



Comparison of growth parameters of the predator, *Chrysoperla nipponensis*-B (Neuroptera: Chrysopidae) reared on a diet of eggs of *Corcyra cephalonica* (Lepidoptera: Pyralidae) and an artificial diet containing ginger

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Abstract. The growth parameters of the green lacewing, *Chrysoperla nipponensis*-B (Okamoto), were studied under laboratory conditions. The highest mortality was recorded in the immature stages (instars 1st, 2nd, 3rd and pupae) of *C. nipponensis* fed on the eggs of *Corcyra cephalonica* (37.26%). The sex ratios (proportion of female to male) when reared on the eggs of *C. cephalonica* and an artificial diet with ginger were 0.93 : 1.00 and 0.87 : 1.00, respectively. The maximum life spans of females reared on the eggs of *C. cephalonica* and an artificial diet with ginger were 63 and 64 days, respectively. The females reared on the eggs of *C. cephalonica* produced the highest number of eggs (10.4) on the fifth day of oviposition, whereas on the artificial diet with ginger it was 9.26 on the eighth day of oviposition. The net reproductive rate (R₀) and maximum gross reproductive rate (GRR) of *C. nipponensis* fed on the eggs of *C. cephalonica* were 69.50 and 223.10 females per female per generation, respectively, whereas for the artificial diet with ginger they were 117.24 and 236.89 females per female per generation, respectively. Mean generation time (T) was 37.06 and 48.16 for the eggs of *C. cephalonica* and artificial diet with ginger, respectively. The intrinsic rate of natural increase (r) was 0.11 and 0.09 females per female per day for the eggs of *C. cephalonica* and artificial diet with ginger, respectively. The finite rate of increase (λ) was 1.12 and 1.11 females per female per day for the eggs of *C. cephalonica* and artificial diet with ginger, respectively. The population doubling time (DT) was 6.05 days on the diet of eggs of *C. cephalonica* and 7.00 on the artificial diet with ginger.

INTRODUCTION

Green lacewings are important predatory biological control agents that can be used in biological control programs (Gautam, 1994; Venkatsan et al., 2008). *Chrysoperla* (*carnea*-group) and *Mallada desjardinsi* (Navas) are well recognized and widely distributed green lacewing species in India, Europe, USSR, North America, South America and Central Africa. The green lacewings, *Chrysoperla* spp. (Neuroptera: Chrysopidae) are cosmopolitan predators that occur in a wide range of agricultural habitats. The larvae of *Chrysoperla* spp. are voracious and efficient biological control agents of various phytophagous arthropods such as aphids, caterpillars, leafhoppers, whiteflies, thrips and insect eggs (McEwen et al., 2001; Carrillo & Elanov, 2004). It is estimated that up to one third of the successful biological insect pest control programs are attributed to the

introduction of *Chrysoperla carnea* (Williamson & Smith, 1994). *Chrysoperla* spp. are easily mass reared in the laboratory on their natural prey for augmentative use against many insect pests (Syed et al., 2008). However, continuous maintenance of host populations for the mass rearing of *Chrysoperla* spp. is very difficult and expensive, which necessitates the development of alternative methods for their mass production. Many artificial diets have been evaluated for rearing *Chrysoperla* spp. with varying success (Vanderzant, 1969; Yazlovetsky, 1992; Cohen & Smith, 1998; Zhang et al., 2004). These artificial diets mostly contain beef, hen eggs, yeast, honey, sucrose, vitamins, minerals, propionate, potassium sorbate, streptomycin sulfate and chlortetracycline, and most are costly (Yazlovetsky, 1992; Cohen & Smith, 1998; Sattar et al., 2007). This resulted in the development of a cost effective artificial diet for

the mass rearing of *Chrysoperla nipponensis*-B, which includes ginger.

There are several studies on the life table parameters of *Chrysoperla* spp. reared on natural prey as life tables are one of the most important tools in entomological research (Win et al., 2009). Cohort life table provide a comprehensive description of the survivorship, development and reproduction of a population, which are fundamental factors in both theoretical and applied population ecology (Taghizadeh et al., 2008). Moreover, there are no comparative life table studies of *C. nipponensis* reared on different diets in Malaysia. Therefore, this study was conducted to determine the growth parameters of *C. nipponensis* reared on the eggs of *Corcyra cephalonica* and an artificial diet that included ginger, with the view of improving the mass and quality production of *C. nipponensis* for use against insect pests.

MATERIALS AND METHODS

Rearing of *C. nipponensis* on the eggs of *Corcyra cephalonica*

Chrysoperla nipponensis adults were reared in rectangular cages 37 × 28 × 22 cm in size. Adults were supplied with an artificial standard diet consisting of yeast, sugar, honey, casein and distilled water. Wet cotton was provided in glass vials as a source of water. For the oviposition of females, a black organza cloth was placed on top of the cage and the eggs deposited on this cloth were removed daily. The larvae from the eggs were then reared on the eggs of *Corcyra cephalonica*. The eggs of *C. cephalonica* were spread on a sterilized mixture of maize, rice, wheat and semolina (1 : 1 : 1 : 1) on which they developed up to the adult stage and were then collected for mating in a plastic cage. The eggs laid by these adults were then collected and killed by placing them in a freezer before being used to rear *C. nipponensis* larvae.

Composition of the artificial diet for larvae

The artificial diet for the larvae consisted of 100 g ground beef (with 25% fat), 100 g ground beef liver, 15 g sucrose, 100 g hen eggs, 10 ml distilled water, 20 g honey (5 g dissolved in 15 ml of water), 14 g brewer's yeast, 5 ml acetic acid, 0.5 g potassium sorbate, 0.5g ginger and 5 ml vitamin solution. All the ingredients used were weighed carefully using a Digital Analytical Balance (Sartorius, BT-224S, Germany). The ground beef and ground beef liver were cut into small pieces using a knife and were kept in a refrigerator for 24 h. The mixture of meat, honey, water, ginger and brewer's yeast were blended in a food processor (Panasonic, MK-5087M, Japan). In a beaker, 20 ml of water was heated to 80 to 90°C on a hot plate (IKA-COMBIMAG RCT 31197, China) and 15 g sucrose, 5 ml of acetic acid and potassium sorbate were added and stirred using a magnetic stirrer. Then, 100 g of blended eggs were added. All ingredients were blended (BRAUN, ZK-200, Germany) for 5 to 6 min until the entire mixture had a stringy paste-like consistency. The diet was then fed to the larvae in trays that are used in ELISA tests.

Life table experiments

The life table of *C. nipponensis* was constructed using data obtained when the larvae were fed *C. cephalonica* eggs and the above artificial diet at 25 ± 2°C, 55–85% RH and a 12L:12D photoperiod. Three separate groups of 148 (cohort 1), 123 (cohort 2) and 106 (cohort 3) freshly laid eggs of *C. nipponensis*, were used to construct life tables for individuals reared on these two diets. The eggs were placed individually in the cells of ELISA

trays to prevent cannibalism. The larvae of the different cohorts of eggs were fed either frozen eggs of *C. cephalonica* or the artificial diet with ginger. The diets were changed every two days, when 1.5 g of both diets were provided. Daily records of the survival and development of the larvae were kept until the adults emerged. After the emergence of the adults, they were transferred to an oviposition cage and provided with a standard adult diet. The fecundity and mortality were recorded daily until the last adult died. Construction of the life table was done following the procedures described by Birch (1948) and Southwood (1978).

The life table and fecundity schedule were constructed using the following parameters:

Life table

X: The pivotal age for the age class in units of time (days).

lx: The number of surviving individuals at the beginning of age class x.

Lx: The number of individuals alive between age class x and x+1.

Tx: Total number of individuals beyond age class x.

dx: The number of individual dying during age interval x.

ex: The expectation of life remaining for individuals of age class x.

RM%: Percentage of real mortality calculated based on the population density at the beginning of the generation.

RM = (dx/lo) 100.

IM%: Indispensable (irreplaceable) mortality, which is the portion of generation mortality that would not occur if the apparent mortality (qx) of an age interval was removed from the life system. It is assumed that the subsequent mortality factors will destroy the same percentage of the population independent of any change in population density.

Fecundity schedule

X: The pivotal age for the age class in units of time (days).

lx: The number of females surviving at the beginning of age class x (given as a fraction of 1.0).

mx: The number of female eggs laid by age class x.

lxmx: Total number of female eggs laid by age class x.

Ro: Net reproductive rate. It is equal to the sum of lxmx or Ro = Σ lxmx.

T: Cohort generation time (in days), approximated by T = Σ Xlxmx/Σlxmx.

r: Innate capacity for increase, calculated using $rc = \ln Ro/Tc$.

rm: The maximum population growth, the innate capacity for increase, calculated by iteration of Euler's equation, Σe-r.x lxmx.

λ: Finite rate of increase, number of female offspring per female per day, calculated using, $\lambda = er$.

DT: Doubling time, the number of days required by a population to double, calculated using, $DT = \ln 2/r$.

b: Intrinsic birth rate, $1/\Sigma e^{-r.x}lx$.

d: Intrinsic death rate, $b - rm$.

GRR: Gross reproduction rate calculated using Σmx.

The population parameters of the life and fecundity tables were constructed separately for *C. nipponensis* reared on both diets based on 3 cohorts for each diet. Moreover, comparison between life parameters of *C. nipponensis* reared on the diet with ginger and the eggs of *C. cephalonica* were statistically compared using Student t-test and presented as Mean ± SE.

RESULTS AND DISCUSSION

Age-specific survival life table

Fig. 1 shows the patterns in survivorship curves (lx) for six cohorts of *C. nipponensis* reared on eggs of *C. cepha-*

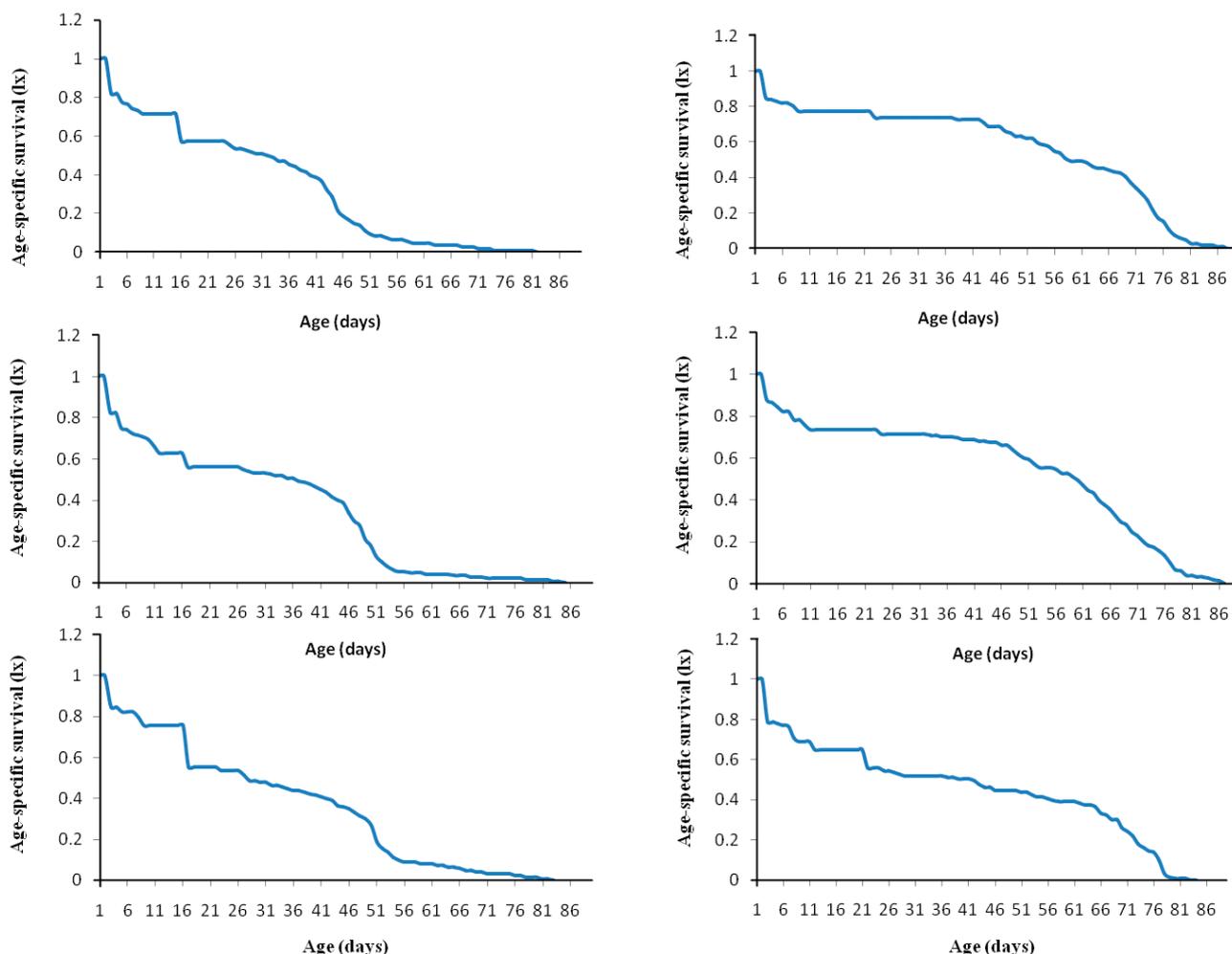


Fig. 1. The survivorship curves (l_x) of *C. nipponensis* reared on the eggs of *C. cephalonica* (left) and an artificial diet with ginger (right).

lonica and an artificial diet with ginger. Fig. 1 indicates that during the life span of the predator, there was a high mortality of those reared on the eggs of *C. cephalonica* during the egg, 2nd instar larval and pupal stages. However, those reared on the artificial diet with ginger suffered a high mortality during the egg, 1st instar larval and pupal stages. Green lacewings are highly sensitive to changes in temperature and water availability, which affects the growth and survival of these predators (Schowalter, 2006). The first emergence of adults reared on eggs of *C. cephalonica* and artificial diets with ginger occurred on day 21, 22 and 22, and day 26, 24 and 24 for cohorts 1, 2, and 3, respectively. The maximum life span of *C. nipponensis* reared on

artificial diet with ginger and eggs of *C. cephalonica* were recorded at 88 and 85 days, respectively. The survivorship curves are of type III based on the classification of Pearl (1928), Speight et al. (1999) and Schowalter (2006).

Mortality of immature stages of *C. nipponensis*

The age specific mortality of the immature stages of *C. nipponensis*, reared on eggs of *C. cephalonica* and the artificial diet with ginger is shown in Table 1. All larvae underwent three larval molts before transforming into pupae. The highest mortality of *C. nipponensis* reared on both diets were recorded in the pupal (19.08 and 6.64, respectively) followed by 2nd instar larval stage (7.39 and 3.89,

Table 1. Life table of green lacewing *C. nipponensis* reared on an artificial diet with ginger (Art. diet) and on the eggs of *C. cephalonica* (Nat. diet).

Age (days)	l_x		L_x		d_x		$100q_x$		S_x		T_x		e_x		K-value	
	Art. diet	Nat. diet														
Eggs	377	377	347.00	347.00	60	60	15.92	15.92	84.08	84.08	1,773.00	1,715.00	5.11	4.94	0.08	0.08
Instar 1	317	317	300.00	300.50	34	33	10.73	10.41	89.27	89.59	1,396.00	1,338.00	4.65	4.45	0.05	0.05
Instar 2	283	284	277.50	273.50	11	21	3.89	7.39	96.11	92.61	1,079.00	1,021.00	3.89	3.73	0.02	0.03
Instar 3	272	263	265.33	245.67	1	1	0.37	0.38	99.63	99.62	796.00	737.00	3.00	3.00	0.00	0.00
Pupa	271	262	262.00	237.00	18	50	6.64	19.08	93.36	80.92	524.00	474.00	2.00	2.00	0.03	0.09
Adult	253	212	126.50	106.00	253	212										

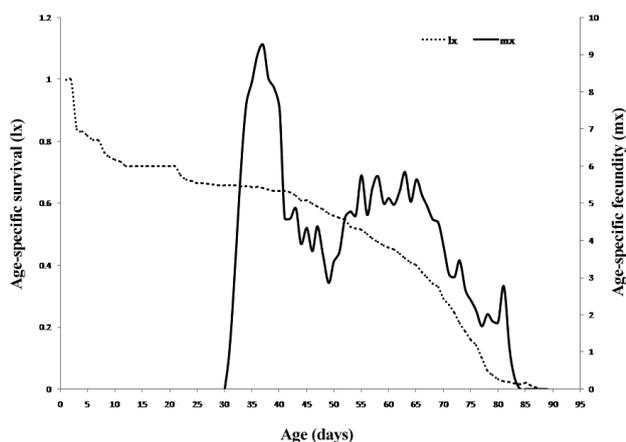


Fig. 2. Life and age-specific fecundity of *C. nipponensis* reared on the artificial diet with ginger.

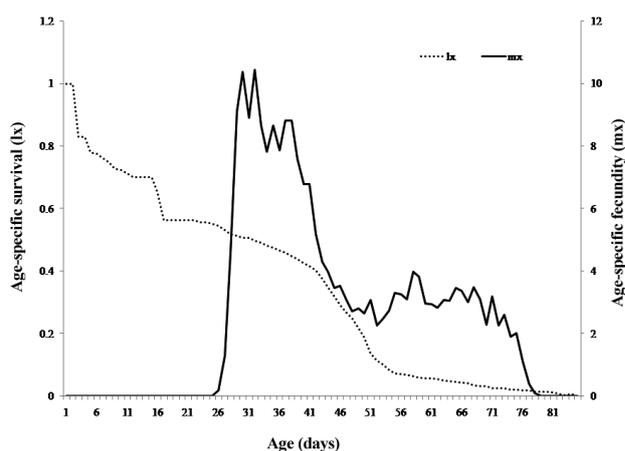


Fig. 3. Life and age-specific fecundity of *C. nipponensis* reared on the eggs of *C. cephalonica*.

respectively). Overall, the total mortality in the immature stages (1st, 2nd, 3rd and pupae) of *C. nipponensis* reared on eggs of *C. cephalonica* was 37.26%, which is higher than that recorded on the artificial diet with ginger (21.62%). The total number of adults that emerged from the artificial diet with ginger was higher (118 females : 134 males) than emerged from those reared on eggs of *C. cephalonica* (103 females : 109 males). The female to male sex ratio recorded for the artificial diet with ginger was 0.87 : 1.00 and that for those reared on eggs of *C. cephalonica* was 0.93 : 1.00. Studies on another lacewing species, *Mallada bioninensis* (Okamoto) also indicate a significant effect of diet on the mortality of the different stages (Shivankar & Singh, 1998; Nehrae et al., 2004; Elsiddig et al., 2006). The high mortality of the immature stages of various species of lacewings is also reported by Alasady et al. (2010) for *Apertochrysa* sp. and Gautam et al. (2009) for *Chrysoperla* sp. and *Mallada desjardinsi* (Navas).

Age-specific fertility schedule

Age-specific survivorship (l_x) and fecundity (m_x) of *C. nipponensis* are shown in Figs 2 and 3. For those reared on the artificial diet with ginger and eggs of *C. cephalonica*, the first adult female emerged on day 25 and 21, whereas, the death of last female reared on artificial diet with ginger and eggs of *C. cephalonica* was recorded on day 88 and 85, respectively. The maximum life span of females

reared on eggs of *C. cephalonica* and an artificial diet with ginger were 63 and 64 days, respectively that is similar to that reported in several previous studies, which show that the longevity of lacewings depends on the food available to the adults and the diet the larval stages were fed on (Joshi & Yadav, 1990; Nehrae et al., 2004; Senthil Kumar & Gautam, 2007). Females reared on the artificial diet with ginger started egg laying on day 30, or 5 days after emergence, whereas those reared on eggs of *C. cephalonica*, started laying eggs on day 26, or 5 days after emergence. The highest number of eggs produced per female reared on the artificial diet with ginger was 9.26 on the fourth day of oviposition, whereas on the eggs of *C. cephalonica*, it was 10.4 on the fifth day of oviposition. Insect fecundity and life span are both influenced by the quality of the food (Siswanto et al., 2008).

Table 2 summarizes the population and reproductive parameters of *C. nipponensis*. Maximum mean generation time (T) of the individuals reared on the artificial diet with ginger was 42.19 ± 0.12 days compared to the 37.06 ± 0.15 days for those reared on eggs of *C. cephalonica*. The intrinsic rate of natural increase (r) recorded for those reared on the artificial diet with ginger was 0.11 ± 0.01 and on the eggs of *C. cephalonica* (natural) 0.12 ± 0.01 females per female per day. Jervis et al. (2005) also report that prey species can influence the intrinsic rate of natural

Table 2. Population and reproductive parameters of *C. nipponensis* reared on the eggs of *C. cephalonica* (natural diet) and the artificial diet with ginger (artificial diet) (Mean \pm S.E).

No.	Parameters	Formula	Values	
			Artificial diet (n = 118)	Natural diet (n = 101)
1	Approximate generation time (T_c), (days)	$\sum l_x m_x x / \sum l_x m_x$	48.16 \pm 0.15a	37.06 \pm 0.15b
2	Corrected generation time (T), (days)	$\ln Ro / r_m$	42.19 \pm 0.12a	37.06 \pm 0.15b
3	Innate capacity for increase (r_c)	$\ln Ro / T_c$	0.09 \pm 0.01b	0.11 \pm 0.01a
4	Intrinsic rate of increase (r_m)	$\sum e^{-r_m x} l_x m_x = 1$	0.11 \pm 0.01a	0.12 \pm 0.01a
5	Finite rate of increase (λ)	e^r	1.11 \pm 0.02a	1.12 \pm 0.02a
6	Doubling time (DT), (days)	$\ln 2 / r$	7.00 \pm 0.03a	6.05 \pm 0.02b
7	Gross reproduction rate	$\sum m_x$	236.89 \pm 1.53a	223.1 \pm 1.41b
8	Net reproduction rate (Ro)	$\sum l_x m_x$	117.24 \pm 0.90a	69.5 \pm 0.82b

Means followed by same letters within rows are not significantly different (P > 0.05).

increase of predators. The finite rates of increase (λ) for those reared on the artificial diet with ginger and eggs of *C. cephalonica* were 1.11 ± 0.02 and 1.12 ± 0.02 females per female per day, respectively. These results are in accordance with Jokar et al. (2012) who record a finite rate of increase (λ) of 1.17 ± 0.001 and 1.20 ± 0.002 for *C. carnea* fed on *Anagasta kuehniella* and a semi-artificial diet, respectively. The doubling time (DT) of the predator reared on the eggs of *C. cephalonica* was 6.05 ± 0.02 days, which is less than when reared on the artificial diet with ginger (7.00 ± 0.03 days). Studies show that r , T , and DT are useful indices of population growth of insects under a given set of conditions (Siswanto et al., 2008). Moreover, *C. nipponensis* reared on the eggs of *C. cephalonica* had a lower reproductive performance than those reared on the artificial diet with ginger. The superior performance of the *C. nipponensis* reared on the artificial diet with ginger in terms of several biological parameters may be due to the addition of ginger that not only enhances its active predatory period but also its searching and killing abilities. Natural alternatives to antibiotics, such as ginger, has attracted attention due to its wide range of potential beneficial effects (Manesh et al., 2012). Ginger is used in the preparation of food to impart flavour, colour and food preservation, and also enhances palatability (Polasa & Nirmala, 2003). The net reproductive rate (R_0) was higher on the artificial diet with ginger (117.24 ± 0.90 females per female per generation) than on the eggs of *C. cephalonica* (69.50 ± 0.82 females per female per generation). The maximum gross reproductive rate (GRR) was 236.89 ± 1.53 and 223.10 ± 1.4 females per female per generation for those reared on the artificial diet with ginger and eggs of *C. cephalonica*, respectively. The results are similar to those of Jokar & Zarabi (2012) who record a GRR of 225.5 ± 3.45 and 267.8 ± 4.8 for *C. carnea* fed *A. kuehniella* and a semi artificial diet, respectively.

CONCLUSIONS

This life table study indicates that the survivorship curves of *C. nipponensis* fed on both the eggs of *C. cephalonica* and an artificial diet with ginger is of type III, which is commonly found in insects. The highest mortality of *C. nipponensis* was recorded in the immature stages (1st, 2nd, 3rd and pupae), which are the weakest stages in its life cycle. Rearing *C. nipponensis* on an artificial diet with ginger resulted in the largest number of individuals reaching the adult stage. Higher survival and reproductive potential were recorded for *C. nipponensis* reared on the artificial diet with ginger than on the eggs of *C. cephalonica*. Population parameters (GRR, R_0 , and T) were also higher on the artificial diet ginger except for the finite rate of increase that was same on both diets. The doubling time (DT) was one day longer on the artificial diet with ginger than on the eggs of *C. cephalonica*. Thus an artificial diet with ginger is more suitable for the mass rearing of *C. nipponensis* than the eggs of *C. cephalonica*, and has an additional advantage of an increased shelf life due to the inclusion of ginger in the diet.

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