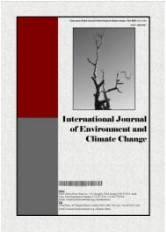

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A Temperature Based Model for Cotton Mealybug to Development, Survival and Population Growth Potential

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Based on the different temperature model, analysis the cotton mealy bug growth, developmental, survival, mortality, and reproduction rate.

Place and Duration of Study: This secondary data were collected from Central Institute of Cotton Research, Coimbatore.

Methodology: In this study, we used models like the Sharpe and DeMichele model, the Wang model, the Polynomial model, the Stinner model, and the Gaussian model. To measure the goodness-of-fit criteria, the model performance has been assured using Coefficient of Determination (R^2), Alkaline Information Criteria (AIC), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE), Mean Absolute error (MAE), Relative Absolute Error (RAE) and Relative Standard Error (RSE).

Result and Conclusion: From the Sharpe and Demichele and Polynomial models, male have highest R^2 and least error values. From the Wang model, nymph 3 has highest R^2 and least error values. When compare all models the Polynomial model have highest R^2 and least error values. So it is the best fit model compare to all the models.

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Keywords: Sharpe and DeMichele model; Wang model; Polynomial model; Stinner model, Gaussian model.

1. INTRODUCTION

Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), a mealy bug is native to Northern America [1]. It is a very harmful pest, an important and serious pest of cotton crops. It has been documented in over 24 countries throughout the world, where it causes severe crop losses. During 2005–2009, India and Pakistan experienced destructive *P. solenopsis* outbreaks on cotton, culminating in 30–60% yield losses. It was first documented in the middle parts of Gujarat State in 2005 [2]. In 2006, *Gossypium hirsutum* was found in all nine cotton growing states of India, such as Punjab, Rajasthan, Haryana, Andhra Pradesh, Gujarat, Karnataka, Tamil Nadu, Madhya Pradesh, and Maharashtra. In 2007, severe economic damage to *G. hirsutum* was reported in four major cotton growing districts of Punjab, two districts such as Hisar and Sirsa of Haryana. It causes low to moderate damage in parts of Maharashtra, Tamil Nadu, and Andhra Pradesh states [3]. For *P. solenopsis*, a linear model degree-day based on the formation of heat units above the lower temperature threshold limit has been developed [4]. To measure the mealy big development, survival, linear and nonlinear models were used. Linear models, especially when subjected to shifting temperature regimes produce mistakes at temperature extremes and are consequently regarded as poor predictors of insect growth [5]. It has the benefit of being simple and allowing estimate of insect species developmental thresholds and degree-day requirements. However, this model is not appropriate for nonlinearity in both high and low temperatures, resulting in inaccurate and biased conclusions. Nonlinear models were created to enhance these results. Most of the nonlinear models are empirical in nature and have four or five parameters. Logan, Briere, Hilbert, Lamb, Sharpe and DeMichele, Wang, Lactin, Stinner, and Gaussian models are used to predict the insect's development, survival and reproduction rate**.** In this study the nonlinear models were used Sharpe and DeMichele model, Wang model, Polynomial model, Stinner model, and Gaussian model. Modified Sharpe and DeMichele's (1977) parameters were based on enzyme kinetics, and each of the three to six factors has a thermodynamic biochemical interpretation.

2. MATERIALS AND METHODS

2.1 Development Rate

The nonlinearity in developmental rate in the temperature extremes was estimated using a modified version of the Sharpe and DeMichele model [6,7]. Poikilotherms derive their body heat entirely from their surroundings. The biological significance of this model to species development dictated that the development of poikilotherms is driven by a rate determining temperature or enzyme complex with the following three basic reversible energy rates. These are inactive at extreme cold condition, active at optimum temperatures, and inactive at high temperature condition. For the different stages, the Sharpe and DeMichele model is

$$r(T)= \frac{p.\frac{T}{T_0}\ .e^{\left[\frac{\Delta H_a}{R}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right]}}{1+e^{\left[\frac{\Delta H_h}{R}\left(\frac{1}{T_h}-\frac{1}{T}\right)\right]}}$$

where, r(T) is rate of development at temperature T (°K), R is the universal gas constant (1.987 cal $degree^{-1}$ mol^{-1}), P represents the development rate at optimum temperature T_o (°K) assuming no enzyme inactivation, ΔH_a is the enthalpy of enzyme activation (cal mol^{-1}), ΔH_h is the change in enthalpy at high temperature (cal mol^{-1}), and T_h is the high temperature at which enzyme is half active.

2.2 Survival Rate

The survivorship of different stages was calculated by Wang model [8]. The Wang model is

$$m(T)=1- \frac{1}{e\left\{\left[1+e\left(-\frac{T-T_{opt}}{B}\right)\right]\left[1+e\left(-\frac{T_{opt}-T}{B}\right)\right]*H\right\}}$$

where, m(T) is the rate of mortality at temperature T (℃), T_{opt} is the optimum temperature for survival (℃), and B is the boundary width at the upper and lower temperatures and H is the value of the upper asymptote of the curve.

The temperature dependence of mortality was described using a second order exponential polynomial function. The following polynomial model expression was used [9,10].

$$m(T) = a+bT+cT^2$$

2.3 Adult Life Span

Adults' mean survival time was recorded for both sexes. To predict the relationship between adult senescence rate and temperature, a modified Stinner model [4] was fitted. The model is

$$r(T) = \frac{c_1}{1 + e(k_1 + k_2 * T)} + \frac{c_2}{1 + e(k_1 + k_2(2 * T_0 - T)}$$

Where, r(T) is the senescence rate at temperature T (℃), T_0 is the optimum temperature (℃), c_1 and c_2 are the maximum and minimum temperatures (℃) when T ≤ To and T > To, respectively, and k_1 and k_2 are constants.

2.4 Reproduction Rate

To determine the influence of temperature on the total number of eggs laid per female, a Gaussian equation [11] was used. The model's expression is

$$r(T) = R_{max} \exp^{\left[-\frac{1}{2}\left(\left(\frac{T - Tmax}{k}\right)\right)^2\right]}$$

Where, r(T) denotes the development rate at temperature T (°C), R_{max} denotes the maximum development rate, T_{max} denotes the temperature (℃) at which the maximum development rate occurs, and k denotes the steepness of this equation.

2.5 Statistical Criteria

Akaike Information Criteria (AIC) = 2k-2 ln(L)

$$MAPE = \frac{100}{N}\sum\left|\frac{\text{Actual} - \text{Predicted}}{\text{Predicted}}\right|$$

$$MAE = \sum\left|\frac{\text{Actual} - \text{Predicted}}{\text{Predicted}}\right|$$

$$RMSE = \sqrt{\frac{\sum(\text{Actual}-\text{Predicted})^2}{N}}$$

$$RSE = \sqrt{\frac{\sum(\text{Actual}-\text{Predicted})^2}{\sum(\text{Actual} - \overline{\text{Actual}})}}$$

$$RAE = \frac{\sum|\text{Actual}-\text{Predicted}|}{\sum|\text{Actual} - \overline{\text{Actual}}|}$$

3. RESULTS AND DISCUSSION

P. solenopsis has the development day for 1 instar is 3-12 days, 2 instar have 3-10 days, 3 instar have 3-9 days, male have 3-8 days, female have 3-7 days. Mean developmental days for 1 instar, 2 instar, 3 instar, male and female have 6 ± 0.174, 5.8 ± 0.134, 4.9 ± 0.112, 5.9 ± 0.16, 4.8±0.101 respectively. The survival of first and third instars was the same percentage of survived (71.4%), the second instar had only 45.5% survived, and females survived 92.7%, male survived 89.9%. Fecundity mean is 199.7905±3.479603 with 132-278 crawlers per female.

3.1 Development Rate

The modified Sharpe and DeMichele model for nymph 1, 2, and 3 development was raised from 20°C to 30°C; after 30°C, the development rate was gradually lowered. The adult male growth rate was raised up to 40°C; over 40°C, development was halted (Fig. 1). Males have a high coefficient of determination (R^2) across all life phases (Table 1). Males also have low error levels (Table 1). As a result, it is the best fit model. The Sharpe and DeMichele model allows for prediction of the projected decline in development rates at temperatures over 40 degrees Celsius [12]. The duration of the first instar and male specimens were reduced three times from 20°C to 30°C and 30 to 35°C, but with a modest increase in duration at 40°C was noticed [13].

3.2 Mortality Rate

Mortality was gradually raised to 38°C using the Wang model for all life phases such as nymphs 1, 2, 3, male, and female. Mortality rose quickly after 38°C (Fig. 2). All life phases had comparable coefficients of determination (R^2). However, when all life stages are included, nymph 3 has the best fit model with a slightly higher coefficient of determination (R^2). As a result, it is the best fit model. Males have the lowest error values based on the error values (Table 2). The Wang model predicted that the temperature-dependent mortality was the best fit for first and second-instar nymphs with R^2 value 0.856 and 0.953, respectively [12].

Table 1. In Sharpe and DeMichele model for the different life stages error measuring statistical tools

Life Stage	Intercept	Slope	R^2	AIC	MAPE	MAE	RMSE	RSE	RAE
Nymph 1	7.18830	0.160190	0.29571	39.55	0.1171385	1.29917	1.50084	0.70428	0.87715
Nymph 2	7.098728	0.12591	0.23774	38.26	0.11744	1.18454	1.36883	0.76225	0.89492
Nymph 3	6.01681	0.11663	0.36819	32.81	0.09060	0.80686	0.92754	0.63180	0.89575
Male	2.81313	0.15448	0.91797	16.06	0.03493	0.24388	0.28035	0.08202	0.31727

Table 2. In Wang model for the different life stages error measuring statistical tools

Life Stage	Intercept	Slope	R^2	AIC	MAPE	MAE	RMSE	RSE	RAE
Nymph 1	0.579303	0.004292	0.908482	-33.27	0.010245	0.007263	0.008269	0.091518	0.329632
Nymph 2	0.556773	0.004349	0.907216	-32.97	0.010779	0.007419	0.008444	0.092796	0.332325
Nymph 3	0.596211	0.004238	0.909465	-33.53	0.021076	0.015294	0.017317	0.412016	0.702727
Male	0.590613	0.004257	0.909136	-33.44	0.009976	0.007174	0.008170	0.090864	0.32823
Female	0.584947	0.004275	0.908807	-33.35	0.010111	0.00722	0.008221	0.091193	0.328935

Table 3. In a polynomial model for the different life stages error-measuring statistical tools

Life Stage	Intercept	Slope (b,c)	R^2	AIC	MAPE	MAE	RMSE	RSE	RAE
Nymph 1	27.186	- 1.201, 0.0155	0.8492	27.52	0.104991	0.559265	0.635658	0.129886	0.400076
Nymph 2	15.202	- 0.4315, 0.0038	0.7666	7.84	0.024884	0.137110	0.155839	0.015662	0.135963
Nymph 3	14.042	- 0.4552, 0.0049	0.8063	11.4	0.036881	0.176800	0.200950	0.040457	0.218603
Male	12.38	- 0.3508, 0.0032	0.9023	5.43	0.024894	0.115461	0.131233	0.018192	0.146494
Female	6.899	0.195, -0.0073	0.7652	16.98	0.082681	0.415943	0.467868	0.096602	0.341294

Table 4. In a Gaussian model for the different life stages error-measuring statistical tools

Life Stage	Intercept	Slope	R^2	AIC	MAPE	MAE	RMSE	RSE	RAE
fecundity	77.41998	0.749865	0.002112	98.19	136.2032	91.29613	98.94862	0.997888	1

Table 5. Analogy study of different empirical models

Model	Intercept	Slope	R^2	MAPE	MAE	RMSE	RSE	RAE
Sharpe and DeMichele model	5.779245	0.13930	0.14700 (3)	0.44317 (2)	4.67893 (2)	5.35570 (3)	5.89522 (3)	2.50710 (3)
Wang model	0.581569	0.00428	0.75123 (2)	7.09282 (3)	4.96725 (3)	5.24088 (2)	30530.7 (4)	209.314 (4)
Polynomial model	15.14200	- 0.4487, 0.004	0.819400 (1)	0.098156 (1)	0.535121 (1)	0.618860 (1)	0.194418 (1)	0.47114 (1)
Gaussian model	77.41998	0.74986	0.00211 (4)	136.203 (4)	91.2961 (4)	98.9486 (4)	0.99788 (2)	1 (2)

***Values in parenthesis refers to the rank of the measures*

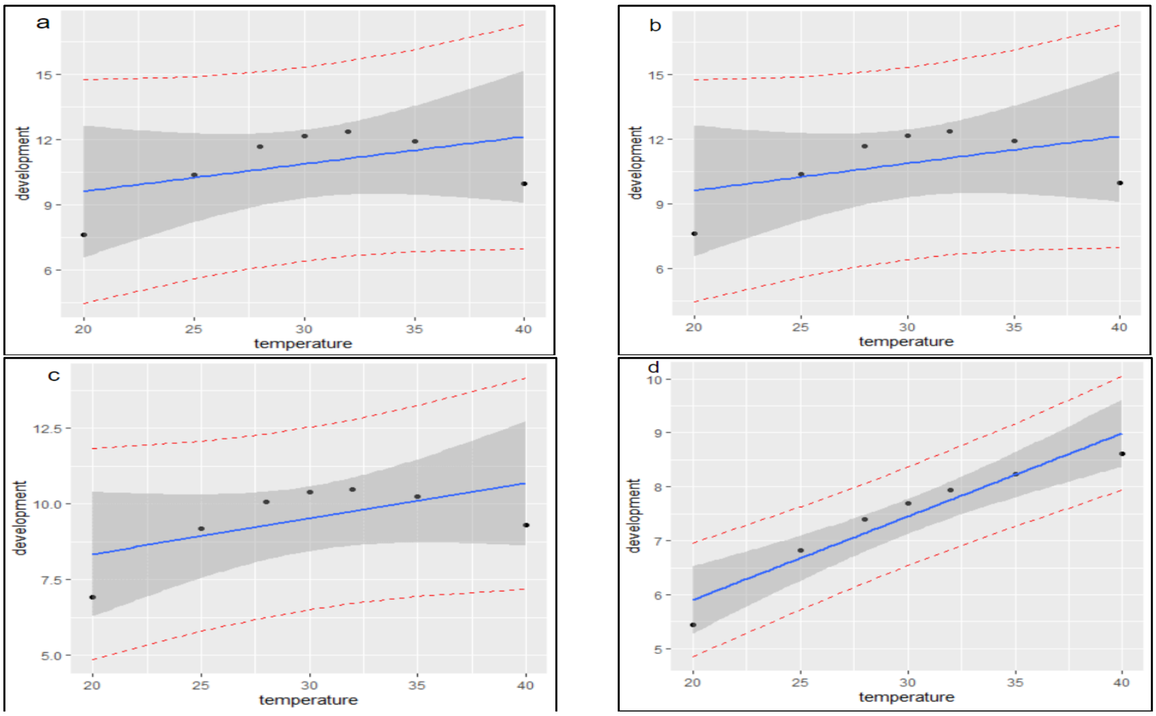
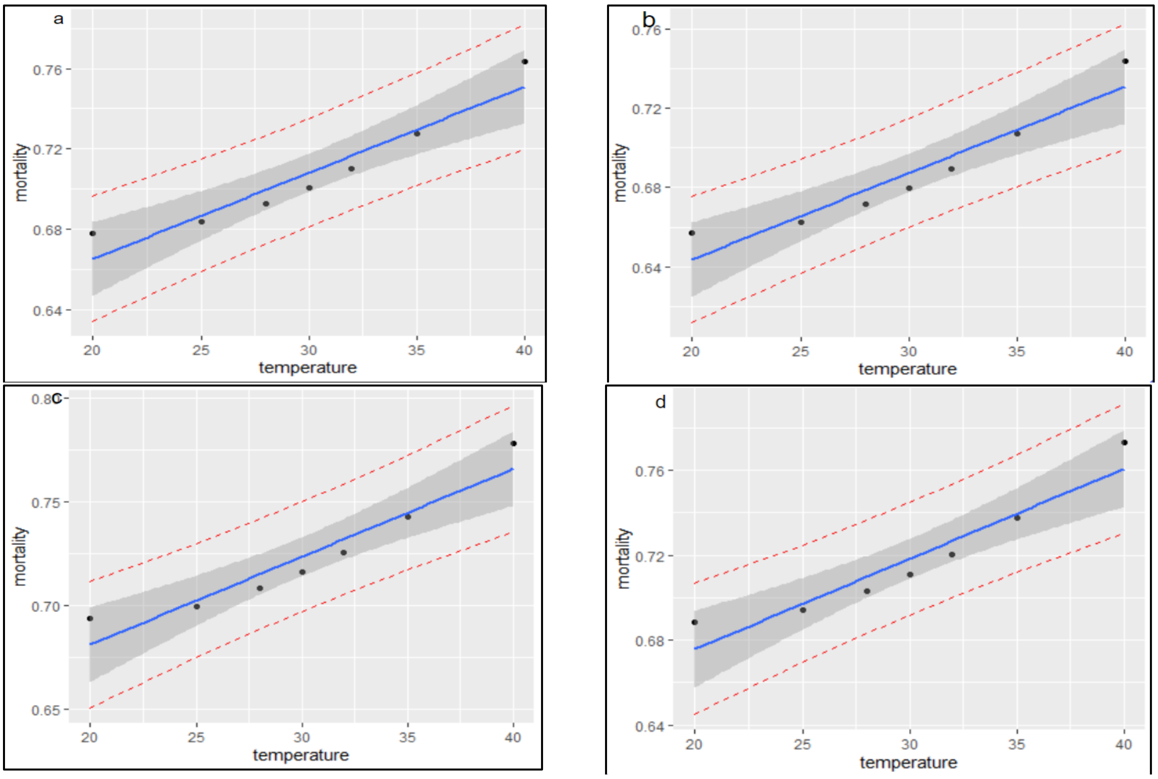


Fig. 1. a) 1 instar b) 2 instar c) 3 instar d) male developmental rate based on different temperature by using Sharpe and DeMichele model at 95% confidence interval



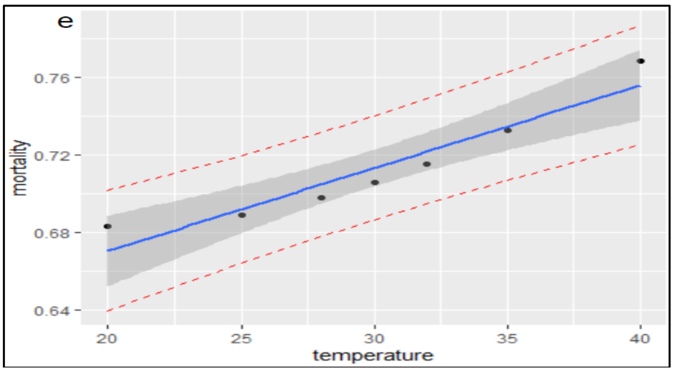


Fig. 2. a) 1 instar b) 2 instar c) 3 instar d) male e) female mortality based on different temperature by using Wang model at 95% confidence interval

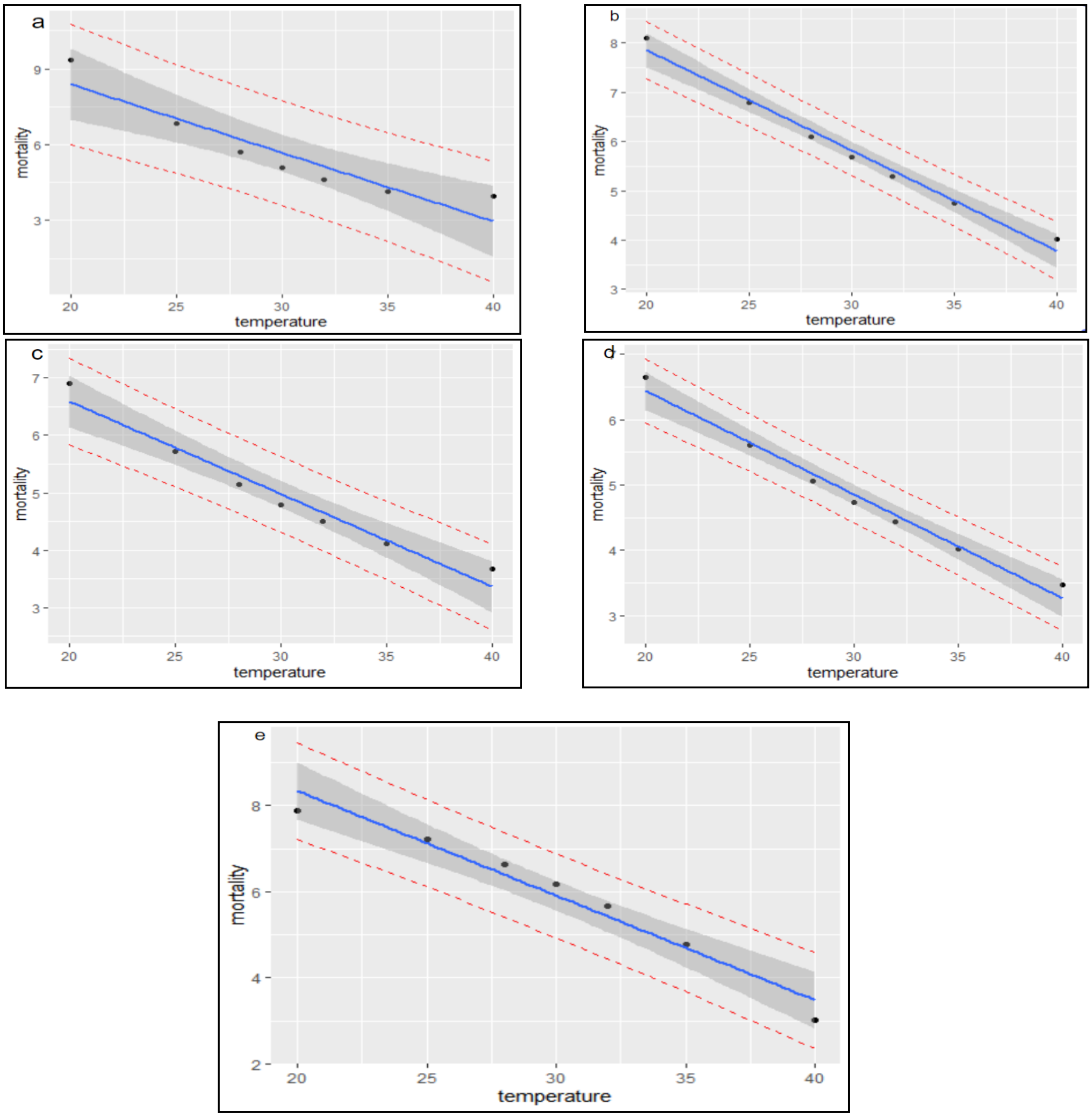


Fig. 3. a) 1 instar b) 2 instar c) 3 instar d) male e) female mortality based on different temperature by using Polynomial model at 95% confidence interval

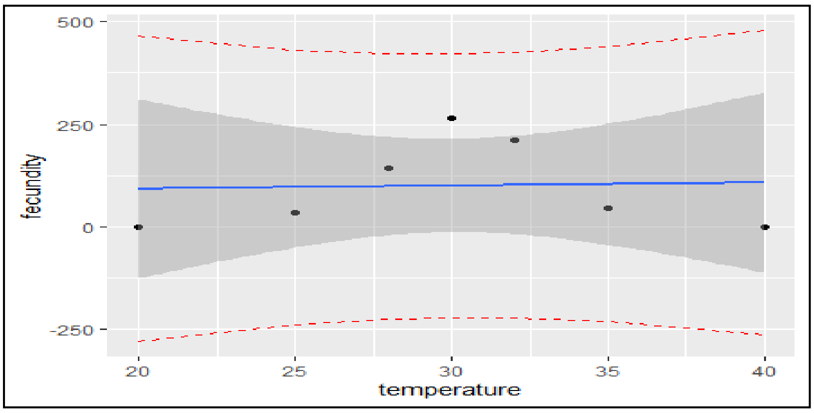


Fig. 4. Fecundity rate based on different temperature by using Gaussian model at 95% confidence interval

From the polynomial model, the mortality rate for nymph 1 declined with increasing temperature until 35°C; at 40°C, it remained at the 35°C levels. Other stages were rapidly reduced from 20°C to 40°C (Fig 3). On average, males have the highest coefficient of determination and, overall the lowest error levels (Table 3). As a result, it is the best fit model. The Polynomial model indicated that temperature-dependent mortality was best suited for third and male-instar nymphs, with R^2 values of 0.873 and 0.895, respectively [12].

3.3 Reproduction Rate

According to the findings, the temperature significantly impacts mealy bug reproduction. The reproductive period was reduced when female life spans decreased owing to increasing temperatures. At 30°C, fecundity is at its peak. At 20°C, the fecundity rate based on the Gaussian equation was quite low. The fecundity rate was gradually increased from 25°C to 30°C. It was lowered after 30°C. It was quite low at 40°C (Fig. 4). It has a very low coefficient of determination and the greatest error values (Table 4). The model projected that the optimal temperature ranges for reproduction would be between 20 and 35 degrees Celsius, with maximum fecundity at 30 degrees Celsius [12].

4. CONCLUSION

Four distinct models were examined in this study to predict mealy bug development, survival, adult life span, and reproduction rate. Statistical approaches such as R^2, MAPE, MAE, RMSE, RSE, and RAE were used to identify the best empirical models. The performance of all models was graded using various goodness-of-fit criteria. When comparing all the other models, the polynomial model has the best fit model with the highest coefficient of determination (R^2) and the lowest MAPE, MAE, RMSE, RAE, and RSE (Table 5). Subsequent investigations that record the biological variables of *P. solenopsis* under changing temperatures are sought. These would aid in valuing idate the temperature based models created for this work and in future contribute to mapping the predicted changes in distribution and in reaction to global warming, there is an increase in the abundance of *P. solenopsis*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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