

## RESEARCH

# Development of Temporal Modeling for Forecasting and Prediction of the Incidence of Lychee, *Tessaratoma papillosa* (Hemiptera: Tessaratomidae), Using Time-Series (ARIMA) Analysis

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**ABSTRACT.** The most destructive enemy of the lychee, *Litchi chinensis* Sonn. (Sapindales: Sapindaceae), in India is a stink bug, *Tessaratoma papillosa* (Drury) (Hemiptera: Tessaratomidae). The population of *T. papillosa* on lychee trees varied from  $1.43 \pm 0.501$  to  $9.85 \pm 3.924$  insects per branch in this study. An increase in the temperature and a decrease in the relative humidity during summer months (April to July) favor the population buildup of *T. papillosa*. A forecasting model to predict *T. papillosa* incidences in lychee orchards was developed using the autoregressive integrated moving average (ARIMA) model of time-series analysis. The best-fit model for the *T. papillosa* incidence was ARIMA (1,1), where the *P*-value was significant at 0.01. The highest *T. papillosa* incidences were predicted for April in 2010, January in 2011, May in 2012, and February in 2013. A model based on time series offers longer-term forecasting. The forecasting model, ARIMA (1,1), developed in this study will predict *T. papillosa* incidences in advance, thus providing functional guidelines for effective planning of timely prevention and control measures.

**Key Words:** *Tessaratoma papillosa*, *Litchi chinensis*, population, prediction model, weather factor

The lychee, *Litchi chinensis* Sonn. (Sapindales: Sapindaceae), is an important subtropical evergreen fruit crop known for its deliciously fragrant, juicy and quality fruits and is economically important to growers in India. It has highly specific climatic requirements, and thus its cultivation is restricted to few countries in the world. India and China account for 91% of the world lychee production but the fruit is mainly marketed locally. India is the second largest producer of lychee in the world after China. Among fruit crops, the lychee ranks seventh in area and ninth in production levels but is sixth in terms of value in India. Because it has adapted to variable climatic conditions, the production and productivity are limited by insect pests, non-insect pests, and diseases causing yield losses up to 70% (Boopathi et al. 2011). Among various insect pests of the lychee, a stink bug, *Tessaratoma papillosa* (Drury) (Hemiptera: Tessaratomidae), is considered to be a major destructive pest causing extensive damage to the lychee (Butani 1977, Boopathi et al. 2011). The bug lays globular off-pink eggs, mostly in bunches of 14, on the lower surface of leaves. A newly emerged nymph is dirty white and soft-bodied, and the color changes to yellow-red after few days. Both adults and nymphs feed mostly on tender plant parts such as growing buds, leaf petioles, fruit stalks, and tender branches of a lychee tree. Excessive feeding causes growing buds and tender shoots to dry, and ultimately fruits drop. The bugs, when fed on developing fruits and seeds, cause the fruits to fall in a couple of days. The puncture mark is invisible on the fruit surface, and the only way to distinguish the pest damage from the natural fruit drop is to dissect the fruit. When frightened, the bug shoots a foul-smelling liquid, which can burn or darken flowers, tender tips and leaves and young fruits and even lead to downy mildew. Fruits that have been attacked typically have a tan lesion on the seed testa. Liu and Lai (1998) claimed that up to 30% of fruits are damaged by the lychee stink bug in commercial orchards despite chemical applications. Recently, an outbreak of the lychee stink bug occurred in the Chotanagpur plateau of Jharkhand, India, during February-April 2011 (Choudhary et al. 2013).

Perusal of the literature showed that weather factors do not influence the *T. papillosa* incidence, which is essential for the development of management strategies. Recent studies have shown, however, that although the infestation is observed throughout the year, it is high in summer, moderate during the post-rainy season and low in the rainy season (Liu and Lai 1998, Boopathi et al. 2011). Therefore, these studies clearly indicate that, besides the availability of new flowers and shoots, weather factors also play an important role in the *T. papillosa* incidence. The population buildup of any insect is very intimately associated with the weather factors prevailing during preceding and corresponding periods (Boopathi et al. 2014). The pest status does not remain static throughout the year but changes depending on abiotic factors such as the temperature, relative humidity, rainfall, rainy days, etc. (Boopathi et al. 2015). The forecasting of the *T. papillosa* incidence would enable the prevention of outbreaks and epidemics. There has been no such modeling of the *T. papillosa* incidence in India before. Hence, this study aims to propose (1) a forecasting model for the *T. papillosa* incidence based on time-series analysis and (2) a prediction model incorporating weather factors, which are important in the development of the *T. papillosa* population.

## Materials and Methods

**Sampling and Observation of *T. papillosa*.** The present study was carried out during 2009 and 2010 in an 8-yr-old lychee orchard (cv. Shashi) at the ICAR Research Complex for NEH Region, Mizoram Centre, Kolasib, Mizoram, India. Ten trees were randomly selected for the study and were kept free from insecticides during the period of observation. Sampling was done at weekly intervals and included all stages of *T. papillosa*, except eggs. On each tree, four terminal shoots were selected at random from the entire canopy. Thus, 40 shoots growing in all directions were sampled per week.

**Meteorological Data.** A weather record from March 2009 to March 2010 was obtained from the Meteorological Unit, ICAR Research

Complex for NEH Region, Mizoram Centre, Kolasib, Mizoram, India. The daily reported weather variables collected and recorded at the weather station included the mean, minimum and maximum temperature, the minimum and maximum humidity and the rainfall.

**Autoregressive Integrated Moving Average (ARIMA) Modeling Methods.** The forecasting model proposed in this study was a multiplicative seasonal autoregressive integrated moving average (ARIMA) model. A seasonal ARIMA model is expressed as  $ARIMA(p, q)(P, Q)_s$  model, where  $p$  and  $P$  are the orders of the autoregressive and seasonal autoregressive parts, respectively;  $q$  and  $Q$  are the orders of the moving average and seasonal moving average parameters, respectively; and  $s$  is the length of the seasonal period.

From the autocorrelation functions (ACFs), partial autocorrelation functions (PACFs), inverse autocorrelation function (IACF), and

cross-correlation function (CCF), plausible models were identified. Forecasting models were developed for the *T. papillosa* incidence. The model diagnostics was performed using Akaike's information criterion (AIC), Schwarz's Bayesian criterion (SBC) and the  $P$ -value. The lowest SBC value with a  $P$ -value less than 0.05 was considered a good model (Chafield 1975, Bowerman and O'Connell 1987, Box et al. 1994).

Good ARIMA models from different data series were explored, in which actual and predicted *T. papillosa* incidences were closely matched as shown in Table 1. The mean average percentage errors (MAPEs) were computed. The best model with the smallest MAPE value was used to predict *T. papillosa* incidences for the years 2010 to 2013. The ARIMA modeling was performed using the SAS Software Version 9.3 (SAS Institute, Inc. 2011).

**Table 1. Observed and autoregressive integrated moving average (ARIMA) predicted population of *Tessaratoma papillosa* in lychee**

Date	Observed	ARIMA predicted
04.03.2009	5.92 ± 1.432	5.92
11.03.2009	3.50 ± 0.871	3.50
18.03.2009	4.52 ± 0.987	3.54
25.03.2009	4.90 ± 0.574	4.23
01.04.2009	4.72 ± 0.811	4.77
08.04.2009	6.93 ± 1.309	4.76
15.04.2009	9.19 ± 3.084	6.29
22.04.2009	9.25 ± 3.847	8.49
29.04.2009	9.85 ± 3.924	9.19
06.05.2009	8.28 ± 3.170	9.67
13.05.2009	7.31 ± 2.799	8.73
20.05.2009	9.22 ± 3.181	7.62
27.05.2009	8.53 ± 2.780	8.68
03.06.2009	7.96 ± 2.496	8.70
10.06.2009	8.50 ± 2.846	8.14
17.06.2009	6.90 ± 2.553	8.35
24.06.2009	7.56 ± 2.911	7.36
01.07.2009	7.58 ± 2.947	7.40
08.07.2009	6.93 ± 2.591	7.56
15.07.2009	9.33 ± 3.199	7.12
22.07.2009	2.90 ± 1.115	8.64
29.07.2009	2.62 ± 1.197	4.73
05.08.2009	2.78 ± 1.158	2.82
12.08.2009	2.59 ± 0.881	2.75
19.08.2009	2.40 ± 0.850	2.64
26.08.2009	1.87 ± 0.862	2.46
02.09.2009	1.79 ± 0.710	2.03
09.09.2009	1.97 ± 0.556	1.82
16.09.2009	1.79 ± 0.613	1.92
23.09.2009	3.38 ± 1.542	1.84
30.09.2009	2.50 ± 0.900	2.92
07.10.2009	2.41 ± 0.960	2.73
14.10.2009	2.50 ± 0.925	2.45
21.10.2009	2.49 ± 1.072	2.48
28.10.2009	3.16 ± 1.328	2.49
04.11.2009	3.64 ± 1.570	2.96
11.11.2009	3.87 ± 1.707	3.49
18.11.2009	3.21 ± 1.588	3.79
25.11.2009	3.30 ± 1.482	3.40
02.12.2009	2.40 ± 0.988	3.29
09.12.2009	1.43 ± 0.501	2.66
16.12.2009	2.76 ± 0.596	1.73
23.12.2009	3.13 ± 0.961	2.39
30.12.2009	3.81 ± 0.995	3.00
06.01.2010	2.87 ± 1.073	3.60
13.01.2010	3.50 ± 0.903	3.13
20.01.2010	3.94 ± 0.715	3.33
27.01.2010	3.74 ± 0.865	3.80
03.02.2010	6.30 ± 1.502	3.79
10.02.2010	4.50 ± 1.423	5.56
17.02.2010	5.71 ± 0.954	4.98
24.02.2010	4.90 ± 0.852	5.39
03.03.2010	3.40 ± 1.126	5.12
10.03.2010	5.13 ± 0.848	3.85
17.03.2010	5.10 ± 0.629	4.65
24.03.2010	6.47 ± 0.705	5.08
31.03.2010	4.66 ± 1.073	6.07

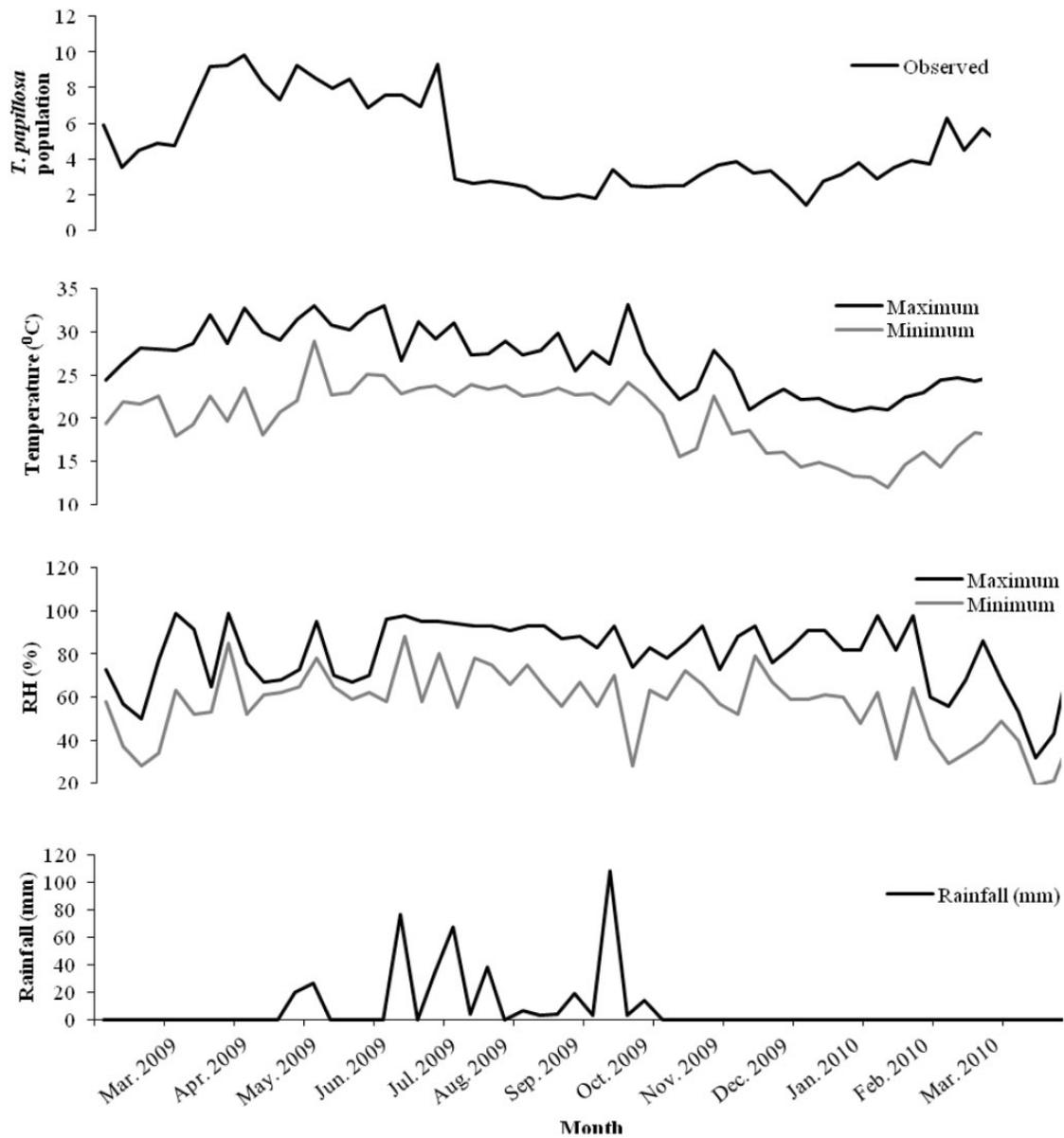


Fig. 1. Weekly observed *Tessarotoma papillosa* population in lychee with temperature, humidity and rainfall from March 2009 to March 2010.

## Results and Discussion

***T. papillosa* Incidence.** The population of *T. papillosa* varied from  $1.43 \pm 0.501$  to  $9.85 \pm 3.924$  insects per branch (Table 1) and reached maximums on 29 April 2009 ( $9.85 \pm 3.924$ ), 20 May 2009 ( $9.22 \pm 3.181$ ), and 15 July 2009 ( $9.33 \pm 3.199$ ). A rapid decline in the *T. papillosa* population was observed on 22 July 2009 and continued till the last week of March 2010 with small fluctuations in the *T. papillosa* population. Overall, the maximum temperature varied between 21 and 33°C and the mean minimum temperature varied between 12 and 29°C. The weekly maximum relative humidity ranged between 32 and 99%, and the mean minimum relative humidity ranged between 19 and 88%. The amount of rainfall greatly varied from week to week, ranging from zero to 108 mm per week (Fig. 1). An increase in the maximum (29 to 33°C) and minimum (20 to 24°C) temperatures, a decrease in the maximum (99 to 76%) and minimum (85 to 52%) relative humidity and no rain during summer months, April (39.94), May (33.34), June (30.92), and July (29.36), favored the population buildup of *T. papillosa*. Earlier, Liu and Lai (1998) and

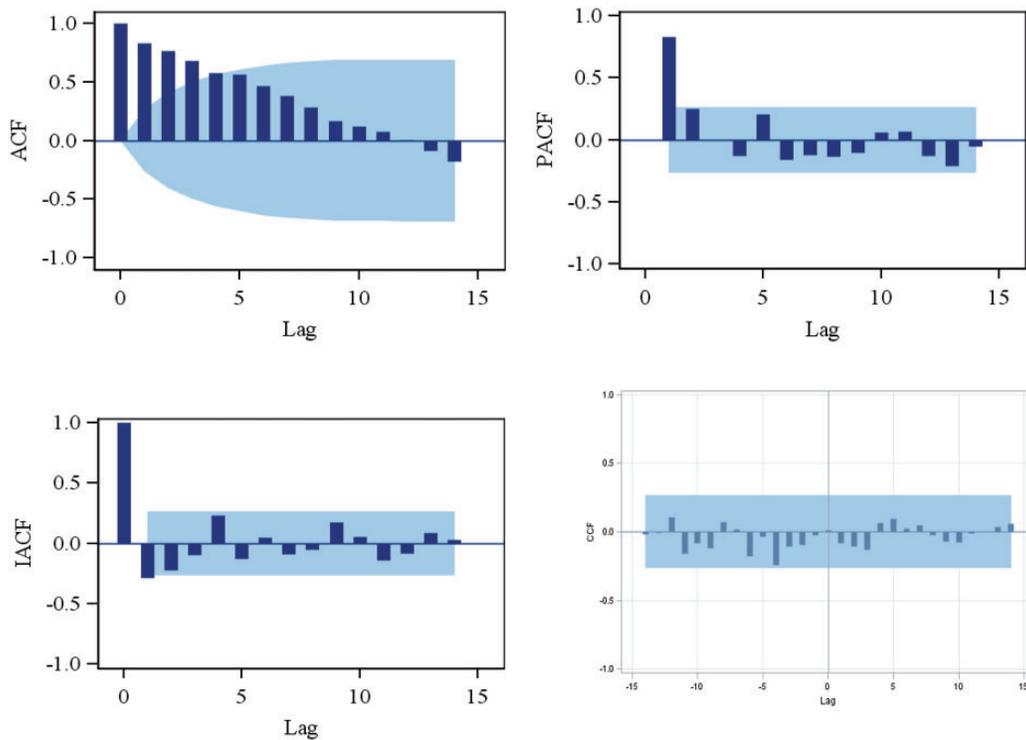
Table 2. *t*-value and *P*-value of conditional least squares estimation of *T. papillosa* population in different ARIMA models

Model	Standard error	<i>t</i> -value	<i>P</i> -value
ARIMA (1,1)	0.1336	4.67	<0.0001**
ARIMA (1,2)	0.1341	1.87	0.0675 ns
MA (1,1)	0.2852	1.71	0.0924 ns

\*\* , significant at 0.01; ns, non-significant.

Boopathi et al. (2011) reported higher populations of the lychee stink bug during summer compared with the other seasons, which is in line with the present findings.

**Time Series Forecasting Models (ARIMA).** The best-fit models for the observed and predicted *T. papillosa* populations are shown in Table 2. The best-fit model for the *T. papillosa* incidence was ARIMA (1,1), where the *P*-value was significant at 0.01 ( $P = < 0.0001$ ). At the same time, the ARIMA (1,2) and MA (1,1) models had non-significant



**Fig. 2.** Correlation analysis for *T. papillosa* population (ACF, autocorrelation function; PACF, partial autocorrelation function; IACF, inverse autocorrelation function; CCF, cross-correlation function).

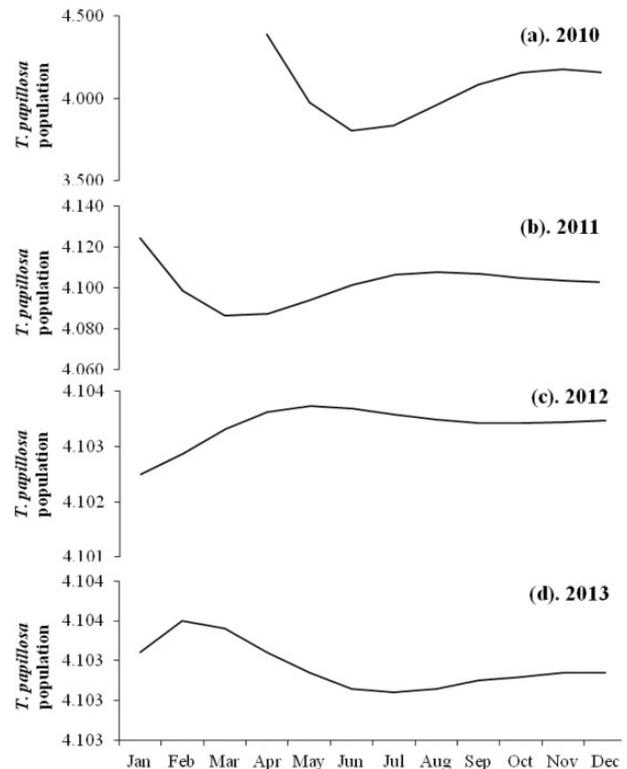
*P*-values ( $P=0.0675$  and  $P=0.0924$ ) for the *T. papillosa* incidence. The ARIMA-predicted population of *T. papillosa* varied from 1.73 to 9.67. The ARIMA model predicted that the *T. papillosa* incidence would be highest during summer months, April (33.50), May (34.70), June (32.55), and July (35.45). It also predicted a sharp decline in the *T. papillosa* population during August 2009 and then a steady increase in the *T. papillosa* incidence from October 2009 and continuing till March 2010.

The plausible models were identified from ACFs, PACFs, IACF, and CCF (Fig. 2). The values of ACF varied from 0.465 to 0.830. The best model was fitted to predict *T. papillosa* incidences for 2010 to 2013 (Fig. 3). The highest *T. papillosa* incidences were predicted for April in 2010 (4.393), January in 2011 (4.124), May in 2012 (4.104), and February in 2013 (4.104). The lowest incidence of *T. papillosa* was predicted for June in 2010 (3.805), March and April in 2011 (4.087), January in 2012 (4.102), and July in 2013 (4.103).

This investigation provides an example of applying a simple ARIMA model to predict *T. papillosa* incidences, for which targeted interventions are highly recommended to provide the most effective control. This model was developed according to the trend of the *T. papillosa* incidence over a period of time and presuming pattern stability of all other conditions such as weather factors and control and preventive measures. The models developed were validated and appeared to fit well, thus providing tolerable error levels in forecasting.

## Conclusions

The objective of this study was to develop a reasonable prediction model for the lychee stink bug, *T. papillosa*, using reliable and dependable weather variables that have direct influence on the *T. papillosa* incidence. By using the prediction model developed in the present study, it might be possible to predict a *T. papillosa* incidence in advance, thus providing a functional guideline for effective planning of timely prevention and control measures. This method is highly useful for estimating the *T. papillosa* incidence and saves precious time by avoiding field observations. Knowledge of the spatial distribution of



**Fig. 3.** Forecasted monthly *T. papillosa* population in lychee from 2010 to 2013.

*T. papillosa* would also assist in applying targeted control measures. A model based on time series would offer longer-term forecasting. However, further research is suggested to evaluate the efficiency of integrating a forecasting model into the existing control program in

terms of its impact on reducing the *T. papillosa* incidence and also the cost of control interventions.

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