Journal of Applied and Natural Science
17(2), 460 - 471 (2025)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Feeding and growth pattern of rice moth *Corcyra cephalonica* (Stainton) on different diets

Reem Mohammad*
Department of Entomology, Institute of Agricultural Sciences (IAS), SOADU, Bhubaneswar-751029 (Odisha), India
Braja Kishore Sahoo
Department of Entomology, Institute of Agricultural Sciences (IAS), SOADU, Bhubaneswar-751029 (Odisha), India
Subhalaxmi Roy
Department of Entomology, Institute of Agricultural Sciences (IAS), SOADU, Bhubaneswar-751029 (Odisha), India
Rajasekhara Rao Korada
Division of Crop Management, ICAR-Central Tobacco Research Institute, Rajahmundry (Andhra Pradesh), India

*Corresponding author. E-mail: reemabdullatifmoh1994@gmail.com

Article Info
https://doi.org/10.31018/jans.v17i2.6225
Received: October 01, 2024
Revised: April 26, 2025
Accepted: May 03, 2025

How to Cite
Mohammad, R. *et al.* (2025). Feeding and growth pattern of rice moth *Corcyra cephalonica* (Stainton) on different diets. *Journal of Applied and Natural Science*, 17(2), 460 - 471. https://doi.org/10.31018/jans.v17i2.6225

Abstract
Food is a decisive factor affecting the insects' biological parameters and physiological functions, including the rice moth *Corcyra cephalonica* (Stainton). Seeds' physical and biochemical properties influence the insect's feeding behaviour and the decisions it makes during its development. The present study aimed to investigate the relationship between the diet and the growth of the rice moth. Four different seeds: rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.) were used in the experiments as diets for *C. cephalonica* larvae to investigate their properties' impact on the biological parameters (durations and dimensions of egg, larval instars, pupa and adults, weights of the full-grown larva, pupa and adults, and female fecundity) of the insect. The results confirmed that seeds' physical and biochemical properties significantly affect the rice moth's fitness. Groundnut and maize seeds were superior in almost all the parameters studied, followed by wheat to a lesser degree, while rice came last. The total life cycle was 106.66, 81.37, 76.63 and 68.64 days for rice, wheat, groundnut and maize, respectively. The eggs took between 5.03 to 5.59 days to hatch. Total larval period ranged between 48.62 days in groundnut and 82.83 days in rice. Similarly, pupal period was maximum in rice (10.4 days) and minimum in groundnut (7.4 days). Male longevity was insignificant among treatments, ranging between 8.2 to 10.48 days, while female longevity ranged from 5.44 to 6.82 days. So, the present study could conclude that groundnut and maize were the most suitable hosts for rice moth growth.

Keywords: Biological parameters, *Corcyra cephalonica,* Rice moth, Seed characteristics, Stored seeds

INTRODUCTION

Food is considered one of the decisive factors affecting the insect's growth and development, and many studies have confirmed this by reviewing the effect of various sources and levels of nutrition on the insect's growth rate, size and weight, and many other biological parameters (Shah, 2017). Since feeding is a continuous activity during most of the organism's life and has a strong influence on most of the insect's other vital processes, investigating the nutritional basis of the decisions made by the insect will help to explain why the insect makes these decisions, and thus explain many vital aspects related to nutrition and growth of the insect (Kraus *et al*., 2022). Protein, carbohydrates, lipids and other minerals and vitamins are considered, within certain ratios, very necessary for the optimal growth of the insect. Carbohydrates are very important for energy and interfere with the synthesis of fats and glycogen. Protein has a crucial role in the process of morphogenesis, in enzyme synthesis and egg production. Lipids are essential cell wall components for reproduction, neurotransmission, and synthesis of some hormones. Minerals are important in hardening the cuticle of mandibles in many insects, e.g. Fe, Zn, Mn etc. (Liu *et al*., 2017; Bala *et al*., 2018). Therefore, each feeding pattern is linked to a growth pattern resulting primarily from the interaction of the insect with the food provided to it.

Stored products in the storage are highly susceptible to a wide range of insect pests, many of them destructive. The rice moth *Corcyra cephalonica* (Stainton) is one of these pests, resulting in great damage to a large number of stored items. The life history of the rice moth has been investigated on many diets and foodstuff, and this has given a clear idea about the nutritional requirements and preferences of this insect (Menge *et al*., 2016; Arun Kumar *et al*., 2018). These biological data provide us with valuable knowledge about the most preferred host, which could be used impressively in the mass rearing of this insect used effectively as a host or prey for the breading of several natural enemies and related studies (Manjunath, 2014; Chaudhuri and Senapati, 2017). Also, the worth of documentation of the biological parameters of the insect pest comes from needing them usefully in predicting the insect population dynamics in the different foodstuff. Therefore, to get precious knowledge regarding infection development and the possibility of managing a specific case, which control method is preferred? And, at which stage? (Rossini *et al*., 2021).

Virtually several criteria are there interfering with the insect's biological parameters in the storage, such as the conditions related to the surrounding atmosphere (temperature, relative humidity, etc.), the stored product (Species and variety, physical and biochemical characteristics, etc.) and the insect itself (feeding habits, nutritional requirements, etc.) (House, 1969). Several studies, conducted under different levels of these norms have reported various values of the rice moth biological parameters, while keeping these values within fairly close logical limits (Devi *et al*., 2013; Bhardwaj *et al*., 2017; Jhala *et al*., 2019; Bankapur *et al*., 2022; Ramanaji *et al*., 2020; Singh, 2022; Kaur *et al*., 2023). Under a specific set of conditions, the present study discusses the biological parameters of the rice moth from the side of the seed properties, regarding how the food will affect the growth of the rice moth?; which seed characteristics are involved in the acceptance of the insect to the specific seeds (resistance or susceptibility)? And then, which decisions the insect will make?

MATERIALS AND METHODS

Tested seeds

The experiment was conducted at the Institute of Agricultural Sciences (IAS), Siksha 'O' Anusandhan Deemed to be University (SOADU), Bhubaneswar, Odisha, India. Four different seeds; T_1- rice (*Oryza sativa* L.), T_2- wheat (*Triticum aestivum* L.), T_3- maize (*Zea mays* L.) and T_4- groundnut (*Arachis hypogaea* L.) were used in the experiments as diets for *C. cephalonica* larvae. The seeds were obtained from a local convenience store in Bhubaneswar. All the seeds were free of pesticides and sterilized in the oven at 100 °C for one hour. The tested groundnut seeds were raw, and the rice was polished (the rice that has been milled to remove the germ, husk, bran, and various amounts of nutrients, leaving behind a grain high in starch). The food was introduced as half-broken seeds to make it easier for young larvae to feed on.

Rearing insect

The adults of *C. cephalonica* were obtained from the Laboratory of Biological Control at the Institute of Agricultural Sciences (IAS), Siksha 'O' Anusandhan Deemed to be University (SOADU), Bhubaneswar, Odisha, India. About 30 pairs of rice moth adults were released into an oviposition cage supplied with pieces of cotton saturated with a sugar solution (1 honey: 1 water) for feeding adults. The eggs were collected a day later and used in the experiment. The experiment was conducted following the method of Menge *et al*. (2018) with suitable modifications.

Life history parameters

The study on the feeding and growth pattern of *C. cephalonica* was carried out in petri dishes, as an experimental unit, starting from the eggs. In each dish, 100 one day old- eggs were added with 5 gm of broken seeds. The early larval instars were tiny, and their food consumption was very low, so 5 gm seeds were enough for these instars. Additional amounts were added while the larvae grew when needed. The dishes were put in the incubator at 31°C and 75±5% R.H. till the end of the experiment. Daily monitoring was done to determine the time of moulting and the duration of each instar and each stage. The dimensions (length and width) of the insect's different stages (eggs, larval instars, pupae and adults) were measured under a stereoscope with the help of mill-metric paper. An electric balance was used to measure the weight of the full-grown larvae, the pupae, and the adults. To evaluate female fecundity, one new emerging pair was placed in a small oviposition cage, and the eggs were collected and counted daily till the death of the female. The longevity of the males and the females also was recorded. To evaluate incubation period, 100 newly laid eggs were put in a petri dish and monitored daily to record the number of hatches per day.

Statistical analysis

The Completely Randomized Design (CRD) was applied to the experiment, which included 4 treatments with 5 replicates for each one. ANOVA test was used for data analysis and the Duncan method was used for Post Hoc analysis using SPSS software. All charts were created using Microsoft Excel software. Bars holding the same letters within the specific parameter are significantly indifferent (p >0.05). NS indicates that there are no significant differences between the treatments.

RESULTS

Details of the life cycle stages

Eggs

After the adults emerged, the males and females mated and the female started to lay eggs one day after emergence, singly in batches (Fig. 1 a). The first batch of eggs was the highest in number, and then, it became less gradual till the ovipositing stopped on day 4^{th}-5^{th}. And then, the female died (lived for 4-6 days on average), while the male kept alive more (8-13 days on average). The female in this study laid a large number of eggs during her life (300-600 eggs). The eggs hatched within 4-5 days of laying at 31°C. It was observed that the female could lay unfertile eggs without mating, and they did not hatch. The eggs were oval with a prominent bump at one of its poles. When laid, the eggs were bright, and the colour was light creamy to white (Fig. 1 b), which gradually changed to light yellow when ripe (Fig. 1 c). The eggshell seemed to be granular to reticulate. Upon laying, the egg appeared dense in texture and became less dense as hatching approached, where, the first instar larva could be seen, with its brown head capsule in a U-shape inside the egg wrapped around itself (Fig. 1 c).

Larval stage

Seven larval instars were observed (Fig. 2.). The first larval instars were small, with a creamy-white colour, glossy and slightly transparent body. The head capsule and the tregum of the prothorax were brown. Before moulting, it was possible to notice the approaching moulting by comparing the size of the head capsule diameter with the size of the body diameter. When the diameter of the body became larger than the diameter of the head, this indicated that the larva was about to moult to the next instar. Another point that was, before moulting, the larval feeding and movement activities decreased, and the larva settled under a silken net (mixed with some fraises and feeding residue) that it weaved around itself until its moulting, after which it exited and resumed activity and feeding again, leaving the exuviae and the head capsule that may sometimes remain stuck under the net. The newly moulted larva was characterized by the new head capsule and the first thorax being transparent at first, after which the chitin began to harden and acquire a brown colour after contact with air. The size of the head capsule was larger than the size of the body diameter, and it was also larger and shinier than that of the previous instar. Body spines also were more prominent and visible in the newly moulted larvae. It was noticed that the larvae that will develop to produce males complete the larval period earlier than those that will develop to produce females, and then the males emerge earlier than the females. Also, the weight and dimensions of the full-grown larvae were less in those who will produce males.

Pupal stage

Before pupation, the larva stopped moving and feeding and began to weave a network of dense and solid white threads (Fig. 3 a), where it spent the pre-pupal stage, which was prolonged for one day. The larva shrunk and became shorter and thicker. After pupation, the exuvea and the head capsule of the last larval instar were observed inside the silken cocoon. Directly after pupation, the pupa was of a creamy colour, and became light brown, then darker with time, with black eye spots and burrs (Fig. 3 b, c, d). The weight of the pupa varied between the new- and the old-aged pupae, as the weight decreased with the approaching of the adults' emergence. Same for the larva, the weight and dimensions of the pupae which will produce females were more than those producing males.

Adults

At the end of the pupation period, the adult's body details became a little more visible under the pupal skin. After emergence, the adults were attracted to each

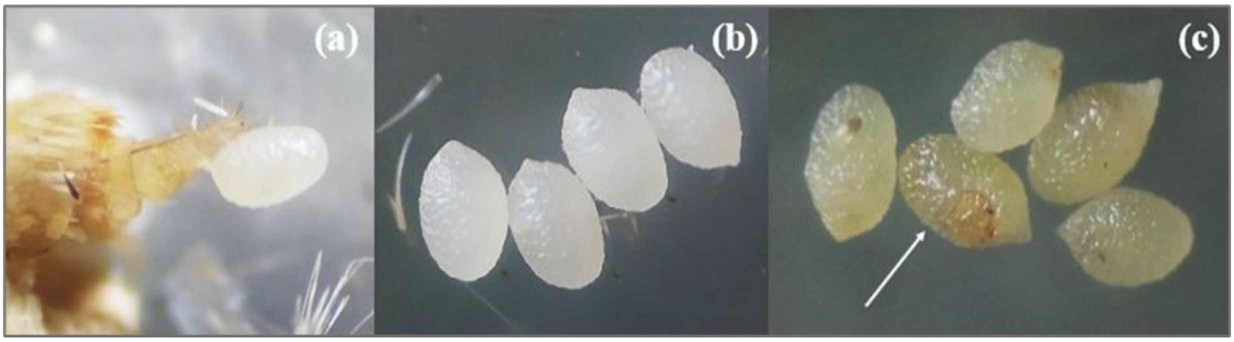

Fig. 1. *Eggs of Corcyra cephalonica; (a) Oviposition: Egg laying through the ovipositor (b) Newly- laid eggs (c) Eggs before hatching; the larva could be seen inside the egg under the egg shell (near the borrow) (Magnification: 4X)*

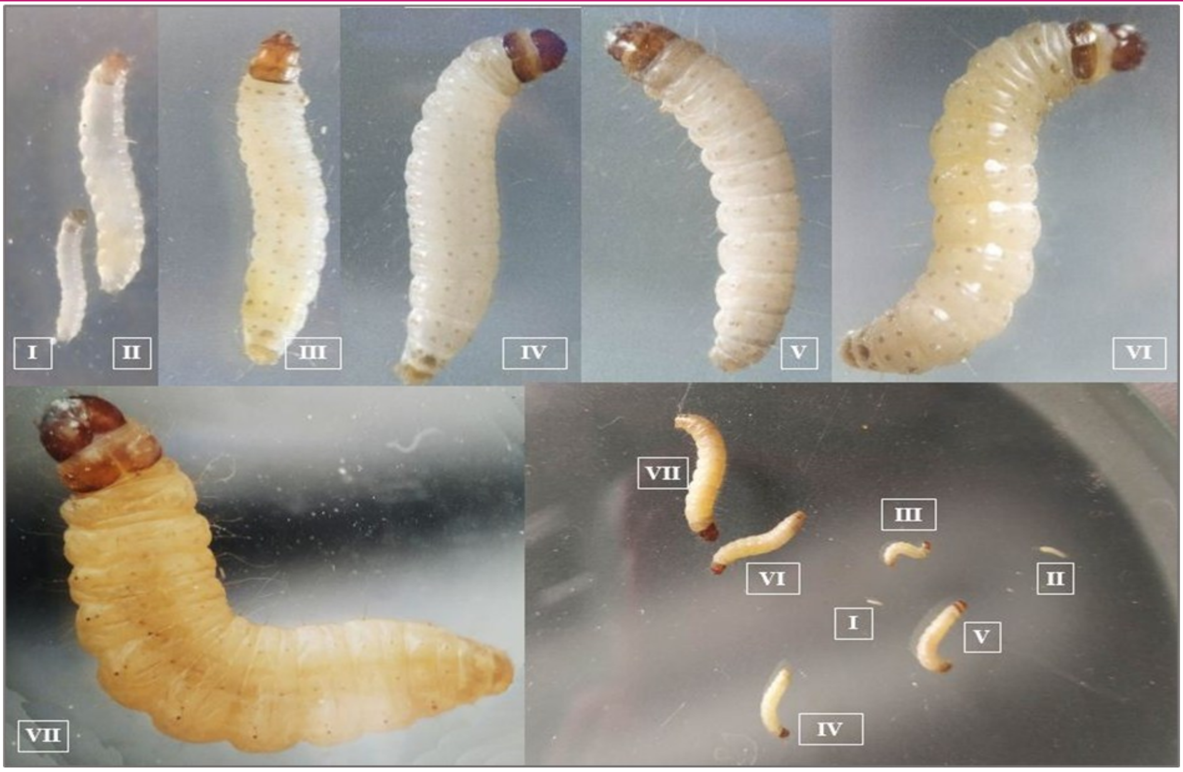

Fig. 2. *Larval instars of Corcyra cephalonica; I- First instar, II- Second instar, III- Third instar, IV- Forth instar, V- Fifth instar, VI- Sixth instar and VII- Seventh instar (Magnification: 4X for (I and II) and 2X for (III, IV, V, VI and VII))*

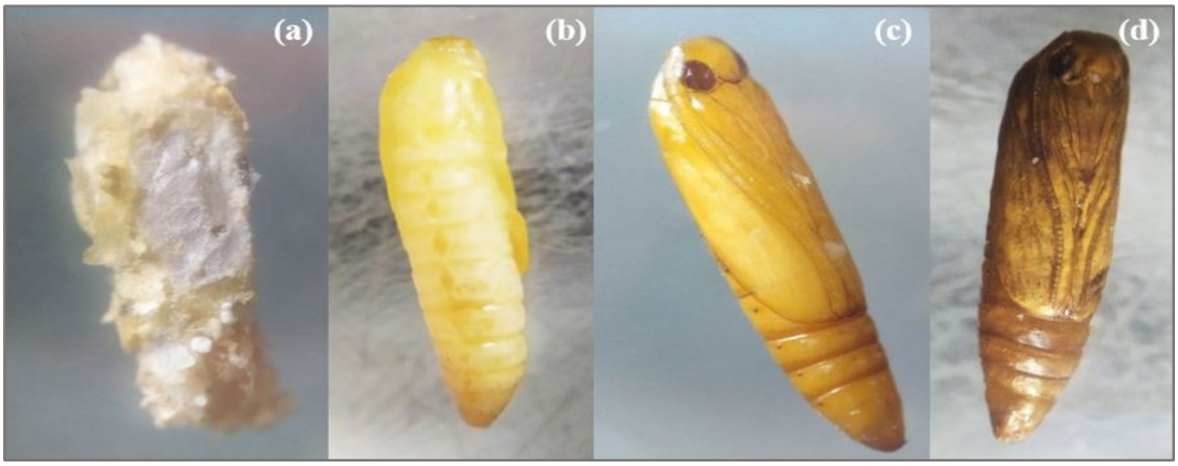

Fig. 3. *Pupal stage of Corcyra cephalonica; (a) The silken cocoon surrounding the pupa (b) The new pupa having the creamy colour (c) The pupa after the hardening of the cuticle with the light brown colour (d) The pupa before emerging of the adults having the dark colour and the adult features (Magnification: 2X)*

other and mated. The males were smaller than the females. The adult gender could be distinguished, mainly, by notifying the labial palps, which were tall and conspicuous in females while very short and inconspicuous in males, which could be observed easily (Fig. 4 c, e). Also, if possible, by checking the end of the abdomen, in females, the ovipositor was present (Fig. 4 b, f), while in males, the forceps (cerci) were there (Fig. 4 a, d).

Duration of the life cycle stages

The observations recorded on durations of the life cycle stages are presented in Fig. 5. It was noticed that the eggs laid by females emerged from wheat and maize cultures took 5.03 and 5.04 days to hatch, respectively, which were the shortest incubation periods, followed by groundnut (5.33 days) and then rice (5.59 days). The total larval period varied significantly among the four diets. It took 82.83 days for the larvae feeding on rice to complete the larval stage. Meanwhile, larval development proceeded faster for larvae feeding on wheat, maize, and groundnut, recording 60.32, 54.17, and 48.62 days, respectively. Similarly, pupae on rice needed 10.4 days, in average, to complete the pupal development. This was followed by wheat (9.2 days) and maize (8.8 days), and then groundnut having the shortest pupal period (7.4 days), where the adults emerging

Table 1. Dimensions of *Corcyra cephalonica* different stages on different seeds

	T_1-Rice Mean±SD	T_2-Wheat Mean±SD	T_3-Maize Mean±SD	T_4-Groundnut Mean±SD
Egg length (mm) NS	0.61±0.055	0.64±0.050	0.67±0.057	0.63±0.023
Egg width (mm)	0.39±0.053 ab	0.40±0.032 ab	0.44±0.025 b	0.37±0.015 a
1st instar larval length (mm)	1.38±0.08 a	1.51±0.14 ab	1.60±0.083 b	1.64±0.076 b
2nd instar larval length (mm)	2.04±0.097 a	2.18±0.138 a	2.60±0.1 b	2.75±0.173 b
3rd instar larval length (mm)	2.62±0.036 a	3.24±0.180 b	3.61±0.409 c	4.42±0.294 d
4th instar larval length (mm)	3.77±0.29 a	4.69±0.36 b	5.03±0.52 bc	5.35±0.38 c
5th instar larval length (mm)	5.43±0.48 a	7.21±0.43 b	7.41±0.54 b	7.86±0.46 b
6th instar larval length (mm)	7.44±0.22 a	8.80±0.86 b	9.62±1.2 b	9.86±0.5 b
7th instar larval length (mm)	12.58±1.21 a	15.42±0.44 b	18.04±1.04 c	18.26±1.28 c
1st instar larval width (mm)	0.20±0.013 a	0.22±0.026 ab	0.24±0.018 b	0.25±0.011 b
2nd instar larval width (mm)	0.32±0.019 a	0.34±0.024 a	0.42±0.018 b	0.44±0.033 b
3rd instar larval width (mm)	0.47±0.029 a	0.61±0.064 b	0.69±0.099 b	0.85±0.036 c
4th instar larval width (mm)	0.67±0.065 a	0.89±0.089 b	0.93±0.069 b	1.00±0.107 b
5th instar larval width (mm)	0.86±0.015 a	1.13±0.086 b	1.19±0.133 bc	1.28±0.060 c
6th instar larval width (mm)	1.29±0.13 a	1.58±0.26 b	1.74±0.21 bc	1.85±0.1 c
7th instar larval width (mm)	2.26±0.28 a	3.01±0.14 b	3.51±0.2 c	3.57±0.26 c
Pupa length (mm) NS	7.27±0.87	7.88±0.98	8.80±1.24	8.39±1.30
Pupa width (mm) NS	1.93±0.28	2.14±0.45	2.31±0.48	2.29±0.46
Male length (mm) NS	7.43±0.37	7.74±1.2	8.15±0.66	7.50±1.08
Female length (mm)	8.38±1.02 a	9.28±0.74 ab	9.99±1.37 b	9.40±1.17 ab
Male width (mm) NS	17.09±0.6	17.83±1.55	18.28±2.01	17.91±2.16
Female width (mm)	19.45±1.83 a	22.14±1.1 b	22.84±1.1 b	22.47±1.43 b

was the faster. There were no significant differences in male longevity among the four diets arranged between 8.20 and 10.40 days. Meanwhile, the female longevity was the shortest in wheat (5.44 days), followed by groundnut (5.69 days) and rice (5.72 days), and longest in maize (6.82 days). Consequently, there was high variation in the total life span. The life cycle of rice moth needed 106.66 days to be completed when the insect was reared on rice; this was the longest developmental period among the studied diets. On the other hand, it took the least number of days to complete the moth's life cycle in groundnut (68.64 days). The life cycle durations in maize (76.63 days) and wheat (81.37 days) were also short compared to rice and at the same time, longer than that recorded in groundnut.

Duration of the larval instars

Seven larval instars of different durations of rice moth were distinguished in each of the studied crops, as illustrated in Fig. 6. For the four diets, the same tendency was observed in the developmental periods of the larval instars. The larval development accelerated from the first to the third instar, the shortest, and then began to slow down to record the longest period in the last larval instar. Larval development in rice took the longest periods, for all instars, compared to other crops, followed by wheat, which recorded developmental periods slightly similar to those in maize and groundnut. The first instar extended between 4.98 to 6.38 days. Other instars ranged between 3.58- 5.5, 3.09- 4.41, 3.44- 4.91, 6.86- 8.10, 10.71- 21.34 and 15.64- 32.19 days for second, third, fourth, fifth, sixth and seventh, respectively.

Dimensions of the rice moth stages

Dimensions (length and width) of each stage of the rice moth are presented in Table 1. There were no remarkable differences in egg length among the four groups arranged between 0.61- 0.67 mm. Otherwise, the egg width was a little bit disparate, with a distinct variation between the maximum width in maize (0.44 mm) and the minimum width in groundnut (0.37 mm).

By feeding on various diets, the lengths and widths of the larval instars were disparate. Nearly a comparable trend was observed in larval dimensions among the tested crops for the seven instars, where larvae feeding on rice were the smallest, followed by wheat, maize, and groundnut. Almost in the early instars (1st and 2nd), T_1 and T_2 had approximate length and width. In the subsequent instars, larvae in T_2 were distinctly bigger. For T_3 and T_4, these dimensions were almost equal in all instars. Sometimes, in T_2 and T_3, larvae reached a similar size. Recorded length and width ranged between (1.38- 1.64 mm) and (0.20- 0.25 mm), (2.04- 2.75 mm) and (0.32- 0.44 mm), (2.62- 4.42 mm) and (0.47- 0.85 mm), (3.77- 5.35 mm) and (0.76- 1.00 mm),

Fig. 4. *Adults of C. cephalonica; (a) Ventral and dorsal side of the male (b) Ventral and dorsal side of the female (c) Unconspicuous labial palps in male (d) Cerci (Forceps) at the end of the male abdomen (e) Conspicuous labial palps (f) Ovipositor at the end of the female abdomen. Red circles indicates the position of the labial palps and the external genitalia in both genders which helping in differentiate between them (Magnification: 2X in (a and b) and 4X in (c, d, e and f))*

(5.43- 7.86 mm) and (0.86- 1.28 mm), (7.44- 9.86 mm) and (1.29- 1.85 mm), (12.58- 18.26 mm) and (2.26- 3.57 mm) for the seven instars, respectively.

There were distinct variations in size between pupae having males and those having females, which were larger, so standard deviations in pupae measurements were high. T_3 and T_4 had the largest pupae. However, pupae measurements did not differ significantly between the different treatments. The lengths ranged between 7.27- 8.80 mm, while the widths were between 1.93- 2.31 mm.

It was obvious that the females were larger in size than the males. Nearly, it could be noticed that T_3 adults were the biggest and T_1 ones were the smallest. However, there were no significant variations among the treatments for male length and wing span, which recorded values between (7.43- 8.15 mm) and (17.09- 18.28 mm), respectively. Otherwise, for females, remarkable differences appeared, and the observations ranged between (8.38- 9.99 mm) for length and (19.45- 22.84 mm) for wing span.

Weights of the rice moth stages

The weights of the different life cycle stages of rice moth were taken and exhibited in Table 2. The weight of the full-grown larva was minimum in T_1 (16 mg), and the next was T_2 (36 mg). T_3 and T_4 were almost equal in weight, having 50 and 55 mg, respectively. Unlike, the variations among the treatments in pupae weight were not significant and ranged between (15- 31 mg). As these values represent the weight of the pupae, which were males and females, the standard deviations were big because of the distinct variance between the weights of both genders. The females were absolutely heavier than the males. Among the treatments, T_1 had the lightest males and females of 8 and 12 mg, respectively. T_2 (15 mg), T_3 (16 mg) and T_4 (17 mg) were equal in males weight. T_2 had the next lighter females at 29 mg, while T_3 (39 mg) and T_4 (37 mg) recorded the maximum female weights.

Fecundity of the rice moth female

The total number of eggs laid by a single female during life for each crop is recorded in Table 2. Insects feeding on maize, groundnut and wheat had no significant differences in females' fecundity (475, 472 and 435 eggs/ female), while those feeding on rice had minimum fecundity (228 eggs/ female).

DISCUSSION

The impact of the different tested diets on the biological parameters of the rice moth was obvious from the beginning of the first larval instar till the adult emergence

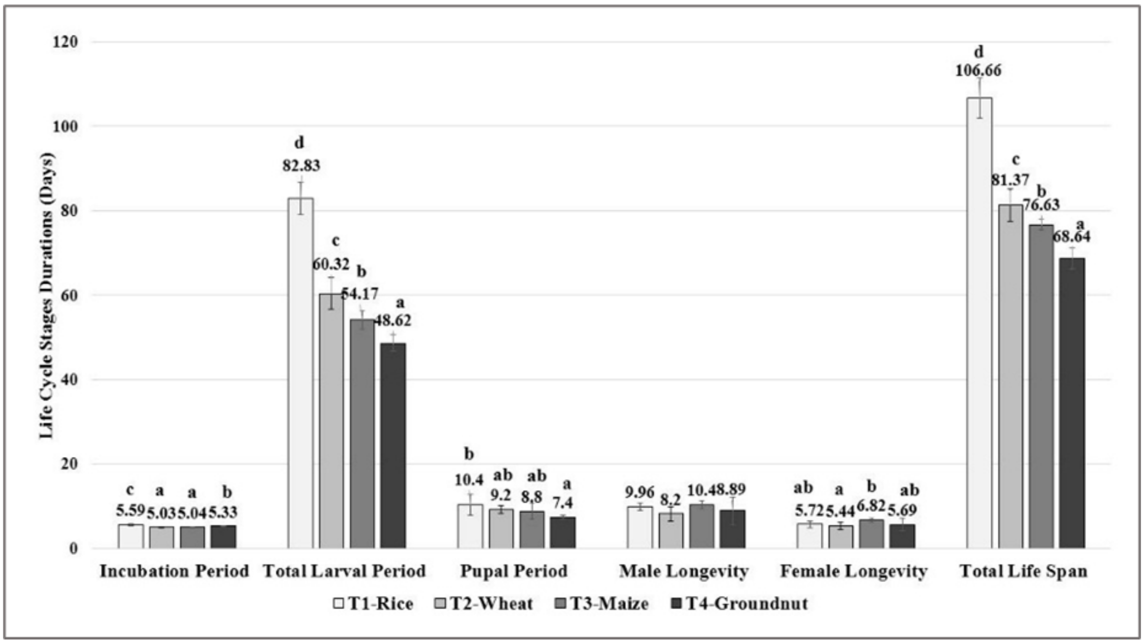

Fig. 5. *Life cycle durations of Corcyra cephalonica stages feeding on different seeds; rice, wheat, maize and groundnut. Bars having the same alphabets are indifferent significantly according to DMRT analysis*

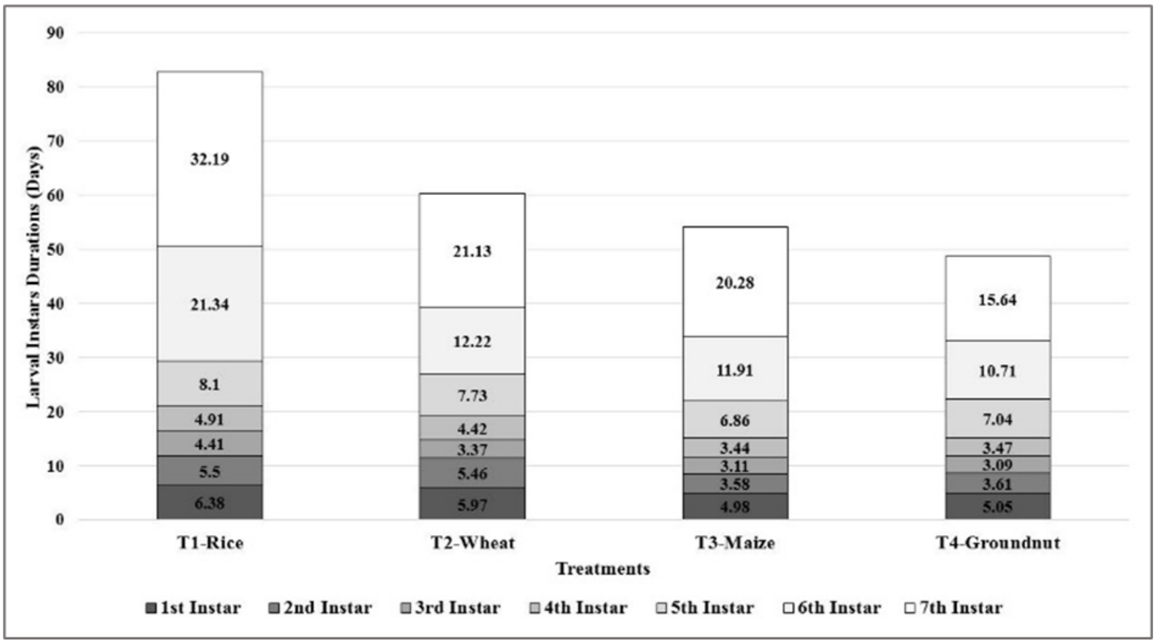

Fig. 6. *Durations of the larval instars of Corcyra cephalonica feeding on different seeds; rice, wheat, maize and groundnut. Values inside the bars boxes represent the durations of the larval instars (days) starting from 1st to 7th (from bottom to top)*

and the oviposition and hatching after that. The percentages of nutrients in each type of the studied seed differed, especially the percentage of protein, carbohydrates, and fats. This plays a very important role in the quality and quantity of food that the larvae obtain during their growth, which is reflected in the insect's total growth and development process (Kraus *et al*., 2022). Therefore, the differences in larval biological parameters among the treatments are mainly affected by the insects' qualitative and quantitative nutritional requirements obtained from the introduced food. Qualitative nutritional requirements mean that there must be a specific balance among the essential arrays of nutrients (protein, carbohydrates, fats, minerals, vitamins, etc.) required for optimal insect growth during its feeding period. And the quantitative requirements represent the amount of each nutrient in the insect's foodstuff, which gives it the best growth (House, 1969; Offor, 2010; Leonhardt *et al*., 2020). Not only are the basic nutritional requirements important for optimal growth, but both basic nutrients and non-nutritional compounds (e.g., allelochemics) in the food are also involved. And there-

Table 2. Fecundity and weights of *Corcyra cephalonica* different stages on different seeds

	T_1-Rice Mean±SD	T_2-Wheat Mean±SD	T_3-Maize Mean±SD	T_4-Groundnut Mean±SD
Female fecundity (No. Eggs)	228±46 a	435±98 b	475±107 b	472±104 b
Full- grown larval (mg)	16±5.2 a	36±4.8 b	50±6.9 c	55±11.5 c
Pupa (mg) NS	15±3.5	24±9.1	31±10.5	30±9.1
Male (mg)	8±1.6 a	15±1.5 b	16±2 b	17±4.6 b
Female (mg)	12±4.3 a	29±4.8 b	39±4.8 c	37±5.6 c

fore, the optimal requirements will result in maximal fitness for the individual (Slansky, 1982). This can express these factors affecting the insect's biological parameters in another way: the seed's physical (seed hardness, size, colour, etc.) and biochemical (nutritional content, allelochemicals, etc.) characteristics. The effect of these factors is discussed in the study of Borzoui *et al*. (2017) on the biology of the Angoumois grain moth *Sitotroga cerealella*; they hypothesized that the lengthened duration of the larval and pupal stages on certain crops may be primarily caused by variations in the critical nutritional factors or in the physical characteristics of the grains under investigation.

The present study noticed that the larval stage was faster in groundnuts, maize, and wheat, with the most prolonged duration in rice. This point could be explained by reviewing the nutritional components of each of the tested diets (Ikese *et al*., 2016; Meherunnahar *et al*., 2018; Mohidem *et al*., 2022; Balasubramanian *et al*., 2023; Kaushal *et al*., 2023) as the following: Protein content: Groundnut> wheat > maize > rice. Fat content: Groundnut> maize> wheat> rice. Carbohydrate content: Rice > maize> wheat> groundnut. That leads to the conclusion that diets with high protein and fat content caused faster development than those with a higher carbohydrate level. House (1969) has confirmed this previously, reporting that the best diets for growth and development contain a higher content of amino acids and a lower glucose content. A deficiency in the optimal amounts of the essential nutrients (poor foodstuff) may negatively impact the processes by which these nutrients participate and thus the insect’s biological function (Kirk, 2004). And here, rice is considered a poor foodstuff compared to other seeds with higher nutritional contents, especially since the present study used polished rice. So, larvae feeding on rice did not get adequate nutritional and energetic requirements for faster growth.

Therefore, as feeding behaviour interacts with other key behaviours (survival, reproduction, growth and movement), poor food will negatively affect the biological parameters and lead to a prolonged developmental period and produce individuals with reduced weight and size (Phillipson, 1981; Lee, 2007; Borzoui *et al*., 2017; Dobson *et al*., 2018). The duration of each stage and each larval instar is associated with the moulting and the metamorphosis process, which are very influential for insects (Ishimaru *et al*., 2016). The energetic requirements for this process are supplied from that accumulated during the larval period (Merkey *et al*., 2011; Wang *et al*., 2020). According to Kang *et al*. (2022) and Aguila *et al*. (2013), if the larval stage was prolonged, that means that the stored energy during the larval stage was not adequate to uphold the moulting of the larva to pupa. The same thing also explains the duration of the pupation period and the adults’ longevity. The results showed that adults' longevity did not differ so much among the studied diets. With that, we could notice that the diets with high protein content (groundnut and wheat) had shorter longevity, compared to rice, where the adults’ longevity was prolonged. Low-quality diets may frequently extend an insect's life span, and this also reduces vitality and health. The crucial component in this is the ratio of protein to non-protein energy intake (Simpson and Raubenheimer, 2007; Solon-Biet *et al*., 2014; Dobson *et al*., 2018). This may interpret the insect’s biological data obtained in rice.

Seed hardness is a mechanical factor affecting the fitness of the rice moth, which may partially explain the observations above. Seed hardness is described as the resistance of the kernel to the mechanical forces. Its variations among seeds is due to the variable degree of interaction between the endosperm components- starch grains and protein matrix (Grundas, 2004; Pauly *et al*., 2013; Nucia *et al*., 2021). The harder the seed, the more difficult it is for the insect to consume food and then the less insect’s fitness. The insect population build-up is correlated negatively with the seed hardness and positively with the protein content of the seed (Sahoo and Sahoo, 2016).

As clarified in the present study, larvae feeding on soft seeds, such as groundnut, had increased in weight, size, activity and developmental speed. While those feeding on hard seeds, such as rice, where the food consumption decreased and the larval metabolism slowed down, had exhibited a prolonged developmental period and low-value bio- parameters. Here, the larvae's potential for growth is presumably limited because they must expend more energy feeding and digesting. This point is discussed clearly in several studies (Ofuya and Credland, 1995; Sulehrie *et al*., 2003; Fouad *et al*., 2013; Oloyede-Kamiyo and Adetumbi, 2017).

One of the biochemical factors affecting the utilization of the ingested food is the level of proteinaceous inhibitors in the seeds (which decrease the activity of the digestive enzymes and affect the development of the insect negatively) and the amylolytic activity in the larval midgut, which interferes with the seed hardness (Farias *et al*., 2007; Chougule *et al*., 2008). Different levels of amylolytic activity, α-amylase inhibition and seed hardness could be correlated with the developmental characteristics of the insect. The high level of the inhibitor in the seed will reduce the enzyme activity in the larval midgut. It is suggested that seeds that are more suitable for rice moth (maize and groundnut) contain less level of inhibitors, with a high level of the enzyme in the larval midgut, and this interaction between these components is under the control of the endocrinal system of the insect (Behmer, 2009; Kotkar *et al*., 2009; Karasov *et al*., 2011; Borzoui *et al*., 2015). Maize and groundnut, and then wheat in a lower degree, and rice at the end were different in their suitability to *C. cephalonica* larvae, which lead us to suppose that the enzyme inhibitors are at low level in maize and groundnut, and higher in wheat, and the highest in rice. This point was supported by Borzoui *et al*. (2017), where, in seeds that were more hardening and where α-amylase inhibition level is higher, the food consumption was not comfortable and this made the developmental period of *S. cerealella* longer and the adults' weight and the female fecundity lower. Therefore, in the present case, the insect fitness was reduced in larvae feeding on rice. Despite maize seeds being harder than wheat seeds, the inhibitor level in maize is less than that in wheat, making the maize seeds a better diet for *C. cephalonica*.

As mentioned above, the variations of the weight and the size of the different stages among the treatments are also due to the availability of the nutrients and the factors affecting food consumption as discussed above. The seeds with high protein and fat content (groundnut and maize) produce larger and weightier individuals. This is also related to the amount of nutrients stored at the larval stage, which was richer in groundnut and maize (Rion and Kawecki, 2007; Hamed and Nadeem, 2012; Borzoui *et al*., 2017; Kang *et al*., 2022). The results of the present study reveal that larvae feeding on groundnut and maize had grown faster and bigger than those feeding on wheat and rice. Those larvae had large well- developed mandibles in all instars, which improved their feeding performance and produced large full-grown larvae at the end of the larval stage, which was supported by Sulehrie *et al*. (2003). Typically, pupa produced from a well fed larva will be larger, as it is developed from a larva of a high energetic content. Borzoui *et al*. (2017) recorded a higher level of energy in pupae from well- fed larvae. The ultimate goal of a larva is to develop into an adult of a good reproductive capability. During its life cycle, the insect larva makes decisions relating to molt and develops when the specific stage gets the adequate energy for transforming to the next stage until it reaches the reproductive adult. The poor quality food causes the insect to prolong its developmental period to get the optimal or minimal energetic level for reaching the reproductive stage (Slansky, 1982). That may be a brief explanation for the variations in life cycle durations among seeds of different physical and biochemical properties.

The present study shows that the nutritional balance at the larval stage has a remarkable impact on the reproductive performance of the adults (Slansky, 1982; Warbrick-Smith *et al*., 2006; Simpson and Raubenheimer, 2009; Borzoui *et al*., 2017). During ovipostion, the female uses proteins largely for egg production (Telang *et al*., 2003; Ma *et al*., 2022). Therefore, females accumulating a high energetic content from the larval stage (as in groundnut, maize and wheat at a lesser degree) have a higher fecundity and produce more eggs (Telang and Wells, 2004). In the case of poor energetic content, the ovarian development slows down, with imperfect ovarian morphology, in addition to reducing or inhibiting Vg expression, responsible for creating Vg proteins involved in the yolk formation, leading ultimately to immature eggs and atrophy (Pan *et al*., 2014; Shen *et al*., 2019; Kang *et al*., 2022).

The duration of the egg incubation period is related to the time required for embryonic development (embryogenesis), which in turn ends when the yolk is consumed in order to form the larva (Bajpeyi *et al*., 2023). Therefore, the more abundant the nutritional contents in the egg yolk, the faster the embryogenesis. The degree of egg maturity, size and nutritional content are also related to the size of the female and maturity of its ovaries, which in turn is related to the amount of nutrients that is stored in the larval stage (Moreau *et al*., 2016). Therefore, it can be said that, in the current study, larvae that received poor nutrition and low protein and fat content, such as rice, will produce females with low fecundity and lower nutritional content compared to those that received better nutrition and higher protein and fat content. This is reflected in the speed of development of the embryo in the egg. That is, it can be said, in short, that the speed of embryogenesis in the rice was less than in the other diets, and therefore the incubation period was longer.

Conclusion

This study has investigated the relationship between the diet and the growth of the rice moth *C. cephalonica* (Stainton). The results confirmed that seeds' physical and biochemical properties significantly affect the rice moth's fitness through their reflection on the biological parameters. According to the findings, groundnut and maize seeds were considered suitable for the growth of the insect, followed by wheat at a lesser degree, while rice comes last as the least suitable hosts. The seeds' characteristics, which make them unsuitable for insect growth (such as hardness and the presence of proteinaceous inhibitors) are remarkable points that could be used beneficially to understand and develop the mechanisms of seed resistance to insect infection. As for the seeds' characteristics that resulted in superior biological parameters, these have an important use in the mass breeding of rice moths for biological studies.

ACKNOWLEDGMENTS

This work was supported by grants from the Department of Entomology, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Aguila, J. R., Hoshizaki, D. K., & Gibbs, A. G. (2013). Contribution of larval nutrition to adult reproduction in Drosophila melanogaster. *Journal of Experimental Biology*, *216*(3), 399-406. DOI: https://doi.org/10.1242/jeb.078311
2. Arun Kumar, K. M., Tambe, V. J., Rehaman, S. K., Choudhuri, B. N., & Thakur, K. D. (2018). Effect of different diets on the biology of rice moth, Corcyra cephalonica (Stainton). *Journal of Entomology and Zoology Studies*, *6* (3), 251-254. DOI: https://api.semanticscholar.org/CorpusID:54886964
3. Bajpeyi, M. M., Kumar, S., Kumar, A. (2023). Chapter-2 *Embriological Development in Insect in [Modern Aspects of Entomology].* Integrated Publications, New Delhi 17-41. DOI: https://doi.org/10.22271/int.book.261
4. Bala, K., Sood, A. K., Pathania, V. S., & Thakur, S. (2018). Effect of plant nutrition in insect pest management: A review. *Journal of Pharmacognosy and Phytochemistry*, *7*(4), 2737-2742. DOI: https://api.semanticscholar.org/CorpusID:221759331
5. Balasubramanian, P., Subbulakshmi, B., Balmurugan, M., Gurumeenakshi, G., Prasanth, R. C., Deepika, R., & Surya, R. (2023). Nutritional Profiling and its Significance in Groundnut: A Review. *Asian Journal of Dairy and Food Research. doi*, *10*. DOI: https://10.18805/ajdfr.DR-2136
6. Bankapur, R., Mule, R. S., Gurav, S. S., Kadam, J. J., Munj, S. S., & Dethe, S. R. (2022). Comparative biology of rice moth, Corcyra cephalonica (Stainton)(Lepidoptera: Pyralidae) on rice varieties.
7. Behmer, S. T. (2009). Insect herbivore nutrient regulation. *Annual review of entomology*, *54*(1), 165-187. DOI: https://10.1146/annurev.ento.54.110807.090537
8. Bhardwaj, J. R., Ganguli, J. L., Khan, H. H., & Sahu, R. (2017). Bionomics of the rice meal moth, Corcyra cephalonica (Stainton) reared under laboratory condition on different diets. *Journal of Entomology and Zoology studies*, *5* (5), 722-727. DOI: https://api.semanticscholar.org/CorpusID:59405756
9. Borzoui, E., Naseri, B., & Namin, F. R. (2015). Different diets affecting biology and digestive physiology of the Khapra beetle, Trogoderma granarium Everts (Coleoptera: Dermestidae). *Journal of Stored Products Research*, *62*, 1-7. DOI: https://doi.org/10.1016/j.jspr.2015.03.003
10. Borzoui, E., Naseri, B., & Nouri-Ganbalani, G. (2017). Effects of food quality on biology and physiological traits of Sitotroga cerealella (Lepidoptera: Gelechiidae). *Journal of Economic Entomology*, *110*(1), 266-273. DOI: https://10.1093/jee/tow284
11. Chaudhuri, N., & Senapati, S. K. (2017). Development and reproductive performance of rice moth Corcyra cephalonica Stainton (Lepidoptera: Pyralidae) in different rearing media. *Journal of the Saudi Society of Agricultural Sciences*, *16*(4), 337-343. DOI: https://doi.org/10.1016/j.jssas.2015.11.004
12. Chougule, N. P., Doyle, E., Fitches, E., & Gatehouse, J. A. (2008). Biochemical characterization of midgut digestive proteases from Mamestra brassicae (cabbage moth; Lepidoptera: Noctuidae) and effect of soybean Kunitz inhibitor (SKTI) in feeding assays. *Journal of Insect Physiology*, *54*(3), 563-572. DOI: https://doi.org/10.1016/j.jinsphys.2007.12.005
13. Devi, M. B., Devi, N., Devi, S. R., & Singh, P. R. (2013). Biology and morphometric of rice moth, Corcyra cephalonica. *Annals of Plant Protection Sciences*, *21*(1), 87-89. DOI: https://api.semanticscholar.org/CorpusID:85980534
14. Dobson, A. J., He, X., Blanc, E., Bolukbasi, E., Feseha, Y., Yang, M., & Piper, M. D. (2018). Tissue-specific transcriptome profiling of Drosophila reveals roles for GATA transcription factors in longevity by dietary restriction. *npj Aging and Mechanisms of Disease*, *4*(1), 5. DOI: https://doi.org/10.1038/s41514-018-0024-4
15. Farias, L. R., Costa, F. T., Souza, L. A., Pelegrini, P. B., Grossi-de-Sá, M. F., Neto, S. M., ... & Franco, O. L. (2007). Isolation of a novel Carica papaya α-amylase inhibitor with deleterious activity toward Callosobruchus maculatus. *Pesticide Biochemistry and Physiology*, *87*(3), 255-260. DOI: https://doi.org/10.1016/j.pestbp.2006.08.004
16. Fouad, H. A., Faroni, L. R. D., Lima, E. D., & Vilela, E. F. (2013). Relationship between physical-chemical characteristics of corn kernels and susceptibility to Sitotroga cerealella. *Short Communication, 58*: 169-172
17. Grundas, S. (2004). Charakterystyka wlasciwosci fizycznych ziarniakow w klosach pszenicy zwyczajnej Triticum aestivum L. *Acta Agrophysica,* 102 (2): 1-65.
18. Hamed, M., & Nadeem, S. (2012). Effect of cereals on the development of Sitotroga cerealella (Olivier)(Lepidoptera: Gelechiidae) and subsequent quality of the egg parasitoid, Trichogramma chilonis (Ishii)(Hymenoptera: Trichogrammatidae). *Pakistan journal of Zoology*, *44*(4). DOI: https://www.proquest.com/scholarly-journals/effect-cereals-on-development-sitotroga/docview/1220799836/se-2?accountid=131615
19. House, H. L. (1969). Effects of different proportions of nutrients on insects. *Entomologia experimentalis et appli-*

cata, *12*(5), 651-669.

20. Ikese, O., Ubwa, S., Adoga, S., Lenka, J., Inalegwu, J., Ocheje, M., & Inegedu, A. (2016). Proximate composition, antinutrients and some functional properties of a potential infant food made from wheat and groundnut. *Int. J. Food Sci. Nutr*, *1*(5), 59-63. DOI: https://api.semanticscholar.org/CorpusID:10058706
21. Ishimaru, Y., Tomonari, S., Matsuoka, Y., Watanabe, T., Miyawaki, K., Bando, T., ... & Mito, T. (2016). TGF-β signaling in insects regulates metamorphosis via juvenile hormone biosynthesis. *Proceedings of the National Academy of Sciences*, *113*(20), 5634-5639. DOI: https://doi.org/10.1073/pnas.1600612113
22. Jhala, J., Vyas, A. K., Rajput, V. S., & Sharma, S. (2019). Biology of (Corcyra cephalonica, Stainton) on different host. *Journal of Pharmacognosy and Phytochemistry*, *8* (5), 476-479.
23. Kang, K., Cai, Y., Yue, L., & Zhang, W. (2022). Effects of different nutritional conditions on the growth and reproduction of Nilaparvata lugens (Stål). *Frontiers in Physiology*, *12*, 794721. DOI: https://10.3389/fphys.2021.794721
24. Karasov, W. H., Martinez del Rio, C., & Caviedes-Vidal, E. (2011). Ecological physiology of diet and digestive systems. *Annual review of physiology*, *73*(1), 69-93. DOI: https://10.1146/annurev-physiol-012110-142152
25. Kaur, L., Kalkal, D., & Jakhar, A. (2023). Impact of Diets on the Biology of Corcyra cephalonica (Stainton). *Indian Journal of Entomology*, 1-4. DOI: https://10.55446/IJE.2023.1129
26. Kaushal, M., Sharma, R., Vaidya, D., Gupta, A., Saini, H. K., Anand, A., ... & KC, D. (2023). Maize: an underexploited golden cereal crop. *Cereal Research Communications*, *51*(1), 3-14. DOI: https://doi.org/10.1007/s42976-022-00280-3
27. Kirk, D. E. (2004). *Optimal control theory: an introduction*. Courier Corporation, United States.
28. Kotkar, H. M., Sarate, P. J., Tamhane, V. A., Gupta, V. S., & Giri, A. P. (2009). Responses of midgut amylases of Helicoverpa armigera to feeding on various host plants. *Journal of Insect Physiology*, *55*(8), 663-670. DOI: https://doi.org/10.1016/j.jinsphys.2009.05.004
29. Kraus, S., Monchanin, C., Gomez-Moracho, T., & Lihoreau, M. (2022). Insect diet. In *Encyclopedia of animal cognition and behavior* (pp. 3471-3479). Cham: Springer International Publishing. DOI: https://doi.org/10.1007/978-3-319-55065-7_1137
30. Lee, K. P. (2007). The interactive effects of protein quality and macronutrient imbalance on nutrient balancing in an insect herbivore. *Journal of Experimental Biology*, *210* (18), 3236-3244. DOI: https://10.1242/jeb.008060
31. Leonhardt, S. D., Lihoreau, M., & Spaethe, J. (2020). Mechanisms of nutritional resource exploitation by insects. *Insects*, *11*(9), 570. DOI: https://t10.3390/insects11090570
32. Liu, C., Du, B., Hao, F., Lei, H., Wan, Q., He, G., ... & Tang, H. (2017). Dynamic metabolic responses of brown planthoppers towards susceptible and resistant rice plants. *Plant Biotechnology Journal*, *15*(10), 1346-1357. DOI: https://10.1111/pbi.12721
33. Ma, C., Mirth, C. K., Hall, M. D., & Piper, M. D. (2022). Amino acid quality modifies the quantitative availability of protein for reproduction in Drosophila melanogaster. *Journal of insect physiology*, *139*, 104050. DOI: https://doi.org/10.1016/j.jinsphys.2020.104050
34. Manjunath, T. M. (2014). A semi-automatic device for mass production of the rice moth, Corcyra cephalonica (Stainton)(Lep., Pyralidae), and evaluation of several biological and economic parameters to develop a package of practice for its commercial production. *Journal of Biological Control*, *28*(2), 93–108. DOI: https://api.semanticscholar.org/CorpusID:89154261
35. Meherunnahar, M., Chowdhury, R. S., Hoque, M. M., Satter, M. A., & Islam, M. F. (2018). Comparison of nutritional and functional properties of BK2 foxtail millet with rice, wheat and maize flour. *Progressive Agriculture*, *29*(2), 186-194. DOI: https://doi.org/10.3329/pa.v29i2.38305
36. Menge, A. K., Naik, K. V., Mehendale, S. K., & Raut, P. (2016). Biology of rice moth, Corcyra cephalonica (Stainton) on groundnut variety Konkan Tapora. *Adv. Life Sci*, *5*(21), 9733-9735. DOI: https://api.semanticscholar.org/CorpusID:208232979
37. Menge, A. K., Naik, K. V., Jalgaonkar, V. N., & Golvankar, G. M. (2018). Bionomics of rice moth, Corcyra cephalonica (st.) on groundnut variety TG–37. *J Entomol Zool Stud*, *6*, 36-38. DOI: https://api.semanticscholar.org/CorpusID:222281621
38. Merkey, A. B., Wong, C. K., Hoshizaki, D. K., & Gibbs, A. G. (2011). Energetics of metamorphosis in Drosophila melanogaster. *Journal of insect physiology*, *57*(10), 1437-1445. DOI: https://doi.org/10.1016/j.jinsphys.2011.07.013
39. Mohidem, N. A., Hashim, N., Shamsudin, R., & Che Man, H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*, *12*(6), 741. DOI: https://10.3390/agriculture12060741
40. Moreau, J., Monceau, K., & Thiéry, D. (2016). Larval food influences temporal oviposition and egg quality traits in females of Lobesia botrana. *Journal of Pest Science*, *89*, 439-448. DOI: https://doi.org/10.1007/s10340-015-0695-6
41. Nucia, A., Okoń, S., Tomczyńska-Mleko, M., & Nawrocka, A. (2021). Molecular and physical characterization of grain hardness in European spring common wheat (Triticum aestivum L.). *3 Biotech*, *11*(7), 345. DOI: https://doi.org/10.1007/s13205-021-02897-3
42. Offor, E. (2010). The nutritional requirements of phytophagous insects: why do insects feed on plants?. *Available at SSRN 1535274*. DOI: https://10.2139/ssrn.1535274
43. Ofuya, T. E., & Credland, P. F. (1995). Responses of three populations of the seed beetle, Callosobruchus maculatus (F.)(Coleoptera: Bruchidae), to seed resistance in selected varieties of cowpea, Vigna unguiculata (L.) Walp. *Journal of Stored Products Research*, *31*(1), 17-27. DOI: https://doi.org/10.1016/0022-474X(95)91807-D
44. Oloyede-Kamiyo, Q. O., & Adetumbi, J. A. (2017). Relationship between seed physical traits and maize weevil (Sitophilus zeamais) damage parameters in selected Quality Protein Maize (QPM) varieties. *Journal of Stored Products Research*, *73*, 42-46. DOI: https://doi.org/10.1016/j.jspr.2017.06.003
45. Pan, X., Lu, K., Qi, S., Zhou, Q., & Zhou, Q. (2014). The content of amino acids in artificial diet influences the development and reproduction of brown planthopper, Nilaparvata lugens (Stål). *Archives of insect biochemistry and physiology*, *86*(2), 75-84. DOI: https://doi.org/10.1002/

arch.21162
46. Pauly, A., Pareyt, B., Fierens, E., & Delcour, J. A. (2013). Wheat (Triticum aestivum L. and T. turgidum L. ssp. durum) kernel hardness: I. Current view on the role of puroindolines and polar lipids. *Comprehensive Reviews in Food Science and Food Safety*, *12*(4), 413-426. DOI: https://doi.org/10.1111/1541-4337.12018
47. Phillipson, J. (1981). Bioenergetic options and phylogeny. *Physiological ecology; an evolutionary approach to resource use*. Sinauer Associates, Michigan, pp. 20-45.
48. Ramanaji, N., Dabhi, M. V., & Thangavel, S. (2020). Bioecology of rice moth Corcyra cephalonica (Stainton) on groundnut seeds. *Journal of Entomology and Zoology Studies*, *8*(5), 2406-2410. DOI: https://api.semanticscholar.org/CorpusID:229265124
49. Rion, S., & Kawecki, T. J. (2007). Evolutionary biology of starvation resistance: what we have learned from Drosophila. *Journal of evolutionary biology*, *20*(5), 1655-1664. DOI: https://doi.org/10.1111/j.1420-9101.2007.01405.x
50. Rossini, L., Speranza, S., Severini, M., Locatelli, D. P., & Limonta, L. (2021). Life tables and a physiologically based model application to Corcyra cephalonica (Stainton) populations. *Journal of Stored Products Research*, *91*, 101781. DOI: https://doi.org/10.1016/j.jspr.2021.101781
51. Sahoo, G., & Sahoo, B. K. (2016). Grain hardness and protein content of milled rice grains and their relationship with infestation of rice weevil Sitophilusoryzae L., (Coleoptera: Curculionidae). *ORYZA-An International Journal on Rice*, *53*(3), 332-336. DOI: https://epubs.icar.org.in/index.php/OIJR/article/view/71221
52. Shah, T. H. (2017). Plant nutrients and insects development. *International Journal of Entomology Research*, *2*(6), 54-57.
53. Shen, Y., Chen, Y. Z., Lou, Y. H., & Zhang, C. X. (2019). Vitellogenin and vitellogenin-like genes in the brown planthopper. *Frontiers in Physiology*, *10*, 1181. DOI: https://10.3389/fphys.2019.01181
54. Simpson, S. J., & Raubenheimer, D. (2007). Caloric restriction and aging revisited: the need for a geometric analysis of the nutritional bases of aging. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(7), 707-713. DOI: https://doi.org/10.1093/gerona/62.7.707
55. Simpson, S. J., & Raubenheimer, D. (2009). Macronutrient balance and lifespan. *Aging (Albany NY)*, *1*(10), 875. DOI: https://doi.org/10.18632/aging.100098
56. Singh, H. (2022). Biology and control of rice moth, Corcyra cephalonica (Lepidoptera: Pyralidae) by using botanical. *The Pharma Innovation Journal*, *11*: 1907-1910.
57. Slansky, F. (1982). Insect nutrition: an adaptationist's perspective. *The Florida Entomologist*, *65*(1), 45-71. DOI: https://www.jstor.org/stable/3494145
58. Solon-Biet, S. M., McMahon, A. C., Ballard, J. W. O., Ruohonen, K., Wu, L. E., Cogger, V. C., ... & Simpson, S. J. (2014). The ratio of macronutrients, not caloric intake, dictates cardiometabolic health, aging, and longevity in ad libitum-fed mice. *Cell metabolism*, *19*(3), 418-430. DOI: https://doi.org/10.1016/j.cmet.2014.02.009
59. Sulehrie, M. A. Q., Golob, P., Tran, B. M. D., & Farrell, G. (2003). Use of a biomonitor to assess the effect of seed hardness on larval feeding of Callosobruchus maculatus in Vigna varieties. *Bioacoustics*, *14*(1), 35-46. DOI: https://doi.org/10.1080/09524622.2003.9753511
60. Telang, A., Buck, N. A., Chapman, R. F., & Wheeler, D. E. (2003). Sexual differences in postingestive processing of dietary protein and carbohydrate in caterpillars of two species. *Physiological and Biochemical Zoology*, *76*(2), 247-255. DOI: https://www.jstor.org/stable/10.1086/367947
61. Telang, A., & Wells, M. A. (2004). The effect of larval and adult nutrition on successful autogenous egg production by a mosquito. *Journal of Insect Physiology*, *50*(7), 677-685. Doi: https://doi.org/10.1016/j.jinsphys.2004.05.001
62. Wang, S. S., Li, G. Y., Liu, Y. K., Luo, Y. J., Xu, C. D., Li, C., & Tang, B. (2020). Regulation of carbohydrate metabolism by trehalose-6-phosphate synthase 3 in the brown planthopper, Nilaparvata lugens. *Frontiers in Physiology*, *11*, 575485. Doi: https://10.3389/fphys.2020.575485
63. Warbrick-Smith, J., Behmer, S. T., Lee, K. P., Raubenheimer, D., & Simpson, S. J. (2006). Evolving resistance to obesity in an insect. *Proceedings of the National Academy of Sciences*, *103*(38), 14045-14049. Doi: https://doi.org/10.1073/pnas.0605225103