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# Effect of temperature and food on the biology of Khapra beetle, *Trogoderma granarium* Everts

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**Abstract**
The effect of temperature and type of food on biology of khapra beetle, *Trogoderma granarium* was determined at temperatures of 30 °C, 32 °C, 35 °C and 40 °C and on different types of food *viz*., whole grain, crushed grain and flour of wheat in laboratory. The results show that unmated females lived 12-28 days, mated females 5-11 days and unmated males 4-17 days, mated mates 3-13 days, and the adult longevity decreased with increasing temperature. The fecundity and fertility were the maximum at 35 °C which declined at lower and higher ranges of temperature. The incubation period was the maximum at 30 °C which decreased with increasing temperature. The larval life was the shortest at 35 °C, of 19.5 days for males on flour and 23 days for female on crushed grain. The pupal period of females was usually longer than the males and duration decreased with an increase in temperature. The total developmental period was the minimum at 35 °C while maximum at 30 °C on all the tested food types. The survival rate was the maximum at 35 °C on flour whereas; it was markedly decreased at 40 °C and on whole grain.

**Keywords:** *Trogoderma granarium*, Khapra beetle, temperature, biology, life cycle

## 1. Introduction
The Khapra beetle (*Trogoderma granarium* Everts), also called cabinet beetle or warehouse beetle [1] at some places, is a cosmopolitan insect and considered to be one of the most destructive pest of stored grain products [2]. It is categorized among the 100 worst invasive species worldwide [3]. It is believed to be native to Indian subcontinent and spread to Africa, Europe, South America and eastern Asia through trade [4, 5]. Many countries have specific quarantine regulations against possible importation [6]. It occurs in hot, dry conditions with a mean temperature greater than 20 °C and an RH below 50%, and may be found in grain stores, food stores, malt houses, seed processing plants fodder production plants, dried milk factories, merchant stores, stores of packing materials. They prefer grains, oilseeds, cereal products particularly wheat, barley, oats, rye, maize, rice, flour, malt and noodles and, to a lesser extent, pulses [7]. They can feed on dried products with as little as 2% moisture contents [8, 9]. In India, it is a serious pest of stored wheat [10]. The larval stage is generally responsible for damage and adults don not normally feed or feed very little, if at all. Young larvae feed on damaged grains, while older larvae are able to feed on whole grains [11, 12]. They can cause a weight loss between 5-30% and may be extent up to 70% in severe cases [8]. In addition, it is pest of health concern, its exuviae, hairs and other body parts may cause respiratory diseases and skin irritation [13, 14].
In India, *T. granarium* causes significant weight loss in wheat in Punjab [15]. In term of number of grains, they may cause an average damage ranged from 6 to 33% in a single storage season and may go up to 73% [4]. At 36 ºC and 15% infestation level, they may cause 2.6% weight loss and 24% viability loss in wheat [16]. Moreover, it decreases the amount of protein, gluten, crude fat, sedimentation value, reducing and non-reducing sugars and ash, and also affects germination and causes a weight loss of 16.36% in wheat [17].
Its development rate and survival is generally affected by host species, temperature, light, moisture and season [8]. Optimum conditions for development do not correspond well with its geographic distribution. Its life cycle greatly depends on food availability and quality, temperature and humidity, and can complete one to more than ten generations per year [6]. The larval stage enters diapause during winter season and may last from a month to a year, and also can survive without food for several years [8]. Larval development is very rapid in hot, humid conditions and does not occur at temperatures below 21 °C, but can proceed at very low humidity, for example at 25 °C and 2% RH [7].

In nature, constant condition of environment does not exist. Duration of different stages in the life cycle of *T. granarium* is significantly affected due to daily fluctuations of temperature and relative humidity [18]. At low temperature, the population growth is decreased significantly and larvae may undergo diapause [19]. Therefore, the present study was carried out under laboratory condition to determine the effect of temperature and food on the biology of khapra beetle, *Trogoderma granarium* Everts.

## 2. Materials and methods

The present study was carried out during July-August, 2016 in BOD incubator in Division of Entomology, Indian Agricultural Research Institute, New Delhi to determine the effect of temperature and food on different stages of *T. granarium*.

### 2.1 Rearing of insect and egg laying

Culture of *T. granarium* was maintained in glass jars containing wheat at a temperature of 32±1 ºC and relative humidity of 65±5%. The whole wheat grains were sterilized in oven at 60 ºC for five hours. The sterilized grains were, then broken in grinder and poured in jars covered with muslin cloth. Five pairs of newly emerged beetle from the culture were placed separately in egg laying jars and allowed them to lay eggs at each temperature *i.e.* 30 ºC, 32 ºC, 35 ºC and 40 ºC. The folded pieces of paper were also placed with adult beetles to facilitate the egg laying.

### 2.2 Observation

Once the egg laying started, eggs were collected daily in separate petri dishes and total numbers of eggs, incubation period, hatchability percentage, oviposition period and longevity of adults were recorded. Number and hatching of eggs were recorded with the help of binocular microscope. To record incubation period, ten eggs were placed in a petri dish and replicated thrice. The same numbers of adult beetles at each temperature were also maintaining separately to record the longevity of unmated adults. The newly hatched larvae were separated and placed in the plastic vials containing 2 g of different foods *viz*., whole grain, crushed grain and flour of wheat. Only one larva was kept in each vial and replicated ten times for each food and temperature. The larvae were examined daily and moults were identified by the presence of exuviae of previous instar. In this way, the duration of different larval instars and pupal stage was recorded.

## 3. Results

The female was bigger than the male, nearly double in size. In general, female lifespan was longer than the male. The longevity of unmated females was longer than the mated females. For example, at 30 ºC, unmated females lived from 21 to 28 days while mated females lived from 9 to 11 days. Same trends were found in case of males. The longevity of unmated males was ranged from 11 to 17 days while it was ranged from 5 to 13 days in case of mated males at 30 ºC. The longevity of adults decreased with increasing temperature. For instance, at 40 ºC, unmated females lived from 12 to 16 days while mated females lived from 5 to 7 days. Similarly, unmated males lived from 4 to 8 days while mated males lived from 3 to 5 days at 40 ºC (Table 1).

The oviposition period decreased with increasing temperature. For example, at 30 ºC, the egg laying period was ranged from 5 to 8 days while, from 3 to 4 days at 40 ºC (Table 1). Eggs are deposited singly. The number of eggs laid by the females ranged from 35 to 52 at different ranges of temperature. At 30 ºC, number of eggs was ranged from 35 to 46. The number of eggs increased with an increase in temperature to a maximum at 35 ºC which ranged from 42 to 52. A further increasing in temperature to 40 ºC resulted in decreasing the number of eggs (Table 1). The egg hatching was taken place at all ranges of temperature with a maximum percentage at 35 ºC. Relatively lower percentages of hatching were recorded at 30 ºC and 40 ºC (Table 1). The incubation period was decreased with an increase in temperature. It was recorded an average of 6.5, 5.5, 4.5 and 4.5 days at temperature of 30 ºC, 32 ºC, 35 ºC and 40 ºC respectively (Table 3).

Generally, female larva had one additional moult than the male and required some more days to complete development than the male. Mostly, females moulted five times and males moulted four times. However, at higher temperature of 40 ºC, males were found to be moulted five times. The larval duration was decreased with an increase in temperature from 30 ºC to 35 ºC and again increased with a further increase in temperature to 40 ºC. The shortest length of larval period was noted at 35 ºC. Regarding different types of food, the minimum larval period was found with broken grain for all the ranges of temperature (Table 2&3).

Pupation takes place within the skin of last larval instar. The male pupa was smaller than the female. The duration of pupal stage was decreased with an increase in temperature. The pupal periods of both sexes showed little variation. In most of cases, female pupal period was longer than that of male (Table 3).

The total developmental period from egg to adult for male was ranged from 30.25 to 38.17 days and for female, from 33 to 49 days at all the ranges of temperature in all types of food. The shortest developmental period for both the sexes was noted at 35 ºC in the food of crushed grain (Table 3).

The survival rate was markedly decreased at 40 ºC. It was also greatly affected by food. The insects reared in flour showed highest survival rates than that of crushed or whole grain. Cent percent survival rate was recorded at 35 ºC in flour. Up to 80 and 60 percent survival rates were noted in insects reared on crushed and whole grain, respectively (Table 3).

**Table 1:** Adult longevity, oviposition period, and fecundity (mean±SE), and percent hatchability of *Trogoderma granarium* at different temperatures

| Temperature | Longevity (in days) | | | | Oviposition period (in days) | Eggs/ female | Hatchability (%) |
|---|---|---|---|---|---|---|---|
| | Unmated male | Unmated female | Mated male | Mated female | | | |
| 30 °C | 13.8±1.06 | 25.4±1.20 | 10.8±1.49 | 10.2±0.37 | 6.2±0.48 | 40±1.9 | 73.50 |
| 32 °C | 11.8±0.86 | 23.2±1.01 | 9.6±0.92 | 9.2±0.48 | 5.6±0.24 | 42±2.4 | 83.33 |
| 35 °C | 9.0±1.00 | 19.4±1.30 | 7.4±0.87 | 7.8±0.37 | 4.8±0.37 | 46±1.8 | 86.95 |
| 40 °C | 6.0±0.63 | 14.2±0.73 | 4.4±0.40 | 5.6±0.40 | 3.4±0.24 | 39±1.4 | 73.33 |

**Table 2:** Duration (mean±SE) of larval instars of *Trogoderma granarium* at different food and temperatures

| Food | Sex | Mean duration of larval instar (in days) | | | | | | Total larval duration |
|---|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI | |
| 30° ± 1° C and 65 ± 5% RH | | | | | | | | |
| Flour | M | 5.17±0.54 | 4.5±0.34 | 4.67±0.42 | 4.33±0.55 | 5.5±0.56 | - | 24.17±0.3 |
| | F | 6.00±0.00 | 5.0±1.00 | 4.50±0.50 | 6.00±0.00 | 6.0±1.00 | 8.0±3.00 | 35.50±2.5 |
| Crushed grain | M | 5.50±0.50 | 4.0±0.00 | 5.00±0.00 | 3.50±0.50 | 4.0±0.00 | - | 22.00±1.0 |
| | F | 5.33±0.30 | 4.0±0.57 | 4.67±0.30 | 5.00±0.57 | 6.0±0.57 | - | 25.00±1.0 |
| Whole grain | M | 6.00±0.00 | 5.0±1.00 | 3.50±0.50 | 4.50±0.50 | 5.5±0.50 | - | 24.50±0.5 |
| | F | 6.25±0.25 | 4.5±0.28 | 4.75±0.25 | 4.50±0.28 | 6.0±0.40 | 5.5±0.64 | 31.50±0.8 |
| 32° ± 1° C and 65 ± 5% RH | | | | | | | | |
| Flour | M | 6.4±0.24 | 4.6±0.5 | 4.4±0.24 | 4.6±0.24 | 5.2±0.37 | - | 25.2±0.58 |
| | F | 6.0±0.00 | 4.0±0.0 | 5.0±0.00 | 4.5±0.50 | 5.5±0.50 | 5.0±1.00 | 30.0±1.00 |
| Crushed grain | M | 5.0±0.00 | 4.0±0.0 | 4.5±0.50 | 4.0±1.00 | 4.5±0.50 | - | 22.0±1.00 |
| | F | 4.5±0.50 | 4.5±0.5 | 4.0±0.00 | 4.5±0.50 | 5.0±0.00 | 5.0±0.00 | 27.5±0.50 |
| Whole grain | M | 5.5±0.50 | 4.5±0.5 | 4.5±0.50 | 5.0±1.00 | 5.5±0.50 | - | 25.0±1.00 |
| | F | 6.5±0.50 | 4.0±1.0 | 4.5±0.50 | 4.5±0.50 | 5.0±1.00 | 5.5±0.50 | 30.0±2.00 |
| 35° ± 1° C and 65 ± 5% RH | | | | | | | | |
| Flour | M | 3.83±0.30 | 3.67±0.21 | 3.83±0.16 | 3.83±0.16 | 4.33±0.42 | - | 19.5±0.56 |
| | F | 4.25±0.25 | 3.50±0.28 | 4.00±0.00 | 3.75±0.25 | 5.75±1.37 | 4.25±0.25 | 25.5±1.70 |
| Crushed grain | M | 5.00±1.00 | 4.00±0.00 | 3.50±0.28 | 3.50±0.28 | 4.00±0.40 | - | 20.0±1.35 |
| | F | 5.00±0.70 | 5.00±0.70 | 3.75±0.25 | 3.75±0.25 | 5.50±0.86 | - | 23.0±1.35 |
| Whole grain | M | 6.00±0.40 | 3.50±0.28 | 4.00±0.40 | 4.00±0.00 | 4.50±0.28 | - | 22.0±0.40 |
| | F | 4.50±0.50 | 4.50±0.50 | 4.00±0.00 | 4.00±0.00 | 4.00±0.00 | 4.50±0.50 | 25.5±0.50 |
| 40° ± 1° C and 65 ± 5% RH | | | | | | | | |
| Flour | M | 5.0±0.0 | 4.0±0.0 | 3.0±0.0 | 4.0±0.0 | 3.5±0.5 | 4.5±0.5 | 24.0±0.0 |
| | F | 5.5±0.5 | 4.0±0.0 | 3.0±0.0 | 4.5±0.5 | 3.0±0.0 | 7.0±1.0 | 27.0±2.0 |
| Crushed grain | M | 5.0±0.0 | 3.5±0.5 | 4.0±0.0 | 3.5±0.5 | 3.5±0.5 | 4.0±0.0 | 23.5±0.5 |
| | F | 5.5±0.5 | 4.0±1.0 | 3.5±0.5 | 4.5±0.5 | 5.0±1.0 | 4.5±0.5 | 27.0±4.0 |
| Whole grain | M | 4.5±0.5 | 3.5±0.5 | 4.5±0.5 | 4.5±0.5 | 5.0±0.0 | 5.0±1.0 | 27.0±2.0 |
| | F | 6.5±0.5 | 4.0±0.0 | 3.5±0.5 | 4.0±0.0 | 4.5±1.5 | 6.5±1.5 | 29.0±1.0 |

M = male F = female

**Table 3:** Duration (mean±SE) of different stages of *Trogoderma granarium* at different food and temperatures

| Food | Sex | Mean duration of different stages (in days) | | | Total duration | Percentage survival |
|---|---|---|---|---|---|---|
| | | Egg | Larval | Pupal | | |
| 30° ± 1° C and 65 ± 5% RH | | | | | | |
| Flour | M | 6.5±0.5 | 24.17±0.30 | 7.50±0.99 | 38.17±1.10 | 80 |
| | F | | 35.50±2.50 | 7.00±0.00 | 49.00±2.5 | |
| Crushed grain | M | 6.5±0.5 | 22.00±1.00 | 6.50±0.50 | 35.00±1.50 | 60 |
| | F | | 25.00±1.00 | 7.00±0.57 | 38.50±1.52 | |
| Whole grain | M | 6.5±0.5 | 24.50±0.50 | 7.00±0.00 | 38.00±0.50 | 60 |
| | F | | 31.50±0.86 | 8.25±0.62 | 46.25±0.62 | |
| 32° ± 1° C and 65 ± 5% RH | | | | | | |
| Flour | M | 5.5±0.5 | 25.2±0.58 | 6.0±0.31 | 36.7±0.48 | 70 |
| | F | | 30.0±1.00 | 6.5±0.50 | 42.0±0.50 | |
| Crushed grain | M | 5.5±0.5 | 22.0±1.00 | 5.5±0.50 | 33.0±1.50 | 60 |
| | F | | 27.5±0.50 | 8.5±2.50 | 41.5±2.00 | |
| Whole grain | M | 5.5±0.5 | 25.0±1.00 | 6.5±0.50 | 37.0±1.50 | 50 |
| | F | | 30.0±2.00 | 7.5±0.50 | 43.0±1.50 | |
| 35° ± 1° C and 65 ± 5% RH | | | | | | |
| Flour | M | 4.5±0.64 | 19.5±0.56 | 6.83±0.87 | 30.83±1.20 | 100 |
| | F | | 25.5±1.70 | 6.25±0.85 | 36.25±1.60 | |
| Crushed grain | M | 4.5±0.64 | 20.0±1.35 | 5.75±0.25 | 30.25±1.43 | 80 |
| | F | | 23.0±1.35 | 5.50±0.50 | 33.00±1.55 | |
| Whole grain | M | 4.5±0.64 | 22.0±0.40 | 5.25±0.25 | 31.75±0.62 | 60 |
| | F | | 25.5±0.50 | 6.00±1.00 | 36.00±1.50 | |
| 40° ± 1° C and 65 ± 5% RH | | | | | | |
| Flour | M | 4.5±0.5 | 24.0±0.0 | 6.0±1.0 | 34.5±1.0 | 50 |
| | F | | 27.0±2.0 | 6.5±1.5 | 38.0±3.5 | |
| Crushed grain | M | 4.5±0.5 | 23.5±0.5 | 5.5±0.5 | 33.5±0.0 | 40 |
| | F | | 27.0±4.0 | 6.0±0.0 | 37.5±4.0 | |
| Whole grain | M | 4.5±0.5 | 27.0±2.0 | 4.5±0.5 | 36.0±2.5 | 40 |
| | F | | 29.0±1.0 | 6.5±1.5 | 40.0±2.5 | |

M = male F = female

## 4. Discussion

This study shows the effect of temperature and types of food on the adult longevity, oviposition period, fecundity, fertility, and incubation period, developmental period of larvae and pupae, and survival. This pest prefers hot and dry condition, and can develop at a temperature ranged from 20˚ to 41 °C [20]. It can reproduce adequately at a minimum temperature of 24 °C and r.h. of 1% to become a pest but optimum range is 33-37 °C [21].

Male and female can be distinguished by their size because male is much smaller than the female [11, 22]. Adults are short-lived and life span of female is considerably longer than the male [11, 18]. They may live from a few days to several months, according to temperature [9]. The longevity of adults increases with a decrease in temperature in a certain range of development [9, 11, 18, 19, 23]. At or below 20 °C, the beetles become inactive and subsist for a relatively long period at low temperature [11]. Mated females live for 4-7 days, while unmated females live for 20-25 days. Males both mated and unmated live for 7-12 days [24]. Males generally emerge earlier than females with the intention that to have sufficient time to seek out for an appropriate site for mating [9, 18].

Oviposition is over in only some days. Oviposition period tends to increase with a decrease in temperature [11, 18]. For example, at 40 °C, oviposition period is completed after 3 or 4 days but, can extend up to 12 days at 25 °C. The number of eggs of *T. granarium* shows little variation but decline significantly at too low and high temperature [19, 23]. Under optimum conditions, the number of eggs is between 30 and 50 [11]. At or below 20 °C, no eggs are laid [11, 25]. The hatching percentage is maximum at 35 °C and relatively poorer at too low and high temperature [11, 18]. The incubation period decreases with an increase in temperature [9, 11, 18, 19, 26, 27]. In contrast, [23] obtained some different results. The incubation period decreases with an increase in temperature up to 35 °C and again increases significantly at 40 °C.

The number of larval instar varies and no definite number can be certain at any given temperature and humidity. Moreover, the number can vary among the individual of same female reared under similar conditions. The female generally undergoes one more moult than the male [11]. Usually females moult five times and males moult four times [18]. The overwintering larvae also moult occasionally to facilitate changes in the size and behavior [28]. The development period of larvae increases inversely with temperature [9, 19, 23, 25, 27]. It has a minimum larval period of 15 days at 35 °C that increases with a decrease in temperature below 35 °C, until 20 °C, where the larvae go into a state of quiescence. At 40 °C, larval period is again lengthened [11, 26].

The pupation takes place within the last larval skin. The size of male pupa is smaller than the female [11]. The pupal life of both sexes shows little variation [18]. The pupal period decreases as the temperature increases [9, 11, 19, 23, 27].

The total developmental period for males is shorter than females [19]. Under fluctuating condition of 25±5 °C, total life cycle is completed from 37 to 40 days [29]. The total duration may extend up to 220 days due to low temperature and may complete from 1 to 5 generations depending on food, temperature, and moisture [9]. The total duration may also be increased due to high temperature to some extend that creates adverse conditions for development [18].

Survival of insects highly depends on type of food. A high percentage of larval survival can be achieved when reared them on crushed wheat or whole wheat flour [22]. Young larvae are unable to attack and penetrate whole grain, until after the third moult [9, 11]. The survival rate is decreased considerably at 40 °C [11, 26]. It is also reduced considerably at 20 °C [23].

## 5. Conclusion

This comprehensive study of the biology of Khapra beetle may help in the implementation of suitable control measure.

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