Korean Journal of Environmental Biology

Original article

https://doi.org/10.11626/KJEB.2021.39.4.536

Korean J. Environ. Biol.
39(4) : 536-541 (2021)
ISSN 1226-9999 (print)
ISSN 2287-7851 (online)

Effects of temperature and water management in rice fields on larval growth of *Pantala flavescens* (Odonata: Libellulidae)

Bosomtwe Augustine, Jinu Eo[1,*], Myung-Hyun Kim[1], Min-Kyeong Kim[1], Soon-Kun Choi[1], So-Jin Yeob[1], Jeong-Hwan Bang[1] and Owusu Danquah Eric[2]

CSIR-Plant Genetic Resources Research Institute, Bunso Box 7, Ghana
[1]National Institute of Agricultural Sciences, Wanju 55365, Republic of Korea
[2]CSIR-Crops Research Institute, Kumasi Box 3785, Ghana

***Corresponding author**
Jinu Eo
Tel. 063-238-2507
E-mail. eojiny@korea.kr

Received: 24 November 2021
First Revised: 8 December 2021
Second Revised: 12 December 2021
Revision accepted: 14 December 2021

Abstract: *Pantala flavescens* is a dominant *Odonata* species in the rice fields in Korea. To determine the effects of different temperatures on its larval growth and emergence, field and laboratory experiments were conducted. Larval growth was also monitored in mono-cropping and double-cropping rice fields. The growth of larvae was monitored every week by measuring the head width. In the field experiment, no difference was found in larval growth and emergence between the control temperature and +1.9°C of the control temperature. The larval growth was greater at 23°C than at 20°C laboratory temperatures, and no emergence was recorded at either temperature after eight weeks of monitoring. There was a quadratic relationship between larval growth and temperature in an incubator at five temperature regimes of 15, 20, 25, 30, and 35°C. Midseason water drainage caused the extinction of the existing individuals and newly hatched larvae dominated after re-watering in the rice fields. Larval size was greater in double-cropping fields than in mono-cropping fields in late July but the tendency was reversed in early August. The results of this study suggest that temperature warming will directly promote the larval growth of *P. flavescens* and indirectly influence seasonal growth via changes in water management in rice fields.

Keywords: climate warming, midseason drainage, temperature response, growth rate, emergence

INTRODUCTION

Pantala flavescens, the wandering glider or globe skimmer, is known for its remarkable migration and has the most extensive cosmopolitan range among all known dragonflies (Russell *et al.* 1998; Hobson *et al.* 2012). They use prevailing seasonal winds to migrate to all continents with the exception of Antarctica (Corbet 1999; Anderson 2009; Hobson *et al.* 2012; May 2013). Dragonflies are important ecosystem service providers in agricultural ecosystems, and their larvae play a role in controlling other insects with aquatic larval stages including mosquitoes (Singh *et al.* 2003; Mandel *et al.* 2008; Acquah-Lamptey and Brandl 2018). Additionally, adult dragonflies are known to control disease vectors such as stable flies and some crop pests in soybean and rice fields (Neal and Whitcomb 1972; Yasumatsu *et al.* 1975; Suh and Samways 2001).

As common to the ecophysiological performance of ectotherms, the rate of development of the aquatic larval stage of *P. flavescens* is directly influenced by water temperature (Angilletta *et al.* 2002). Temperature is commonly considered as a proximate predictor for modelling species response to global warming because distribution of most species are influenced by the particular temperature ranges they are adapted to (Elith and Leathwick 2009; Dell *et al.* 2011; Yoon *et al.* 2020). By the end of the 21st century, the global average temperature is expected to increase by about 4°C (IPCC 2013). The warmer climate is expected to increase the pace of development in most ectotherms which may alter key phenological processes such as metamorphosis (Angilletta *et al.* 2002; Doi 2008; Jeon *et al.* 2019; Park *et al.* 2020).

Aquatic organisms are influenced by cropping systems and water management in rice fields. In particular, the practice of midseason drainage generally applied in rice fields to control tillering is known to have a detrimental effect on aquatic organisms and alters seasonal variation in their community structure (Yamazaki *et al.* 2003). The period of midseason drainage is different between cropping systems and rice cultivation is delayed in double cropping fields compared to mono cropping fields. Area of rice fields for double cropping system has been expanded due to climate warming (Yang *et al.* 2011).

The study aimed to determine the effects of temperature on larval growth and emergence of *P. flavescens*, and to investigate the effect of water management on larval growth in rice fields. Larvae were reared in different field and laboratory temperatures to monitor growth. Larval growth was also compared in mono and double cropping rice fields with different periods of midseason drainage.

MATERIALS AND METHODS

1. Field experiment under temperature controlling system

Larvae of *P. flavescens* were collected from rice paddy fields at the Rural Development Administration (RDA), Wanju, Republic of Korea in August 2021 with a hand net (mesh size: 1 mm). These fields had been flooded for about two weeks prior to the collection. The larvae were sorted into sizes, and only smaller uniform-sized larvae with head width less than 2 mm were used for the experiment. Larvae were reared in two field temperature conditions; control (prevailing water temperature) and increased water temperature (+1.9°C of control temperature). The increase in water temperature by 1.9°C reflects the projected increase in the global mean surface temperature by the end of 21st century (IPCC 2013). The experiment was conducted at a research field in RDA during August to September in 2021. Water temperature was controlled using a heating cable buried in the soil. Each larva was reared in a bowl (27 cm × 20 cm × 17 cm) which was filled with water up to a depth of about 6 cm. The experiment was conducted with 10 replicates. Larvae were fed daily, and the choice of prey was dependent on the stage of growth. However, all individuals were giving the same prey at any particular time. Different kinds of prey such as *Brachinella kugenumaensis*, *Tubifex* spp., *Sigara* spp., *Chironomus dorsalis* and some crustaceans were used as food. The growth of larvae was determined by measuring the head width every week while emergence was monitored every day after the first adult emerged. The head width was used because it is the reliable dimension for specifying size of odonates larvae (Corbet 2002). All the bowls were covered with a plastic net to inhibit intrusion by other organisms. Three weeks after the larvae were introduced, supporting frames for adult emergence were placed in each bowl.

2. Field survey in rice fields

Seasonal changes in larval growth were monitored in rice fields located in Kimje and Wanju, from June to September 2015. Annual mean temperature and precipitation (1991–2020) of the monitored area were 13.7°C and 1299.3 mm, respectively. Monthly mean temperature was 21.0 to 25.6°C during June to September in 2015. The survey was conducted in 10 and 7 of mono cropping and double cropping fields, respectively. Samples were transported to laboratory and their head width was measured.

3. Laboratory experiments

Two experiments were conducted using two and five temperature regimes. In the first experiment, larvae were reared in 20°C and 23°C in temperature controlled rooms. One larva was reared in a bowl (11 cm × 8 cm × 8 cm) with 4 replicates. The bowls were perforated at the bottom to allow water entry, and afterwards placed in a container (45 cm × 32 cm × 24 cm) filled with soil and water to a depth of 10 cm. The soil used to fill the containers was taken from the same rice fields where larvae were collected. The second experiment was conducted in incubators to determine the effects of large temperature variations (5°C) on larval growth rate using five temperature regimes; 15, 20, 25, 30 and 35°C. Four individuals were reared in each temperature regime using the same procedure as described in the first experiment. The larvae were incubated with white LED lights under a 12 h light : 12 h dark photoperiod. Larval growth was measured as described in the field experiment under temperature controlling system.

4. Statistical analysis

Differences in means of larval growth between two temperature regimes in the field and laboratory experiments were analyzed with *t*-test, and between five regimes with analysis of variance using R 4.1.1 (R Core Team 2021). The devRate package (v0.2.1) for R (Rebaudo and Regnier 2021) was used to determine the relationship between temperature and growth rate.

RESULTS

1. Field experiment under temperature controlling

The data from the field experiment showed no difference in larval growth and emergence between control temperature and +1.9°C of control temperature (Fig. 1). The average of the control water temperature during the experiment was 25.6°C. The first adult emerged on September 10, and emergence was observed every day until September 17.

2. Seasonal variation in larval growth in rice fields

Mono and double cropping paddy fields have different midseason drainage periods (Fig. 2). A total of 411 individuals were observed. Larval size increased gradually during June and no larva was present in July 20 in mono cropping fields. Small-sized larvae were later observed from July 27 and their size increased until Aug 31. In double cropping fields, no larva was found in Aug 3, and small-sized larvae were later found on Aug 10.

3. Laboratory experiments

In the experiment with two temperature regimes, larval growth was greater at 23°C than at 20°C across all sampling weeks (Fig. 3a). However, no emergence was recorded in both temperatures because all the larvae died after the eighth week of monitoring. In the experiment with five temperature regimes to determine larval growth rate, there was a quadratic relation between increasing temperature and growth rate, with the fastest growth rate of 0.193 mm day^{-1} at 35°C whereas the slowest growth rate of 0.015 mm day^{-1} was at 15°C (Fig. 3b). The growth rate was different between the five temperatures, nonetheless, no emergence was recorded in any of them.

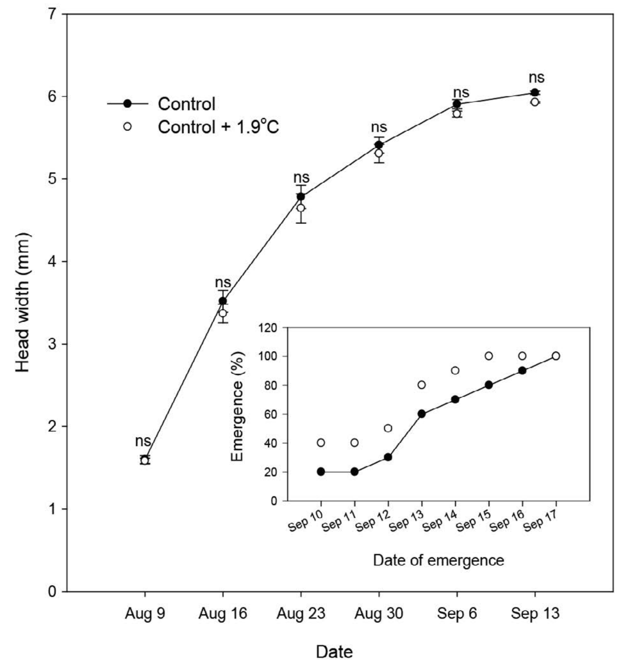

Fig. 1. Larval growth and accumulated emergence rate of *Pantala flavescens* in two field temperature conditions in 2021. ns; no significance.

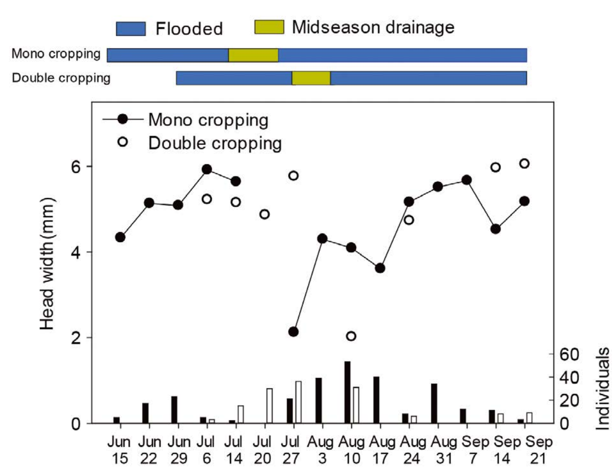

Fig. 2. Seasonal changes in the head width of *Pantala flavescens* in rice fields in 2015.

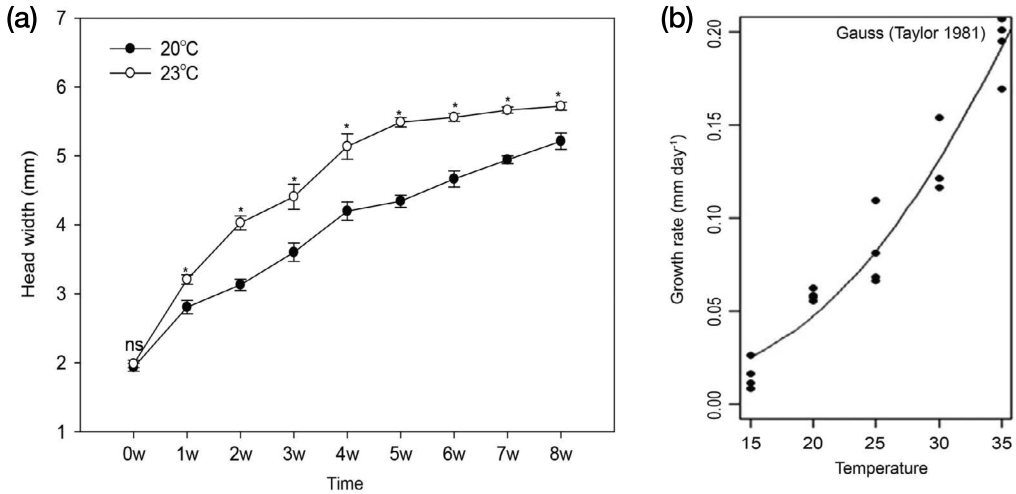

Fig. 3. Growth of *Pantala flavescens* larvae at two laboratory temperature conditions (a) and the growth rate curve of larvae in five temperature conditions (b). ns, no significance; $*P<0.05$.

DISCUSSION

Phenological shifts such as early emergence is one of the widely-known biological responses to climate change, and this can be directly affected by temperature influences on growth rate and development of organisms (Parmesan 2006; Forrest and Miller-Rushing 2010). *Pachidiplax longipennis* emerged earlier at increased temperatures (ambient +2.5°C and ambient +5°C) than at ambient temperature (McCauley *et al.* 2015). Moreover, a 6°C increase above ambient temperature shifted forward the onset of emergence by 28 days (Ritcher *et al.* 2008). However, the similar larval growth and emergence we observed between control temperature and +1.9°C of control temperature is not consistent with the observations of previous studies. It seemed that the temperature differential between the two treatments may not have substantially influenced larval growth.

Watering and midseason drainage were critical factors which determined seasonal changes in larval growth in rice fields. Water drainage disrupted the life cycle of *P. flavescens* larvae and re-watering induced commencement of new generations. Climate warming is expected to expand northern limits of rice double cropping and delay planting of rice (Yang *et al.* 2011; Hu *et al.* 2017). These results suggest that shifts in water management may alter seasonal development of larvae in regional scale. Temperature increase can directly promote dominance of *P. flavescens* because rice fields are dominated by species with short life cycles which are adapted to temporary flooded habitats (Heiss *et al.* 1986). *P. flavescens* is one of the major odonates species in rice fields (Salmah *et al.* 2017), and increased development rate of larvae may accelerate their colonization in aquatic ecosystem. In addition, temperature may alter their interactions with other aquatic taxa in different cultivation phases (Salmah *et al.* 2017).

Temperature is a critical abiotic factor which affects the ecophysiological performance of ectotherms (Angilletta 2002). Laboratory experiments have demonstrated that temperature has a direct effect on larval development rate of odonates (Krishnaraj and Pritchard 1995; Pritchard *et al.* 2000; Van Doorslaer and Stoks 2005). The results of our laboratory experiments are consistent with Inoue and Tani (2010) who observed a rapid development of eggs and larvae of *P. flavescens* in increased water temperatures in the laboratory. Suhling *et al.* (2004) also reported a constant and rapid growth rate of *P. flavescens* with an estimated duration of complete larval development at 33 days compared to *Orthetrum chrysostigma*, *Crocothemis erythraea* and *Trithemis kirbyi* with an estimated larval duration of 45, 56 and 58 days, respectively, in hot arid desert ponds in Namibia.

It is known that within the thermal range of an organism, increasing temperature increases the rate of development up to an optimum temperature, above which the rate decreases (Trudgill *et al.* 2005; Dixon *et al.* 2009; Dell *et al.* 2011). The temperature response curve from our experiment did not show a decline in growth rate at 35°C. However, Suhling *et al.* (2015) reported about 30°C as the optimum temperature for larval growth of four related dragonfly species; *Leucorrhinia pectoralis*, *L. rubicunda*, *Libellula depressa* and *L. quadrimaculata*. Most eggs of *P. flavescens* hatched in 5 days at high water temperatures of 30°C and 35°C (Ichikawa *et al.* 2016). This would suggest that the upper thermal limit for larval growth of *P. flavecens* could be above 35°C.

The laboratory experiments were conducted with only 4 replicates because of difficulty in collecting sufficient number of larvae. The small sample size can increase error in statistical analysis and make the results uncertain (Richards and Villet 2008; Lee *et al.* 2013). Hence, the results may have a limitation in showing actual response of larval growth to specific temperatures and could reflect only a trend in growth in response to temperature change.

In conclusion, the study showed that thermal conditions of an environment affect larval growth of *P. flavescens*. Also, the optimum temperature for larval growth and development of *P. flavescens* could be above 35°C. Therefore, it can be inferred that global warming will have a promotional effect on larval growth of *P. flavescens* in rice fields. The field survey results showed that temperature warming indirectly influences seasonal larval growth via altered water management and cropping system in rice fields. Further researches are warranted to investigate the effect of altered emergence time accompanied by climate warming on the function of adult dragonflies.

ACKNOWLEDGEMENTS

This study was carried out with the support of "Research Program for Agricultural Science & Technology Development (Project No. PJ01507301), National Institute of Agricultural Sciences, Rural Development Administration, Republic of Korea".

REFERENCES

Acquah-Lamptey D and R Brandl. 2018. Effect of dragonfly (*Bradinopyga strachani* Kirby) on the density of mosquito larvae in a field experiment using mesocosms. Web Ecol. 18:81–89.

Anderson RC. 2009. Do dragonflies migrate across the western Indian ocean? J. Trop. Ecol. 25:347–358.

Angilletta MJ, PH Niewiarowski and CA Navas. 2002. The evolution of thermal physiology in ectotherms. J. Therm. Biol. 27: 249–268.

Corbet PS. 2002. Stadia and growth ratios of Odonata: a review. Int. J. Odonatol. 5:45–73.

Corbet PS.1999. Dragonflies: Behaviour and Ecology of Odonata. Harley Books. Colchester, UK. p. 829.

Dell AI, S Pawar and VM Savage. 2011. Systematic variation in the temperature dependence of physiological and ecological traits. Proc. Natl. Acad. Sci. U.S.A. 108:10591–10596.

Dixon AFG, A Honěk, P Keil, MAA Kotela, AL Sizling and V Jarošik. 2009. Relationship between the minimum and maximum temperature thresholds for development in insects. Funct. Ecol. 23:257–264.

Doi H. 2008. Delayed phenological timing of dragonfly emergence in Japan over five decades. Biol. Lett. 4:388–391.

Elith J and JR Leathwick. 2009. Species distribution models: Ecological explanation and prediction across space and time. Annu. Rev. Ecol. Evol. Syst. 40:677–697.

Forest J and AJ Miller-Rushing. 2010. Toward a synthetic understanding of the role of phenology in the ecology and evolution. Philos. Trans. R. Soc. B-Biol. Sci. 365:3101–3112.

Heiss JS, GL Harp and MV Meisch. 1986. Aquatic Coleoptera associated with Arkansas rice, with observations on the effects of Carbofuran, Molinate, predatory fish and late-planting. Southwest. Nat. 31:521–525.

Hobson KA, RC Anderson, DX Soto and LI Wassenaar. 2012. Isotopic evidence that dragonflies (*Pantala flavescence*) migrating through the Maldives come from the northern Indian Subcontinent. PLoS One 7:e52594.

Hu X, Y Huang, W Sun and L Yu. 2017. Shifts in cultivar and planting date have regulated rice growth duration under climate warming in China since the early 1980s. Agi. For. Meteorol. 247:34–41.

Ichikawa Y, T Yokoi and M Watanabe. 2016. Thermal factors affecting egg development in the wandering glider dragonfly, *Pantala flavescens* (Odonata: Lebellulidae). App. Entomol. Zool. 52:89–95.

Inoue K and K Tani. 2010. All about Red Dragonflies. Tombow Publishing. Osaka, Japan.

IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of IPCC. Cambridge University Press. Cambridge, UK.

Jeon S, K Kim, SG Lee, YH Lee, SK Park, WS Kang, B Park and K Kim. 2019. Temperature-dependent developmental models and fertility life table of the potato aphid *Macrosiphum euphorbiae* Thomas on eggplant. Korean J. Environ. Biol. 37:568–578.

Krishnaraj R and G Pritchard. 1995. The influence of larval size, temperature, and components of the functional response to prey density on growth rates of the dragonflies *Lestes dis-*

junctus and *Coenagrion resolutum* (Insecta: Odonata). Can. J. Zool. 73:1672–1680.

Lee H, Y Kim and I Park. 2013. Calculation of sample size in clinical trials. Clin. Shoulder Elbow 16:53–57.

Mandal SK, A Ghosh, I Bhattacharjee and G Chandra. 2008. Biocontrol efficiency of odonate nymphs against larvae of mosquito, *Culex quinquefasciatus* Say. Acta Trop. 106:109–114.

May ML. 2013. A critical overview of progress in the studies of migration of dragonflies (Odonata: Anisoptera), with emphasis on North America. J. Insect Conserv. 17:1–15.

McCauley SJ, JI Hammond, DN Frances and KE Mabry. 2015. Effects of experimental warming on survival, phenology and morphology of an aquatic insect (Odonata). Ecol. Entomol. 40:211–220.

Neal TM and WH Whitcomb. 1972. Odonata in the Florida soybean agroecosystem. Fla. Entomol. 55:107–114.

Park J, Y Lee, D Kim and S Shin. 2020. Effects of temperature and salinity on egg development and larval settlement of an invasive ascidian species, *Herdmania momus* (Savigny, 1816). Korean J. Environ. Biol. 38:625–633.

Parmesan C. 2006. Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37:637–669.

Pritchard G, LD Harder, A Kortello and R Krishnaraj. 2000. The response of larval growth rate to temperature in three species of coenagrionid dragonflies with some comments on *Lestes disjunctus* (Odonata: Coenagrionidae). Int. J. Odonatol. 3:105–110.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Rebaudo F and B Regnier. 2021. devRate: Quantify the relationship between development rate and temperature in ectotherms. R package version 0.2.1.

Richards CS and MH Villet. 2008. Factors affecting accuracy and precision of thermal summation models of insect development used to estimate post-mortem intervals. Int. J. Legal Med. 122:401–408.

Richter O, F Suhling, O Müller and D Kern 2008. A model to predict dragonfly emergence pattern under climate change scenarios. Freshw. Biol. 53:1868–1880.

Russell RW, ML May, KL Soltesz and JW Fitzpatrick. 1998. Massive swarm migration of dragonflies (Odonata) in eastern North America. Am. Midl. Nat. 140:325–342.

Salmah MRC, AZ Siregar, AA Hassan and Z Nasution. 2017. Dynamics of aquatic organisms in a rice field ecosystem: effects of seasons and cultivation phases on abundance and predator-prey interactions. Trop. Ecol. 58:177–191.

Singh RK, RC Dhiman and SP Singh. 2003. Laboratory studies on the predatory potential of dragonfly nymphs on mosquito larvae. J. Commun. Dis. 35:96–101.

Suh AN and MJ Samways. 2001. Development of a dragonfly awareness trail in an African botanical garden. Biol. Conserv. 100:345–353.

Suhling F, I Suhling and O Richter. 2015. Temperature response of growth of larval dragonflies – an overview. Int. J. Odonatol. 18:15–30.

Suhling F, K Schenk, T Padeffke and A Martens. 2004. A field study of larval development in a dragonfly assemblage in African desert ponds (Odonata). Hydrobiologia 528:75–85.

Trudgill DL, A Honek, D Li and NM Van Straalen. 2005. Thermal time- Concepts and utility. Ann. Appl. Biol. 146:1–14.

Van Doorslaer W and R Stoks. 2005. Growth rate plasticity to temperature in two damselfly species differing in latitude: contributions of behaviour and physiology. Oikos 111:599–605.

Yamazaki M, Y Aiba, Y Hamada, N Yasuda, N Kimamoto, S Mizuno, T Momii, S Yoshida and M Kimura. 2003. Changes in the community structure of aquatic organisms after midseason drainage in the floodwater of Japanese paddy fields. Soil Sci. Plant Nutr. 49:125–135.

Yang X, Z Liu and F Chen. 2011. The possible effect of climate warming on northern limits of cropping system and crop yield in China. Agri. Sci. China 10:585–594.

Yasumatsu K, T Wongsiris, S Navavichit and C Tirawat. 1975. Approaches toward an integrated control of rice pests. Part I, Survey of natural enemies of important rice pests in Thailand. Plant Prot. Serv. Tech. Bull. 24:131–149.

Yoon S, M Kim, J Eo and Y Song. 2020. Temperature-dependent development models and phenology of *Hydrochara affinis*. Korean J. Environ. Biol. 38:222–230.