CHAPTER 1

INTRODUCTION

The growing world population that is expected to reach 9 billion by 2050 will necessitate increased production and supply of food crops to support their lives (Nelson *et al.,* 2010; Tscharntke *et al.,* 2012). Accordingly, rice, *Oryza sativa* L. holds the key importance as it is the most important staple food and source of livelihood for more than a billion population of the globe (Pandey *et al.,* 2012; Tobias, 2012). Moreover, after the food crisis of 2007-2008, the importance of rice has increased as a strategic food crop. Accordingly, many countries have changed their policies for attaining the 100% food self sufficiency, where rice holds a key position (Dawe, 2012).

In Malaysia, rice is mostly grown under flooded conditions in eight granary areas of Peninsular Malaysia, Sabah and Sarawak (Akinbile *et al.,* 2011). Malaysia is ranked 24th in terms of rice production in the world with annual production of 2.627 million tons (FAO, 2014). Total area under rice cultivation in Malaysia in 2013 was 688,207 hectares, out of which 43,118 hectares were situated in Sabah and 124,241 in Sarawak (DOA, 2014). Presently, Muda Agricultural Development Authority (MADA) and Kemudu Agriculture Development Authority (KADA) are the two main rice growing areas in Malaysia.

Currently, rice production in Malaysia is insufficient for the food requirements of the local population that has increased tremendously during 1990-2007. Accordingly, the demand for rice has increased from 1.5 million tons to 2.3 million tons in the same period (Vengedasalam *et al.,* 2011). Furthermore, during the 2008 global financial crises, Malaysia found it hard to fulfill its rice demand due to high import cost of rice. Considering the same, Malaysian government started initiatives to make the country 100% self-sufficient by 2015 in 9th Malaysian Plan (2006-2010). Despite the government's efforts that includes an allocation of the additional rice area in Sabah, Sarawak and Pahang, rehabilitation of land under rice cultivation, improvement of agriculture infrastructure and development of high yielding and early maturing rice varieties; the country failed to achieve the target. Presently, the country is 73% self sufficient in terms of rice demand, while the remaining is imported from different countries (Akinbbile *et al.,* 2011).

There are many factors affecting the rice production in the country. Reduction or no increase in the area under rice cultivation due to urbanization and cultivation of more economical crops and reduction of labor force especially youths affected the rice productivity. Increase in rice yield from 2.1 tons / ha in 1960 to 3.6 tons / ha in 2008, is the only factor that contributed towards the country's increased rice production. Moreover, pests remained the major threat to the rice productivity, reducing its both quantity and quality (Wong *et al.,* 2010; Akinbbile *et al.,* 2011).

Rice is attacked by a number of pests including weeds, pathogens, arthropods, rodents and birds (Jahn *et al.,* 2005). Recently, apple snails, *Pomacea* spp. belonging to genus *Pomacea* (Mollusca: Ampullariidae) are posing great threat to rice productivity in many countries of the world, including Malaysia (Halwart, 1994a; Rawlings *et al.,* 2007; Hayes *et al.,* 2008).

Apple snails, *Pomacea* spp. were first found in Peninsular Malaysia in 1991and were identified as *Pomacea canaliculata* and *Pomacea maculata* (Teo, 2005; Yahaya *et al.,* 2006). These snail species are native to South America and were introduced to many countries of the world, including Southeast Asia for aquariums and food trade. However, snails failed to achieve the intended uses, discarded in the wild and established as major pests of many macrophytes including rice (Rawlings *et al.,* 2007; Hayes *et al.,* 2008; Horgan *et al.,* 2012). Considering their invasive attributes, i.e., high breeding potential and survival under various harsh environments, one of the species, *P. canaliculata* was included in the World's worst 100 invasive species (Lowe *et al.,* 2000).

Now, these pomacean snails are present in all granary areas of Peninsular Malaysia and Sabah and Sarawak. Since 1991, these snails have attacked more than 17,000 ha of rice area in the Peninsular Malaysia. The snails caused heavy losses during the early growth of rice, especially in direct seeded rice. Often, severe infestation of the snails can cause complete loss of rice crop in the field. In Malaysia, these snails are more devastating than other countries because of large scale direct seeding and flooded conditions in rice fields either because of irrigation water or heavy rains (Yahaya *et al.,* 2006). The estimated losses due to attack of *Pomacea* spp. were approximately RM82.5Million in 2009 (DOA, 2014).

When infestation of freshwater apple snails (*Pomacea* spp.) to rice increased continuously, no serious research has been done on their ecology, biology or damage potential in Peninsular Malaysia. Therefore, considering the economic and ecological importance of the apple snails to rice; the staple food of Malaysia, it has become imperative to plan some basic studies on their ecobiological aspects. This study focused on the identification and distribution of different apple snail species in the main rice growing areas of Peninsular Malaysia along with their feeding, growth and damage potential to rice. Accordingly, this research study was conducted with the following objectives:

1. To study the distribution of apple snails in rice fields of Peninsular Malaysia
2. To study the population fluctuation of apple snails in a rice field
3. To study the comparative growth, mating and oviposition of apple snails
4. To investigate feeding preference of apple snails on rice and yellow bur-head
5. To evaluate damage potential of apple snails to rice

It is expected that the results of this study will contribute towards better understanding of the basic aspects of apple snail's behavior and damage potential to rice. Information obtained can be utilized for their proper management by integrating different control measures. Such efforts will further result in the better and improved rice productivity in Malaysia, a step towards the self-sufficiency in rice productivity.

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