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KM Ajaykumara
M. Sc. (Agri.), Department of Entomology, UAS, GKVK, Bengaluru, Karnataka, India

GT Thirumalaraju
Professor of Entomology, AICRP on Seed Technology, NSP, UAS, GKVK, Bengaluru, Karnataka, India

Anjali AS
M. Sc. (Agri.), Department of Entomology, UAS, GKVK, Bengaluru, Karnataka, India

Correspondence
KM Ajaykumara
M. Sc. (Agri.), Department of Entomology, UAS, GKVK, Bengaluru, Karnataka, India

Seasonal Variations in the Biology of Lesser Grain Borer *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) on Stored Maize under Laboratory Conditions

KM Ajaykumara, GT Thirumalaraju and Anjali AS

Abstract
Laboratory experiments were conducted during *kharif* 2014 (July-August), *rabi*/winter 2014 (November-December) and summer 2015 (April-May) seasons at Agricultural Entomology laboratory, UAS, GKVK, Bengaluru to study the seasonal variations in the biology of the *R. dominica.* The results revealed that the mean incubation period of 9.64 and 7.56 days, the mean duration of first instar grub was 10.44 and 8.28 days, second instar – 9.32 and 7.48 days, third instar – 9.24 and 7.28 days and fourth instar – 10.34 and 8.24 days during *kharif* and summer seasons, respectively. Total grub period occupied relatively longer duration of 39.32 days during *kharif*, while in summer it with shorter duration of 31.28 days. The male and female adult beetles respectively lived for longer duration of 26.08 and 28.64 days in *kharif* season and for shorter duration of 19.52 and 21.88 days during summer seasons. The mean total life cycle occupied 60.96 and 49.76 days during *kharif* and summer seasons, respectively.

Keywords: Maize, *Rhyzopertha dominica*, biology, seasonal variations and mortality

1. Introduction
Maize or Corn (*Zea mays* L.) is a versatile cereal crop grown over a range of agro climatic zones. Globally, maize is known as queen of cereals because, it has the highest genetic yield potential among the cereals. It is not only an important human nutrient, but also a basic element of animal feed and raw material for manufacture of many industrial products like corn starch, corn oil, corn syrup and bio-fuel [1]. It is cultivating on nearly 150 m ha in about 160 countries that contributes 36 per cent (782 m t) in the global grain production [2]. India has 5 per cent of maize acreage and contributes 2.5 per cent of world production. During 2015, it was cultivated on about 9.5 million hectares; producing 23.29 million tons of grains with 2451 kg/hectare yield [3].

During postharvest storage, maize grains are vulnerable to many insects. Among those, lesser grain borer *Rhyzopertha dominica*, Weevils complex *Sitophlilus* spp., Angoumois grain moth *Sitotroga cerealella* (Olivier), Khapra beetle *Trogoderma granarium* Everts and Red flour beetle *Tribolium castaneum* (Herbst) are important [4]. It is estimated that 5 to 10 per cent of world's grain production is lost due to ravages of insect pests. These losses reach to 50 per cent in tropical countries where temperature and humidity run high during summer season [5]. Estimates of post-harvest losses of cereal grains ranged between 5 to 35 per cent in the world [6]. In India, up to 12 per cent of post-harvest losses were caused by insect pests [7]. This reflects on the magnitude of pest problem in storage.

The *R. dominica* is a serious and primary pest that feeds internally on stored commodities such as paddy, wheat, maize and sorghum including pulses [8]. The beetle has been reported to be highly polyphagous and cosmopolitan in tropical and subtropical regions of the world, but it has also been found in warm and temperate regions [9]. The biology of lesser grain borer studied by various workers on different cereals showed variation in the developmental periods of different life stages. It was also observed that various environmental factors influence the biology of the pest. Literature pertaining to biology of lesser grain borer on maize is also limited [10]. Keeping the above facts in view, the present investigations was carried out with the study of the biology to know seasonal variability of pest on stored Maize seeds. The different objectives were included in the study are morphometric measurements, accounting the duration (days) and mean survival (%) of different developmental stages namely egg, grub, pre

pupa, pupa and adult during different seasons. Apart from this, fecundity, sex ratio, pre mating, mating, pre oviposition, and oviposition periods are also been considered under the study.

2. Materials and methods

Studies on biology of the lesser grain borer was conducted on Hema hybrid maize seeds having 10.00 per cent moisture content under laboratory condition at temperature range from 18 to 32 °C and 58 to 86 per cent relative humidity.

2.1 Maintenance of stock culture: Culture of the lesser grain borer was initiated by releasing adult beetles into plastic container of one kg capacity containing broken maize seeds. Fresh broken seeds were introduced periodically for proper development of beetles. Culture thus maintained was used throughout the period of investigation. Dead adult beetles and frass were periodically removed to avoid storage mite infestation.

2.2 Biology of *R. dominica* on maize seeds: Twenty five specimen tubes (10 x 1.5 cm) were taken and in each tube, broken maize seeds with freshly laid eggs of *R. dominica* were introduced and the open end of the tube was plugged with cotton. The observations on different parameters like incubation, grub, pupal, pre mating, mating, pre-oviposition, oviposition period, fecundity, adult longevity and total life period were studied during *kharif* 2014 (July-August), *rabi*/winter 2014 (November-December) and summer 2015 (April-May) seasons at Agricultural Entomology laboratory, University of Agricultural Sciences, Gandhi Krishi Vigyana Kendra, Bengaluru.

2.2.1 Incubation period: Two pairs of newly emerged adults were transferred into petriplates having maize seeds where they are allowed to mate and oviposite for about ten days. Seeds containing eggs were separated out daily by examining under microscope. Three replications were maintained. Incubation period was recorded as the duration of time taken from egg laying to hatching which was recognized by appearance of dark tips of the larva through the egg chorion.

2.2.2 Grub period: The duration of grub period was recorded as the number of days taken from hatching of egg till the last instar grub pupated. To determine the number of larval instars and the duration of each instar, seeds with eggs laid on the same day were segregated and placed in petri plates. From these, seeds with the eggs hatching on the same day were separated and pooled. Each day three to four broken seeds were carefully dissected and the stage (instar) of larva present inside the seed was determined based on the number of castings of head capsules. The process was continued till the dissection of all the seeds showed only pupal stages.

2.2.3 Pre pupal and pupal period: The pre pupal stage does not involve molting and can be distinguished from the mature larva by its elongated cylindrical shape and extended head. Pre pupal period was determined by subtracting it by the larval period. Pupal period was recorded from the formation of pupa till the emergence of adult.

2.2.4 Sex ratio determination in adults: Twenty randomly taken newly emerged test insects were examined under compound microscope with high resolution to determine the sex ratio. Male and female adults were differentiated based on the presence of transverse groove on fifth abdominal sternum of male while it was absent in females [11].

2.2.5 Pre mating and mating period: Ten pairs of adults were released individually in petriplates to observe pre mating and mating period at two hours interval during day time.

2.2.6 Pre oviposition and oviposition period: The mated females were taken and kept individually in different petriplates along with the maize seeds to know the pre-oviposition and oviposition periods.

2.2.7 Fecundity: Fecundity was recorded by counting the number of eggs laid during the oviposition period for each female.

2.2.8 Adult longevity: The life span of lesser grain borer adults was recorded by enclosing male and female adults in a glass vials with food. Ten such vials were maintained for each male and female with and without food.

2.3 Morphometric measurements: In the laboratory, following measurements were made for all the stages by using **'**Leica software based computer system' i.e., length and breadth of egg, grub, pre pupa, pupa and adults considering ten sample observations. The cast off exuviae and the different size of the grubs were used as an indication of the possible number of larval instars. At each instar apart from larval length (mm) and width (mm), head capsule (length and width) measurements were also recorded. The recorded observations were computed and expressed in range and mean with standard deviation. Dyar's law was used to differentiate instars of immature insects to predict size of instars. Head capsule width of larvae follow a geometric progression.

Geometric progression: $y = abx$

Where, y= measure of size

x= instar number

a and b= constants

2.4 Statistical analysis

The data were subjected to statistical analysis following analysis of variance (ANOVA) technique for completely randomized design (CRD) to draw inference at 5 % level of significance. Sample size of 20 and 25 was considered for morphometric measurements and biology studies, respectively with 3 replications. Results were expressed in Range and Mean ±S.D.

3. Results and discussion

3.1 Morphometric observations and measurements

3.1.1 Egg: They were nearly oblong shaped with round ends, waxy in appearance and opaque. Freshly laid eggs were white in color but later turned into light pink color. The egg length ranged from 0.45 to 0.63 mm with an average of 0.56 mm and egg width ranged from 0.20 to 0.29 mm with an average of 0.22 mm. The present observations and measurements are in confirmation with Kucerova and Stejskal [12] who recorded the measurements of egg as 0.5 mm to 0.6 mm length and diameter of 0.2 to 0.3 mm on wheat.

3.1.2 First instar grub: The insect underwent three molts and four instars. Larval development took place inside the broken grain. Dyar's law was used to differentiate instars and head capsule width of larvae follows a geometric progression (Table 1). The period occupied by each instars were noted

along with their size (Table 2). The first instar larva was small, whitish and scarabaeiform with a curved spine at the terminal abdominal segment. The length ranged from 0.65 to 0.82 mm with an average of 0.74 mm and width ranged from 0.27 to 0.36 mm with an average of 0.32 mm. These observations are in contrasting with the results of Potter [13] who noticed that the shape of the first instar is campodeiform, his findings regarding morphometric measurements (mean length of 0.78 mm) supported the present observations. However, the observations with respect to shape are supported by the results of Gururaj [14] who noticed the scarabaeiform first instar larva.

3.1.3 Second instar grub: It closely resembled the first instar larva except for the larger size and absence of process at the terminal abdominal segment. The larval length ranged from 0.89 to 1.21 mm with an average of 1.09 mm and width ranged from 0.48 to 0.68 mm with an average of 0.58 mm. Morphological observations were found similar to the results obtained by Potter [13] who visualised the second instar was similar in shape to the first instar with 1.1 mm long and Gururaj [14] reported the 1.024 mm length and 0.315 mm width in second instar grub.

Table 1: Head capsule length and width of larval stages of *R. dominica* grub

Instars	Length (mm)		Width (mm)		Ratio
	Range	Mean±S.D.	Range	Mean±S.D.	
I instar	0.07 to 0.11	0.09±0.01	0.12 to 0.13	0.13±0.00	-
II instar	0.10 to 0.12	0.11±0.01	0.16 to 0.18	0.17±0.01	1.30
III instar	0.15 to 0.17	0.16±0.01	0.26 to 0.28	0.27±0.01	1.58
IV instar	0.21 to 0.24	0.22±0.01	0.41 to 0.43	0.42±0.01	1.55

n=10 grubs in each instar; *Ratio calculated for head capsule width only

Table 2: Morphometric data of *R. dominica* on maize seeds

Insect stages	Length (mm)		Width (mm)	
	Range	Mean±S.D.	Range	Mean±S.D.
Egg	0.45 to 0.63	0.56±0.06	0.20 to 0.29	0.22±0.02
I instar	0.65 to 0.82	0.74±0.05	0.27 to 0.36	0.32±0.03
II instar	0.89 to 1.21	1.09±0.08	0.48 to 0.68	0.58±0.05
III instar	1.69 to 2.15	2.01±0.14	0.69 to 0.85	0.74±0.05
IV instar	2.35 to 2.99	2.78±0.19	0.83 to 1.12	0.92±0.08
Pre-pupa	2.62 to 2.94	2.82±0.11	0.86 to 1.13	0.94±0.07
Pupa	2.83 to 3.39	3.07±0.16	0.93 to 1.21	1.03±0.09
Male adult	2.91 to 3.48	3.31±0.18	1.12 to 1.45	1.26±0.08
Female adult	3.01to 3.79	3.63±0.22	1.21 to 1.75	1.47±0.14

n=20

3.1.4 Third instar grub: Larva differed markedly from the two preceding stages. The body of larva was scarabeiform in shape with retracted head. The length was 1.69 to 2.15 mm (2.01) and the width was recorded in the range of 0.69 to 0.85 mm (0.74). The morphological observations were also found similar to the results obtained by Potter [13] who noticed that the third instar was scaraebiform in shape with 2.04 mm long, and Gururaj [14] observed 2.058 mm length and 0.650 mm breadth in third instar grub, respectively.

3.1.5 Fourth instar grub: Fourth instar resembled the third instar larva except for its size. Head was light brown and the mandibles appeared with dark-brown color. The larval length ranged from 2.35 to 2.99 mm with average of 2.78 mm and width ranged from 0.83 to 1.12 mm with an average of 0.92 mm. Morphometric measurements are found in close confirmation with the results of Gururaj [14] who recorded the mean length of 2.900 mm and width of 0.826 mm.

3.1.6 Pre-pupa: It was relatively immobile, but capable of limited wriggling. The length was 2.62 to 2.94 mm with an average of 2.82 mm and width ranged from 0.86 to 1.13 mm with an average of 0.94 mm. The morphometric measurements were not in confirmation with Potter [13] who recorded the mean length of 3.15 mm. This difference may be due to the variation in seed physical and bio-chemical quality parameters of different cereals.

3.1.7 Pupa: The pupa was execrate in form, whitish in colour, with a depressed head and enlarged thorax. The length was 2.83 to 3.39 mm with an average of 3.07 and width was 0.93 to 1.21 mm with an average of 1.03 mm. The morphometric measurements are contrasting to results obtained by Gururaj [14], who recorded the mean pupal body length of 3.422 mm and width of 0.927 mm. These variations could be due to the differences in seed quality, size, presence of nutrients and biochemical constituents in different cereals as well as weather conditions prevailing in their locations.

3.1.8 Adult: Body was cylindrical in shape and reddish-brown to dark brown in color. Head retracted into the hood like pronotum, antennae ten segmented with a terminal three segments jointed to form loose club. The elytra were slightly convex with series of rows of small depressions and backwardly projected short setae. Externally males and females were similar. Adult males were differentiated by the presence of a distinct transverse, punctuate groove on the fifth abdominal sternite of the male while that was absent in females. These present observations are in agreement with the results of Ghorpade and Thyagarajan [11]. The male adults measured with 3.31(± 0.18) mm length and 1.26 (± 0.08) mm width. The female adult beetles were comparatively larger in size than male beetles with a length of 3.63 (± 0.22) mm and width of 1.47 (± 0.14) mm.

3.2 Biology of lesser grain borer *R. dominica* on Maize seeds

Higher mortality rates of eggs and first instar larvae were

recorded during winter (November-December, 2014) due to the following reasons, namely 1) incidence of larval parasitoids like, *Anisopteromalus calandrae* (Howard) and *Theocolax elegans* (Westwood) (Hymenoptera: Pteromalidae), 2) predatory mite infestation *Pyemotes ventricosus* Newport (Acari: Pyemotidae) on eggs and grubs and 3) due to the low temperature prevailed during that season. Due to low temperature *R. dominica* laid lower number of eggs which could not hatched because of unfavorable conditions. Because of the above mentioned reasons we did not get required number of larvae to carry out further biology studies in *rabi*/winter season.

3.2.1 Duration (days) of different immature stages

Incubation period was ranged from 8 to 13 days with an average 9.64 days during *kharif* and 6 to 9 days with an average 7.56 days during summer season. The first, second, third, fourth larval, prepupal and pupal stages occupied duration of 9 to 13 (10.44), 8 to 12 (9.32), 8 to 11 (9.24), 9 to 13 (10.32), 1 to 2 (1.68) and 8 to 12 (10.32) days, respectively during *kharif* season. In the same manner the first, second, third, fourth larval, prepupal and pupal stages completed their duration in 7 to 10 (8.28), 6 to 9 (7.48), 6 to 9 (7.28), 7 to 10 (8.24), 1 to 2 (1.44) and 6 to 9 (7.96) days, respectively during summer season. The total grub period ranged from 35 to 45 (39.32) during *kharif* and in 27 to 35 with an average of 31.28 days in summer season.

The results match the observations by Kumawat [15] who recorded incubation period of 9.3 days at 25±1 °C and 65±5 percent relative humidity on wheat. Thomson [16], Sattigi *et al.* [17] and Elek [18] also recorded similar incubation period of 9 days on milo grains, 5 to 9 days on sorghum and 8.7 days on wheat, respectively under laboratory conditions. The results obtained during *kharif* season are not in confirmity with the findings of Elek [18] who recoded the mean grub duration of 13.9, 6.3 days for first and second larval instars at 26 °C in wheat; however his observations on first instar as 9.6 days at 30 °C and fourth instar as 9 days at 26 °C supported the present results. The results obtained during summer season are in close conformity with the observations made by Gururaj [14] who recorded the mean second, third and fourth instar larval duration as 7.82, 7.04 and 9.27 days on finger millet. The present findings on mean prepupal duration are supported by Potter [12] and Sattigi *el al.* [17] who recorded the pre-pupal period of 1½ days days in wheat and 1 to 2 days in sorghum respectively. However, the reports on mean pupal period of 5 to 8 days on sorghum [17], 6.5 days on wheat [19] and 7 to 8 days on finger millet contradict the present results [14]. These results regarding total grub period are not in agreement with that of Pruthi and Singh [20], Sattigi *et al.* [17], Hashem [19] and Gururaj [14] they reported that the total larval duration lasts for 20 to 30 days in wheat, in India, 14 to 28 days on sorghum in Karnataka, 19 days on wheat in Germany and 28 to 34 days on finger millet, in Karnataka respectively. These variations could be due to the differences in seed physical and bio-chemical quality parameters of different cereals as well as the effect of weather conditions prevailing in their locations on larval development.

Table 3: Developmental period (days) of different stages of *R. dominica* on seeds during *kharif* season (July-August, 2014) and summer season (March-April, 2015)

Insect stages	*Kharif* season		Summer season	
	Range	Mean±S.D.	Range	Mean±S.D.
Egg	8 to 13	9.64±1.47	6 to 9	7.56±1.12
I instar	9 to 13	10.44±1.42	7 to 10	8.28±0.98
II instar	8 to 12	9.32±1.28	6 to 9	7.48±1.16
III instar	8 to 11	9.24±1.09	6 to 9	7.28±1.17
IV instar	9 to 13	10.32±1.44	7 to 10	8.24±1.13
Total larval period	35 to 45	39.32±2.85	27 to 35	31.28±2.35
Pre-pupa	1 to 2	1.68±0.48	1 to 2	1.44±0.51
Pupa	8 to 12	10.32±1.31	6 to 9	7.96±0.73
Total Developmental Period	54 to 72	60.96±4.12	42 to 52	48.24±2.47

n=25

3.2.2 Total development period

The shorter developmental periods were recorded in summer season, 48.24 days (42 to 52) and longer developmental periods were recorded during *kharif* season, 54 to 72 with an average of 60.96 days. These results are closely supported by the findings of Gururaj [14], Kumawat [15] and Sujatha *et al.* [21] they reported the mean total developmental period of 45.69 days on finger millet, 46.49 days at 30±1 °C in wheat and 44.99 days on maize under laboratory conditions, respectively. This variation was in agreement with the results of Kumawat [15] who registered the mean total developmental period of 61.67 days at 25±1 °C in wheat. These variations in total developmental period may be due to the difference in temperature and relative humidity in both seasons. As temperature increased during summer season, the feeding and metabolic activities of insect also increased, thereby larval development was faster and completed its development with a shorter duration in summer as compared to that in *kharif* season. The obtained results on total developmental period of *R. dominica* on maize seeds showed that, it took relatively longer duration as compared to the other hosts. This was supported by the findings of Kumawat [15] who reported the lowest growth index of *R. dominica* on maize (1.38) which differed from that on wheat (1.89) and paddy (1.71). This result is also further supported by Sujatha *et al.* [21] who studied the population growth of *R. dominica* on different host grains and reported that total developmental period was longer in maize (44.99 days) which differed considerably from that on wheat (39.63 days) and paddy (41.15 days).

3.3 Duration (days) of different activities in adult stage

3.3.1 Pre-mating period: The study on pre mating period revealed a mean of 18.16 h on during *kharif* and 17.12 h in summer season. Present observations were closely similar to the findings of Thomson [15] and Gururaj [13] who visualized that the mating in *R. dominica* occurs within 24 h after eclosion.

3.3.2 Mating period: The mating period ranged from 45 to 90 min (69.36) during *kharif.* During summer 2015 pre-mating period was took 35 to 80 min (64.32). Thyagarajan [11], Sattigi *et al.* [17] and Gururaj [14] also recorded the mating

period of 85 min in wheat, 43 to 127 min in sorghum and 51 to 123 min with an average of 81.53 min in finger millet, respectively.

3.3.3 Pre-oviposition period: Pre-oviposition period ranged from 6 to 13 (8.96) days during *kharif*. The pre-oviposition period was shorter ranged from 6 to 13 (7.92) days during summer. The present findings are in close agreement with Sattigi *et al.* [17] and Gururaj [14] who recorded 5 to 8 days and 6 to 9 days of pre-oviposition period on sorghum and finger millet under laboratory conditions, respectively. However the pre-oviposition recorded during summer season was contradicting with the findings of Abdul-Matin [22] who observed a pre-oviposition period ranging from 11.8±1.2 days at 31.5 °C and 67 per cent relative humidity. These variations may be due to the effect of temperature and relative humidity on adult reproductive behavior during the course of study, and difference in duration of adult longevity during different seasons.

3.3.4 Oviposition period: Oviposition period ranged from 13 to 29 (19.88) days during *kharif*. During summer season it was in the range of 14 to 26 (17.88) days. The present findings do not agree with the results of Sattigi *et al.* [17] and Gururaj [14] who recoded the oviposition period in the range of 28 to 45 (34.20) days on finger millet. As the longevity of adults were of lesser duration compared to that on other cereals, this might be a reason for the lesser oviposition period on maize compared to other hosts. Other reasons might be the difficulty of adult female in feeding coarse textured maize kernels during the period of oviposition and absence of suitable places for oviposition, as adult female preferably deposited her eggs at the tip of maize seeds that covered by dry papery layers. Adult female was found to deposit the eggs only at tip of maize seeds; however the percentage of egg laying was significantly higher in the seeds that covered with papery layers at the tip. This was supported by Golebioska [23] who reported that oviposition was the highest during the first day, decreasing progressively till the 10th day, increasing up to the 24th day and again decreasing towards the end.

3.4 Sex ratio, Fecundity and Adult longevity

3.4.1 Sex ratio: The sex ratio (female: male) was of 1: 1.10 during *kharif* and in summer season it was observed with high sex ratio i.e., 1: 1.13. The observations made on sex ratio indicated the predominance of males over females, particularly more pronounced in summer season than *kharif* season. Similar results were obtained by Kumawath [15] in wheat, 1: 1.08, 1: 1.15 and 1: 1.14 at 25±1, 30±1 and 35±1 °C, respectively. But the obtained results on sex ratio of *R. dominica* in maize were in contradiction with the results of Gururaj [14] who documented the sex ratio of, 1: 1.135 in laboratory culture and 1:1.675 in godown culture of *R. dominica* on finger millet. These variations may be due to the difference in nutritional quality of hosts and climatological conditions prevailed in different seasons

Table 4: Adult longevity and fecundity of *R. dominica* on maize seeds during *kharif* season (August-September, 2014) and summer season (April-May, 2015)

Insect stages	*Kharif* season		Summer season	
	Range	Mean±S.D.	Range	Mean±S.D.
Pre-mating period (h)	16 to 21	18.16±1.70	14 to 21	17.12±2.05
Mating period (min)	45 to 90	69.36±13.47	35 to 80	64.32±16.06
Pre-oviposition period (d)	6 to 13	8.96±1.99	6 to 13	7.92±2.45
Oviposition period (d)	13 to 29	19.88±4.86	14 to 26	17.88±3.84
Fecundity	45 to 85	71.60±11.20	65 to147	98.92±22.86
Male adult longevity (d)	16 to 30	26.08±4.68	13 to 25	19.52±3.31
Female adult longevity (d)	23 to 33	28.64±2.69	14 to 29	21.88±5.33
Sex ratio (Female: Male)	1.04 to 1.16 :1	1.10:1±0.04	1.08 to 1.22:1	1.13:1±0.04

n=25

3.4.2 Fecundity: Fecundity varied in both seasons as in *kharif* it ranged from 45 to 85 (71.60) and during summer fecundity was significantly higher than *kharif* season, 65 to 147 (98.92). The results are supported by the observations of Sattigi *et al.* [17] who observed average fecundity of 64.5 eggs with a range of 20 to 110 eggs in sorghum. However, present observations on fecundity during different seasons were contrasting with the results of Gururaj [14] and Kumawat [15] who observed the average fecundity of 28.57 eggs in finger millet and 115 to 135 at 25±1 °C and 284 to 307 at 30±1 °C, at 65 to 85±5 per cent RH in wheat respectively. The variation of fecundity levels of *R. dominica* in different cereals may be due to the difference in their physical and bio-chemical properties. The results are supported by the study of Tariq [24] who observed the low rate of reproduction in maize (121 adult emergence per 5 pair of adults released) compared to the higher rate of reproduction in wheat, indicating that maize was not seem to be a productive host for *R. dominica*. The variation in fecundity during different seasons may due to the effect of temperature and relative humidity on oviposition behavior and capacity of female beetle.

3.4.3 Adult longevity: Longevity of males ranged from 16 to 30 (26.08) in *kharif* season to 13 to 25 (19.52) during summer season, while that of females ranged from 23 to 33 (28.64) during *kharif* and 14 to 29 (21.88) days in summer season. The obtained results showed that adult longevity of both sexes were relatively longer during *kharif* season, as during this season the prevailed temperature and relative humidity favored slower development. Present results were in confirmation with the results of Kumawat [15] who reported that the longevity of the male was less than the female in wheat. Mean female longevity was 30.76 days at 25±1 °C and 24.40 days at 30±1 °C, whereas mean male longevity lasted for 28.24 days at 25±1 °C and 22.18 days at 30±1 °C and 65 to 85±5 per cent relative humidity. But the present findings differ from results of Sattigi *et al.* [17] and Gururaj [14] who observed that, the longevity was from 41 days to 87 days for females and 37 to 78 days for males, on sorghum grains and 43 to 71 days (54.70) for females and 37 to 54 (43.20) days for males on finger millet respectively. These results indicated that, adult longevity of both sexes were considerably lower compared to other host grains, this may be due to hardness of kernels and biochemical factors present in maize seeds.

3.5 Mean survival of different developmental stages

The highest per cent (mean: 70.56 %) survival of eggs was recorded during summer season with the range from 41 to 98

per cent, which significantly differed from that of *kharif* season where mean egg survival was in the range of 25 to 58 per cent (40.68 %). Maximum number of first instar larvae survived during summer season where mean survival was 57.32 per cent, which significantly differed from that of *kharif* (35.96 %). Same trend was observed for second instar also, where survival rate was low during *kharif* (33.12 %) compared to 50.28 per cent in summer. Highest mean survival of third instar larvae was recorded from 29 to 68 percent (46.76 %) during summer and lowest mean survival of 21 to 45 per cent (30.68 %) observed in *kharif*. Maximum number of fourth instar larvae survived during summer (42.12 %) and lower survival rate was in *kharif* (28.08 %). Mean survival of pre-pupae was higher in summer ranged (39.72 %) and lower in *kharif* (27.72 %). Similarly maximum number of pupae survived during summer which (33.84 %) and lower survival rate was recorded during *kharif* (23.16 %).

Table 5: Mean survival of different developmental stages (%) of *R. dominica* onmaize seeds during different seasons (2014-2015)

Insect stages	Survival (%)			
	Kharif (July-August,2014)		Summer (March-April,2015)	
	Range	Mean±S.D.	Range	Mean±S.D.
Egg	25 to 58	40.68±10.30	41 to 98	70.56±18.45
I instar	23 to 49	35.96±7.12	36 to 82	57.32±15.29
II instar	22 to 47	33.12±7.28	32 to 74	50.28±14.33
III instar	21 to 45	30.68±7.10	29 to 68	46.76±12.64
IV instar	18 to 37	28.08±5.38	25 to 56	42.12±11.02
Pre-pupa	18 to 39	27.72±6.54	23 to 52	39.72±9.36
Pupa	16 to 34	23.16±4.56	18 to 47	33.84±7.20

These variations with respect to survival rate of different developmental stages during different seasons may be due to the climatic factors that prevailed during those periods. Low temperature prevailed during winter season (November-December, 2014) was one of the major reasons for the highest mortality of eggs than other two seasons. Other possible reasons might be lower fecundity and reproduction levels of *R. domonica* on maize, and hardness of kernels which made it difficult for first instar grub to enter inside and feed further. Apart from these, the larval parasitoids like, *Anisopteromalus calandrae* and *Theocolax elegans*, and egg predatory mite *Pyemotes ventricosus* contributed to increased mortality of eggs and first instar grubs.

These findings were supported by Birch [25] who reported that fewer or no eggs were deposited in wheat grains at temperatures below 18 °C, or above 39 °C. The present findings are also supported by Kumawat [15] who recorded minimum mean egg survival rate (2.00 %) at 40±1 °C temperature and 65±5 per cent RH and maximum (74.00 %) at 30±1 °C temperature and 75±5 and 85±5 per cent RH. The minimum mean survival rate of combined larval and pupal stage (29.50 %) was recorded at 25±1 °C temperature and 65±5 per cent RH and maximum (75.61 %) at 30±1 °C temperatures and 85±5 per cent RH.

4. Conclusion

The present studies clearly revealed that the *R. dominica* completed its total developmental period at slower rate with 54 to 72 (60.96) days of duration during *kharif* season whereas it took relatively shorter developmental duration during summer season i.e., 42 to 52 (48.24) days. Higher mean survival rate of different developmental stages were recorded during summer season (March-April, 2015) and lower survival rate was observed during *kharif* season (July-August, 2014). Highest mean mortality of different developmental stages was observed in winter season (November-December, 2014).

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