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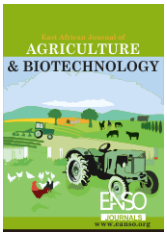

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Original Article

Effects of Temperature on the Development and Survival of Cricket Species; Acheta domesticus and Gryllus bimaculatus (Orthoptera: Gryllidae)

Martha Akello Odhiambo[1], Dr. Calleb Olweny Ochia, PhD[1] & Dr. Erick Otieno Okuto, PhD[1]*

[1] Jaramogi Oginga Odinga University of Science and Technology, P. O. Box 210 – 40601, Bondo, Kenya.
* Author for Correspondence ORCID ID: https://orcid.org/0000-0002-5257-8897; Email: odhiambom2012@gmail.com

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ABSTRACT

Temperature plays an important role in the development and survival of insects. The effects of temperature on the development of two cricket species, *Acheta domesticus* and *Gryllus bimaculatus* were determined at six constant temperatures (18, 22, 26, 30, 34 and 38^{0}C). Parameters for stage-specific development such as fecundity, weight and fat content, structural body size, sex ratio, development time, and longevity were investigated. Relative humidity, light intensity, and photoperiod were set at 60-90 %, 500 ± 25 Lux, and 12:12 L:D, respectively. The results indicated that the duration of eggs and nymphal stages were significantly influenced by increased temperature. The egg-to-adult developmental period of *Acheta domesticus* declined from 200.5 days to 66.26 days as the temperature increased from 18^{0}C to 30 °C while that for *Gryllus bimaculatus* decreased from 231.82 to 62.22 days as the temperature increased from 18 to 34°C. The optimum temperature estimated for egg-to-adult ranged from 26˚C to 34˚C. Longevity of both females and males was significantly higher (female: $F_{5, 401} = 7.5$, $P < 0.001$; male: $F_{5, 401} = 6.4$, $P < 0.001$) at 18^{o}C than at other temperatures, with the shortest recorded for *Acheta domesticus* (female: 20.19 days; male: 26.67 days) and *Gryllus bimaculatus* (Females: 25.56 days; Males: 27.49 days) at 38^{o}C. Fecundity was highest at 26°C (1360 eggs/female/generation) and lowest at 18°C (101 eggs/female/generation) for *Acheta domesticus*. For *Gryllus bimaculatus*, the highest fecundity was recorded at 30°C (1722 eggs/female/generation) and the lowest at 18°C (123 eggs/female/generation). The optimal developmental temperature for crickets was determined to range from 26°C to 34°C. Understanding the impacts of temperature on the development of crickets would provide information on how climate change shapes insect ecologies and enable the development of forecasting models.

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INTRODUCTION

Climate variability has imposed large fitness costs on insects, showing diapause and other life cycle responses, threatening population persistence (Lopatina *et al*., 2014; Gillooly *et al.*, 2002). Phenotypic plasticity, the capacity of a single genotype to exhibit variable phenotypes in different environments, is common in insects and is often highly adaptive (Tomberlin & Sheppard, 2002). Most studies have concluded that insects would become more abundant as temperatures increase through a number of interrelated processes, including range extensions and phenological changes (Reznik & Virghina, 2011). Insects are poikilotherms, significantly affected by climatic factors, with the temperature being the most prominent environmental factor with a marked influence on insect biology and behaviour (Aksit *et al*., 2007; Infante, 2000). However, individual species responses vary when exposed to stressful conditions (Mori *et al*., 2005; Miller & Paustial, 1992). Insects respond either through a change in behaviour to avoid stress by migration or through changed activity patterns (Hagstrum & Miliken, 1988). These insects can continuously adapt to stress conditions through selection or by plastic responses, by changes in morphology, life history, or physiology (Manrique *et al*., 2012; Lopatina *et al*., 2007).

Insect development parameters such as sex ratio, longevity, and fecundity are significantly affected by temperature (Infante, 2000). Since temperature affects the population size and variation of edible insects, under various situations, knowledge of the thermal requirements of crickets is crucial for conservation initiatives.

The insect order, orthoptera, forms part of the hemi metabolic insect groups, characterized by developing nymphal instars resembling the mature adult (Otte, 2007). Egg, nymph, and adult make up the lifecycle of crickets, which undergo incomplete metamorphosis (Chapman *et al*., 2013; Resh *et al*., 2009). Depending on their environment they have a lifecycle that lasts between two to three months and a life span of more than six weeks (Otte, 2007). Temperatures between 27 and 32 ^{0}C are ideal for these crickets growth. To mate, the male crickets chirp their wings together. The female cricket has a long needle-like protrusion (ovipositor) used for laying eggs in addition to two cerci and can lay up to 200 eggs at a time in any available damp substrate (Huber, 1989).

Crickets play an important role in maintaining the balance of ecosystems (Umpold & Schulter, 2013). They break down plant material, renew soil minerals, and are an important source of protein for many households, reducing the pressure on

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fish resources that have been used to formulate poultry feeds (FAO, 2010). The adult cricket is composed of 47% crude protein, 10% carbon, and 25% fat; food nutrients on a dry weight basis (Ayieko *et al*., 2016). In addition, the insect contains a variety of minerals and vitamins. When the diet is enriched with fish offal, the adults are rich in omega-3 and essential unsaturated fatty acids (Umpold & Schluter, 2013). The estimated value of adults as feed when dried is similar to that of soybean or meat and bone meal. If they are used live as a special form of feed, their worth as a product can be higher (FAO, 2010).

A cricket begins its existence as an egg, then cracks the egg capsule and burrows its way out of the substrate. It will have developed into a nymph after roughly 14 days. Nymphs resemble adult crickets with a few exceptions: they lack wings at first and females lack ovipositors (Chapman *et al*., 2013). These juvenile crickets are frequently eaten by larger crickets and other insects (Chapman *et al*., 2013; Resh *et al*., 2009). To grow, a nymph loose its hard exoskeleton and replace it with a new one that is soft and milky white at first but hardens within hours. Moulting occurs every eight to ten times. This process is called moulting and happens eight to ten times (Resh *et al*., 2009). After roughly a month, a nymph will begin to grow wings. When a cricket achieves maturity, its wings are fully formed, and it has just two goals: eating and mating (Hardy *et al*., 1983). A male will endeavour to attract fertile females. After mating has occurred, a female will spend her time looking for good spots to lay her eggs (Resh *et al*., 2009).

In spite of the economic importance of edible crickets little is known about the effects of temperature on their development and survival. This study was conducted to determine the effects of temperature on the development and survival of two cricket species, *Acheta domesticus* and *Gryllus bimaculatus* under laboratory conditions in order to create heat accumulation-based forecasting models for the edible insect. In addition, knowing the best temperature for the primary phonological traits of crickets (nymphal weight, growth rate, development, fecundity, and longevity) would aid in the effective conservation of this edible insect and further used to predict the potential range of the crickets.

MATERIALS AND METHODS

Colony Establishment

The insect colony was established at the Insect Farm of Jaramogi Oginga Odinga University of Science and Technology (JOOUST). The collected insects were fed on poultry growers mash and reared in the insect-rearing unit at JOOUST. Wild adults (2000 individuals, assessed by weight) were gathered in Western Kenya from the designated habitats. The crickets were raised in 60 L plastic buckets, each containing approximately 100 crickets. The buckets were covered with mosquito nettting to keep predators out and crickets in (Mellisa, 2014; Clifford & Woodring, 1990). Drinking water was offered ad libitum in a 16 cm diameter saucer using a moistened cotton wool. To serve as hideouts, egg trays measuring 29 cm x 29.5 cm were placed vertically in the buckets (Mellisa, 2014; Wineriter & Walker, 1988).

Experimental Design

Newly laid cricket eggs were collected randomly from the laboratory colonies to create six sets of crickets colonies for each species; *Acheta domesticus and Gryllus bimaculatus* and reared in an incubator under constant conditions. There were six treatments of temperature regimes on two cricket species. For this experiment, relative humidity, light intensity, and photoperiod were set at 60-90 %, 500 ± 25 Lux, and 12:12, respectively (Das *et al*., 2012).

The treatments were as follows:

T1 = 18 ^{o}C, T2 = 22 ^{o}C, T3 = 26 ^{o}C, T4 = 30 ^{o}C, T5 =34 ^{o}C, T6 = 38 ^{o}C.

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Data Collection

Fecundity

Adults of *Acheta domesticus and Gryllus bimaculatus* were selected and coupled in well ventilated transparent containers (20 cm x 20 cm x 15 cm) and treated to varying temperature regimes (Calvo & Molina, 2005). A total of ten pairings were chosen and an oviposition substrate consisting of a moistened cotton ball was placed within a sterile petri dish in each container for egg laying. The number of eggs in each vial was counted under a stereomicroscope using a fine camel's hair brush (Otieno *et al*., 2019).

Weight and Fat Content

To remove any contaminants, the crickets were cleaned. Fresh body weight was measured at birth and once a week until death with an electronic scale (OHAUS Pioneer TM) set to the nearest 0.1 mg (Zebino *et al*., 2016). Adult males, virgin females and mated females were freeze killed for dry weights, and the specimens were maintained thermo-resistant glass vials and microwaved at 45^0C for 72 hours (Mellisa, 2014). The dry weights were calculated by using the dried specimens. Five grams of each specimen were put into Eppednorf ® tube (1.5 mL) in the soxhlet extractor for fat extraction. This was immersed in a 1:1 (vol:vol) petroleum ether solution and heated for 6 hours. The condensing unit was removed from the extraction unit and the sample was allowed to cool down. The samples were then dried once more for 48 hours and weighed after that (lean dry weight) (Wigglesworth, 1972; Mellisa, 2014). To a precision of 10^{-5} g, every weight was measured using analytical Sartorius ® balance (Infante, 2000). Fat content was calculated using the equation:

$$\text{Crude fat} = \frac{\text{weight of tube with sample} - \text{weight of tube}}{\text{weight of specimen}}$$

Structural Body Size and Sex Ratio

The length of the elytron, which is the distance between the apex and base, the width of the protonum at its widest point, and the hind leg's femur were used to estimate the structural body size. A digital calliper was used to measure each proportion with an accuracy of 0.01mm (Honnek, 1993). The sex ratio of adults was recorded.

Development Time and Longevity

The time to complete each life stage (egg, nymph, and adult) of the crickets was determined. The newly enclosed nymphs were marked with a fine-tipped brush with a small dot of ink in the protonum using non–toxic permanent ink pens (EDDING 751 band) due to its excellent adhesion, quick drying, and good visibility to estimate cricket longevity (Das *et al*., 2012). Different colours were used for each day of emergence (Infante, 2000; Bowling, 1955). Marked nymphs were returned to their respective buckets, daily observations made, and the waste removed and observed under a stereomicroscope to quantify the number of marked nymphs that had died (Bowling, 1955).

Data Analysis

Differences in fecundity, weight and fat content, structural body size and sex ratio, development time, and longevity among temperature treatments were tested using analysis of variance (ANOVA). The significance of pair-wise correlations amongst the measured parameters was tested using Pearson's correlation coefficient (r). The significance of the correlation of the phenotypic factors in relation to changes in temperature was assessed using Spearman's (ρ) correlation coefficient (Pinheiro *et al*., 2018). All the analyses were performed in the R environment (R - Core Team 2017).

RESULTS

Fecundity

The effects of six constant temperatures on the fecundity of two cricket species (*Acheta domesticus* and *Gryllus bimaculatus*) differed significantly ($F_{5, 205} = 272$; $p < 0.001$) (Table 1). *Acheta domesticus* reared at 26 ^{o}C recorded the highest fecundity of 1360 eggs per female. This

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was followed by those reared at 30 ºC at 1342 eggs per female. The lowest fecundity (101 eggs per female was recorded on *Acheta domesticus* reared at 18 ºC. Results indicated that the fecundity of crickets reared at 26 ^{0}C and 30^{0}C were not significantly different, but the two were all different from those reared at 18 ºC, 22 ºC, 34 ºC and 38 ºC. For *Gryllus bimaculatus*, the highest fecundity (1722 eggs per female) was recorded in species reared at 30ºC. This was followed by those reared at 26ºC (680 eggs per female). The lowest fecundity (123 eggs per female) was recorded at 18ºC. The interaction effects of fecundity and species were significant, with the highest fecundity (1722 eggs) recorded in *Gryllus bimaculatus* reared at 30 ºC whereas the lowest (101 eggs) was recorded in *Acheta domesticus* reared at 18ºC (Table 1). In the moistened cotton wool, the majority of the eggs were laid in clusters.

Adult Longevity

Adult longevity of the two cricket species differed significantly ($p \leq 0.05$) among the temperature treatments. Females and males both lived much longer (female: F5, 401 = 7.5, P < 0.001; male: F5, 401 = 6.4, P < 0.001) at 18ºC than at other temperatures, with *Acheta domesticus* living the shortest (female: 20.19 days; male: 26.67 days) and *Gryllus bimaculatus* (Females: 25.56 days; Males: 27.49 days) at 38ºC (Table 1). *Acheta domesticus* reared at 18ºC recorded the highest adult longevity of 92.35 days for the males and 74.26 days for the females. Those reared at 38ºC recorded the lowest adult longevity of 26.67 days for the males and 20.19 days for the females. *Gryllus bimaculatus* had the highest adult longevity of 93.43 days for males and 75.26 days for females at a temperature of 18ºC. The combined impacts of species and temperature revealed no significant differences, though the maximum (93.43 days) adult longevity was reported in *Gryllus bimaculatus* at 18ºC and the shortest (20.19 days) in *Acheta domesticus* at 38ºC (Table 1). At all temperatures, males lived longer than females, but no discernible differences were recorded between the sexes.

Sex Ratio

There was a significant difference (p-value ≤ 0.05) in the analysis of the sex ratio between the two cricket species (Table 1). The sex ratio was female-biased at lower temperatures (18ºC, 22ºC, and 26ºC) but male-biased at 34ºC and 38ºC. Crickets reared at 18ºC had the highest female-to-male ratio of 2.03 and 2.23 for *Acheta domesticus* and *Gryllus bimaculatus,* respectively. The sex ratio was almost equal at a temperature of 30ºC.

Table 1: Effects of temperature on fecundity, adult longevity and sex ratio of two cricket species; *Acheta domesticus* and *Gryllus bimaculatus*

Temperature (^{0}C)	Fecundity (Eggs/ female/ generation)	Adult Longevity (Days) Mean ± SE		Sex ratio (Female: Male)
		Females	Males	
Acheta domesticus				
18	101a	74.25 ±0.03c	92.35 ±0.08f	2.03
22	376b	65.71 ±1.02b	90.28 ±0.06e	1.33
26	1360c	65.40 ±1.14b	88.23 ±0.03d	1.13
30	1342c	61.05 ±0.15b	73.09 ±0.25c	1.04
34	306b	58.15 ±0.07b	62.19 ±0.78b	0.85
38	106a	20.19 ±0.01a	26.67 ±2.14a	0.61
Gryllus bimaculatus				
18	123a	75.26 ±0.13d	93.43 ±1.81f	2.23
22	463b	67.80 ±0.29c	90.22 ±1.05e	1.86
26	680b	68.42 ±0.71c	88.13 ±0.34d	1.27
30	1722c	62.13 ±1.21c	72.12 ±0.22c	1.02
34	660b	54.21 ±0.48b	60.17 ±1.36b	0.67

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Temperature (^{0}C)	Fecundity (Eggs/ female/ generation)	Adult Longevity (Days) Mean ± SE		Sex ratio (Female: Male)
		Females	Males	
38	132a	25.56 ±0.55a	27.49 ±0.09a	0.52

SE - Standard error. Means in the same column followed by different letters were significantly different (Student – Keul's test. P< 0.05)

Effects of Temperature on Adult Weight and Fat Content

Adult Weight

The effects of temperature on adult weight of the crickets differed significantly ($F_{5, 54} = 2.1$; $p < 0.001$). The highest body weight (22.04 g and 20.47 g) for *Acheta domesticus* was recorded at 26˚C for both females and males, respectively (*Table 2*). In *Gryllus bimaculatus*, the highest adult weight of 23.42 g and 21.61 g was recorded at 30ºC for females and males, respectively.

Fat Content

The temperature treatment resulted in significantly different fat contents at the significance level of $p<0.05$) between the two cricket species (Table 2). *Acheta domesticus* reared at 22ºC recorded the highest fat content (19.43 and 17.71 g /100g dry weight) for females and males, respectively. *Gryllus bimaculatus* recorded the highest fat content (11.78 and 9.51 g/100g dry weight) at 30^{0}C for females and males, respectively. The lowest fat content was recorded in crickets reared at 38ºC for both species. Significant ($p < 0.05$) temperature x species interaction effects on fat content were identified, albeit the magnitude of the interaction was relatively small, indicating that temperature treatment influenced fat content more than species.

Table 2: Effects of temperature on adult weight and fat content of two cricket species; *Acheta domesticus* and *Gryllus bimaculatus*

	Temp (^{0}C)	Fat content (g/100g dry weight) Mean ± SE		Adult weight	
		Females	Males	Females	Males
Acheta domesticus	18	18.78e	17.50c	21.5c	18.22c
	22	19.43de	17.71c	21.5c	19.88d
	26	17.66d	15.47b	22.04c	20.47d
	30	15.13c	14.22b	21.43c	20.15d
	34	10.95b	10.40a	18.75b	16.73b
	38	9.71a	9.08a	18.19a	13.19a
Gryllus bimaculatus	18	11.45a	10.45d	18.40a	16.37a
	22	12.11b	10.15c	19.53a	16.84a
	26	11.76a	9.44ab	22.17b	19.86b
	30	11.78a	9.51bc	23.42b	21.61b
	34	10.88a	9.37ab	19.12a	21.53b
	38	10.12a	8.45a	19.04a	17.19a

SE - Standard error. Means in the same column followed by different letters were significantly different (Student – Keul's test. P< 0.05)

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Effect of Temperature On Structural Body Length

Both temperature and cricket species had significant effects on structural body length (p-value = 0.0008 and p-value <.0001, respectively). *Acheta domesticus* reared at 26ºC recorded higher lengths: body lengths of 18.3 mm and 18.4 mm for males and females, respectively. Length of tegmina; 9.2 mm and 13.4 mm; Length of the femur of hind leg: 11.0 mm and 12.0 mm for males and females, respectively. *Gryllus bimaculatus* had a higher (24.1 mm and 24.8 mm) body length at 30ºC for males and females, respectively. The lowest lengths were recorded in crickets reared at 18ºC and 38ºC (Table 3). The interaction effect of temperature and species on structural body length was significant. Crickets with the highest body length (24.8 mm) were obtained from *Gryllus bimaculatus* reared at 30ºC with the shortest (16.0mm) lengths recorded in *Acheta domesticus* reared at 18ºC (*Table 3*).

Table 3: Effects of temperature on the structural body size of two cricket species, *Acheta domesticus* and *Gryllus bimaculatus*

Temp	Body length (mm)		Length of tegmina (mm)		Length of femur of hind leg	
	Mean ± SE					
	Male	Female	Male	Female	Male	Female
Acheta domesticus						
18	16.0 ±0.06b	18.2 ±0.06c	8.5 ±0.13a	8.7 ±1.48a	8.3 ±0.09a	9.4 ±0.07a
22	17.2 ±1.14bc	21.1 ±0.08d	8.5 ±0.09a	8.6 ±1.23a	10.3 ±0.05a	9.8 ±0.34a
26	18.3 ±0.17c	18.4 ±0.12c	9.2 ±0.03a	13.4 ±0.18c	11.0 ±0.02b	12.0 ±2.56c
30	15.7 ±0.04a	16.2 ±0.11b	9.0 ±0.04a	13.0 ±0.03c	10.6 ±0.54b	11.8 ±1.43b
34	15.2 ±0.47a	16.1 ±0.31b	9.0 ±0.07a	12.8 ±0.27c	11.0 ±0.14b	11.8 ±0.76b
38	14.3 ±0.32a	14.4 ±0.72a	8.5 ±1.31a	10.3 ±0.41b	10.7 ±0.06b	11.5 ±0.44b
Gryllus bimaculatus						
18	18.7 ±0.08a	19.6 ±1.35a	15.0 ±0.19a	13.0 ±0.04a	11.0 ±0.04a	10.7 ±1.23a
22	19.4 ±0.23a	20.5 ±0.46a	14.7 ±0.07a	14.2 ±1.32a	11.8 ±1.43a	11.5 ±0.66a
26	22.5 ±0.32b	23.6 ±0.06b	17.2 ±0.01b	17.0 ±2.05b	12.0 ±1.33a	12.2 ±0.08a
30	24.1 ±0.86c	24.8 ±1.22c	18.3 ±0.35b	17.2 ±1.09b	13.6 ±1.28b	13.1 ±1.09b
34	23.8 ±0.71b	24.7 ±1.65c	19.5 ±0.87c	18.2 ±0.08b	14.0 ±0.61b	13.5 ±0.07b
38	23.1 ±0.12b	23.4 ±0.53b	17.5 ±0.06b	17.9 ±0.67b	13.6 ±0.55b	13.6 ±1.14b

SE - Standard error. Means in the same column followed by different letters were significantly different (Student – Keul's test. P< 0.05)

Effect of Temperature on Development of the Different Growth Stages of Crickets

The developmental times for each stage of the two cricket species, *Acheta domesticus* and *Gryllus bimaculatus* at six constant temperatures are presented in Table 4. There were significant differences (p-value ≤ 0.05) in the analysis of development amongst the temperature treatments. The average developmental time for each stage was significantly shortened as the temperature increased. The highest number of moults (10 moults) were recorded in *Gryllus bimaculatus* reared at 18˚C and eight moults from 26˚C to 38˚C. The average egg incubation time reduced from 44.06 days at 18˚C to 9.86 days at 38˚C and that of nymphs decreased from 187.76 days at 18˚C to 57.71 days at 38˚C. Few eggs hatched at 18˚C, and nymphs failed to complete development at 38˚C. *Acheta domesticus* recorded nine moults at 18˚C, followed by eight moults from 22˚C to 38˚C. On average, the overall period from egg to adult was highest at 231.82 days for *Gryllus bimaculatus* and 200.50 days for *Acheta domesticus* at 18˚C. The shortest duration (62.22 days) was recorded at 34˚C for *Gryllus bimaculatus* and 66.26 days for *Acheta domesticus* reared at 30°C.

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Table 4: ***Effects of temperature on development times of the different stages of two cricket species, Acheta domesticus and Gryllus bimaculatus***

	Temp (0C)	Development time (Days) Mean ± SE												
		Egg incubation	**1st instar**	**2nd instar**	**3rd instar**	**4th instar**	**5th instar**	**6th instar**	**7th instar**	**8th instar**	**9th instar**	**10th instar**	**Total nymph**	**Egg – adult**
Acheta domesticus	18	38.20 ±0.04d	14.35 ±0.06d	16.63 ±0.06d	18.68 ±0.04c	18.59 ±0.32d	17.86 ±0.31c	18.17 ±0.18c	18.84 ±0.03d	19.93 ±0.07e	19.25 ±0.09a	-	162.30 ±0.34e	200.50 ±0.89e
	22	35.41 ±0.06c	12.27 ±0.15c	13.65 ±0.06c	16.07 ±0.05b	15.27 ±0.12c	15.55 ±0.06b	15.52 ±0.23b	16.04 ±0.14c	16.31 ±0.05d	-	-	120.68 ±1.23d	156.09 ±0.56d
	26	19.34 ±0.55b	6.61 ±0.22a	6.46 ±0.03ab	6.28 ±0.05a	6.54 ±0.35a	6.91 ±0.46a	6.74 ±0.08a	7.03 ±0.25a	7.43 ±0a.03	-	-	54.00 ±0.76a	73.34 ±0.87b
	30	10.21 ±0.03a	5.76 ±0.03a	5.89 ±0.01a	6.74 ±0.05a	6.58 ±0.09a	6.82 ±0.07a	6.82 ±0.05a	7.83 ±0.42ab	9.61 ±0.25b	-	-	56.05 ±0.54a	66.26 ±0.13a
	34	9.60 ±0.14a	8.32 ±0.01b	7.74 ±0.04b	7.43 ±0.04a	7.56 ±0.14a	6.79 ±0.21a	6.64 ±0.04a	7.81 ±0.29ab	9.53 ±0.36bc	-	-	61.82 ±0.45b	71.42 ±0.08b
	38	9.90 ±0.07a	8.21 ±0.04b	8.44 ±0.03b	7.87 ±0.08a	8.98 ±0.28b	7.14 ±0.11a	8.35 ±0.17a	9.88 ±0.04b	11.04 ±0.35c	-	-	69.91 ±0.67c	79.81 ±0.71c
Gryllus bimaculatus	18	44.06 ±0.62c	16.71 ±0.91c	17.33 ±0.73c	18.22 ±0.27c	19.36 ±0.37c	18.91 ±0.27c	18.02 ±0.08c	19.27 ±0.28c	19.73 ±0.19c	20.03 ±0.45b	20.18 ±0.76b	187.76 ±0.08e	231.82 ±0.07d
	22	37.22 ±0.07b	16.09 ±0.06b	15.47 ±0.05b	15.51 ±0.62b	15.00 ±0.47b	16.29 ±0.15b	16.47 ±0.16b	17.18 ±0.65b	18.48 ±0.26b	16.62 ±0.36a	17.69 ±0.16a	164.8 ±0.07d	202.02 ±0.13c
	26	10.71 ±0.33a	8.37 ±0.49a	8.51 ±0.08a	8.33 ±0.02a	8.61 ±0.43a	8.84 ±0.06a	8.06 ±0.27a	7.11 ±0.72a	7.32 ±0.22a	-	-	65.15 ±0.34c	75.86 ±0.56b
	30	10.56 ±0.51a	7.06 ±0.98a	7.43 ±0.14a	7.82 ±0.35a	7.49 ±0.71a	7.77 ±0.04a	5.98 ±0.18a	5.24 ±0.70a	5.33 ±0.34a	-	-	54.12 ±0.09a	64.68 ±0.65a
	34	9.45 ±0.11a	7.11 ±0.17a	7.57 ±0.14a	7.08 ±0.56a	7.45 ±0.11a	7.77 ±0.07a	5.17 ±0.07a	5.48 ±0.41a	5.14 ±0.72a	-	-	52.77 ±0.32a	62.22 ±0.17a
	38	9.86 ±0.82a	7.00 ±0.48a	7.04 ±0.07a	7.03 ±0.86a	7.27 ±0.21a	7.03 ±0.13a	8.00 ±0.03a	7.11 ±0.55a	7.23 ±0.19a	-	-	57.71 ±0.86b	67.57 ±0.18a

SE - Standard error. Means in the same column followed by different letters were significantly different (Student – Keul's test. P< 0.05)

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Correlations Among the Variables

The correlations between different characters of cricket development and survival are shown in Table 5. Both positive and negative association amongst the variables were identified. Development time was positively correlated with longevity at 30^{o}C (r=0.4546). Adult weight and fat content are positively and closely correlated (r = 0.8692, p-value = 0.004) while fecundity and adult longevity were negatively correlated (r = -0.0953). Increased female longevity has been recorded as a result of reduced egg production in *Drosophila* species (Colin & Spurgeon, 2019). The decrease in female longevity may be due to higher energy diverted towards the reproductive machinery. Significant positive correlations between fecundity and adult weight (r = 0.8424, p-value < 0.0001) were recorded (Table 5). Body size and fecundity are a function of genetics and the environment. Large females have higher fecundity; therefore, selection should favour increased body size (Honek, 1993).

A significant negative correlation was observed between development times (r = 0.7316, p-value = 0.003) and adult sizes, suggesting that an increase in development rate resulted in reduced body size and weight. Correlations between development times and adult weights shows that there is a lot of potential for using them to assess the calibre of insects reared (Lande & Arnold, 1983). This is because insects with lower development rates have high adult weights and sizes and accumulate more fat content. A decline in size was followed by an increase in inhibition of reproductive maturation, as reflected by the decline in fecundity. The increased inhibition of the reproductive cells has been found to be followed by a decrease in size and weight in several insects. Reduced reproductive development associated with a decline in fecundity under low temperatures is caused by poorly developed ovaries.

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Table 5: Correlation coefficients for fecundity, fat content, adult longevity, adult weight, body length, length of tegmina, and length of femur of hind limbs of two cricket species; *Acheta domesticus* and *Gryllus bimaculatus.*

	Adult longevity	**Fat content**	**Fecundity**	**Adult weight**	**Body length**	**Length of tegmina**	**Length of femur of hind leg**	**Development times**
Adult longevity	1.0000	0.6546	-0.0953	0.7338	0.2820	0.2571	0.1640	0.4546
		0.0014	0.0002	<.0001	<.0001	0.2901	<.0001	<.0001
Fat content	0.6546	1.0000	0.7745	0.8962	-0.2316	0.4707	0.5183	-0.0487
	0.0014		0.0003	0.0004	0.0016	<.0001	0.0014	0.0005
Fecundity	-0.0953	0.7745	1.0000	0.8424	0.4715	0.0642	0.0353	-0.2748
	0.0002	0.0003		<.0001	0.0004	<.0001	0.0005	<.0001
Adult weight	07338	0.8962	0.8424	1.0000	0.3041	0.4892	0.2738	-0.7316
	<.0001	0.0004	0.0001		0.2522	0.0003	<.0001	0.0003
Body length	0.2820	-0.2316	0.4715	0.3041	1.0000	0.4318	0.3748	-0.3187
	<.0001	0.0016	0.0004	0.2522		0.0013	<.0001	0.1515
Length of tegmina	0.2571	0.4707	0.0642	0.4892	0.4318	1.0000	0.3172	-0.3019
	0.2901	<.0001	<.0001	0.0003	0.0013		<.0001	0.1727
Length of femur of hind	0.1640	0.5183	0.0353	0.2738	0.3748	0.3172	1.0000	-0.0596
leg	<.0001	0.0014	0.0005	<.0001	<.0001	0.0001		0.8263
Development times	0.4546	-0.0487	-0.2748	0.7316	-0.3187	-0.3019	-0.0596	1.0000
	<.0001	0.8263	<.0001	0.0003	0.1515	0.1727	0.8263	

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Regression Model

Employing a regression model where the dependent variables are development and survival and all the other factors are treated as independent, relationships between cricket development and survival and the other variables were further investigated. When using backward selection, non-significant variables were gradually eliminated. At a 0.05 percent significance level, any parameter still included in the model is significant. The model had a high level of significance and was able to explain 91.3 percent of the data's variability, according to the results shown in *Table 6*, which summarizes the model. According to the model's output, fecundity, adult lifespan, and body weight were the important factors that accounted for the variation in cricket development and survival. This suggests that there is a lot of promise for utilizing them to monitor the growth of crickets.

Table 6: The regression model

Coefficients	Parameter Estimate	Standard Error	t Value	Pr (> |t|)
Intercept	6.003e-14	2.484e-13	2.420e-01	0.817
Fecundity	1.219e-17	7.290e-17	1.670e-01	<2e-16
Adult longevity	2.000e+00	7.821e-15	2.557e+14	<2e-16
Body weight	1.000e+00	3.931e-13	2.544e+12	<2e-16

All parameters left in the model are significant at a 0.05 significance level.

DISCUSSION

According to Colin and Spurgeon (2019), extreme heat could result in either temporary or permanent infertility or the inactivation of sperm stored in the spermatheca, reducing fertility. High temperatures are known to frequently hasten pre-imaginal development in insects that overwinter as adults, ensuring the timely development of the diapausing stage before the start of winter (Manrique *et al*., 2012). Nonetheless, the maturation of different species is restricted naturally and consequently, miniature and diaphanous adults are usually produced with accelerated development (Lamb *et al*., 2009). On the other hand, successful overwintering depends on sufficient fat and glycogen reserves, which are often positively correlated with body weight (Garcia-Barros, 2000). Several researchers have recognized the importance of larger weight in enhancing fat content in insects. High-temperature acceleration of pre-imaginal development combined with its inhibition of reproductive maturation is recorded for several species. Our investigation showed that cricket females stopped laying eggs at 18°C, indicating that low temperatures also caused sterility in these species (Calvo & Molina, 2005). Both extremes of temperatures resulted in moribund ovaries leading to very low or no egg production. In addition, large females have a greater potential for fecundity and some other selective advantages (Padmavathi *et al*., 2008; Aksit *et al*., 2007). Thus, an insect faces two seemingly opposite challenges: increase the adult weight or speed up pre-adult development. Fast development results in small adults, as in the cotton bollworm, *Helicoverpa armigera* (Hubner) and some other species of insects.

An essential aspect that has a significant impact on how insects develop is the temperature (Neven, 2000). Crickets are not an exception. The development of insects due to fluctuating temperatures differs among species (Padmavathi *et al*., 2008). A decrease in the speed of development with reduced temperatures is common, with a marked increase in the period taken in every stage (Ikemoto & Takai, 2000). The findings of this study show that when the temperature rose, the length of time that various stages of crickets took to develop

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decreased. However, most eggs did not hatch when the temperature was 18^0C, and neither the eggs nor the nymphs matured when the temperature was 38^0C. The outcomes from this study were consistent with Colin & Spurgeon's (2019) findings that insects could not finish their normal development at 18 or 38 degrees Celsius. Thus, both low and high temperatures were harmful to the growth of crickets. Under laboratory conditions, a temperature range of 26 to 34^0C proved acceptable for the development of crickets. The growth rate of an insect and temperature show a positive correlation when the temperature range is appropriate, becoming sigmoid over the complete temperature ranges through which insects are capable of developing.

CONCLUSION AND RECOMMENDATIONS

The results provide important information regarding the thermal requirements of *Acheta domesticus* and *Gryllus bimaculatus*. The development of *Acheta domesticus* from egg to adult would occur between the thermal range 22ºC and 30ºC, while that of *Gryllus bimaculatus* would occur between the thermal range 26ºC, and 34ºC. The optimal growth rate was observed at 26ºC for *Acheta domesticus* and 30ºC for *Gryllus bimaculatus*. This study therefore shows that cricket development, survival, and distribution could be affected by future temperature increases.

This data can be used to model development in the wild and estimate potential distribution limits. In addition, parameters such as adult weight, and fecundity, under different temperatures could be used to optimize production under mass rearing.

However, nature does not have a steady temperature; it can change by roughly 10ºC in a day. Therefore, further investigation is needed to determine whether the severe temperatures in this study location prevent some cricket species from spreading in the wild.

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Conflict of Interest

There is no conflict of interest

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