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Population dynamics, weather parameters interaction of insect pests on Indian bean, *Lablab purpureus* and prediction analysis using ARIMAX model

M. Kannan[1]*, M. Ananthan[2], M. Kalyanasundaram[3], S.A. Jayaprakash[4], K. Elango[5] and P. Dinesh Kumar[6]

[1]Department of Nano science and Technology, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[2]Open and Distance Learning, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[3]Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[4]Central Integrated Pest Management Centre, Indore-452 001, India
[5]Kumaraguru Institute of Agriculture, Erode-638 315, India
[6]Department of Agricultural statistics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741 252, India

***Corresponding Author Email :** kanento@gmail.com

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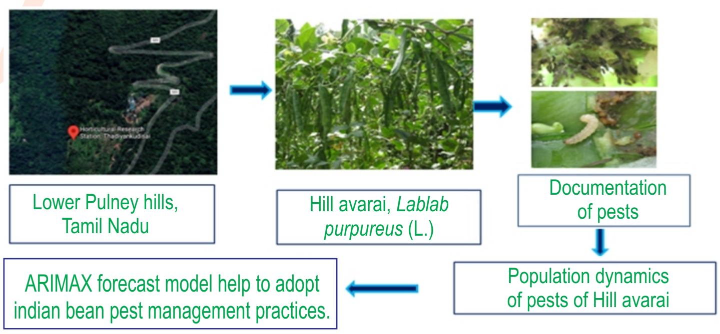
Abstract

Aim: The present study was conducted to find out the dynamics of insect pests in Indian bean, *Lablab purpureus* during different season at Lower Pulney hills in Tamil Nadu and to predict the occurrence of insects/pests for management practices.

Methodology: Field trial was conducted in the rain fed Hill Avarai, *Lablab purpureus* (Linn.) at Thandikudi village of Lower Pulney hills to study the population dynamics and weather factors interaction with sucking pests, leaf, flower eating insects and pod borers. Forecast modeling of major pests of hill avarai were done with ARIMAX analysis.

Results: Around 21 insect species belonging to four major insect orders *viz.,* Hemiptera, Lepidoptera, Coleoptera, Orthoptera with division of three categories namely sucking insects, leaf, flower eating insects and pod borers. Among them the occurrence of sucking pests was maximum and damage followed by leaf, flower eating insects and pod borers. All sucking pests, leaf, flower-eating insects and pod borers showed positive correlation with maximum and minimum temperature, while relative humidity, rain fall and wind speed had negative correlation with sucking pests, however, positive correlation was observed with leaf, flower-eating insects and pod borers.



Interpretation: Under temperate conditions biotic factors such as maximum and minimum temperatures have an important impact in Indian bean pest population fluctuation. ARIMAX model created in this work could be used to forecast the appearance of significant major pests of bean such as *A. craccivora*, *L. trifolii*, and *M. vitrata* in the subtropical areas of Tamil Nadu, India.

Key words: ARIMAX model, Climate, Indian bean, Population dynamics, Seasonal incidence

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Introduction

Hill avarai, *Lablab purpureus* (L.) Sweet (Family: Fabaceae) commonly known as Indian bean, Hyacinth bean, Egyptian bean, Dolichos bean is a perennial herbaceous plant, occupies an important place among the pod vegetable crops grown in field as well as in kitchen gardens (Reddy *et al.,* 2017). It is presently grown throughout the tropical regions in Asia and Africa. It is primarily grown for green pods, while dry seeds are used in food preparations. It is one of the major sources of proteins, minerals and dietary fiber. The green pods have a high nutritive value, comprising 3.8 g protein, 6.7 g carbohydrate, 312 IU vitamin-A, 0.9 g mineral, 0.7 g fat and 1 mg in per 100 g oxalic acid (Kathiravan *et al.,* 2008). India occupies 227.78 ha area under Indian bean cultivation with 2276.95 metric tonnes vegetable bean production and 10 metric tonnes per hectare productivity (Champaneri *et al.,* 2020).

In India, *L. purpureus* as a field crop is mostly confined to the peninsular region and is cultivated to a large extent in Tamil Nadu and adjoining states of Karnataka, Andhra Pradesh and Maharashtra. Insect pests are major constraints in reducing the productivity of Indian bean. Tomar (2014) reported that insect pests pose a challenge to the efficient vegetable production, especially in subtropical region. In order to obtain optimal production of horticulture crops and compete at global level in terms of productivity, the knowledge about insect pests, their biology, bionomics, occurrence and management is of paramount importance. The crop is attacked by a number of insect pests *viz.,* aphid, *Aphis craccivora* Koch.; jassids, *Empoasca fabae* (Harris); *E. krameri* Ross & Moore and *E. kerri* Pruthi; pod borer, *Etiella zinckenella* (Treit.); white fly, *Bemisia tabaci* (Genn.); stem fly, *Ophiomyia phaseoli* (Tryon); hairy caterpillars, *Ascotis imparta* (Walk.); bihar hairy caterpillar, *Spilosoma obliqua* (Walk.) reported by Jakhar *et al.* (2017). The sucking pests complex was causing high damage and yield loses followed by pod borer complex (Tripathi *et al.,* 2018). Indian bean is attacked by as many as 55 species of insects and mites, among them, the pod borers are considered to be the most important group causing crop loss to the tune of 80 to 100 per cent (Jat *et al.,* 2017).

The pod borer complex include avarai pod borer, *Adisura atkinsoni* (Moore); gram pod borer, *Helicoverpa armigera* Hubner; spotted pod borer, *Maruca vitrata* Fab.; bean pod borer moth / pea pod borer, *Etiella zinckenella* Treitschke; soybean pod borer, *Lampiodes boeticus* L. and black cowpea seed moth, *Cydia ptychora* Meyrick. These borer causes substantial damage to flowers by webbing and boring into the pods. In case of severe infestation, these pests attack all parts of the plants including pods which result in stunted growth and decreased yield (Kulhari *et al.,* 2009).The interactions between pest activity with biotic and abiotic factors help in deriving predicative models that in turn forecast the pest incidence. The population buildup of any insect is intimately related to the weather parameters (Boopathi *et al.,* 2014). Climate as an exogenous factor plays a crucial role in determining abundance and distribution of insect and pest population (Chiu *et al.,* 2019). But even today, limited theoretical frameworks are available to examine the effect of climate on population dynamics. Recently, Elango and Nelson (2021) also reported that infestation of pests based on weather parameters will change by ARIMAX model. ARIMAX model (Bierens, 1987) is a generalization of ARIMA model, which is capable of including an exogenous variable (X). Autoregressive Integrated Moving Average with Exogenous variables (ARIMAX) time-series model is applied for modelling and forecasting the pest population after testing for stationarity. In view of the above, this present investigation was conducted to study the population phenology of pests on Indian bean and forecasting using ARIMAX model.

Materials and Methods

The field trial was carried out at Thandikudi village of lower pulney hills (Kodaikanal taluk) in Tamil Nadu. The crop was observed at weekly intervals throughout the crop period till harvest. Observations were recorded during early morning hours to take the advantage of sedentary nature of insects at that time. The population dynamics of sucking pests (whitefly, aphid, leafhopper, thrips, pod bug, green stink bug, green mirid bug), leaf, flower eating insects (hairy caterpillar, leaf miner, leaf folder, tobacco caterpillar, semilooper, grass hopper, ash weevil, flea beetle, blister beetle, chaffer beetle) and pod borers (gram pod borer, blue butterfly, spotted pod borer) were observed by accounting the number of immature and adult stages of insects in three random leaves representing top, middle and bottom canopy from each of the twenty randomly selected plants. The insect pests were categorized as major, minor and stray on the basis of their mean level of incidence.

Correlation of insect population with weather parameters: The influence of abiotic factors on population dynamics of insect pests of hill avarai *viz.,* whitefly, aphid, leafhopper, thrips, pod bug, green stink bug, green mirid bug, hairy caterpillar, leaf miner, leaf folder, tobacco caterpillar, semilooper, grass hopper, ash weevil, flea beetle, blister beetle, chaffer beetle and gram pod borer, blue butterfly, spotted pod borer were carried out by correlating the incidence of insect pests population (dependent variable) with recorded weather factors (independent variable) *viz.,* Maximum temperature (MxT), Minimum temperature (MnT), Relative humidity (RH), total rainfall (RF) and Wind speed (WS), obtained from Regional Coffee Research Station, Thandikudi for the entire study period (2018-19). All together, twenty observations are collected from the 1st Standard Meteorological Week (SMW) to 18^{th} SMW of 2018. Simple correlation was performed using R statistical package to associate the incidence of Hill avarai pests with various biotic factors.

ARIMAX Model: ARIMAX Model was carried out between the data collected on the occurrence of insects and meteorological variables of same time interval. Multivariate time series analysis was employed for predicting the dominant and the maximum damage caused insects namely aphid, *A. craccivora*, serpentine leaf miner, *L. trifolii* and Legume pod borer, *M. vitrata* (number/per plant) of Hill avarai at Lower Pulney hills. Initially, the stationarity of variables was tested using Autocorrelation function (ACF) and Augmented Dicker Fuller (ADF) test. The data was differenced until it became stationary and the difference parameter d was selected. The ACF and PACF were computed to fix the lag parameters p and q for Autoregressive and moving averages respectively. After fitting the ARIMAX models with various combinations, Model selection criterions such as corrected Akaike information criterion (AICc) and Schwartz-Bayesian criterion (BIC) values were employed. The corrected Akaike information criterion (AICc) was given by Cavanaugh (1997), and the Schwartz-Bayesian criterion (BIC) was given by Schwarz (1978),The model with minimum AICc and BIC was selected as the best model for population prediction of aphids, serpentine leaf miner and legume pod borer per plant of Hill avarai.

Results and Discussion

The observation on the population dynamics of insect pests affecting Hill avarai revealed that in total 21 insect species from four major insect orders *viz.,* Hemiptera, Lepidoptera, Coleoptera and Orthoptera belonged to eighteen families. The 21 insect pests species were again subdivided in to three categories *viz.,* sucking insects, leaf, flower eating insects and pod borers, respectively. Among them, the sucking pests showed the maximum incidence and damage followed by leaf, flower eating insects and pod borers (Table.1). One week after sowing, the sucking pest incidences were observed, and population fluctuation persisting to until pre-harvest stage of the beans crop. Among the sucking pests, Aphis craccivora (Koch) incidence was maximum (83 aphids/plant) during 9th SMW followed by whitefly, Bemisia tabaci (Gennadius) 61.5 nymphs/plant and thrips, Thrips palmi (Karny) (9 thrips/plant), respectively. The pod bug, *Rriptortus pedestris* (Fabricius) green stink bug, *Nezara viridula* (Linnaeus) and green mirid bug, *Creontiades biseratense* (Distant) incidence attained peak during 11th SMW (March) and 1st week of April with the population of 6.5, 3.8 and 5.2 number per plant, respectively.

The leaf and flower eating insects incidence were observed during 3rd SMW to 18th SMW (vegetative to flowering stage). Among the defoliators, serpentine leaf miner, *Liriomyza trifolii* (Burgess) incidence was high (7.5 larva/plant) followed by Tobacco caterpillar, *Spodoptera litura* (4 larva/plant) and Leaf folder, *Nacoleia* spp. (2 larvae/plant) during April month. In coleopteran insects, Ash weevil, *Myllocerus subfasciatus* (Guerin) population was maximum (1.8 adults/ plant) during 15th SMW. The incidence of flea beetle, *Phyllotreta striolata* (Fabricius) and chaffer beetle, *Oxycetonia versicolor* (Fabricius) was low with the population of 0.8 adults/plant. The blister beetle, *Mylabris phalerata* (Thunberg) damage was recorded high during flowering stage at 18th SMW (population of 1.2 adult beetles/plant). The occurrence of pod borers were observed from flowering to pod harvest. Among the borers, the incidence and infestation of Spotted pod borer, *Maruca vitrata* (Fabricius) was high during pod formation stage (population of 5.5 larvae/plant) followed by Gram pod borer, *Helicoverpa armigera* (Hübner) (4.0 larvae/plant) at 18th SMW.

The present findings are in line with the reports of Chaudhari *et al.* (2016) who observed that the first and second peak of aphid was recorded in the first and third week of January whereas relatively more numbers of leafhoppers were observed during mid-February to mid-March on Lab lab and the Whitefly population was observed during February to March. The maximum population of thrips was recorded in the second week of February and third week of February during the first and second year of the study, respectively. Likewise, Anandmurthy *et al.* (2018) also stated that the population of whitefly and aphid also appeared from the second week of March in cowpea. The results on the correlation coefficient (r) of sucking pests with weather parameters revealed that maximum temperature influenced all sucking pests with significant positive correlation *viz.,* Aphids (r = 0.364), Whitefly (r = 0.877), Leafhopper (r=0.822), Thrips (r = 0.746), Coried bug (r = 0.77), Pentatomid bug (r= 0.819) and Mirid bug (r = 0.779). Similarly, the minimum temperature also had significant positive correlation with all the sucking pests. Relative humidity was negatively significant with sucking pests and indicated that the sucking pest population may decrease with increase in maximum relative humidity under field condition. Similarly, wind speed and rain fall had negative correlation but showed positive correlation only with leaf hopper (r = 0.074 and r =0.048), respectively.

The present findings are in agreement with the results of Anandmurthy *et al.* (2018), who stated that the maximum temperature showed a significant positive correlation with jassid, whitefly and aphid population in summer cowpea, whereas, wind speed showed negative influence. Chaudhari *et al.* (2016) reported that relative humidity exerted positive influence on aphid whereas it showed negative influence on leafhopper of Indian bean. The maximum temperature positively influenced the infestation in all the leaf and flower eating insect pests showed, except for hairy caterpillar (r = - 0.063), respectively. Minimum temperature significant positive correlation with leaf folder, serpentine leaf miner and *S. litura* larvae (r = 0.811, r = 0.743 and r =0.77). The relative humidity was negatively correlated with all the leaf and flower eating insect pests and positively correlated with blister beetle and Chaffer beetle (r = 0.116 and r = 0.008).

The results are strengthened by Kurly and Singh (2021) who reported the seasonal incidence of defoliators on black gram and recorded that the temperature and relative humidity had positive impact on defoliator population. Rainfall had negative correlation with all the defoliators. In case of pod borers, *M. vitrata* incidence was higher than others, followed by *H. armigera*. The current findings corroborates with the reports of Umbarkar *et al.* (2010) who noted that the population of spotted pod borer started appearing from 5th week after sowing and peak pest density was observed during 7th week after sowing in green gram. Further, Vaibhav *et al.* (2018) stated that the population of *H. armigera* larval reached its peak (10.33 larvae/10 plants) in all control plots on 8th standard week when the maximum and minimum temperature was high in vegetable pea. Moreover, Dubey *et al.* (1993) reported that the peak activity of *H. armigera* was observed in February to March on vegetable pea. Prasad *et al.* (1997) reported that the host range and seasonal incidence of *H. armigera* was maximum adult catches obtain in late week of March. *M. vitrata* was positively influenced by maximum temperature, minimum temperature and rainfall (r = 0. 510, r = 0. 851 and r = 0.084), however, wind speed was negatively correlated with pod borers. Similar positive correlation with

Table.1: Seasonal occurrence of insect pests in Hill avarai, *Lablab purpureus* (Linn.)

Common name	Scientific name	Family	Order	Pest status	Crop growth stage	Pest Incidence	Peak occurrence
Whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera	Major	Vegetative and Pod development	Jan-May	1st week of March
Aphid	*Aphis craccivora* (Koch)	Aphididae	Hemiptera	Major	Vegetative and Pod development	Jan-May	1st week of April
Leafhopper	*Empoasca fabae* (Harris)	Cicadellidae	Hemiptera	Major	Vegetative and Pod development	Jan-May	1st week of April
Thrips	*Thrips palmi* (Karny)	Thripidae	Thysnoptera	Major	Vegetative and Pod development	Jan-May	3rd week of April
Pod bug,	*Rriptortus pedestris* (Fabricius)	Coreidae	Hemiptera	Minor	Vegetative and Pod development	Jan-May	3rd week of March
Green stink bug	*Nezara viridula* (Linnaeus)	Pentatomidae	Hemiptera	Minor	Pod development	Jan-May	3rd week of March
Green mirid bug	*Creontiades biseratense* (Distant)	Miridae	Hemiptera	Minor	Vegetative and Pod development	Feb-May	1st week of April
Leaf and flower eating insects							
Bihar hairy caterpillar	*Spilosoma obliqua* (Walker)	Lymantriidae	Lepidoptera	Minor	Vegetative	Jan-Mar	1st week of March
Leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera	Major	Vegetative	Jan-May	3rd week of April
Leaf folder	*Nacoleia* spp.	Pyralidae	Lepidoptera	Minor	Vegetative	Jan-May	1st week of April
Tobacco caterpillar	*Spodoptera litura* (Fabricius)	Noctuidae	Lepidoptera	Minor	Seedling and Vegetative	Jan-May	1st week of April
Semilooper	*Chrysodeixis chalcites* (Esper)	Noctuidae	Lepidoptera	Minor	Seedling and Vegetative	Feb-Apr	1st week of March
Grass hopper	*Chrotogonus* sp	Acrididae	Orthoptera	stray	Seedling and Vegetative	Feb-Apr	3rd week of March
Ash weevil	*Myllocerus subfasciatus* (Guerin)	Curculionidae	Coleoptera	Minor	Vegetative and Pod development	Feb-May	1st week of April
Flea beetle	*Phyllotreta striolata* (Fabricius)	Chrysomelidae	Coleoptera	stray	Vegetative and Pod development	Feb-Apr	3rd week of March
Blister beetle	*Mylabris phalerata* (Thunberg)	Meloidae	Coleoptera	Minor	Flowering	Mar-May	2nd week of May
Chaffer beetle	*Oxycetonia versicolor* (Fabricius)	Scarabidae	Coleoptera	Minor	Flowering	Mar-May	3rd week of April
Pod borers							
Gram pod borer	*Helicoverpa armigera* (Hübner)	Noctuidae	Lepidoptera	Major	Vegetative and Pod development	Feb-May	2nd week of May
Blue butterfly	*Lampides boeticus* (Linnaeus)	Lycaenidea	Lepidoptera	Major	Vegetative and Pod development	Jan-May	2nd week of May
Spotted pod borer	*Maruca vitrata* (Fabricius) (syn. *M. testulalis*)	Noctuidae	Lepidoptera	Major	Vegetative and Pod development	Jan-May	2nd week of May

maximum and minimum temperature (r) of 0.620 and 0.570 was noted in *M. vitrata* and negative correlation with relative humidity in French bean. Further, the findings of Yadav *et al.* (2015) and Kishor *et al.* (2019) supported the results of the present study. ARIMAX is a predominant time series model employed to predict the pest incidence using weather parameters. The time series data of all the pests were initially tested for its stationarity and necessary number of differentiations has been made to make them stationary. The orders of autoregressive and moving average terms of stationary time series were identified using both PACF and ACF functions, respectively. The 'auto.arima' function from the package 'forecast' did all the preliminary order identification intrinsically and provided the best fitted model.

Weather factors such as maximum temperature, minimum temperature, wind speed, relative humidity, and rainfall

Table. 2: Parameter estimates and its significance of the best fitted ARIMAX model for Aphids, serpentine leaf miner and pod borer

Pests	Parameters	Estimates	Standard error	Pr(>|z|)	Significance
Aphid	AR1	1.556	0.146	<0.001	***
	AR2	-0.714	0.152	<0.001	***
	MxT	0.867	0.261	0.000	***
	RH	0.144	0.076	0.057	-
Serpentine leaf miner	AR1	0.753	0.1721	<0.001	***
	MnT	0.054	0.0210	0.009	**
Pod borer	AR1	0.8446	0.1055	<0.001	***

*** Significance at 0.1% level; ** Significance at 1% level; * Significance at 5% level

Table. 3: Model selection criterion for selected model of aphids, serpentine leaf miner and pod borer

Pests	Model	AIC	AICc	BIC	RMSE	MAE
Aphid	ARIMAX (2,0,0) + MxT, RH	124.14	129.59	128.3	6.327	4.834
Serpentine leaf miner	ARIMAX (1,1,0)	15.38	17.38	17.7	0.3065	0.2284
Pod borer	ARIMAX (1,1,0)	0.63	0.30	0.92	0.1953	0.1538

Table. 4: Auto correlation and randomness of selected model of aphids, serpentine leaf miner and pod borer

Pests	Box pierce test			Box-Ljung test			Runs test		
	Statistic	*p*-value	Inference	Statistic	*p*-value	Inference	Statistics	*p*-value	Inference
Aphid	3.9327	0.9503	No Auto-correlation	5.5164	0.8541	No Auto-correlation	0.000	1	Random
Serpentine leaf miner	2.559	0.99	No auto correlation	4.517	0.921	No Auto correlation	0.517	0.6048	Random
Pod borer	4.263	0.9347	No auto correlation	7.085	0.7173	No auto correlation	1.3641	0.1725	Random

were applied as independent variables to get more accuracy from the models. Among all the fitted models, the model with significant model parameters and with minimum value of model selection criterion statistic would be the best optimum model. The estimates of model parameters and its significance of the selected arimax model for aphid, *A. craccivora*, serpentine leaf miner, *L. trifolii* legume pod borer, *M. vitrata* are given in Table 2. Table 3 explains the test statistic values of all the model selection criterions for the selected model of *A. craccivora*, *L. trifolii* and *M. vitrata*. Parameters with significant coefficient estimates have significant influence over the pest population. The significant model with minimum RMSE and MAE values, and with maximum AIC,AICc and BIC values was selected as the best fitted model for the pest population. The residuals of the selected model were tested for autocorrelation and randomness.

To test autocorrelation, BP test and BL test were employed and both the statistics of those tests did not reject the null hypothesis and proved that the selected model was not autocorrelated. Similarly, for randomness test, Runs test has been employed and the null hypothesis had not been rejected which showed that the residuals of ARIMAX model was random and didn't possess any trend. Since, the model residuals for all three insects passed the autocorrelation and the randomness test as given in Table 4, the selected ARIMAX models were valid models which predicted the insect incidence with maximum accuracy among the possible ARIMAX models. The model ARIMA (2, 0, 0) of aphids showed that the incidence of pest depended on the weather parameters such as maximum temperature and relative humidity, significantly (Fig.1a). The model ARIMA (1, 1, 0) of serpentine leaf miner showed that the incidence of pest depended on the weather parameters such as minimum temperature (Fig.1b) and for *M. vitrata* no weather parameter had made a significant impact over the pest incidence, since ARIMAX (1, 1, 0) model didn't possess any significant weather parameter(Fig.1c). There was no earlier study on Hill avarai and the results of Elango *et al.* (2021) supported that ARIMAX model could be used to predict population fluctuation in insect pests of Hill avarai. In temperate zones, Indian beans may get afflicted by enormous number of insect pests. Sap feeders surpass defoliators and borers in terms of damage-causing abilities among pests. Under temperate conditions, abiotic factors such as maximum and minimum temperatures have an important impact in pest population fluctuation. Furthermore, the ARIMAX

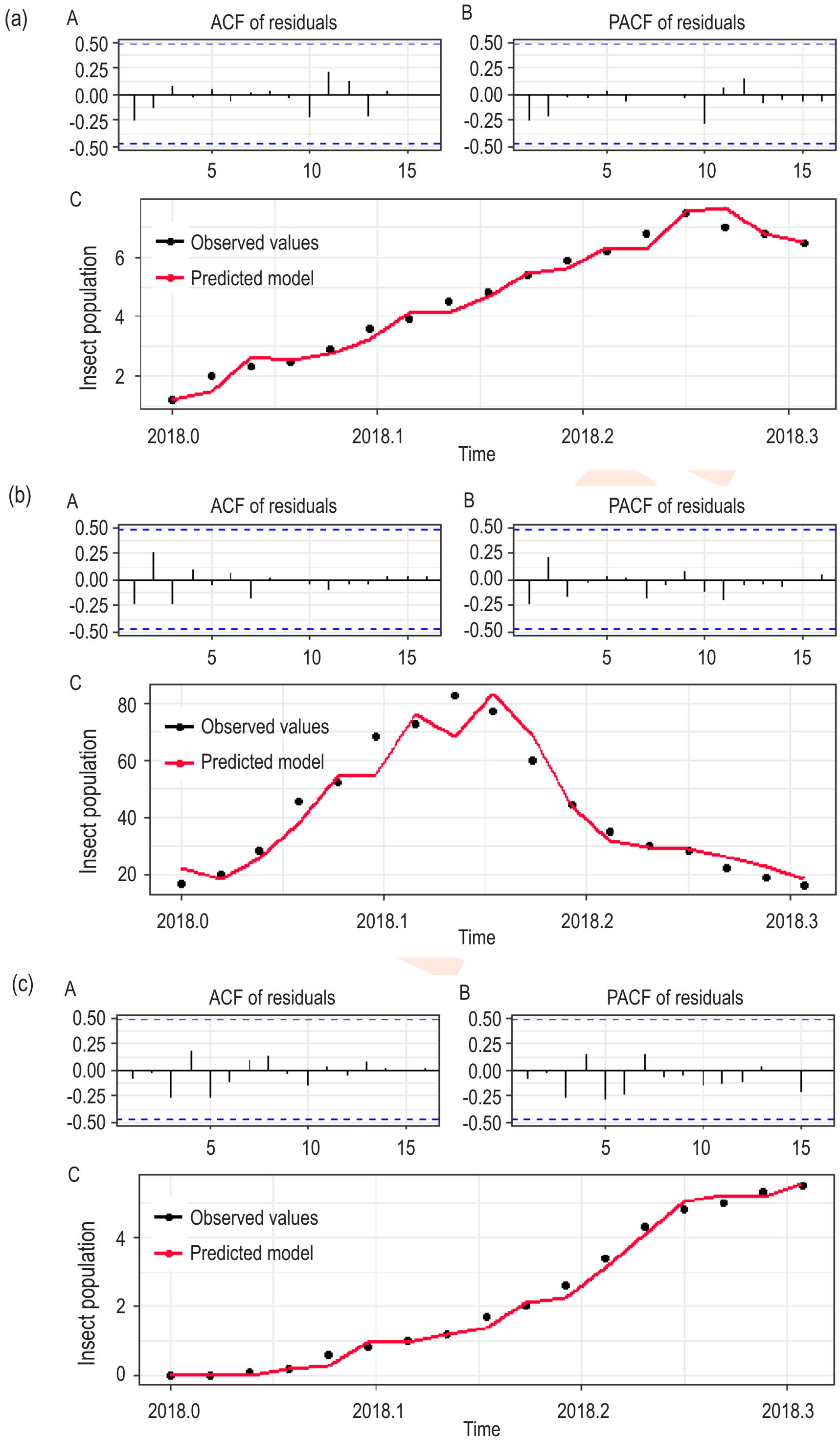

Fig. 1: ARIMAX model for Aphids, serpentine leaf miner and Maruca testulalis in Indian bean - a. Aphid (A-Autocorrelation function for the Second order differentiation data; B- Partial Autocorrelation function of the original series; C- Observed values and predicted values of the model ARIMAX (2, 0, 0) with maximum temperature and relative humidity). b. Serpentine leaf miner (A- Autocorrelation function for the Second order differentiation data; B- Partial Autocorrelation function of the original series; C- Observed values and predicted values of ARIMAX (1, 1, 0) with Minimum temperature). c. Pod borer (A-Autocorrelation function for the Second order differentiation data; B- Partial Autocorrelation function of the original series; C- Observed values and predicted values of ARIMAX (1, 1, 0).

model created in this work could be used to forecast the appearance of significant pests such as *A. craccivora*, *L. trifolii*, and *M. vitrata* in the subtropical areas of Tamil Nadu, India, in advance, allowing for timely preventative and control actions.

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Add-on Information

Authors' contribution: Kannan. M: Conceptualization methodology, data collection and writing original draft preparation; **M. Ananthan:** Conceptualization and manuscript editing; **M. Kalyanasundaram:** Formulation of methodology for the study; **S. A. Jayaprakash:** Formal analysis and writing review; **K. Elango:** Statistical analysis and Manuscript editing; **P. Dinesh Kumar:** Arimax and correlation analysis.

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