LIFE TABLE AND DEMOGRAPHIC PARAMETERS OF RICE LEAFFOLDER, *Cnaphalocrocis medinalis* GUENEE (LEPIDOPTERA: PYRALIDAE)

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ABSTRACT

Rice leaffolder, *Cnaphalocrocis medinalis* is important pest species and become a major threat to rice production in many Asian countries including Malaysia. A range of 30 to 80% of rice yield losses was assessed from severely damage fields under epidemic situation in India. *Cnaphalocrocis medinalis* has history of outbreak in Sekinchan, Selangor in early 1980's. Understanding the biology and factors that could be manipulated for its control are very limited. Life table and demographic parameters play important role in determining the key factors that responsible for the highest mortality within population. Therefore, the objective of our study was to construct life table and demographic parameters of *C. medinalis*. A survivorship and fecundity study of *C. medinalis* was conducted in laboratory (27.2±0.48 °C, 78.4±1.64% RH and 12:12h photoperiod) using three cohorts consisted of 102, 103 and 105 one-day old eggs. The survival and mortality of every life stage were observed and recorded daily. Nine pairs of one-day old *C. medinalis* adults were used in fecundity study. The laid eggs were observed daily and longevity of adults were recorded. Standard life table parameters and population age structures were calculated from daily records of survival, mortality and fecundity of each cohort. Two-sample t-test was performed in comparing of longevity between adult male and female. The highest mortality was recorded in first instar larvae (22.58%) with K-value of 0.125 indicated that this stage is the key factor in regulating *C. medinalis* population. A total of 32.26% individuals has successfully reached at adult stage with average sex ratio was 0.96:1.00 (Female: Male). The emergence of first female was on day 28 whilst the last female died on day 43. The earliest egg was laid on day 30 and continued until day 35 with maximum oviposition was on day 31 and 32 which constitute 57.04% of total eggs. The female lived for about 7.56±0.38 days with fecundity of 104.33±5.43 eggs. The intrinsic rate of natural increase (r_m) was 0.08 per female per day with mean generation time (T_c) of 31.56 days and doubling time (DT) of 8.19days. This shows that *C. medinalis* population has increased and build up rapidly in short time period. Our results suggested that the control program should be done during early stage of larvae in order to suppress the *C. medinalis* population effectively. Life table study of *C. medinalis* on other local rice varieties should be conducted in determining its survivorship and reproduction on other host varieties.

Keywords: Rice leaffolder; *Cnaphalocrocis medinalis*; life table; demographic parameters; intrinsic rate of natural increase

ABSTRAK

Pelipat daun padi, *Cnaphalocrocis medinalis* merupakan species perosak yang penting dan menjadi ancaman besar kepada pengeluaran padi di kebanyakan negara Asia termasuk Malaysia. Sebanyak 30 hingga 80% kehilangan hasil padi telah dinilai daripada sawah yang mengalami kerosakan yang teruk di India. *Cnaphalocrocis medinalis* mempunyai sejarah rebakan serangan di Sekinchan, Selangor pada awal 80an. Kefahaman terhadap biologi dan factor-faktor yang boleh dimanipulasi untuk kawalannya adalah sangat terhad. Jadual hidup dan parameter demografik memainkan peranan penting dalam menentukan faktor kunci yang mengalami kematian tertinggi dalam populasi. Oleh itu, objektif kajian kami adalah untuk membina jadual hidup dan parameter demografik *C. medinalis*. Satu kajian kemandirian dan fekunditi *C. medinalis* telah dijalankan di makmal (27.2±0.48 °C, 78.4±1.64% RH dan 12:12h fotoperiod) menggunakan tiga kohort terdiri daripada 102, 103 dan 105 telur berumur satu hari. Kemandirian dan kematian setiap peringkat hidup telah diperhatikan dan dicatat setiap hari. Sembilan pasangan individu dewasa *C. medinalis* berumur satu hari telah digunakan dalam kajian fekunditi. Telur terhasil telah diperhatikan setiap hari dan tempoh hayat dewasa telah dicatatkan. Parameter jadual hidup standard dan struktur umur populasi telah dikira daripada catatan harian kemandirian, kematian dan fekunditi setiap kohort. Analisis ujian t dua sampel telah dilakukan dalam membandingkan tempoh hayat antara dewasa jantan dan betina. Mortaliti tertinggi telah dicatatkan pada peringkat larva instar pertama (22.58%) dengan nilai K sebanyak 0.125 yang menunjukkan bahawa peringkat ini adalah faktor kunci dalam mengawal populasi *C. medinalis*. Sebanyak 32.26% individu berjaya mencapai peringkat dewasa dengan purata nisbah jantina adalah 0.96:1.00 (Betina: Jantan). Kemunculan betina dewasa pertama adalah pada hari ke 28 manakala betina dewasa terakhir mati pada hari ke 43. Telur terawal dihasilkan pada hari ke 30 dan berterusan sehingga hari ke 35 dengan penghasilan telur maksimum pada hari ke 31 dan 32 yang mana mewakili 57.04% daripada keseluruhan telur. Individu dewasa betina hidup selama 7.56±0.38 hari dengan fekunditinya 104.33±5.43 telur. Kadar pertumbuhan semulajadi intrinsik (r_m) adalah 0.08 bagi setiap betina setiap hari dengan purata masa generasi (T_c) selama 31.56 hari dan masa gandaan dua (DT) berlaku dalam 8.19 hari. Ini menunjukkan bahawa populasi *C. medinalis* meningkat dan berkembang secara pantas dalam tempoh yang singkat. Keputusan kami telah mencadangkan bahawa program kawalan harus dilakukan semasa peringkat awal larva dalam mengurangkan populasi *C. medinalis* dengan berkesan. Kajian jadual hidup *C. medinalis* ke atas varieti padi tempatan yang lain harus dijalankan dalam menentukan kemandirian dan pembiakannya ke atas varieti perumah yang lain.

Kata kunci: Pelipat daun padi; *Cnaphalocrocis medinalis*; jadual hidup; parameter demografi; kadar pertumbuhan semulajadi intrinsik

INTRODUCTION

Rice leaffolder, *Cnaphalocrocis medinalis* is an important rice pest and become a major threat to rice production in many Asian countries including China, Sri Lanka, Vietnam Pakistan, Japan, Korea, Malaysia and India (Padmavathi et al. 2017). A range of 30 to 80% of rice yield losses was assessed from severely damage fields under epidemic situation in India (Kushwaha 1988; Nanda & Bisoi 1990; Satish et al. 2007) while Shanmungam et al. (2006) have reported the losses amount of 11.18% in paddy crop. Pandya et al. (1987) have found rice yield decrease at 14% with every unit of infestation increase during summer season while 1.46% in wet season. *Cnaphalocrocis medinalis* has history of outbreak in Sekinchan, Selangor (Ooi & Yazid 1982) and considered as minor pest before evolving as major pest in late 1980's in many parts of the world including Malaysia due to increase in abundance (Hafeez et al. 2010). Although there has been no published data of *C. medinalis* infestation in rice fields and no record of its outbreak in Malaysia in the last 20 years but the risk of the outbreak is possible. It is due to its existence in local paddy fields (KADA 2011; Ooi 2015).

Several researches on population dynamics of *C. medinalis* and factors that affected the population have been conducted mostly in India and China. Padmavathi et al. (2008) have constructed life table of *C. medinalis* under natural field condition in India to assess the various mortality factors. Then, Padmavathi et al. (2013) and Manikandan et al. (2014) studied the thermal requirements for development in order to estimate temperature thresholds and effects of temperature on population dynamics. In China, the survivorship of *C. medinalis* was monitored when the larvae were reared on rice plants with different magnesium concentration (Xu et al. 2011) and on artificial diet (Xu et al. 2012).

Life table is a system that used by ecologists to monitor the population mortality at stage specific (Kakde et al. 2014). Life table and demographic parameters play important role in determining the key factors that responsible for the highest mortality within population (Kakde et al. 2014). Several analyses such as estimation of population extinction, population growth capacity and prediction of pest outbreak can be measured based on the demographic parameters (Amiri et al. 2010). Therefore, construction of life table contributes into understanding the population dynamics of insects which plays vital role in integrated pest management strategy (Southwood 1978).

However, the life table and demographic parameters of *C. medinalis* on local Malaysian rice variety have not been studied. Thus, a life table study of rice leaffolder, *C. medinalis* on rice variety MR220-CL2 was conducted under laboratory condition in order to construct life table and demographic parameters of the pest.

MATERIALS AND METHODS

Cultures and Rearing of *Cnaphalocrocis medinalis*

Larvae and pupae of *C. medinalis* were collected from rice fields in Tanjung Karang, Selangor and reared on Malaysian local rice variety, MR220-CL2. Larvae were transferred using camel hair brush onto 30-40 day old potted rice plants that were placed in rearing cage (35 x 56 x 56 cm). The rice plants were changed at two-day interval until all larvae entered pupal stage. Pupae were collected and placed in a petri dish padded with moistened tissue paper and placed in oviposition cage (35 x 56 x 56 cm) for adult emergence. The emerged adults were supplied with 15 to 20 day old potted rice plants ad libitum for female oviposition. As for adult food, three units of cotton wool balls that moistened with 20% honey solution were hanged upside down at the top using modified paper clip and safety pin. The cotton wools were replaced daily to avoid fungus growth. The laid eggs were observed daily on both upper and lower surface of leaf, leaf sheath and stem (Kumar Ankit et al. 2016). Plants with eggs were transferred into rearing cage for establishment of new colony. Eggs were not collected and removed from leaves in order to avoid any damage as they were very soft and fragile. They were reared until hatching and growing of first instar larvae. As they were very sensitive, these larvae were not removed from leaves to avoid any damage and interference during transfer process. Therefore, new potted plants were placed just next to old plants to ensure their leaves touching each other so that larvae could move to new plant by themselves. This process continued for the next larval stage. Larvae that has constructed leaf folds were transferred using a fine camel hair brush onto 30 - 40 day old potted plants until all larvae pupate. This process was repeated so as to maintain the leaf folder culture throughout the experimental period. Cultures were reared and maintained under laboratory condition with a temperature of 27.2±0.48 °C and 78.4±1.64 % humidity with 12:12h photoperiod. The techniques were adopted and modified from Manikandan et al. (2014).

Survivorship Study

Survivorship study of *C. medinalis* from egg to adult was conducted using three cohorts consisted of 102, 103 and 105 one-day old eggs. Due to non-uniformity of eggs laying, the eggs number were used was unequal but approximately 100 eggs per cohort. The eggs were laid singly or several units in a row. Rice leaves with eggs were cut and placed into plastic cup (7.5 cm height with 7.5 cm diameter) that padded with moistened tissue paper with approximately ten individuals per cup. After egg hatching, the newly hatched of first instar larvae were supplied with new rice leaves. Rice leaves and tissue paper were changed daily during counting process and supplied ad libitum until they moulted into pupa. The pupae were collected and transferred into petri dish padded with moistened tissue paper and placed in a cage (30 x 30 x 44 cm) supplied with adult food (20% honey solution). The survival and mortality of eggs, larvae, pupa and adults were observed and recorded daily.

Fecundity Study and Adult Longevity

A total of nine pairs of one-day old adult's *C. medinalis* was used with each pair was kept in a oviposition cage (30 x 30 x 44 cm) supplied with a 15–20 day old potted rice plant for egg laying and adult food. Eggs laid were observed daily using magnifying glass and Meiji Techno RZ stereo microscope (Meiji Techno, Japan). The rice plants with eggs were removed from cages to avoid counting overlap and new plants were supplied daily for oviposition. Eggs laid by each female were counted and recorded daily until the death of all individuals. The pre-oviposition and oviposition period, fecundity of females, and adult longevity for both males and females of *C. medinalis* were recorded.

Data Analysis

Two-sample t-test was performed using software Minitab version 16.0 in comparing of longevity between adult male and female. Standard life table parameters and population age structures were calculated from daily records of survival, mortality and fecundity of each cohort. The symbol, formula and definition of parameters were following the procedures outlined by Carey (1993) and Southwood (1978) as shown in Table 1.

Table 1. Definition and formula for life table and demographic parameters

Parameter	Definition	Formula
x	Age internal in days/developmental stage.	
l_x	Proportion of individuals surviving to start of the age interval. The number of individuals alive, during a given age interval class as a fraction.	
L_x	Number of individuals alive between age x and x+1	$(l_x + l_{x+1})/2$
d_x	Number of dying during age interval x	
100_{qx}	Percent apparent mortality	$(d_x/l_x)100$

S_x	Survival stage rate within stage	
T_x	Total number of living individuals at age x and beyond the age x	$L_x + L_{x+1} \ldots L_{x+n}$
e_x	Life expectancy for individuals of age x	T_x/l_x
m_x	Number of female eggs laid by average female at age x	
R_o	Net reproductive rate	$\sum l_x m_x$
T_c	Cohort generation time (in days)	$\sum x l_x m_x / \sum l_x m_x$
r_m	Intrinsic rate of natural increase	lnR_o/T_c
T	Corrected generation time	lnR_o/r_m
λ	Finite rate of increase, the number of female offsprings female-1 day-1	e^{rm}
DT	Doubling time, the number of days required by a population to double	$ln2/r_m$
GRR	Gross reproduction rate, theoretical natality rate during lifetime of organism	$\sum m_x$
Pre-oviposition period	Amount of time prior to eggs being laid	
Daily reproduction	Average number of eggs produced per day in terms of entire female lifespan	
Female longevity	Life-span of female	
Male longevity	Life-span of male	

RESULTS AND DISCUSSION

Age-specific Life Table for *C. medinalis*

The survivorships of three cohorts of *C. medinalis* reared on rice plants are shown in Figure 1. Cohort 1 recorded the egg hatchability of 89.2% with 32.3% out of total individuals had successfully survived until adult. First adult female emerged on day 28, whilst the last adult female died on day 41. The highest mortality occurred in first instar of larval stage (23.5%) and gradually decreased throughout the life span of population. In cohort 2, a total of 91.2% of eggs has successfully hatched with 30.1% out of total individuals had successfully survived until adult. First adult female emerged on day 28, whilst the last adult female died on day 43. Similar to cohort 1, first instar larvae (22.3%) recorded the highest mortalities compared to other stages. A similar pattern of mortalities also was recorded in cohort 3 in which first instar larvae (21.90%) recorded the highest mortalities. Egg hatchability in cohort 3 was 89.5% with the total individuals successfully survived until adult was 34.2%. The first adult female emerged on day 28, whilst the last adult female died on day 40.

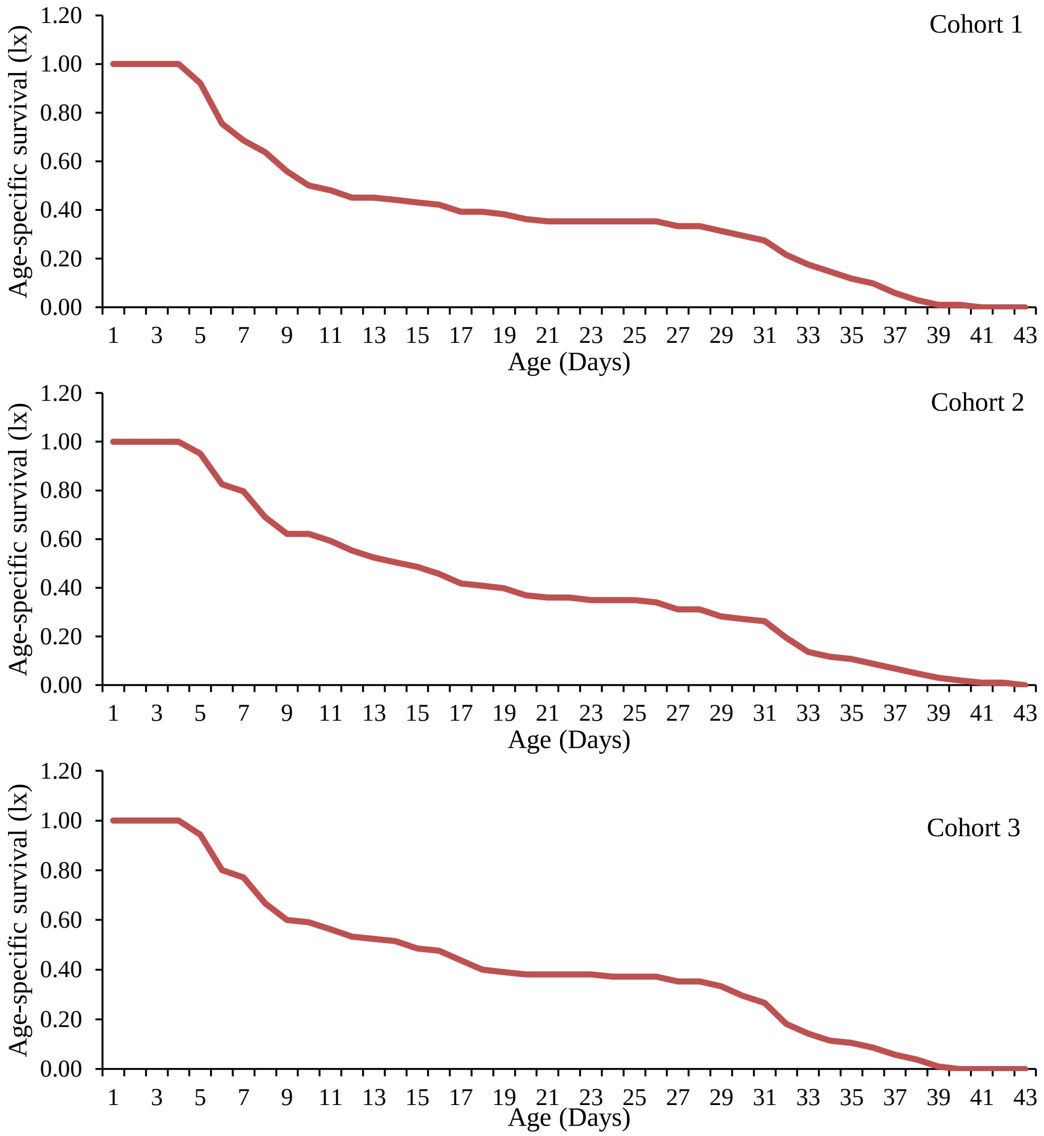

Figure 1. Survivorship curves of three cohorts of *C. medinalis* reared on rice plant

The survivorship pattern of *C. medinalis* was observed to follow type III survivorship curve based on classification made by Schowalter (2016). The curve depicts a population with high mortality occurred in early stages compared to later stages with lower mortality rate and keep decreasing until all individuals died (Schowalter 2016). As stated before, the highest mortality in present study was recorded in first larval instar stage which indicates that early stages were much delicate compared to later stages. It might be contributed by lacking in physical strength to fold rice leaves and also the ability to find the young leaves or shoots (Punithavalli et al. 2013). It is because the newly hatch larvae have to establish feeding site and dealing with rice plant structures such as leaf hairs, surface waxes, leaf thickness, trichome, and glands or tissues filled with allelochemicals (Punithavalli et al. 2014). Due to that reason, they generally become selective as they will settle and establish a feeding site on suitable leaf but they will continue their exploration if the leaf is unsuitable which could cause the death (Zhang et al. 2019).

Table 2 shows the pooled life table of *C. medinalis* for three cohorts. A total of 32.26% individuals had successfully reached at adult stage with 0.96:1.00 (Female: Male) mean sex ratio. Results revealed that the first instar larvae recorded highest mortality (22.58%) with K-value of 0.125 followed by second instar (10.65%) with K-value of 0.075, egg stage (10.00%; K-value =0.046), third instar (8.71%; K-value =0.072), fourth instar (7.10%; K-value =0.069), prepupa and pupa (4.52%; K-value =0.057) and the lowest mortality was recorded in fifth instar larva (4.19%; K-value =0.047). High K-value indicates high mortality rate in that particular stage. It is because K-value was computed as difference between successive values for log "l_x" (Kakde et al. 2014). K-value was defined as the key factor which responsible for increase and decrease of population size (Ali & Rizvi 2010). Therefore, it can be suggested that second instar larva is the ideal stage to be treated with control method in order to suppress the *C. medinalis* population effectively.

Table 2. Stage-specific pooled life table of *C. medinalis*

Stage (x)	l_x	L_x	d_x	100_{qx}	S_x	T_x	e_x	K-value
Eggs	310	294.50	31	10.00	90.00	1309.00	4.44	0.046
Larval								
First instar	279	244.00	70	25.09	74.91	1014.50	4.16	0.125
Second instar	209	192.50	33	15.79	84.21	770.50	4.00	0.075
Third instar	176	162.50	27	15.34	84.66	578.00	3.56	0.072
Fourth instar	149	138.00	22	14.77	85.23	415.50	3.01	0.069
Fifth instar	127	120.50	13	10.24	89.76	277.50	2.30	0.047
Prepupa, Pupa	114	107.00	14	12.28	87.72	157.00	1.47	0.057
Adults	100	50.00						

*Adult sex ratio (Female: Male) = 0.96:1.00

x=developmental stage in days, l_x=proportion of number entering stage, d_x=number of dying in stage x, L_x=number alive between age x and x+1, 100_{qx}=percent apparent mortality, S_x=survival rate within stage, T_x=total number of age x beyond the age, e_x=life expectancy

Age-specific Fecundity Table for *C. medinalis*

Age-specific survivorship (l_x) and fecundity (m_x) of *C. medinalis* are shown in Figure 2. The emergence of first female was on day 28, whilst, the last female died was on day 43. The earliest egg laid was on day 30 which was two days after first female emerged. The oviposition had been continued until day 35 with maximum oviposition was on day 31 and 32 which constituted 57.04% of total eggs laid. The lowest oviposition was recorded on day 35 with value of 2.65%. It indicates the female laid the maximum number of eggs in earlier days of oviposition while much lesser number of eggs were laid in later days of oviposition period which seem to be similar with result of Zhang et al. (2019). Maximum oviposition was recorded on second and third day of oviposition period and then followed by a gradual decline towards the last day of oviposition. This phenomenon also occurred in diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) which reared on brassicaceous host plants (Golizadeh et al. 2009).

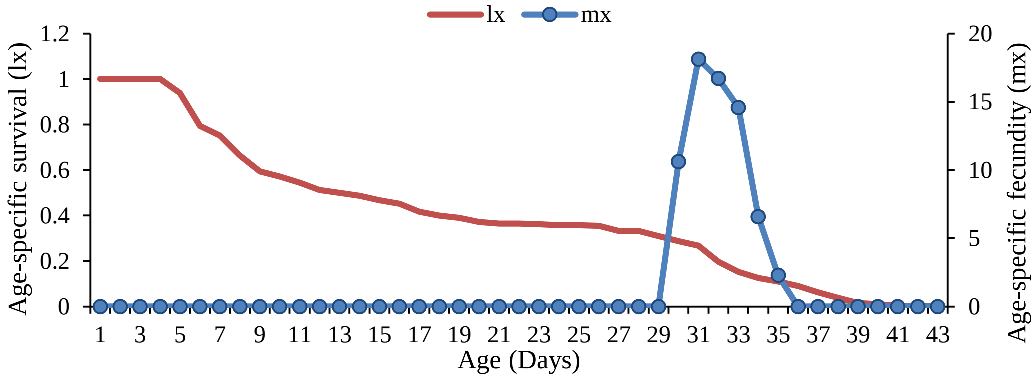

Figure 2. Daily age-specific survival (l_x) and fecundity (m_x) of female *C. medinalis*

Pre-oviposition and oviposition period was recorded at 2.89±0.26 and 4.33±0.17 days, respectively (Table 3). Adult longevity revealed the significant difference (T=8.93; df=1, 16; P<0.05) between male and female. Longevity of adult male (3.56±0.35 days) was shorter than female (7.56±0.38 days). Similar trend was reported by Kumar Ankit et al. (2016) with value of 3.4±0.06 days (male) and 8.7±0.05 (female). The recorded daily eggs was 23.44±5.14 eggs with female fecundity of 104.33±5.43 eggs ranged from 90 to 139 eggs. The number of eggs deposited per surviving individual was varied and ranged from the lowest value of 2.29 and the highest value of 18.12. The recorded female fecundity is within ranges that reported by Gangwar (2015) (135 to 175 eggs) and Kumar Ankit et al. (2016) (74 to 141 eggs) with fecundity of 100.6±8.6 eggs. The reproduction of *C. medinalis* including pre-oviposition and oviposition period, female longevity and fecundity was related to flight activity, migration and ovarian development (Shirai 2006; Sun et al. 2013; Zhang et al. 2015).

Table 3. Oviposition period, adult longevity and fecundity of *C. medinalis*

Parameter	Mean ± SE
Pre-ovipositional period (days)	2.89 ± 0.26
Ovipositional period (days)	4.33 ± 0.17
Male longevity (days)	3.56 ± 0.35a
Female longevity (days)	7.56 ± 0.38b
Daily eggs (eggs/day)	23.44 ± 5.14
Fecundity (eggs/female)	104.33 ± 5.43

Means with different letters within column were significantly different at P=0.05

The population and reproductive parameters of *C. medinalis* was summarized in Table 4. The intrinsic rate of natural increase (r_m) was 0.08 per female per day and the net reproductive rate (R_o) was 14.48 which indicated the population had increased because the value was above 0 and 1, respectively (Manikandan et al. 2014). The daily finite rate of increase (λ) was 1.09 for female offsprings per female per day with mean generation time (T_c) of 31.56 days. The population had doubled up in 8.19 days.

Table 4. Population growth parameters of *C. medinalis*

Parameter	Formula	Values
Gross reproduction rate (GRR)	$\sum m_x$	68.90
Net reproduction rate (R_o)	$\sum l_x m_x$	14.48
Mean generation time (T_c), in days	$\sum x l_x m_x / \sum l_x m_x$	31.56
Intrinsic rate of natural increase (r_m)	lnR_o/T_c	0.08
Finite rate of increase (λ)	e^{rm}	1.09
Doubling time (DT), in days	$ln2/r_m$	8.19

However, the values of the parameters in this study were lower as compared to values reported earlier by Padmavathi et al. (2008) with r_m value of 0.183 and λ value of 1.2008, Xu et al. (2012) (r_m=0.1057, R_o=18.4537, λ=1.1115, T_c=27.5793, DT=6.5572), Manikandan et al. (2014) with r= 0.09016, R_o=26.19, λ=1.09435, T_c=36.22, DT=7.69, and Zhang et al. (2019) with r_m, R_o and T_c values of 0.1100±0.0032, 39.349 and 28.733, respectively. Kocourek et al. (1994) stated that the r_m is a reflective of many factors such as fecundity, survival and generation time which adequately summarizes the physiological qualities of an animal in relation to its capacity to increase. In the same time, the R_o value is a reflection of r_m value (Golizadeh et al. 2009). Therefore, the difference of the population growth parameters of *C. medinalis* between this study and previous studies was contributed by differences in reproduction of population. Southwood and Henderson (2000) had stated that r_m would be a most appropriate index in evaluating insect performance towards different factors and variables.

CONCLUSIONS

In conclusion, survivorship curve pattern of *C. medinalis* population fall into type III curve as mortality rate was higher in early stages and lower in later stages. The first instar larvae recorded the highest K-value and can be concluded as the key factor in regulating *C. medinalis* population. Population growth of *C. medinalis* was rapid and has built up in short time period as the intrinsic rate of natural increase (r_m) was 0.08, net reproduction rate (R_o) of 14.48 and doubling time of 8.19 days. Our results suggested that the control program should be done during early stage of larvae in order to suppress the *C. medinalis* population effectively. Life table study of *C. medinalis* on other local rice varieties that planted by most farmers in Malaysia should be conducted. It is to gain knowledge regarding survivorship and reproduction of *C. medinalis* on other host varieties.

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REFERENCES

Ali, A. & Rizvi, P.Q. 2010. Age and stage specific life table of *Coocinella septemounctata* (Coleoptera: Coccinellidae) at varying temperature. *World Journal of Agricultural Sciences* 6(3): 268-273.

Amiri, A., Talebi, A.A., Zamani, A.A. & Kamali, K. 2010. Effect of temperature on demographic parameters of the hawthorn red midget moth, *Phyllonorycter corylifoliella*, on apple. *Journal of Insect Science* 10(134): 1-12.

Carey, J.R. 1993. *Applied Demography for Biologist with Special Emphasis on Insects*. New York: Oxford University Press.

Gangwar, R.K. 2015. Life cycle and abundance of rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) - A review. *Journal of Natural Sciences Research* 5(15): 103-105.

Golizadeh, A., Kamali, K., Fathipour, Y. & Abbasipour, H. 2009. Effect of temperature on life table parameters of *Plutella xylostella* (Lepidoptera: Plutellidae) on two brassicaceous host plants. *Journal of Asia-Pacific Entomology* 12(4): 207-212.

Hafeez, A., Khan, R.B., Sharma, D., Jamwal, V.V.S. & Gupta, S. 2010. Seasonal incidence, infestation and trap catch of *Cnaphalocrocis medinalis* (Guenee) in rice. *Annals of Plant Protection Science* 8(2): 38-383.

Kakde, A.M., Patel, K.G. & Tayade, S. 2014. Role of life table in insect pest management--A review. *IOSR Journal of Agriculture and Veterinary Science* 7(1): 40-43.

Kemubu Agricultural Development Authority (KADA). 2011. *Buku Panduan Pengurusan Perosak, Penyakit & Rumpai Padi Mengikut Pengalaman Ladang Merdeka KADA*. Kota Bharu: KADA.

Kocourek, F., Havelka, J., Berankova, J. & Jarosik, V. 1994. Effect of temperature on development rate and intrinsic rate of increase of *Aphis gossypii* reared on greenhouse cucumber. *Entomologia Experimentalis et Applicata* 71(1): 59-64.

Kumar Ankit, Maan, S., Ram, S. & Banvir, S. 2016. Life cycle of rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) on rice cultivar HKR-47. *International Journal of Agriculture Sciences* 8(52): 2488-2490.

Kushwaha, K.S. 1988. Leaffolder (LF) epidemic in Haryana (India). *International Rice Research Newsletter* 13(3): 16-17.

Manikandan, N., John, S.K. & Geethalakshmi, V. 2014. Life history and population dynamics of rice leaffolder at different temperatures. *The Ecoscan* 8(3&4); 315-320.

Nanda, V.K. & Bisoi, R.C. 1990. Bionomics of rice leaf folder, *Cnaphalocrocis medinalis*. *Orissa Journal of Agricultural Research*, 3(2): 130-135.

Ooi, P.A.C. & Yazid, M.E. 1982. An outbreak of the rice leaffolder in Sekinchan, Selangor. *MAPPS Newsletter* 6(3): 5-6.

Ooi, P.A.C. 2015. Common insect pests of rice and their natural biological control: An illustrated guide to the insect pests that feed on rice plants and the organisms that feed on and control those pests. *UTAR Agriculture Science Journal* 1(1): 49-59.

Padmavathi, C., Katti, G., Padmakumari, A.P. & Pasalu, I.C. 2008. Mortality and fertility life tables of leaf folder *Cnaphalocrocis medinalis* Guenee (Lepidoptera: Pyralidae) in rice. *Entomon* 33: 1-13.

Padmavathi, C., Katti, G., Sailaja, V., Padmakumari, A.P., Jhansilakshmi, V., Prabhakar, M. & Prasad, Y.G. 2013. Temperature thresholds and thermal requirements for the development of the rice leaf folder, *Cnaphalocrocis medinalis. Journal of Insect Science* 13(96): 1-14.

Padmavathi, C., Javvaji, S. & Gururaj, K. 2017. A rapid field screening method for evaluation of resistance to leaffolder, *Cnaphalocrocis medinalis* Guenee in rice. *Journal of Rice Research* 10(1): 67-70.

Pandya, H.V., Shah, A.H. & Purohit, M.S. 1987. Yield loss caused by leaf folder damage alone and combined with yellow stem borer damage. *International Rice Research Newsletter* 12: 28.

Punithavalli, M., Muthukrishnan, N.M. & Rajkumar, M.B. 2013. Influence of rice genotypes on folding and spinning behaviour of leaffolder (*Cnaphalocrocis medinalis*) and its interaction with leaf damage. *Rice Science* 20(6): 442-450.

Punithavalli, M., Muthukrishnan, N.M. & Rajkumar, M.B. 2014. Impact of rice genotypes on the developmental characteristics of rice leaf folder, *Cnaphalocrocis medinalis*. *Indian Journal of Plant Protection* 42(1): 38-43.

Satish, D., Chander, S. & Reji, G. 2007. Simulation of economic injury levels for leaf folder *Cnaphalocrocis medinalis* (Guenee) on rice (*Oryza sativa* L.). *Journal of Scientific and Industrial Research* 66: 905-911.

Schowalter, T.D. 2016. *Insect Ecology: An Ecosystem Approach (Fourth Edition)*. UK: Elsevier.

Shanmungam, T.R., Sendhil, R. & Thirumalvalavan, V.V. 2006. Quantification and prioritization of constrainst causing yield loss in rice (*Oryza sativa*) in India. *Agricultura Tropica et Subtropica* 39: 194-201.

Shirai, Y. 2006. Flight activity, reproduction, and adult nutrition of the beet webworm, *Spoladea recurvalis* Fabricius (Lepidoptera: Pyralidae). *Applied Entomology and Zoology* 41: 405-414.

Southwood, T.R.E. 1978. *Ecological methods with particular reference to the study of insect populations* (2nd Edition). London: Chapman and Hall.

Southwood, T.R.E. and Henderson, P.A. 2000. *Ecological Methods* (3rd Edition). Oxford: Blackwell Science.

Sun, B.B., Jiang, X.F., Zhang, L., Stanley, D.W., Luo, L.Z. & Long, W. 2013. Methoprene influences reproduction and flight capacity in adults of the rice leaf roller, *Cnaphalocrocis medinalis* (Guenee) (Lepidoptera: Pyralidae). *Archieves of Insect Biochemistry and Physiology* 82: 1-13.

Xu, J., Jiang, L.B., & Wu, J.C. 2011. Changes in the survival rate and fecundity of the rice leaffolder, *Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae), at different magnesium concentrations in hydroponic culture. *Crop Protection* 30: 765-769.

Xu, J., Li, C.M., Yang, Y.J., Qi, J.H., Zheng, X.S., Hu, R.L., Lu, Z.X. & Liu, Q. 2012. Growth and reproduction of artificially fed *Cnaphalocrocis medinalis*. *Rice Science* 19(3): 247-251.

Zhang, L., Pan, P., Sappington, T.W., Lu, W., Luo, L. & Jiang, X. 2015. Accelerated and synchronized oviposition induced by flight of young females may intensify larval outbreaks of the rice leaf roller. *PLoS ONE* 10(3): 1-13.

Zhang, F.X., Zhang, Z.F., Zhang, Y. & Wu, W.J. 2019. Adult oviposition preferences and larval performance of rice leaf folder, *Cnaphalocrocis medinalis* on rice and non-rice graminaceous plants. *Arthropod-Plant Interactions* 13(1): 31-40.