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Research Article

Temperature requirements for immature stages of Sunn pest, *Eurygaster integriceps* Puton (Hemiptera: Scutelleridae)

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Abstract. Sunn Pest, *Eurygaster integriceps* is a serious insect pest of wheat and barley throughout West and Central Asia. Effects of temperature on the development and survival of different stages of *E. integriceps* were studied. The thermal requirements for each stage were determined separately to provide the basis of a phenology model designed to improve chemical control. The standard linear regression method and the Ikemoto and Takai method of insect development were compared for the goodness of fit to the different stage development of Sunn Pest at constant temperatures to determine a developmental lower threshold (T_0) and degree day (*DD*) requirements for each stage separately. Of the two methods, the Ikemoto and Takai method had the better fit and lowest standard error for the parameters of interest. Thus, the Ikemoto and Takai model was chosen to estimate the critical parameters, lower temperature threshold (T_0), and thermal constant for different stages of development of Sunn pest. The estimated low-threshold temperature by Ikemoto and Takai method for egg, NI, NII, NIII, NIV, and NV were 16.226, 14.761, 16.645, 20.675, 21.489 and 19.229 °C respectively. The thermal constants were 51.224, 34.279, 61.017, 33.365, 34.477 and 69.981 *DD* (Degree-day), respectively). Results are useful for predicting the population dynamics of *E. integriceps* and thus provide information on this important insect pest that may assist in its management.

Keywords: population dynamic, Degree day, lower temperature threshold, thermal constant

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Introduction

Sunn Pest, *Eurygaster integriceps* Puton (Hemiptera: Scutelleridae) is considered to be the most damaging insect of wheat and barley throughout West and Central Asia (Critchley, 1998; Parker *et al.*, 2011; Davari & Parker, 2018). To prevent economic damage, management is commonly done with insecticides in IRAN and about 2 million ha of wheat must be sprayed each year to control this insect (Anonymous, 2023). The optimal control of Sunn Pest can be achieved through targeted applications of insecticides against overwintered adults of Sunn Pest and nymphal stages in wheat fields. Pyrethroids are a popular choice due to their low cost. However, their effectiveness is influenced by the critical timing of application when targeted stages are present. Optimal control requires knowledge of the phenology of Sunn Pest, such as the peak of the overwintered adult population and accurate prediction of peak nymphal stages development (Atri & Amir-Maafi, 2006). Population models can range from simple linear ones (Campbell *et al.*, 1974) to more complex nonlinear ones (Worner, 1992).

Simple linear models are often used to estimate the development rates of insects based on temperature, as they are straightforward to apply and provide useful insights into the relationship between temperature and development. There are two essential parameters derived from linear models, lower threshold temperature (T_0) and thermal constant (degree days, DDs). Both are valuable tools for understanding insect development, but they represent only part of the overall picture. Despite the wide use of linear models, it is well known that development rate curves are never fully linear and tend to be curvilinear at extreme temperatures (Worner, 1992; Hannigan *et al.*, 2023).

Relatively little is known about Sunn Pest immature temperature-dependent growth. Some information is available on temperature effects on embryonic development in a limited temperature range (Moeini Naghadeh, 2002; Iranipour *et al.*, 2003; Kivan, 2008). One study has attempted to accumulate degree days to predict immature stage occurrence in the field (Gözüaçik *et al.*, 2016).

The purpose of this study is to compare two potential line-fitting methods to determine the lower temperature threshold for development (T_0) and thermal constant (K) for the different immature stages of Sunn Pest, in IRAN. These parameters are critical for predicting the seasonality and distribution of this pest, facilitating research into its life cycle and management strategies.

Materials and methods

Sunn Pest colonies

In January 2023, approximately 4000 Sunn Pest were collected from an overwintering site in Gharah-Aghaj mountain, located at 30 km north of Varamin. They were used to start a laboratory culture. The insects were sexed and about 100 to 250 pairs were kept in Plexiglas cages (60 × 38 × 30 cm [l × w × d]) at 25 ± 0.5 °C, 65 ± 5% RH., and 16: 8 h (L: D) photoperiod. They were provided with water and wheat grains (Mahdavi variety). Paper strips (60 × 1 cm) were suspended from a metal frame on top of the cages for oviposition. Egg masses were collected by removing the paper strips and cutting them into pieces each containing one egg mass. Each egg mass contained approximately 14 eggs, and they were used in the experiments.

Experimental conditions

Egg masses laid within 4 h by overwintered adults were randomly selected for studying immature development. Each egg mass was placed individually into a Petri dish (10 cm diam., 1.5 cm in height) and was held in an environmentally-controlled growth chamber. A range of constant temperatures 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5 and 40 °C (±0.5), 65 ± 5% RH., and a photoperiod of 16L:8D h were tested. The egg masses were observed daily, and the number of nymphs that emerged were recorded. Each newly hatched nymph was transferred to a separate Petri dish lined with filter paper. A 2-ml Eppendorf tube (1 cm in diameter, 3.5 cm in length) containing water with a cotton wick was placed in each Petri dish to maintain humidity. The nymphs were reared on fresh wheat seeds (variety Mahdavi) that had been presoaked in water for one day. Ten new seeds were supplied daily to each nymph and the seeds from the previous day removed to prevent fungal growth. Petri dishes were kept in the same conditions as above. The developmental stage and survival of each nymph were recorded daily until its death or until it molted into an adult.

Data Analysis

Analysis of variance (ANOVA) was used to test statistical differences in developmental times of different immature stages among temperatures. PROC GLM (SAS ver. 9.4, SAS Institute 2019) and means were separated by the Tukey studentized range test ($P < 0.05$, SAS ver. 9.4, SAS Institute 2019).

Development rate model

In this study, two linear methods, the standard regression (Campbell *et al.*, 1974) and the Ikemoto and Takai (Ikemoto & Takai, 2000) were used to determine the relationships between temperature and the mean developmental rates of the different immature stages (egg, NI, NII, NIII, NIV, and NV) of *E. integriceps*.

The standard linear model is: $$r(T) = a + bT$$

Where $r(T)$ is the development rate (i.e. 1/development duration), T is the temperature (°C), a is the y intercept, b is the slope. The parameter T_0 was estimated by $T_0 = -a/b$. The parameter K, represents the thermal constant, (DD required for complete development) was estimated by $1/b$ (Campbell et al., 1974).

The Ikemoto & Takai (2000) formula as: $$DT = K + tD$$

Where D represents developmental duration (days), T represents constant temperature (°C), K represents the sum of effective temperatures or the thermal constant (*DD*) and *t* represents the lower developmental threshold (T_0). Because the variables in the Ikemoto–Takai method are not independent, fitting the Ikemoto-Takai equation involves using the reduced major axis (RMA) method to estimate *K* and *t* (Ikemoto & Takai, 2000).

Because different fitting methods are used for the two lines in a linear equation, the standard error of the regression is a more appropriate statistic to use than the coefficient of determination (R^2) as a measure of goodness of fit. The lower developmental threshold and thermal constant and their standard errors (SE) were calculated for the standard regression and the Ikemoto and Takai linear model by using the method developed by Ikemoto & Takai (2000).

Results

Temperature-dependent development

The duration of the developmental period of immature stages of Sunn Pest at different constant temperatures is given in Table 1. Males and females developed successfully from egg to adult over a range from 20-35 °C, except at 12.5, 15, 17.5, and 37.5 °C. All eggs exposed to 40 °C were dead and were not included in this study. Development time of each stage was significantly influenced by temperature (Egg: F = 33106.2; d.f. = 10, 5433; P < 0.001; NI: F =5821.22; d.f. = 7, 4093; P < 0.001; NII: F = 1903.43; d.f. = 6, 2621; P < 0.001; NIII: F = 949.3; d.f. = 6, 1529; P < 0.001; NIV: F = 438.21; d.f. = 6, 1165; P < 0.001; NV: F = 308.63; d.f. = 6, 962; P < 0.001) (Table 1). The development time of the eggs decreased as temperatures increased to 30 °C, ranging from 35.788 days at 12.5 °C to 3.438 days at 30 °C and after 30 °C the development time of the eggs increased as temperatures increased. The nymphal period (NI to NV) decreased as temperatures increased to 32.5 °C and increased at 35 °C (Table 1).

Linear methods for immature stages development

The temperature-dependent development data of immature stages of *E. integriceps* were analyzed by standard regression and the Ikemoto and Takai linear model. It should be emphasized that the Ikemoto and Takai method enabled the determination of the optimum temperature range more precisely than the standard regression method (Ikemoto & Takai, 2000; Atijegbe *et al.*, 2022). The data for the temperature-dependent development of the immature stages of *E. integriceps* are quite similar in the two methods (Table 2).

The model coefficients and the values of the lower temperature threshold (T_0) and thermal constant (*K*) were for both linear models (standard regression and Ikemoto linear model) for each life stage are shown in Table 2. The relationships between the developmental rate and temperature for each immature stage were described by linear regressions ($R^2 > 0.93$). The analysis of developmental parameters using both the standard regression method and the Ikemoto and Takai method reveals significant differences in the precision of the estimates for the key parameter, T_0 (the lower temperature threshold), while showing no significant differences in estimating the thermal constant (degree-days, *DD*) (Fig. 1, Table 2). The Ikemoto and Takai method consistently provided lower relative standard errors for T_0 across all immature stages, indicating a higher precision in parameter estimation compared to the standard regression method. The T_0 estimate for the egg stage using the Ikemoto and Takai method was 5.1%, while the standard regression method yielded a much higher relative standard error of 24.1% (Table 2). For the thermal constant (degree-days, *DD*), there are no significant differences in the parameter *DD* when comparing the Ikemoto and Takai to standard regression methods.

The analysis of nymphal stages using the Ikemoto and Takai method demonstrated a more precise estimation of the lower temperature threshold, with relative standard errors (RSE) below 10%. This suggests that this method provides a reliable and consistent measure for determining the lower temperature threshold in nymphal stages.

In contrast, the standard regression method showed significantly higher relative standard errors, ranging from 13.85% to 29.69% (Table 2). This indicates a greater variability and less reliability in the estimates produced by the standard regression approach for the same parameter. The estimated low-threshold temperature by Ikemoto and Takai method for egg, NI, NII, NIII, NIV and NV were 16.226, 14.761, 16.645, 20.675, 21.489 and 19.229 °C, respectively (Table 2, Fig. 1). The thermal constants for egg, NI, NII, NIII, NIV and NV were 51.224, 34.279, 61.017, 33.365, 34.477 and 69.981 *DD* (Degree-day), respectively (Table 2). The results suggest that the Ikemoto and Takai method is more reliable for estimating developmental parameters, as it yields lower standard errors and thus higher confidence in the estimates. This is particularly important for applications in ecological modeling and pest management, where accurate predictions of developmental rates are crucial.

Discussion

Temperature is a fundamental factor that shapes the development, population dynamics, distribution, and abundance of insect species. Understanding these relationships is essential for predicting how insects will respond to ongoing climate change and for managing their impacts on ecosystems and human activities. This research estimates key developmental parameters, including the lower threshold (T_0) and the thermal constant (K) for immature stages of Sunn Pest. Research on the temperature-dependent growth of the genus *Eurygaster*, particularly *E. integriceps*, is limited. Only one study has been done on the temperature-dependent growth of the *E. austriaca* Schrk., *E. maura* L. and *Aelia acuminate* L. (Konjevic *et al*., 2014). Moeini Naghadeh (2002) studied the thermal development of *E. integriceps* egg and estimated a lower threshold for the development at 12 °C. A second, more detailed study was carried out by Iranipour *et al.* (2003) who examined the immature stage development of *E. integriceps* at four temperatures (22, 25, 27, and 30 °C). They reported a lower threshold and thermal constant for all stages were 18.85 °C and 275.26 DD, respectively. Kivan (2008) studied the time taken for the egg to hatch at five constant temperatures (17, 20, 23, 26, and 32°C) in detail.

She reported that the lower development threshold temperature was 11.7 °C and the thermal constant was 90.9 degree-days. Gozuacik *et al.* (2016) conducted research on threshold temperature eggs, NI-to-NIII, NI-to-NV, and egg-to-adult, reporting 12.4, 14.7, 12.89, and 13.3°C, respectively. The physiological time required for the completion (thermal constant) of Sunn Pest eggs, NI-to-NIII, NI-to-NV, and egg-to-adult were 93.20, 214.24, 422.61, and 527.67 degree-days, respectively.

Our study calculated the development threshold temperature and thermal constant of different stages of Sunn Pest separately. We have employed two distinct methods (Ikemoto and Takai and standard regression methods) to achieve this (Table 2). Comparisons of our findings with those of other researchers are primarily reasonable for the egg stage because there is no data for other developmental stages separately.

In our study, the development threshold temperatures for the Sunn Pest egg were found to be 16.435 °C using standard regression. These values are higher than those reported in other studies (Moeini Naghadeh, 2002; Gozuacik *et al*., 2016; Kivan, 2008) and lower than reported by Iranipour *et al.* (2003). The threshold temperature is often determined empirically by extrapolating a straight line to the temperature axis (Krogh, 1914), which may cause a different threshold temperature according to temperature ranges included by researchers.

Iranipour *et al.* (2003) examined temperatures between 20 to 30°C and Kivan (2008) examined between 17 to 32°C. Gozuacik *et al.* (2016) examined only two temperatures (25 and 30°C) utilizing the hyperbola method for their calculation. Moeini Naghadeh, (2002) examined a wider range of temperatures (12.5 to 35 °C). They examined different ranges of temperatures but did not explain how they chose them. The selection of temperature ranges in studies on insect development is crucial, as it directly impacts the estimated thermal thresholds for various life stages. Different researchers have employed varying methodologies and temperature ranges, leading to diverse findings (Krogh, 1914).

When developing temperature-dependent growth models for insect development, it is indeed critical to select data from the temperature range where the relationship between temperature and development rate is approximately linea. To identify the linear range, researchers typically analyze the development rate data across a range of temperatures. The data points that show a consistent, linear increase in development rate with temperature are selected for model development. This selection process is often based on statistical analysis and visual inspection of the data. By focusing on the linear part of the temperature-dependent growth curve, researchers can develop models that are both simple and biologically relevant, thereby enhancing the accuracy and applicability of the models in predicting insect development rates under various temperature conditions (Dixon *et al*., 2009; Ikemoto & Kiritani, 2019).

Previous work on Sunn Pest development is insufficiently detailed or incompletely reported. Much of the published information in this area is of limited use for the general analysis of life cycles. This is the first study that evaluates the impact of temperature on the developmental duration of the immatures, NI – to -NV separately for the Sunn Pest, *E. integriceps*, on wheat. Studying the temperature effects on each stage individually allows for more precise modeling and prediction of insect development and population dynamics and improving management strategies. This study demonstrated that low-threshold temperature (Ikemoto and Takai method) for NI, NII, NIII, NIV and NV were 14.761, 16.645, 20.675, 21.489 and 19.229 °C, respectively (Table 2, Fig. 1). The thermal constants for NI, NII, NIII, NIV and NV were 34.279, 61.017, 33.365, 34.487, and 68.981 DD (Degree-day), respectively (Table 2). To compare our results with those of other researchers, we re-analyzed our data for the first three nymphal stages (NI-NIII), the entire nymphal stages (NI-NV) and the entire immature stages (Egg-NV). Our results are shown in Table 2.

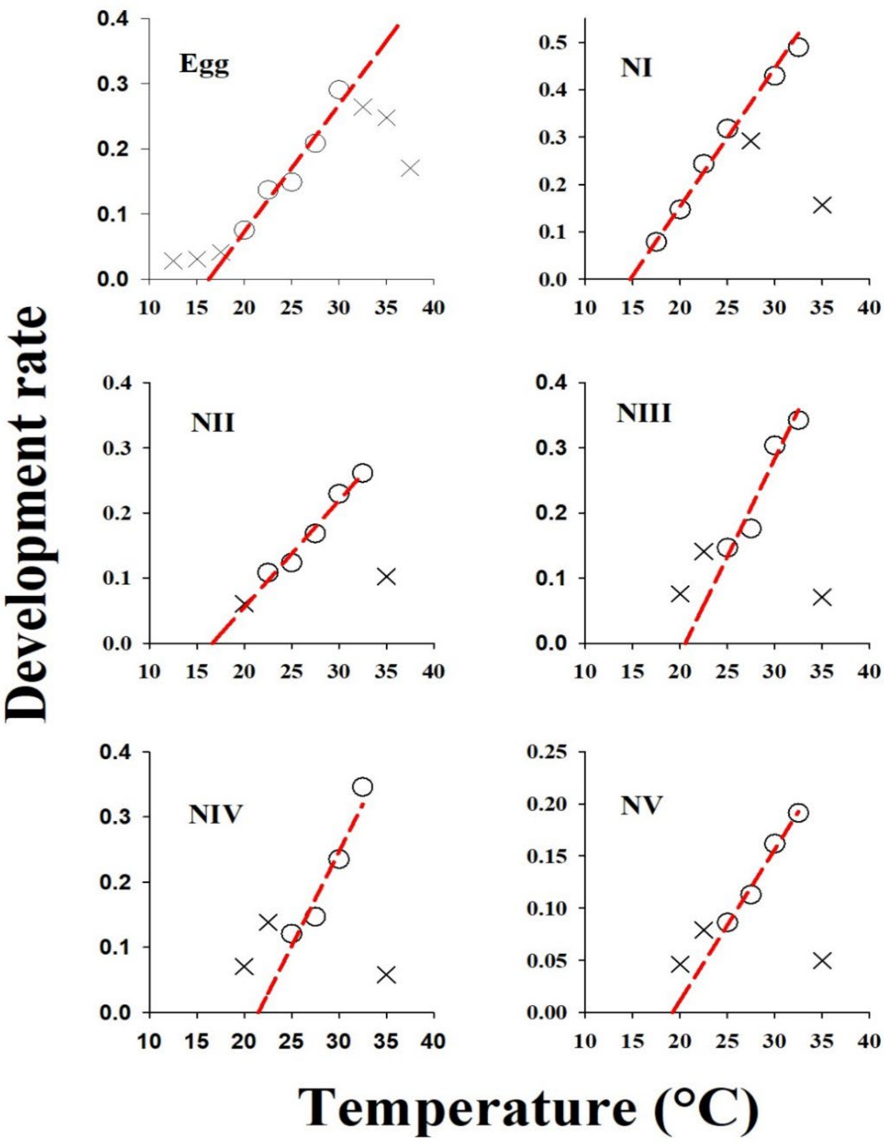

Fig. 1. Fitted lines (dashed red line) for different stages of Sunn Pest using the Ikemoto and Takai (2000) regression method Points shown by × were excluded in fitting the line in the original analysis.

Table 1. Average development time (days) ± SEM for egg, and nymphal stages of *Eurygaster integriceps* at different temperatures.

Temperature (°C)	n*	Egg	% Survival	Nymphal Stages									
				NI	% Survival	NII	% Survival	NIII	% Survival	NIV	% Survival	NV	% Survival
12.5	490	35.788±0.137**a** (80)	16.33	-	-	-	-	-	-	-	-	-	-
15	490	31.99±0.056**b** (100)	20.41	-	-	-	-	-	-	-	-	-	-
17.5	420	24.144±0.127**c** (347)	82.62	12.667±0.183**a** (133)	38.33	-	-	-	-	-	-	-	-
20	280	13.266±0.039**d** (263)	93.93	6.802±0.044**b** (262)	99.62	16.519±0.282**a** (187)	71.37	13.237±0.331**b** (131)	70.05	14.202±0.447**b** (89)	67.94	21.662±0.829**a** (68)	100
22.5	392	7.295±0.024**e** (363)	92.60	4.107±0.025**d** (355)	97.79	9.238±0.106**c** (303)	85.35	7.105±0.132**c** (275)	90.76	7.223±0.177**d** (233)	84.73	12.628±0.441**c** (148)	100
25	420	6.715±0.044**f** (390)	92.86	3.147±0.034**f** (382)	97.95	8.098±0.078**d** (306)	80.11	6.826±0.169**c** (224)	73.20	8.275±0.262**c** (178)	79.46	11.585±0.337**c** (147)	100
27.5	392	4.792±0.087**h** (336)	85.71	3.425±0.048**e** (327)	97.32	5.939±0.071**e** (294)	89.91	5.673±0.136**d** (251)	85.37	6.803±0.166**d** (218)	86.85	8.843±0.22**d** (191)	100
30	280	3.438±0.034**j** (242)	86.43	2.33±0.041**g** (221)	91.32	4.357±0.06**f** (185)	83.71	3.292±0.081**e** (168)	90.81	4.25±0.138**e** (148)	88.09	6.178±0.169**e** (135)	100
32.5	490	3.782±0.023**i** (412)	84.08	2.043±0.013**h** (329)	79.85	3.828±0.062**g** (274)	83.28	2.919±0.058**e** (259)	94.53	2.89±0.061**f** (237)	91.51	5.227±0.105**e** (211)	100
35	5000	4.029±0.008**i** (2499)	49.98	6.394±0.012**c** (2092)	83.71	9.791±0.022**b** (1079)	51.58	14.149±0.06**a** (228)	21.13	17.304±0.158**a** (69)	30.26	20.116±0.21**b** (69)	100
37.5	5000	5.862±0.056**g** (412)	8.24	-	-	-	-	-	-	-	-	-	-
40	5000	-	-	-	-	-	-	-	-	-	-	-	-

*initial number

Numbers in parentheses are sample size. Within column means with the same letters are not significantly different ($P < 0.05$, Tukey studentized range test).

Table 2. Parameters estimated for different stages development using the and Ikemoto and Takai (2000) and standard regression methods for Sunn pest, *Eurygaster integriceps.*

Linear Method	Parameters	Stages																	
		Egg	RSE (%)	NI	RSE (%)	NII	RSE (%)	NIII	RSE (%)	NIV	RSE (%)	NV	RSE (%)	NI-NIII	RSE (%)	NI-NV	RSE (%)	Egg-NV	RSE (%)
Standard regression method	T_0	16.435 (3.952)	24.1	13.711 (1.899)	13.85	16.689 (3.224)	19.32	20.288 (6.538)	32.23	21.802 (6.474)	29.69	19.256 (2.819)	14.64	16.187 (3.195)	19.74	16.429 (3.736)	22.47	16.2 (3.398)	20.975
	DD	49.744 (6.526)	13.12	37.769 (2.41)	6.38	60.68 (6.229)	10.27	34.929 (6.469)	18.52	32.73 (5.855)	17.89	68.725 (5.581)	8.12	146.528 (15.035)	10.261	286.423 (34.228)	11.95	347.443 (37.909)	10.911
	R^2	0.951		0.988		0.969		0.936		0.939		0.987		0.96		0.95		0.95	
Ikemoto and Takai method	T_0 (=t)	16.226 (0.813)	5.01	14.761 (0.632)	4.28	16.645 (1.304)	7.83	20.675 (1.56)	7.55	21.489 (1.504)	6.99	19.229 (0.753)	3.92	15.969 (0.741)	4.064	16.045 (0.918)	5.721	15.959 (0.841)	5.269
	DD(=*k*)	51.224 (6.393)	12.48	34.279 (2.569)	7.49	61.017 (8.648)	14.17	33.365 (7.73)	23.17	34.487 (8.933)	25.9	68.981 (6.279)	9.1	150.459 (15.084)	10.025	300.131 (37.383)	12.456	357.867 (40.424)	11.296
	R^2	0.993		0.995		0.982		0.989		0.99		0.997		0.99		0.99		0.99	

Note: Values in brackets are the standard errors.

Abbreviation: DD, degree day.

Abbreviation: RSE, Relative standard errors

The current study reports slightly higher threshold temperatures compared to Gozuacik *et al.* (2016) but lower than Iranipour *et al.* (2003). The threshold temperatures for NI to NIII, NI to NV, and egg to adult in the current study are relatively consistent, ranging from 15.97 °C to 16.045 °C (Table 2). The thermal constants are significantly lower than those reported by Gozuacik *et al.* (2016) but closer to Iranipour *et al.* (2003) when considering the overall developmental stages. The thermal constants for NI to NIII, NI to NV, and egg to adult in the current study are 150.459 DD, 300.131 DD, and 357.867 DD, respectively. The differences in threshold temperatures and thermal constants across studies may be due to variations in experimental conditions, such as temperature range. These variations highlight the importance of standardized conditions and detailed reporting of experimental parameters to ensure comparability across studies (Dank, 2000). The study by Gozuacik *et al.* (2016) on Sunn Pest highlights the variability in thermal requirements for the pest's life cycle across different regions and years. They reported that the appearance of a new generation of Sunn Pest in the field requires between 270 to 405 degree-days. This range reflects the variability in thermal requirements due to different environmental conditions across various regions and years. Our laboratory results indicated that the Sunn Pest life cycle requires approximately 357.867 degree-days (Table 2). This value falls within the range reported by Gozuacik *et al.* (2016), suggesting that laboratory conditions can closely mimic certain field conditions.

Sunn Pest control is based on insecticides. Predicting the seasonal development of this pest especially nymphal stage II and III, is essential for accurate scheduling of chemical control; thus, studying the temperature effects on each stage separately provides valuable information for understanding the population dynamics of pests in different ecosystems (Andreadis *et al.*, 2017), and provides the most accurate and comprehensive data for modeling population growth, predicting outbreaks (Malekera *et al.*, 2022), and developing effective pest management strategies (Herrera *et al.*, 2005). Understanding these developmental parameters is crucial for developing effective pest management strategies. By using degree-day models, farmers can predict the timing of the Sunn pest's life stages, allowing for timely interventions to control populations and minimize damage to wheat and barley crops. This predictive approach can significantly enhance the efficiency of pest control measures, ultimately leading to better crop yields and reduced economic losses.

Author's Contributions

Masood Amir-Maafi: Conceptualization; methodology; formal analysis; investigation; draft preparation; final review and edit; visualization; supervision; project administration and funding acquisition; **Bruce L. Parker**: Conceptualization, draft preparation, final review.

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Data Availability Statement

All data supporting the findings of this study are available within the paper.

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Ethics Approval

Insects were used in this study. All applicable international, national, and institutional guide lines for the care and use of animals were followed. This article does not contain any studies with human participants performed by any of the authors.

Conflict of Interest

The authors declare no conflict of interest.

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نیاز دمایی مراحل مختلف رشدی سن گندم *Eurygaster integriceps* Puton (Hemiptera: Scutelleridae)

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چکیده: سن گندم، *Eurygaster integriceps* مهمترین آفت گندم و جو در سراسر آسیای غربی و مرکزی است. در این مطالعه اثرات دما بر رشد و بقای مراحل مختلف سن گندم بررسی شد. نیاز دمایی برای هر مرحله به طور جداگانه تعیین شد تا مبنای یک مدل فنولوژی برای بهبود کنترل شیمیایی فراهم شود. روش رگرسیون خطی استاندارد و روش ایکموتو و تاکای برای مدل‌سازی رشد مراحل مختلف رشدی سن گندم در دماهای ثابت برای تعیین آستانه پایین دما (T_0) و نیازهای دمایی (درجه روز، DD) مقایسه شدند. روش ایکموتو و تاکای برازش بهتر و کمترین خطای استاندارد را برای پارامترهای مورد نظر داشتند. بنابراین، مدل ایکموتو و تاکای برای برآورد پارامترهای بحرانی، آستانه دمای پایین (T_0) و نیاز دمایی برای مراحل مختلف رشدی سن گندم انتخاب شد. دمای آستانه پایین تخمین زده شده با روش ایکموتو و تاکای برای تخم ، پوره سن ۱، ۲، ۳، ۴ و ۵ به ترتیب ۱۶/۲۲۶، ۱۴/۷۶۱، ۱۶/۶۴۵، ۲۰/۶۷۵، ۲۱/۴۸۹ و ۱۹/۲۲۹ درجه سلسیوس بود. نیاز دمایی به ترتیب ۵۱/۲۲۴، ۳۴/۲۷۹، ۶۱/۰۱۷، ۳۳/۳۶۵، ۳۴/۴۷۷ و ۶۹/۹۸۱ روز–درجه بود. نتایج این مطالعه ممکن است برای پیش‌بینی پویایی جمعیت سن گندم مفید بوده و اطلاعاتی در مورد این آفت مهم ارائه می‌کند که ممکن است برای مدیریت آن مفید باشد.

کلمات کلیدی: پویایی جمعیت، روز–درجه، آستانه دمای پایین، نیاز دمایی

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