



## A Comparative Analysis of Age-Stage Two Sex Life Tables in Distinct Forms of *Callosobruchus maculatus* (F.): Insights into Population Dynamics and Reproductive Strategies

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| Article History                                                          | Abstract                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
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| Received: 06 June 2023<br>Revised: 25 Sept 2023<br>Accepted: 01 Oct 2023 | <p><i>Callosobruchus maculatus</i>, the bean weevil, is a fascinating insect that showcases remarkable adaptations for survival. Found in tropical and subtropical regions, it has become a global pest due to its adaptability and hitchhiking capabilities, causing substantial grain losses. This small beetle, part of the Chrysomelidae family, serves as a valuable model organism in entomology and agricultural research. One of the key aspects of <i>Callosobruchus maculatus</i> that captures the attention of scientists is its dichotomy between active and inactive forms. These two forms represent distinct survival strategies employed by the beetle to navigate its ever-changing environment. The present study provides a comprehensive overview of the study on <i>Callosobruchus maculatus</i>, highlighting the two distinct forms of the species, their adaptations, and the significance of understanding their life table parameters. It emphasizes the ecological, practical, and research-oriented implications of this study, ranging from ecological insights to pest management strategies and the optimization of mass multiplication protocols. These forms exhibited notable differences in various life history parameters and survival characteristics. Flightless-inactive females had longer preoviposition and oviposition period and laid a significantly higher average of eggs per female with higher reproduction potential. Female fecundity (eggs/female) was much lower in the flight-active form (18.6) than in the flightless-inactive form (84.10) and maintained constant survival rate. Life expectancy values were generally lower for the flightless-inactive form compared to the flight-active form across different stages and sexes. Both males and females in the flight-active form exhibited a consistent and relatively high life expectancy, with a 100% chance of survival throughout all age intervals. Overall, these findings provide a comprehensive understanding of the differences in life history traits, reproductive strategies, and survival patterns between the flight-active and flightless-inactive forms of <i>Callosobruchus</i> beetles in a controlled laboratory environment.</p> |
| CC License<br>CC-BY-NC-SA 4.0                                            | <b>Keywords:</b> <i>Callosobruchus maculatus</i> , Green gram, Flight active, Flight inactive                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

### 1. Introduction

In the vast realm of the natural world, there exists a myriad of organisms that have developed extraordinary adaptations to ensure their survival. Among these remarkable creatures, the bean weevil *Callosobruchus maculatus* holds a special place. *Callosobruchus* beetles have gained prominence as model organisms due to their economic importance as pests of stored grains, as well as their biological characteristics that make them amenable to laboratory studies which are widely studied in entomology and agricultural research [1]. This small insect, belonging to the family Chrysomelidae, exhibits a fascinating dichotomy between its active and inactive forms, representing two distinct survival strategies employed to navigate its ever-changing environment. The characteristics, behaviors, and

adaptations associated with its active and inactive forms were explored. Originating from tropical and subtropical regions, this species has managed to spread globally due to its adaptability and hitchhiking abilities, posing significant economic implications in terms of grain losses.

The active form of *Callosobruchus maculatus* represents the weevil's primary mode of existence during favorable growing seasons. These individuals possess highly developed physiological and behavioral adaptations that facilitate their successful colonization and exploitation of host plants. Active *C. maculatus* showcase remarkable mobility, enabling them to disperse over long distances in search of suitable food sources. Equipped with strong mandibles adapted for piercing and chewing, they can penetrate the external layers of legume seeds, gaining access to the nutritive contents within. In terms of behavior, active *C. maculatus* exhibit the ability to locate suitable host plants through chemical cues emitted by the legumes. Courtship and reproduction are guided by mating displays and pheromones, ensuring the continuation of the species. Female weevils lay their eggs on the surface of cowpea seeds, providing the next generation with a nutritious environment in which to develop. In contrast to their active counterparts, the inactive form of *Callosobruchus maculatus* employs a fascinating strategy known as diapause, a state of arrested development triggered by unfavorable environmental conditions. Diapause allows these insects to withstand adverse periods such as drought, extreme temperatures, or scarcity of host plants. This inactive form is particularly prevalent in regions with pronounced seasonal changes, where it serves as an essential survival mechanism.

During diapause, the metabolic rate of *Callosobruchus maculatus* significantly decreases, leading to a reduction in overall energy requirements. This metabolic depression allows the weevils to conserve energy and endure extended periods of inactivity until conditions improve. Diapause is often regulated by external cues such as photoperiod (length of day and night), temperature, and humidity [2]. Once favorable conditions return, diapause is broken, and the weevil's transition back to their active state, resuming their life cycle. The distinct forms of *Callosobruchus maculatus*, active and inactive, are accompanied by a suite of adaptations that enable these insects to thrive in their respective environments. The active form's adaptations primarily revolve around host finding, feeding, and reproductive success. They possess sensory structures, such as antennae, that detect chemical cues released by host plants and potential mates. Additionally, their strong mandibles and specialized digestive systems allow them to extract nutrients from legume seeds effectively. The inactive form, on the other hand, relies on adaptations associated with survival during periods of unfavorable conditions. One such adaptation is the ability to enter diapause, which allows the weevils to escape environmental stressors and maximize their chances of survival. The metabolic adjustments during diapause ensure the conservation of energy reserves, facilitating prolonged survival until suitable conditions for activity return. From an ecological perspective, the duality of active and inactive states demonstrates the species' adaptability and versatility in coping with changing environments. Exploring the mechanisms behind diapause and its regulation provides valuable insights into the physiological and molecular aspects of dormancy. From an applied standpoint, studying *Callosobruchus maculatus* offers potential avenues for developing effective pest management strategies. By comprehending the weevils' behaviors, life cycle dynamics, and adaptations, researchers can devise innovative approaches to control infestations and minimize crop losses. This knowledge can contribute to the development of sustainable agricultural practices, ensuring food security in regions prone to *C. maculatus* outbreaks. Studying the life table of the active and inactive forms of *C. maculatus* plays a crucial role in understanding the population dynamics and life cycle of this species. This knowledge can greatly assist in mass multiplication efforts. Here are several ways in which studying the life table contributes to the success of mass multiplication:

- Identifying key life stages and their duration: The life table provides detailed information about the different life stages of *C. maculatus*, such as egg, larva, pupa, and adult. It helps determine the duration of each stage and the overall development time. Understanding the time required for each life stage allows researchers to optimize rearing conditions, predict population growth rates, and plan mass multiplication strategies accordingly.
- Estimating survival rates: The life table provides valuable insights into the survival rates at each life stage. By monitoring the number of individuals that successfully transition from one stage to another, researchers can calculate survival probabilities. This information is crucial for estimating population growth rates, predicting population sizes, and ensuring sufficient numbers of individuals for mass multiplication efforts.
- Assessing fecundity and reproductive potential: The life table allows researchers to determine the fecundity (number of offspring

produced) of *Callosobruchus maculatus* individuals. By examining the reproductive output of females, including the number of eggs laid and the fertility rate, researchers can estimate the reproductive potential of the population. This information is vital for optimizing breeding programs and ensuring a steady supply of individuals for mass multiplication. d) Understanding age-specific mortality and life expectancy: Analyzing the mortality rates at different life stages helps identify critical periods of vulnerability and mortality factors. This knowledge can guide the implementation of control measures to minimize losses during mass multiplication. Additionally, the life table allows for the calculation of life expectancy, which provides an estimate of the average lifespan of individuals. This information aids in determining the optimal timing for collecting and utilizing individuals for mass multiplication purposes. e) Predicting population growth and establishing production schedules: By incorporating the survival rates, fecundity, and development time derived from the life table, researchers can construct population projection models. These models provide insights into population growth patterns, allowing for the prediction of population sizes over time. With this information, production schedules can be established to ensure a continuous and sustainable supply of individuals for mass multiplication. Studying the life table of both the active and inactive forms of *Callosobruchus maculatus* provides a comprehensive understanding of their population dynamics, survival rates, reproductive potential, and development time. This knowledge assists in optimizing rearing conditions, estimating population sizes, predicting growth rates, and establishing production schedules for mass multiplication efforts. By leveraging this information, researchers can enhance the efficiency and success of mass multiplication programs, thereby meeting the demands for various applications, including research, biological control, or other purposes.

The flight-active form, characterized by a delayed period before oviposition and an extended lifespan, relies on energy reserves accumulated during the larval stages to support flight, egg production, and adult survival. In contrast, the flightless-inactive form encompasses the eggs, larvae, and pupae and displays different characteristics and behaviors. Analyzing and comparing the lifetable parameters of these forms provide valuable insights into their reproductive abilities, population growth potential, and survival strategies. The implications of studying the lifetable parameters of both forms extend to various fields of research. Firstly, it contributes to our understanding of the biology and behavior of *Callosobruchus* beetles. Researchers gain insights into their reproductive capabilities, energy allocation, and survival mechanisms, providing a comprehensive understanding of the species as a whole. This knowledge enhances research in ecology, entomology, evolution, and genetics, enabling more accurate modeling and prediction of population dynamics. Secondly, the lifetable study of *Callosobruchus* beetles holds significance for optimizing mass multiplication protocols. Mass multiplication is essential for ensuring a consistent and abundant supply of individuals for research and applications. By understanding the specific requirements and characteristics of each form, researchers can develop rearing protocols that maximize reproductive output, minimize mortality, and ensure a reliable supply of individuals. This contributes to the scalability and reproducibility of experiments involving *Callosobruchus* beetles. Furthermore, the lifetable study has practical implications for pest management. *Callosobruchus* beetles are notorious pests of stored grains, leading to significant economic losses globally. Understanding their lifecycles, reproductive potential, and population dynamics is crucial for developing effective pest management strategies. By identifying critical life stages, such as the flight-active form, interventions can be targeted to disrupt mating behaviors or target vulnerable developmental stages, mitigating infestations and minimizing grain losses. In conclusion, studying the lifetable parameters of flight-active and flightless-inactive forms of *Callosobruchus* beetles provides valuable insights into their biology, reproductive abilities, and population dynamics. It contributes to research in various fields, optimization of mass multiplication protocols, and the development of effective pest management strategies. The findings enhance our understanding of these pests, paving the way for advances in ecology, entomology, genetics, and agricultural research. By comprehensively examining the lifetable parameters of both forms, researchers can develop strategies to control and manage *Callosobruchus* beetles and improve the efficiency and sustainability of mass multiplication protocols.

## 2. Materials And Methods

Insect rearing: CO6 seeds which is highly susceptible to *Callosobruchus maculatus* were obtained from the ARS, Bhavanisagar and used for the rearing of test insect cultures and feeding experiments. The

initial population was obtained from a colony of this insect in a stored grain from ARS, Bhavanisagar. The insects were maintained on CO6 seeds at  $30 \pm 2$  °C,  $60 \pm 5\%$  RH and 12L: 12D h (light: dark) photoperiod. To maintain rearing conditions, cowpea weevil colonies were grown for two complete generations. Then, the third-generation adult cowpea weevil without anatomical deformities were used to perform the following experiments.

**Developmental time and survival:** All experiments were done in a growth chamber set at  $30 \pm 1$  °C, relative humidity of  $65 \pm 5\%$  and in complete darkness. To obtain *C. maculatus* eggs of the same age on each host seed, three male female pairs of the newly emerged beetles (reared from the same host) of the fourth laboratory generation were transferred to Petri dishes (diameter 9 cm, depth 2 cm). In order to assess the developmental time and survival, 80 eggs (one-day-old) of *C. maculatus* deposited on seeds of each legume species were transferred individually into Petri dishes (diameter 6 cm, depth 2 cm). Each Petri dish consisted of one egg laid on one seed. The eggs were inspected daily until hatching. Then, the Petri dishes were monitored daily until the emergence of all adults. The developmental time of immature stages and their survival were recorded.

**Adult life history:** For each treatment, one-day old virgin of both active and inactive female and male adults reared on the seeds were paired, and transferred into a Petri dish (diameter 6 cm, depth 2 cm). The adult female and male were sexed by the coloration, shape and size of their abdomens. The last segments of the female abdomen is enlarged and dark in color along both sides, whereas the last segments of the male abdomen is smaller and curves downward sharper than the female. These insects were checked daily for oviposition, and the number of eggs laid by the adults was recorded. This study was continued until the death of the female and male adults. Adult life history parameters including the fecundity (number of eggs laid per reproductive period), longevity (the duration between an adult emergence and its death), adult preoviposition period (APOP: the time between a female adult emergence and its first oviposition), total preoviposition period (TPOP: the time from the birth to the first oviposition) and oviposition period (the duration of adult oviposition) were recorded on each host seed.

**Life table parameters:** The age-specific survival rate ( $l_x$ ) and age-specific fecundity ( $m_x$ ) of active and inactive form of *C. maculatus* on CO6 seeds was calculated according to [3] Chi and Su (2006). The life table parameters including intrinsic rate of increase ( $r_m$ ), gross reproductive rate (GRR), net reproductive rate ( $R_0$ ), mean generation time ( $T$ ), and finite rate of increase ( $\lambda$ ) were calculated according to the age-stage, two-sex life table method using TWOSEX-MSChart [4] (Chi, 2016). The age-specific survival rate and age-specific fecundity were used to measure the intrinsic rate of increase ( $r_m$ ) using the following formula [5] (Huang and Chi, 2013):  $1/\lambda = \sum_{x=0}^{\infty} l_x m_x e^{-rx}$  Where  $l_x$  is the proportion of surviving individuals at age  $x$  and  $m_x$  is the number of female offspring per female in the age interval  $x$ . The gross reproductive rate (GRR) and net reproductive rate ( $R_0$ ) were measured as  $GRR = \sum_{x=0}^{\infty} P m_x$  and  $R_0 = \sum_{x=0}^{\infty} P l_x m_x$ . The mean generation time ( $T$ ) and finite rate of increase ( $\lambda$ ) were calculated as  $T = (\ln R_0) / r$  and  $\lambda = e^r$  [6] (Carey, 1993). The collected eggs were checked daily until the emergence of adults. Duration of adult longevity was also recorded daily until the death of the last female. After the emergence of adults, the females with males were placed into each plastic case containing chickpea. The duration of oviposition and post-oviposition periods as well as longevity, daily fecundity (eggs/ reproduction day), and total fecundity (eggs during reproduction period) were recorded for one generation. The life table was built based on the concepts as studied by [7] Chakraborty and Mondal (2015). For calculating the age-specific survivorship different parameters viz., age-specific survival ( $l_x$ ) and mortality ( $d_x$ ) were built. In case of age-specific female fertility life table age specific survival ( $l_x$ ) and average number of female offsprings ( $m_x$ ) for each age interval ( $x$ ) were employed. The other demographic parameters including gross reproductive rate (GRR) or potential fecundity, net reproductive rate ( $R_0$ ), approximate generation time ( $T_c$ ), innate capacity for natural increase ( $r_c$ ), true intrinsic rate of increase ( $r_m$ ), true generation time ( $T$ ), finite rate of natural increase ( $\lambda$ ), doubling time (DT), and weekly multiplication rate (WR), were calculated using survivorship and fertility schedules. Life table analysis using age-stage, two-sex life table approach from the raw life-history data of the 100 individuals of each species, parameters, i.e., developmental time, adult longevity, fecundity, adult mortality, intrinsic rate of increase ( $r$ ), the finite rate of increase ( $\lambda$ ), the net reproductive rate ( $R_0$ ), and the mean generation time ( $T$ ), were analyzed using the age-stage, two-sex life table approach

[7,8(Chi,1988; Chi and Su, 2006;). The mean and standard error of life table parameters were estimated using a bootstrap technique TWOSEX-MS Chart for the age-stage, two-sex life table analysis [9] (Chi, 1997). The program was designed in Visual BASIC for the Windows operating system and is available from [http:// 140.120.197.173/Ecology/prod02.htm](http://140.120.197.173/Ecology/prod02.htm) (Chung Hsing University) and <http://nhsbig.inhs.uiuc.edu.tw/wes/chi.html> (Illinois Natural History Survey).

**Data analysis:** The bootstrap technique uses 100,000 samples to obtain consistent estimates of the standard error of the life table parameters [11,12] assessed the variations between different pulses using a paired bootstrap study according to bootstrap percentile discrepancy confidence interval [13]. Data were analyzed using the SAS software version 9.3 [14] for assessing the host preference of *C. maculatus* cultured on different pulses and the susceptibility of green gram germplasm to *C. chinensis*. The one-way analysis of variance was performed for the original values of both host preference and growth index experiments for each parameter. Statistical interaction of the average values of host preference and growth index experiments was determined using the post hoc Tukey's Honestly Significant Difference test at  $P \leq 0.001$ .

### 3. Results and Discussion

Studying the lifetable parameters of flight-active and flightless-inactive forms of *Callosobruchus* beetles provides valuable insights into their biology, reproductive abilities, and population dynamics. This research contributes to various fields, including ecology, entomology, evolution, genetics, and agricultural research. It also helps optimize mass multiplication protocols and facilitates the development of effective pest management strategies. By comprehensively examining the lifetable parameters of both forms, researchers can improve our understanding of *Callosobruchus* beetles and work towards more efficient and sustainable approaches in their control and management

This is the 1<sup>st</sup> study of studying the comparative life table analysis of active and inactive form in India. Females of active and inactive forms laid average of 6.29 (0.52) and 84.10 (1.605) eggs/female, respectively. Thirty-nine eggs (n=40) were hatched successfully within the mean  $5.72 \pm 0.09$  days for active and  $5.74 \pm 0.095$  for inactive forms, and of these 82.5% (n = 33, with 19 females and 14 males) and 87.5% (n = 35, with 20 females and 15 males) emerged as adults, respectively (Table 1). The mean immature period was  $27.94 \pm 0.144$  and  $19.63 \pm 0.156$  days for active and inactive, respectively. Significant differences were observed in the total developmental times (egg to immature) of both sexes between the 2 forms,  $33.66 \pm 0.21$  days for active and  $25.37 \pm 0.251$  days for inactive. For Active, the female adult longevity ( $49.14 \pm 0.45$ ) was insignificantly longer than that of male ( $49.16 \pm 0.38$  days,  $P < 0.05$ ). The female adult longevity of Active was  $49.14 \pm 0.45$  days and of inactive was  $32.96 \pm 0.045$  ( $P < 0.05$ ), while the male adult longevity was  $49.16 \pm 0.385$  days and  $32.52 \pm 0.036$  days ( $P < 0.05$ ), respectively (Table 1).

**Table 1.** Developmental time (days), longevity (days), and fecundity (eggs/female) of *Callosobruchus maculatus*.

| Parameters                | Stage    | Active          |                   | Inactive        |                   |
|---------------------------|----------|-----------------|-------------------|-----------------|-------------------|
|                           |          | Sample size (n) | Mean $\pm$ SE     | Sample size (n) | Mean $\pm$ SE     |
| Development time (d)      | Egg      | 40(39)          | $5.72 \pm 0.09$   | 40(38)          | $5.74 \pm 0.095$  |
|                           | Immature | 39(33)          | $27.94 \pm 0.144$ | 40(35)          | $19.63 \pm 0.156$ |
| Adult longevity (d)       | Male     | 33(14)          | $49.16 \pm 0.38$  | 40(15)          | $32.52 \pm 0.036$ |
|                           | Female   | 33(19)          | $49.14 \pm 0.45$  | 40(20)          | $32.96 \pm 0.045$ |
| preadult                  | Preadult | 39(33)          | $33.67 \pm 0.178$ | 40(35)          | $25.13 \pm 0.091$ |
| Total longevity           | All      | 40(40)          | $43.08 \pm 2.156$ | 40(40)          | $31.03 \pm 0.117$ |
| APOP(d)                   | Female   | 33(19)          | $2.21 \pm 0.2487$ | 40(20)          | $0.23 \pm 0.416$  |
| TPOP(d)                   | Female   | 33(19)          | $35.63 \pm 0.434$ | 40(20)00        | $25.29 \pm 0.291$ |
| Fecundity(F) (egg/female) | Female   | 33(19)          | $6.29 \pm 0.52$   | 40(20)          | $84.10 \pm 1.605$ |
| Oviposition (days)        | Female   | 33(19)          | $3.68 \pm 0.24$   | 40(20)          | $7.62 \pm 0.023$  |

Additionally, the flight-active form had a shorter oviposition period with an average of 3.68 days, whereas the flightless-inactive form had a longer oviposition period with an average of 7.62 days. Adult preoviposition period, the duration from adult emergence to 1st oviposition, was 2.21(0.2487) days for active and was longer than that of inactive ( $0.23 \pm 0.416$ ,  $P < 0.05$ ). Also, the total preoviposition period (TPOP), i.e., the duration from egg to 1st oviposition, of active was significantly longer ( $35.63 \pm 0.434$ ) than that of inactive ( $25.29 \pm 0.291$ ,  $P < 0.05$ ). The female fecundity (eggs/female) was  $18.6 \pm 1.21$  for Active and  $84.10$  (1.605) for Inactive (Table 1). Relationship between female mean fecundity (F) and the net reproduction rate (R0) was given as  $F = (N/N_f) R_0$ , where N was the number of eggs used at the beginning of the life table study, and Nf as the number of females emerging from the N eggs [16] (Chi, 1988). In this paper, with  $N = 40$ ,  $N_f = 19$ , and  $F = 6.29$  for Active,  $R_0$  was  $2.82 \pm 0.066$ ; and with  $N = 40$ ,  $N_f = 20$ , and  $F = 84.10$  for Inactive,  $R_0$  was  $43.24 \pm 0.948$ . Population parameters calculated using the  $0.02 \pm 0.001$  for Active and  $0.14 \pm 0.001$  for Inactive; mean finite rate of increase (l) of  $1.03 \pm 0.001$  for Active and  $1.14 \pm 0.001$  for Inactive ( $P < 0.05$ ) per day (Table 2). The mean finite rate of increase (l) for both forms was followed by high net reproductive rate (R0) of  $2.82 \pm 0.066$  for Active and  $43.24 \pm 0.948$  for Inactive, with significant differences between means of the 2 parameters for each female offspring. There were significant differences between mean generation times (T) and the 2 other parameters (r and l),  $39.38 \pm 0.052$  days for Active and  $27.77 \pm 0.045$  days for Inactive ( $P < 0.05$ ). The gross reproductive rate (GRR) was 3.37 with a standard error of 0.074 for the flight-active form, indicating the average number of female offspring produced per female during her lifetime. In comparison, the flightless-inactive form exhibited a significantly higher GRR of 51.17 with a standard error of 1.210, indicating a much higher reproductive potential (Table 2).

**Table 2.** Population parameters of active and inactive *Callosobruchus maculatus*. Means within a column followed by the same letter are not significantly different ( $P < 0.05$ ).

| Parameters                         | Active          |                   | Inactive        |                   |
|------------------------------------|-----------------|-------------------|-----------------|-------------------|
|                                    | Sample size (n) | Mean $\pm$ SE     | Sample size (n) | Mean $\pm$ SE     |
| The intrinsic rate of increase (r) | 40 (19)         | $0.02 \pm 0.001$  | 40 (19)         | $0.14 \pm 0.001$  |
| The finite rate of increase (l)    | 40 (19)         | $1.03 \pm 0.001$  | 40 (19)         | $1.14 \pm 0.001$  |
| The net reproduction rate (R)      | 40 (19)         | $2.82 \pm 0.066$  | 40 (19)         | $43.24 \pm 0.948$ |
| The mean generation time (T)       | 40 (19)         | $39.38 \pm 0.052$ | 40 (19)         | $27.77 \pm 0.045$ |
| GRR                                | 40 (19)         | $3.37 \pm 0.074$  | 40 (19)         | $51.17 \pm 1.210$ |

The distribution of mortality during the entire life span of Inactive and Active is shown in Table 3. For the active form, the mortality percentages were generally low throughout the development stages. In the egg stage, no mortality was observed until day 4, where a slight increase of 0.025% was recorded. From day 5 onwards, the mortality remained negligible for all stages, indicating high survival rates for the active form. In contrast, the inactive form exhibited higher mortality percentages at various stages. In the egg stage, mortality started from day 1, with a gradual increase up to day 4, where it reached 0.025%. In the immature stage, mortality remained relatively low, with occasional fluctuations. The female and male stages also experienced some mortality, with intermittent increases at specific time points. For active, the 1st peak in mortality occurred at the egg stage (0.025%), with 2nd major peaks of 0.15% at the immature stages. For inactive, the 1st peak in mortality occurred at the egg stage (0.2%), with 2nd major peaks of 0.05% each at the immature stages. The 3rd major peak of 0.1% occurred in the male stage for Active and while a similar 3rd and 4th occurred in the male and female stages for inactive, with a peak of 0.15%. Out of the 40 eggs, 19 females and 14 0.00 ( $P < 0.05$ ) males emerged for Active and 20 0.00 females and 15 ( $P < 0.05$ ) males for Inactive (Table 3). The stage-specific mortality rates were 2%, 5%, 10% and 10.5% (Inactive) and, and 2.5%, 5%, 10.5% and 10.5% (Active) for egg, immature, female, and male, respectively. Mortality during most time of the adult stage ranged between 0.0025% and 0.15 % for both sexes and forms, showing an even distribution of mortality in adult life span. The age-specific survival rate (lx) starts at 1 for ages 0 to 10, indicating that all individuals in the inactive form survive during this period. From age 11 onwards, the lx values gradually decline, indicating a decrease in the survival rate as individuals age. The survival rate continues to decline until age 23, where it reaches 0.93. This suggests that the probability of survival decreases as individuals in the inactive form grow older. Reproductive activity, the age-specific fecundity (mx) values for the inactive form are 0 for ages 0 to 10, indicating no reproductive output during this period. However,

starting from age 11, the mx values begin to increase. The highest mx value is observed at age 23, where it reaches 0.93. This indicates that individuals in the inactive form start exhibiting age-specific fecundity and contribute to reproductive output from age 11 onwards, with the maximum fecundity observed at age 23.

**Table 3.** Age-stage-specific mortality  $p(x,j)$  1 (matrix p) of *Callosobruchus maculatus*

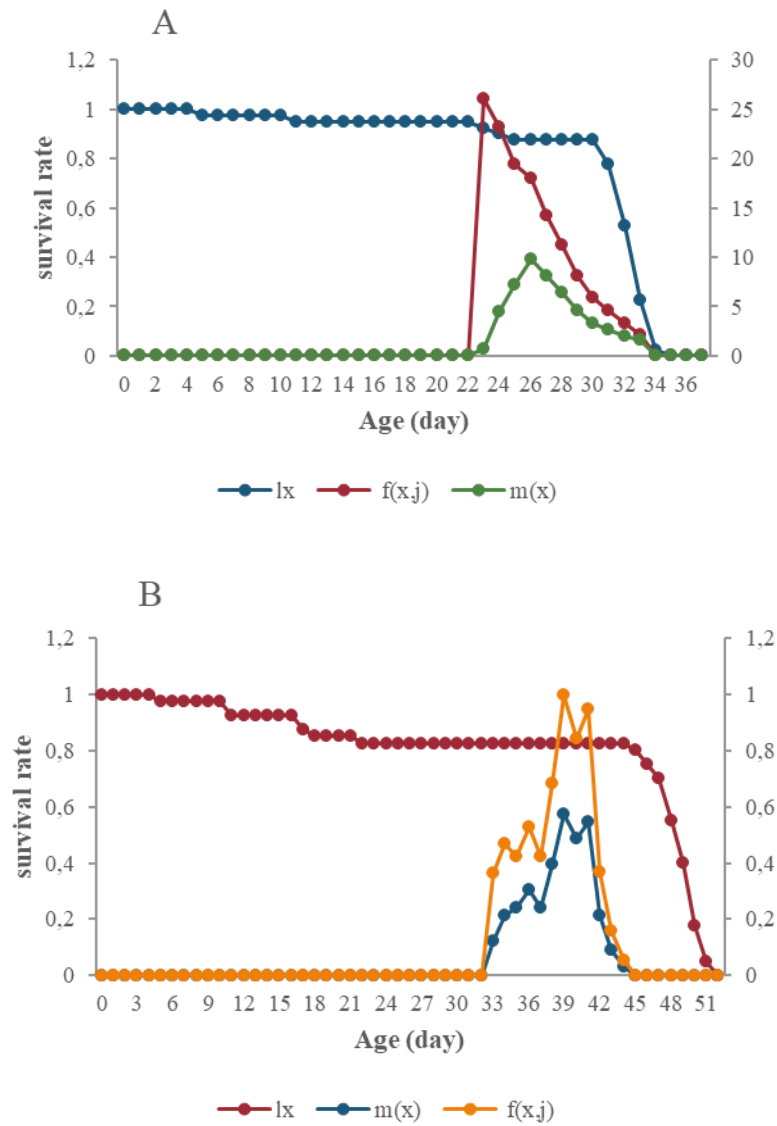
| Age (d) | Active form         |          |        |      | Inactive form       |          |        |       |       |
|---------|---------------------|----------|--------|------|---------------------|----------|--------|-------|-------|
|         | Stage (% mortality) |          |        |      | Stage (% mortality) |          |        |       |       |
|         | Egg                 | Immature | Female | Male | Egg                 | Immature | Female | Male  | Egg   |
| 0       | 0                   | -        | -      | -    | 0                   | 0        | -      | -     | -     |
| 1       | 0                   | -        | -      | -    | 0                   | 0        | -      | -     | -     |
| 2       | 0                   | -        | -      | -    | 0                   | 0        | -      | -     | -     |
| 3       | 0                   | -        | -      | -    | 0                   | 0        | -      | -     | -     |
| 4       | 0.025               | -        | -      | -    | 0.025               | 0.025    | -      | -     | -     |
| 5       | 0                   | 0        | -      | -    | 0                   | 0        | 0      | -     | -     |
| 6       | 0                   | 0        | -      | -    | 0                   | 0        | 0      | -     | -     |
| 7       | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 8       | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 9       | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 10      | -                   | 0.05     | -      | -    | -                   | -        | 0.025  | -     | -     |
| 11      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 12      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 13      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 14      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 15      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 16      | -                   | 0.05     | -      | -    | -                   | -        | 0      | -     | -     |
| 17      | -                   | 0.025    | -      | -    | -                   | -        | 0      | -     | -     |
| 18      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 19      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 20      | -                   | 0        | -      | -    | -                   | -        | 0      | -     | -     |
| 21      | -                   | 0.025    | -      | -    | -                   | -        | 0      | -     | -     |
| 22      | -                   | 0        | -      | -    | -                   | -        | 0.025  | -     | -     |
| 23      | -                   | 0        | -      | -    | -                   | -        | 0.025  | 0     | -     |
| 24      | -                   | 0        | -      | -    | -                   | -        | 0.025  | 0     | -     |
| 25      | -                   | 0        | -      | -    | -                   | -        | 0      | 0     | 0     |
| 26      | -                   | 0        | -      | -    | -                   | -        | 0      | 0     | 0     |
| 27      | -                   | 0        | -      | -    | -                   | -        | -      | 0     | 0     |
| 28      | -                   | 0        | -      | -    | -                   | -        | -      | 0     | 0     |
| 29      | -                   | 0        | -      | -    | -                   | -        | -      | 0     | 0     |
| 30      | -                   | 0        | -      | -    | -                   | -        | -      | 0.05  | 0.05  |
| 31      | -                   | 0        | -      | -    | -                   | -        | -      | 0.125 | 0.125 |
| 32      | -                   | 0        | 0      | -    | -                   | -        | -      | 0.15  | 0.15  |
| 33      | -                   | 0        | 0      | 0    | -                   | -        | -      | 0.15  | 0.05  |
| 34      | -                   | 0        | 0      | 0    | -                   | -        | -      | 0.025 | -     |
| 35      | -                   | -        | 0      | 0    | 0                   | 0        | -      | -     | -     |
| 36      | -                   | -        | 0      | 0    | 0                   | 0        | -      | -     | -     |
| 37      | -                   | -        | 0      | 0    | 0                   | 0        | -      | -     | -     |
| 38      | -                   | -        | 0      | 0    | 0                   | 0        | -      | -     | -     |
| 39      | -                   | -        | 0      | 0    | 0.025               | 0.025    | -      | -     | -     |
| 40      | -                   | -        | 0      | 0    | 0                   | 0        | 0      | -     | -     |
| 41      | -                   | -        | 0      | 0    | 0                   | 0        | 0      | -     | -     |
| 42      | -                   | -        | 0      | 0    | -                   | -        | 0      | -     | -     |
| 43      | -                   | -        | 0      | 0    | -                   | -        | 0      | -     | -     |

|    |   |   |       |       |   |   |       |   |   |
|----|---|---|-------|-------|---|---|-------|---|---|
| 44 | - | - | 0.025 | 0     | - | - | 0     | - | - |
| 45 | - | - | 0.025 | 0.025 | - | - | 0.025 | - | - |
| 46 | - | - | 0.05  | 0     | - |   |       |   |   |
| 47 | - | - | 0.05  | 0.1   | - |   |       |   |   |
| 48 | - | - | 0.1   | 0.05  | - |   |       |   |   |
| 49 | - | - | 0.1   | 0.125 | - |   |       |   |   |
| 50 | - | - | 0.075 | 0.05  |   |   |       |   |   |
| 51 | - | - | 0.05  | -     |   |   |       |   |   |

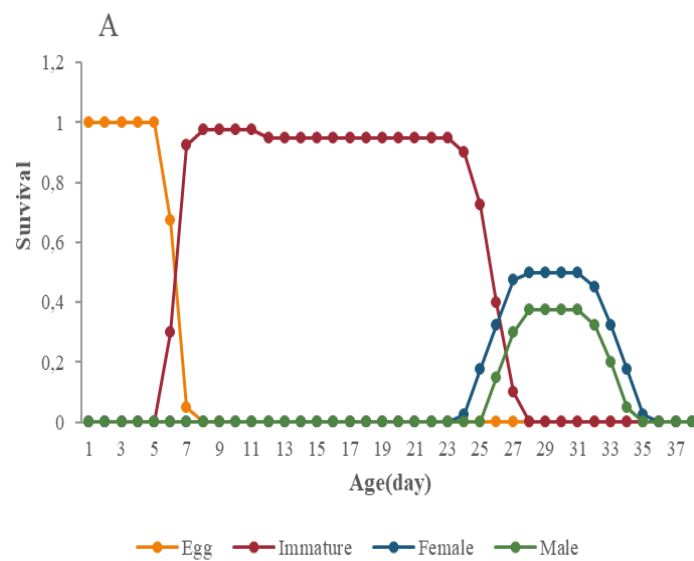
$P(x, j)$  is the probability that a newborn individual will die in age  $x$  and stage  $j$ .

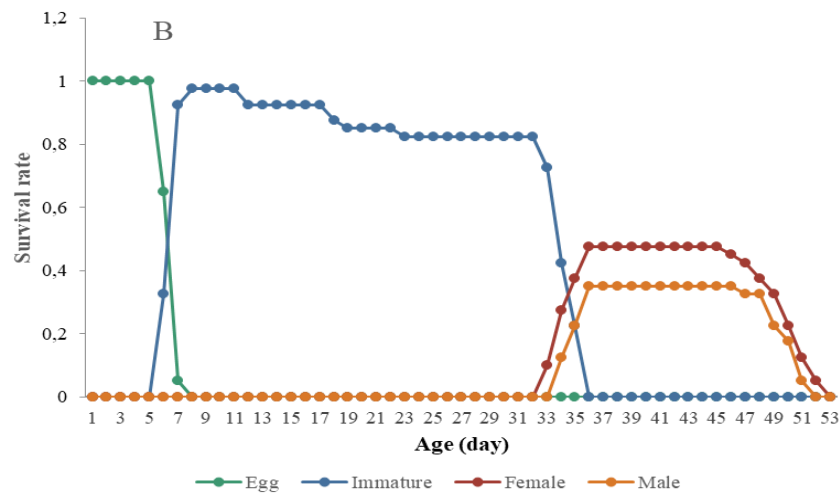
Additionally, the age-stage-specific fecundity ( $fx_j$ ) values for the inactive form are 0 for ages 0 to 10, suggesting no reproductive output during this period. However, starting from age 11, the  $fx_j$  values also increase. The highest  $fx_j$  value is observed at age 23, where it reaches 26. In contrast, the active form maintains a constant survival rate of 1 throughout all ages from 0 to 51. There is no decline in survival probability with age in the active form. Also, the age-specific fecundity remains consistently low, with a value of 0 for all ages except at age 33, where it is 0.037. This suggests that the active form has negligible reproductive output throughout most of its lifespan, except for a small increase in fecundity at age 33. In the case of the age-stage-specific fecundity, ( $fx_j$ ) is 0 for ages 0 to 10, indicating no reproductive output during this period. From age 11, the fecundity gradually increases and peaks at 26 at age 23. This implies that the inactive form exhibits a delayed onset of reproductive output, with the maximum number of offspring produced per individual observed at age 23. In the active form, the age-stage-specific fecundity remains negligible ( $fx_j = 0$ ) until age 33, where it increases to 0.037. This indicates a minimal reproductive output until age 33, after which there is a slight increase in the number of offspring produced per individual. The fig represents the survival rate of the inactive and active forms of the insect across different age-stage intervals.

The survival rates were recorded for both males and females, as well as for eggs and immature stages. Upon analyzing the data, several patterns emerge. In general, the survival rate of the active form appears to be higher compared to the inactive form. The active form consistently shows a higher survival rate in the early stages, starting from the egg stage (where it remains at 1) and continuing through the immature stages. However, as the beetles progress to older age intervals, particularly beyond the 23rd age interval, the survival rate of the active form starts to decline. This decline is particularly notable in the female population, where a decrease in survival rate is observed. In contrast, the survival rate of the inactive form remains relatively stable throughout most age intervals, albeit at a lower overall level (Fig 2). The life expectancy ( $ei_j$ ) of each age-stage group of active and inactive is plotted in (Fig 3). The figure shows that the inactive form generally has lower life expectancy values compared to the active form across different stages and sexes. The life expectancies of the inactive form of *Callosobruchus maculatus* are approximately 4.24 days for males and 24.47 days for females. For the active form, both males and females exhibit a consistent and relatively high life expectancy. The survival rates for males and females remain constant at 1 throughout all age intervals, indicating a 100% chance of survival.

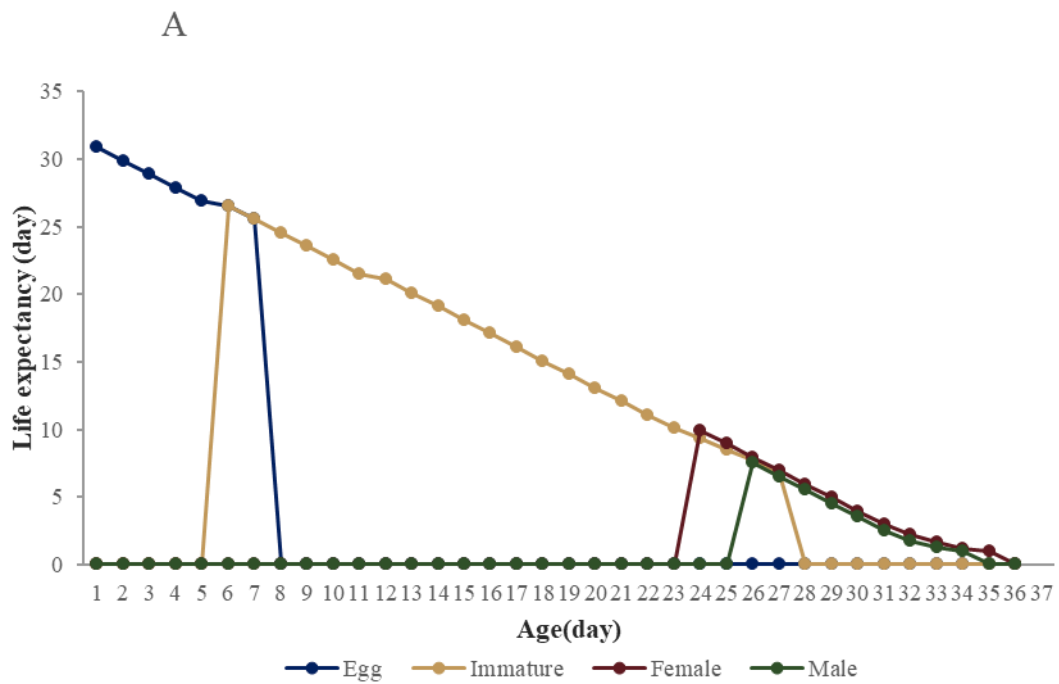


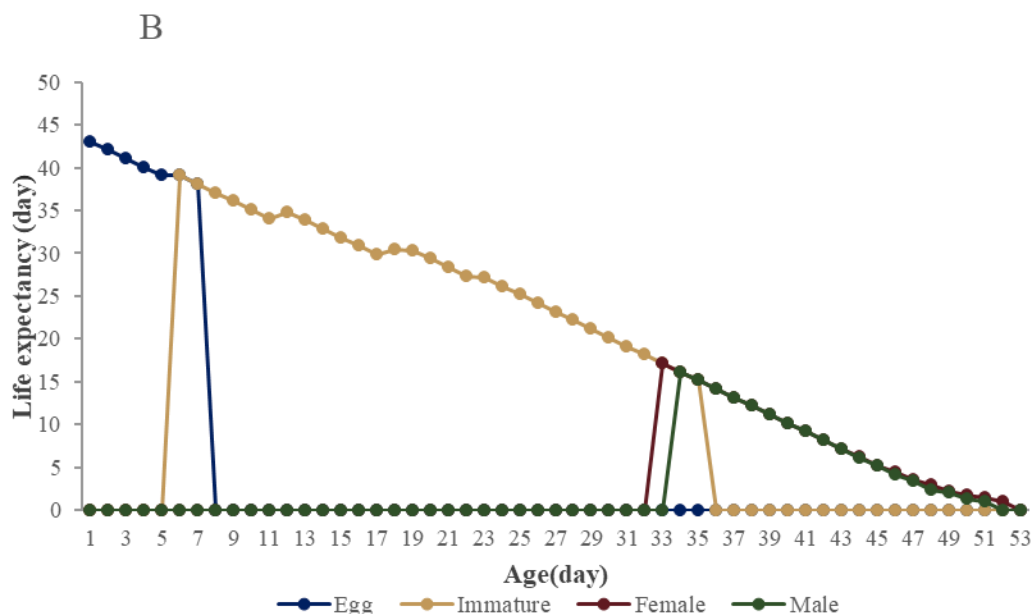
**Fig. 1.** Age-stage-specific survival rate of (A) Inactive form (B) Active form





**Fig. 2.** Age-specific survival rate ( $l_x$ ), age-stage-specific fecundity ( $fx_3$ ), age-specific fecundity ( $mx$ ) of (A) Inactive form (B) Active form





**Fig. 3.** Age-stage-specific life expectancy of (A) active forms and (B) inactive form

The cowpea weevil, *Callosobruchus maculatus* (F.), under certain environmental conditions, such as crowding and high temperatures, exhibits a phase dimorphism in the adult stage [15], [16] reported that the differences observed in the two morphs of *C. chinensis* and ascribed to the flight and flightless forms, are thought to be adaptations for survival and propagation under field and storage conditions, respectively. The induced phase has been described as the ‘flight form’ [16] or “active form” [17], and possesses morphological, behavioral and physiological characteristics distinct from the normal form. The flight form has been regarded as a migratory phase similar to those produced in migratory locusts and in aphids [18]

The predominance of emerged adults of the flightless forms from dry seed and the flight forms from green pods were associated with low moisture content in dry seed and high moisture content in green pods, respectively. These observations show that bruchid control measures are needed in the field as well as in storage. Further research is necessary to elucidate the underlying factors and mechanisms driving the differences in reproductive behavior between the two forms. Exploring the physiological, ecological, and genetic factors that contribute to these distinct reproductive patterns will provide valuable insights into the reproductive strategies and adaptations of beetles.

#### 4. Conclusion

It The survival rates for both forms of *Callosobruchus* beetles show that the active form generally has higher survival rates compared to the inactive form. This suggests that the active form is better at handling environmental challenges and progressing through different life stages. The active form's better survival rates may be due to its mobility, adaptability, and energy allocation for activities like flight and exploration. In terms of how long they live, the active form has a longer lifespan compared to the inactive form. This longer lifespan is linked to flight and migration, which require energy reserves built up during their larval stages to support flight, egg production, and adult survival. This longer life also allows the active form to engage in migration and explore new habitats for resources and reproduction. Understanding the unique characteristics and life strategies of these two forms of *Callosobruchus* beetles is essential for managing pest populations, conservation efforts, and developing sustainable agricultural practices. The findings also have implications for understanding population dynamics, ecological interactions, and the species' ability to adapt to changing environments. In conclusion, the lifetable study provides a comprehensive understanding of the distinct characteristics, reproductive abilities, and population dynamics of these two forms of *Callosobruchus* beetles. This knowledge contributes to the broader field of insect biology and has practical implications for pest management, conservation, and sustainable agriculture

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