Agr. Nat. Resour. 56 (2022) 169–179

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Population dynamics and projections of fruit flies *Bactrocera dorsalis* and *B. carambolae* in Indonesian mango plantation

Agus Susanto[a,*], Agus Dana Permana[b], Tati Suryati Subahar[b], Raden Christianus Hidayat Soesilohadi[c], Amin Setyo Leksono[d], Adji Achmad Rinaldo Fernandes[e]

[a] *Department of Pest and Plant Disease, Faculty of Agriculture, Universitas Padjadjaran, Bandung 45363, Indonesia*
[b] *School of Life Sciences & Technology, Institut Teknologi Bandung, Bandung 40132, Indonesia*
[c] *Laboratory of Entomology, Faculty of Biology, Universitas Gadjah Mada, Teknika Selatan Street, Yogyakarta 55281, Indonesia*
[d] *Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang 65145, Indonesia*
[e] *Department of Statistic, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang 65145, Indonesia*

Article Info

Article history:
Received 3 September 2021
Revised 29 November 2021
Accepted 13 January 2022
Available online 25 February 2022

Keywords:
Abiotic factors,
Abundance,
Fruit fly,
Population projection

Abstract

Importance of the work: The availability of information about fruit fly population dynamics, determinant factors and predictions for the future are pivotal for establishing control measures and are important study topics.
Objectives: The objectives of this study were: to analyze the population dynamics of *Bactrocera dorsalis* and *B. carambolae* fruit flies; to evaluate the effect of abiotic factors on population abundance; and to estimate the projection of population dynamics using a mathematical model.
Materials & Methods: Fruit flies were collected using modified Steiner traps filled with methyl eugenol. The traps were suspended on tree branches 2 m above the ground, with 20 replications. Fruit flies were collected weekly, with the samples transferred to the laboratory for further identification.
Results: In total, 1,011,820 individual fruit flies were collected, consisting of *B. dorsalis* (964,204 individuals or 71.74 individuals per trap) and *B. carambolae* (47,616 individuals or 3.54 individuals per trap. Sunshine duration had a significant, negative correlation with the abundance of *B. dorsalis* (r = -0.206; p = 0.004) and *B. carambolae* (r = -0.217; p = 0.002). The wind speed had a significant, negative correlation with the abundance of *B. dorsalis* (r = -0.211; p = 0.003) and *B. carambolae* (r = -0.162; p = 0.018); while wind direction had a significant, positive correlation with the abundance of *B. dorsalis* (r = 0.155; p = 0.023). Humidity had a significant, positive correlation with the abundance of *B. dorsalis* (r = -0.129; p = 0.048). The effects of temperature and rainfall were not significant on both species. Based on the ARIMA (1,0,3) model, the three-year projection indicated a fairly high population potential in 2021, even in months when the fruit fly population is usually low (March–July). Projections in 2022 and 2023 indicated an increasing trend in the population from August to December.
Main finding: With high population levels, *B. dorsalis* is a main pest of mangoes. Populations of both fruit fly species started to increase from October to December and then decreased from February to June. Population management efforts need to consider population determinants, especially wind direction.

* Corresponding author.
E-mail address: asusanto@unpad.ac.id (A. Susanto)

https://doi.org/10.34044/j.anres.2021.56.1.16

Introduction

Fruit flies belonging to the family Tephritidae consists of about 4,500 species that are considered serious pests on soft fruits distributed globally (Khan and Naveed, 2017). One of the fruit fly genera that is considered an important pest is *Bactrocera*. The genus contains approximately 40 species of important pests including *Bactrocera dorsalis* (the oriental fruit fly) and *B. carambolae* (the carambola fruit fly), with both species being among the most economically important pest species, attacking many host fruits in tropical and subtropical regions in the world (Salmah et al., 2017; Jayanthi et al., 2021). *B. dorsalis* is the main polyphagous fruit fly that infests more than 300 hosts and is widely distributed in both the Asia-Pacific and Africa (Vargas et al., 2015; Vayssières et al., 2015; Salmah et al., 2017), whereas, *B. carambolae* has a distribution area in a narrower range in Southeast Asia and has recently been introduced to South America (Win et al., 2014; Vargas et al., 2015; Marchioro, 2016; Leblanc et al., 2019). Most of the recent studies on *B. carambolae* have been reported in Brazil and other South American countries, because the star fruit fly invasion of this region can lead to serious economic losses (Marchioro, 2016; Midgarden et al., 2016).

Both species of *B. dorsalis* and *B. carambolae* are major pests on mango plantations worldwide, including in Indonesia (Pujiastuti et al., 2020), consuming the mango as a source of food and using it as a medium for laying their eggs. Mango as a seasonal fruit may regulate the abundance of fruit fly populations in the plantations. In addition, these two species attack alternative host plants, such as guava (*Psidium guajava*), star fruit (*Averrhoa carambola*), banana (*Musa paradisiaca*), watery rose apple (*Syzygium aqueum*), sapodilla (*Achras zapota*), papaya (*Carica papaya*), jackfruit (*Artocarpus heterophyllus*) and orange (*Citrus* spp.) (Marchioro, 2016; Pujiastuti et al., 2020). Some other hosts are perennial vegetables, such as banana, chili (*Capsicum futescens*) and tomato (*Solanum lycopersicum*) (Sahetapy et al., 2019). The large number of fruit plants that can host fruit flies increases the risk of their spread throughout the world. This should be a serious concern, especially in areas where fruit crops are cultivated on a large scale. The existence of alternative host plants provides an opportunity for fruit flies to survive while the main host plant is in the vegetative phase. When mangoes start ripening, fruit flies have the opportunity to re-colonize in the mango fruit as their main host. There are two types of host plants for insects, namely annual and perennial host plants that may in turn provide different patterns of fluctuations in fruit flies.

Population estimates are fundamental information in ecology and a consideration for effective pest control. For example, fruit fly population estimation is a prerequisite for successful control based on the sterile insect technique (Sutantawong et al. 2004). The availability of information on the population dynamics of fruit flies, its determinant factors and predictions for the future are very important for determining control measures (Castilho et al., 2019). Abiotic factors, including temperature, light intensity, rainfall, relative humidity, photoperiod, and wind, greatly affect the abundance of fruit flies throughout the year (Khan et al., 2021). *B. dorsalis* populations have a strong correlation with the temperature, rainfall, and host fruits, which play important roles in regulating its population abundance (Ye and Liu, 2007). One optimized model developed using rainfall and wind velocity predicted fruit fly catches based on a coefficient of determination (R^2) value of 78%; this forewarning model may help mango farmers to make advance decisions to minimize quantitative and qualitative crop losses caused by fruit flies in a region (Bana et al., 2017). Similarly, other studies reported that the population fluctuation of male fruit flies was positively correlated with temperature (Yin et al., 2018; Khan et al., 2021). However, the effect of sun irradiation seemed to be different, as in the study of Khan et al. (2021), the duration of sun irradiation was negatively correlated with the population of *B. dorsalis*, Yin et al. (2018) reported the opposite result. Understanding fluctuations in pest populations throughout the year and their relationship to metrological factors is important for developing an effective integrated pest control program. The objectives of this study were: to analyze the population dynamics of *B. dorsalis* and *B. carambolae* fruit flies; to evaluate the effect of abiotic factors on population abundance; and to estimate the projection of population dynamics using a mathematical model.

Materials and Methods

Insect population

This research was conducted from January 2007 to December 2020 within 1 ha of an orchard of mixed mango varieties (known in Indonesia as ‘cengkir’, ‘gedong’ and ‘arumanis’) in Sumedang district, West Java, Indonesia (Fig. 1).

Fig. 1 Location of study site in West Java, Indonesia

Study design

Fruit fly samplings were carried out using a modification of the Steiner trap, containing 1.5 mL of methyl eugenol (94.09%), with the traps suspended in tree branches 2 m above the ground. Samplings were carried out with 20 replications. Fruit flies were collected every week and transferred to the laboratory for further identification. Identification of adult fruit flies was performed based on the thorax, wings, legs, the abdomen of adults and examination of female genital morphology, using a stereomicroscope and taxonomic identification keys (Suputa et al., 2006; Drew and Romig, 2013; Choudhary et al., 2014). Abiotic factor parameters were measured at each sampling, consisting of sunshine hours, wind speed, wind direction, rainfall, temperature, and humidity,

Analysis

Data of monthly fluctuations were analyzed using a general linear model with repeated measurement of the analysis of variance (ANOVA). Before commencing the core analysis, two assumptions underlying the repeated measurement ANOVA analysis, were tested, namely specificity (independent observation test) and multivariate normality. Based on the analysis, the obtained *p* value was 0.78 that was greater than 0.05 and so the null hypothesis was accepted and the specificity assumption was met, meaning that the observations are mutually independent. For the multivariate normality test, the p-values for skewness and kurtosis were greater than 0.05, namely 0.54 and 0.32, respectively. Therefore, the data could be approximated using a normal distribution. Because these assumptions were met, repeated measurement ANOVA was applied. Principal component analysis (PCA) was performed to reduce factors and determine correlations between factors. Before performing PCA analysis, the data were standardized because the units for each variable were different. The best standardization was achieved based on the square root.

Population projection estimation was undertaken using mathematical modeling based on the auto-regressive integrated moving average (ARIMA) method because it is most suitable for stationary time series (Anwar et al., 2016). The ARIMA analysis was carried out using the R Software, an open source statistical software for all platforms. The procedure of the analysis was done by following Box et al. (2015). The first step investigated the stationary characteristic of the time series data. In addition, to determine the d value, at this stage, the degree of residual of lag values (q) and dependent lag values (p) were evaluated in this model using the auto correlation function (ACF) and partial auto correlation function (PACF), and a correlogram showing the plot of ACF and PACF values was evaluated against the lag. The partial autocorrelation coefficient calculated the degree of closeness of the relationship between X_t and X_{t-k}, while the effect of time lag 1, 2, 3, ..., k-1 was considered constant. Furthermore, the selection of the best ARIMA model was evaluated by estimating the auto-regressive and moving average parameters in the model. After estimating and obtaining parameter estimators, before the temporary model can be used for forecasting, it is necessary to conduct a feasibility test on the model. After the best model was obtained, then data projection can be estimated.

Results

Population dynamics

Overall, 1,011,820 individual fruit flies were collected, consisting of *B. dorsalis* (964,204 individuals or 71.74 individuals per trap) and *B. carambolae* (47,616 individuals or 3.54 individuals per trap). The annual mean abundance of populations for both *B. dorsalis* and *B. carambolae* showed fluctuations. *B. dorsalis* has four-year fluctuations, except in 2017–2018 (Fig. 2A). *B. carambolae* had biennial fluctuations, except in 2018, which increased until 2019 (Fig. 2B).

The monthly abundance of the *B. dorsalis* population showed the peak of abundance occurred in December. From January to April there was a decrease in population abundance. From May to August it fluctuated, while from August to December there was a sharp increase. The analysis showed that the difference in the mean monthly abundance was significant ($F = 71.23$; $p < 0.001$).

The monthly abundance of the *B. carambolae* population showed the same peak in December, followed by a decrease in population abundance in March; then, the population tended to be stable until July. The population increased in August and decreased in September. Furthermore, from October to December there was a sharp increase. The analysis showed that the difference in the average monthly abundance was significant ($F = 9.05$; $p = 0.010$) (Fig. 3).

Data of abiotic factors showed that the sunshine duration was in the range 36.24–268 hours/month, with an average of 165.29 hours/month. The smallest average wind direction was 30°, while the largest was 360°, with an average of 182.32°. The minimum wind speed was 8 knots, while the highest speed was 32 knots. The minimum monthly rainfall was 0 mm (no rain) while the maximum monthly rainfall was 705.80 mm, with an average monthly rainfall of 221.01 mm. The minimum monthly temperature was 24.90°C, while the maximum monthly temperature was 30.10°C, with an average monthly temperature of 27.53°C. The lowest air humidity was 58.9% while the maximum was 90%, with an average air humidity of 77.95% (Table 1).

Among the six abiotic factors, sunshine duration had a significant, negative correlation with the abundance of *B. dorsalis* ($r = -0.206$; $P = 0.004$) and *B. carambolae* ($r = -0.217$; $P = 0.002$). The wind speed had a significant, negative correlation with the abundance of *B. dorsalis* ($r = -0.211$; $P = 0.003$) and *B. carambolae* ($r = -0.162$; $P = 0.018$);

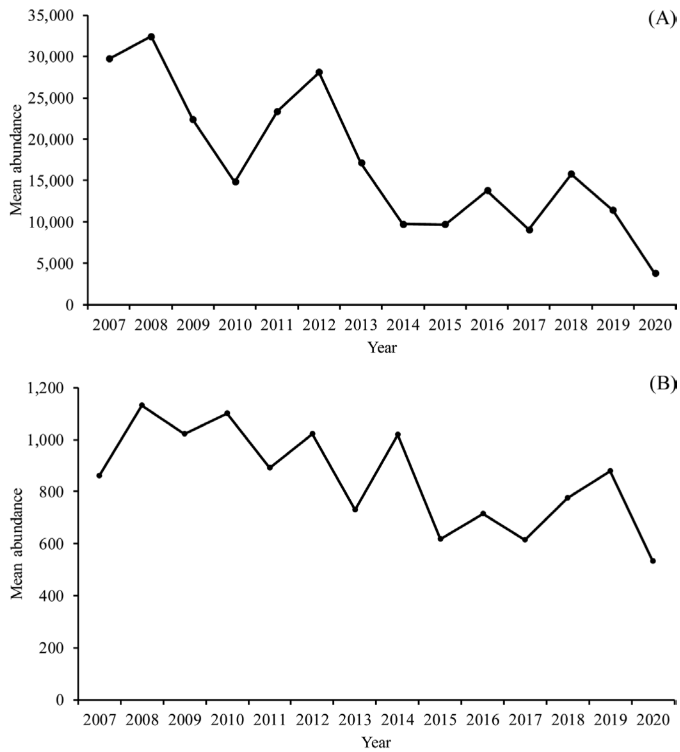


Fig. 2 Fluctuations in populations from 2007 to 2020 of: (A) *B. dorsalis*; (B) *B. carambolae*

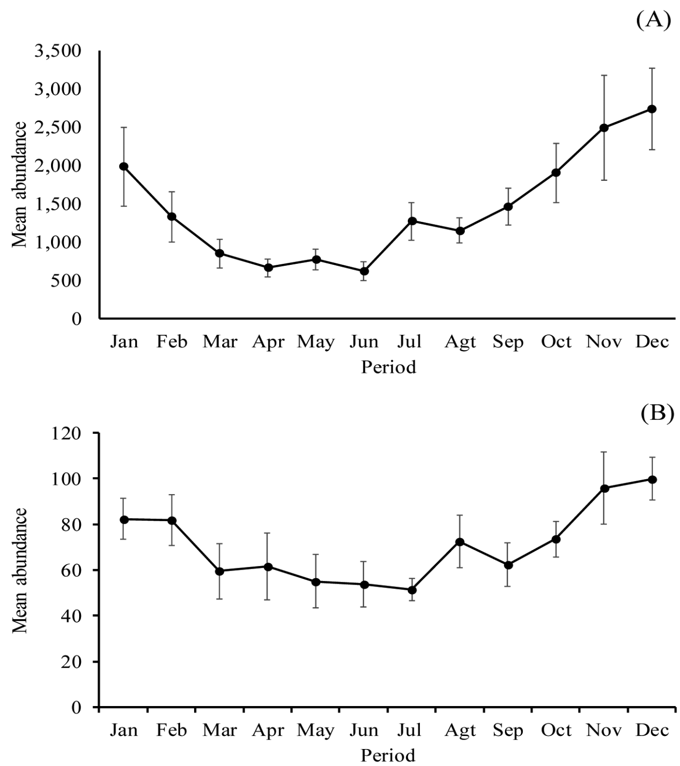


Fig. 3 Monthly population dynamics of: (A) *B. dorsalis*; (B) *B. carambolae* (B), where error bars indicate ± SD

while wind direction had a significant, positive correlation with the abundance of *B. dorsalis* (r = 0.155; P = 0.023). Humidity had a significant, positive correlation with the abundance of *B. dorsalis* (r = -0.129; P = 0.048). The effects of temperature and rainfall were not significant on both species (Table 2).

Based on the PCA analysis results, 63.5% of the total diversity was explained by the first, and second principal components. The value of the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.697. Because the value was greater than 0.05, three principal components were determined. The eigenvalues for each of the two components were 3.352 and 1.729 (Table 3). The first component factor consisted of sunshine duration, wind direction, rainfall, temperature and humidity, which had an eigenvalue of 3.352 and accounted for 41.89% of the data variability. The second component was wind speed and had an eigenvalue of 1.729 and accounted for 21.61% of the data variability (Table 3).

Among the abiotic factors, the sunshine duration had negative significant correlations with rainfall and humidity. The sunshine duration had a positive significant correlation with temperature. Rainfall had a negative correlation with temperature but a positive correlation with humidity. The temperature had a negative correlation with humidity. The other correlations between the variables were not significant (Table 4).

Population projection

Because of the small amount of population data for *B. carambolae*, the population projection data were combined for the two fruit fly species. Initially, a time series plot was used to investigate the trend or seasonality of the data pattern of the number of fruit flies per month for the period January 2007–December 2020. The average fruit fly numbers fluctuated from time to time, with two population peaks in 2008 and 2012 (Fig. 4).

Table 1 Research variable statistics

Variable	Minimum	Maximum	Average
Sunshine duration (hours/month)	36.24	268.00	165.29
Wind speed (Knots)	8.00	32.00	18.24
Wind direction (°)	30.00	360.00	182.32
Rainfall (mm/month)	0.00	705.80	221.01
Temperature (°C)	24.90	30.10	27.53
Humidity (%)	58.90	90.00	77.95

Table 2 Correlation coefficient and *p*- value (in parenthesis) between each abiotic factor and abundance of *B. dorsalis* and *B. carambolae*

Abiotic factor	B. dorsalis	B. carambolae
Sunshine duration (X1)	-0.206 (0.004)	-0.217 (0.002)
Wind speed (X2)	-0.211 (0.003)	-0.162 (0.018)
Wind direction (X3)	0.155 (0.023)	0.067 (0.193)
Rainfall (X4)	0.053 (0.247)	0.113 (0.073)
Temperature (X5)	0.049 (0.264)	-0.020 (0.401)
Humidity (X6)	-0.129 (0.048)	0.020 (0.399)

Table 3 Eigenvalues and cumulative proportion of abiotic factors

Principal component	Eigenvalues	Variance (%)	Cumulative proportion
PC1	3.352	41.894	41.894
PC2	1.729	21.607	63.502

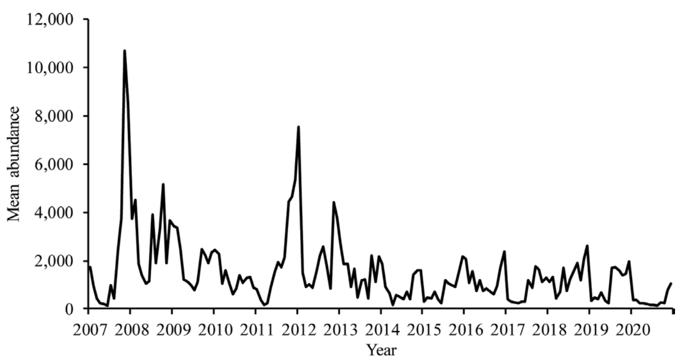


Fig. 4 Fluctuations in monthly abundance of fruit fly populations 2007–2020

Table 4 Correlation matrix among abiotic factors

Variable	X1 (Sunshine duration)	X2 (Wind speed)	X3 (Wind direction)	X4 (Rainfall)	X5 (Temperature)	X6 (Humidity)
X1 (Sunshine duration)		0.032	-0.419	-0.728	0.594	-0.726
X2 (Wind speed)			0.015	0.041	0.096	-0.046
X3 (Wind direction)				0.352	-0.399	0.356
X4 (Rainfall)					-0.527	0.861
X5 (Temperature)						-0.695

Number in highlighted cells indicate significant correlation between variable

Variance stationarity test

The stationarity test of variance was carried out using the Box-Cox transformation (Fig. 5), with a value of 0.00, having a lower limit of -0.07 and an upper limit of 0.21. Thus, it was concluded that the data on the numbers of fruit flies per month for the period January 2007–December 2020 were stationary concerning variance because the value was within the interval (Fig. 5).

Average stationarity test

Stationarity testing of the average was carried out using the augmented Dickey-Fuller test to test the hypotheses of $H_0 = 0$ (data not stationary with respect to the mean) versus $H_1 = 0$ (stationary data to the mean). Based on the augmented Dickey-Fuller test in Table 5, both with constant and with constant and trend, the *p* value was 0.000, which was less than 0.05. Thus, H_0 was rejected, indicating the data were stationary concerning the average. From the two augmented Dickey-Fuller tests, it was concluded that the data on the number of fruit flies per month was stationary with respect to the average.

Model identification

The tentative ARIMA model was determined by identifying the ACF and PACF plots. The results showed the first three significant lags, with PACF indicating that that the first lag was significant, so the model obtained was of order p = 1 and q = 3. The first real lag indicated that the current fruit fly number was affected by the abundance of fruit flies one month earlier; thus, the number of flies at the end of each month continued to increase. The data on the number of fruit flies were not differentiated, so that d = 0. Thus, the data order of the number of fruit flies every month during January 2007–December 2020 was ARIMA (1, 0, 3), as shown in Fig. 6.

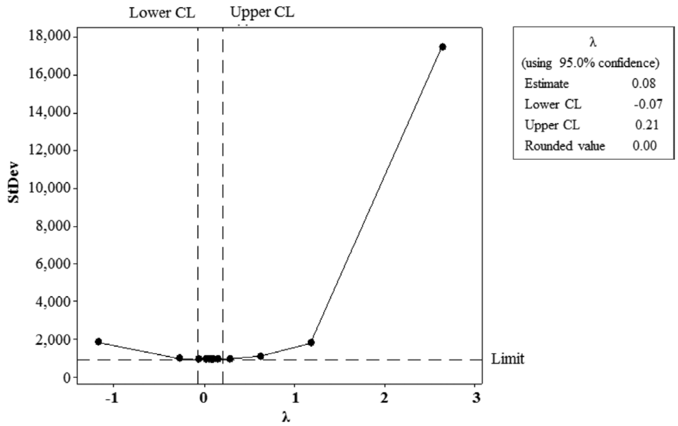


Fig. 5 Box-Cox plot of fruit fly, where CL = confidence limit

Table 5 Augmented Dickey-Fuller test results

Test	*p*-value	Decision
With constant	0.000	H_0 rejected
With constant and trend	0.000	H_0 rejected

Estimation and testing of model parameters

Based on the results of ACF and PACF, tentative models weres obtained consisting of the ARIMA (1, 0, 3), ARIMA (1, 0, 2), ARIMA (1, 0, 1) and ARIMA (1, 0, 0) models. After obtaining each tentative model, model parameter estimation and feasibility test were carried out. Table 6 indicates that the tentative model had the real parameter ARIMA (1, 0, 0) because it was significant for all parameters. In contrast, for ARIMA (1, 0, 3) some parameters were not significant, namely _1, in ARIMA (1, 0, 2) where the parameters _1 and _2 were not significant, while in ARIMA (1, 0, 1), the parameter _1 was not significant (Table 6).

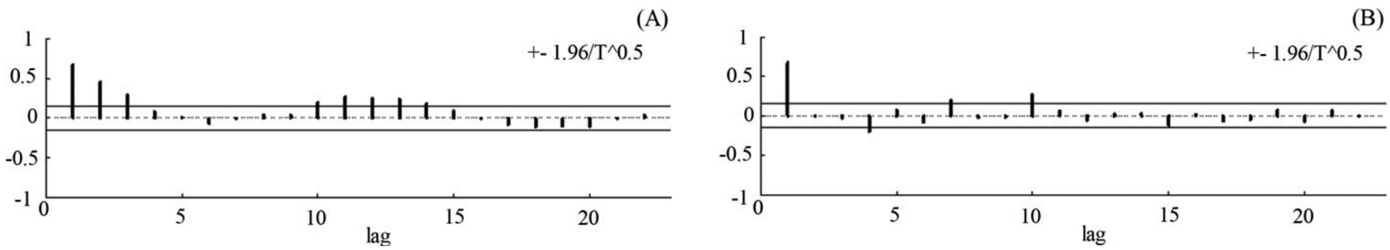


Fig. 6 Fruit fly plots of: (A) autocorrelation function; (B) partial autocorrelation function

Table 6 Estimation and testing of model parameters

Model	Parameter	Estimate	*p*-value	Decision
ARIMA (1, 0, 3)	μ	1510.400	0.000	Significant
	ϕ_1	0.305	0.081	Not significant
	θ_1	0.383	0.021	Significant
	θ_2	0.243	0.047	Significant
	θ_3	0.328	0.000	Significant
ARIMA (1, 0, 2)	μ	1504.430	0.000	Significant
	ϕ_1	0.647	0.000	Significant
	θ_1	0.011	0.925	Not significant
	θ_2	0.045	0.684	Not significant
ARIMA (1, 0, 1)	μ	1503.380	0.000	Significant
	ϕ_1	0.670	0.000	Significant
	θ_1	-0.001	0.991	Not significant
ARIMA (1, 0, 0)	μ	1503.400	0.000	Significant
	ϕ_1	0.670	0.000	

Model diagnostics

Model diagnostics were carried out to determine the feasibility of the model based on residual analysis, namely the 'white noise' of the residual ACF plot. White noise associated with the residual ACF plot indicated that there was no significant correlation for each lag. The results of the residual ACF plots from the two tentative models are presented in Table 7. The tentative model with real parameters that conformed to the assumption of white noise residue was the ARIMA (1, 0, 3) model because in the ACF plot there was no significant correlation in each lag.

Best model selection

The criterion for selecting the best model was the smallest Akaike information criterion (AIC) value, with the remainder being white noise. The results are presented in Table 8, with the best model being the ARIMA model (1, 0, 3) as it had the smallest AIC value (2,828.757).

The ARIMA (1, 0, 3) model formula was considered suitable for projection and is presented in Equations 1 and 2:

$$Z_t = \mu + \varnothing_1 Z_{t-1} + \alpha_t - \theta_1\alpha_{t-1} - \theta_2\alpha_{t-2} - \theta_3\alpha_{t-3} \quad (1)$$

$$Z_t = 1510.40 + 0.30 + Z_{t-1} + \alpha_t - 0.38\alpha_{(t-1)} - 0.24a38a_{t-1}0.32a38a_{t-1} \quad (2)$$

where t = the current time period and t-1 = the previous time period.

Projections were made for the next 12 periods using the ARIMA (1,0,3) model (Fig. 7A). In 2021, it projected that the fruit fly population would increase from January to July 2021, then decrease until December. In 2022, the fruit fly population was projected to decrease from January to August 2022 and then increase until November. In 2023, the fruit fly population would decrease from February to June 2023 and then increase from July to September (Fig. 7B).

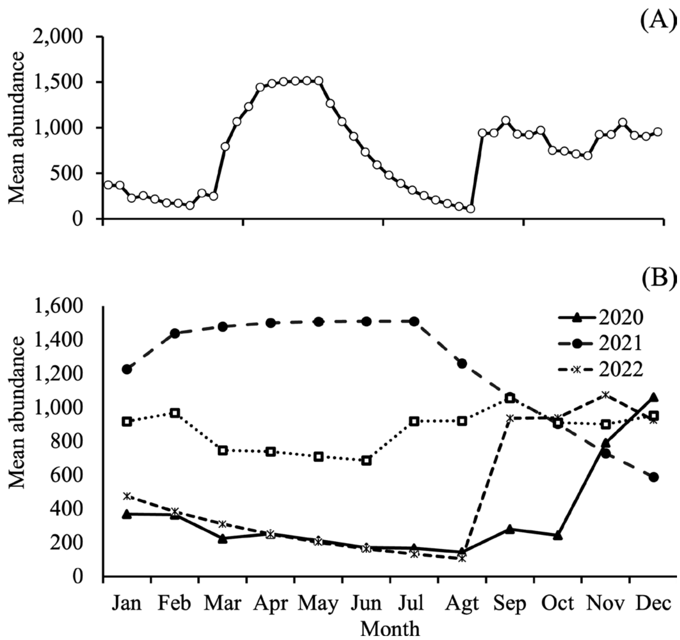
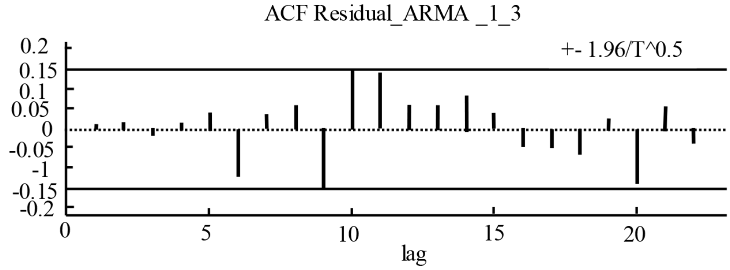
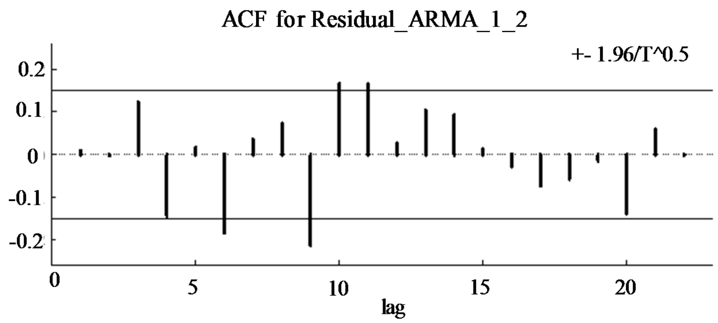
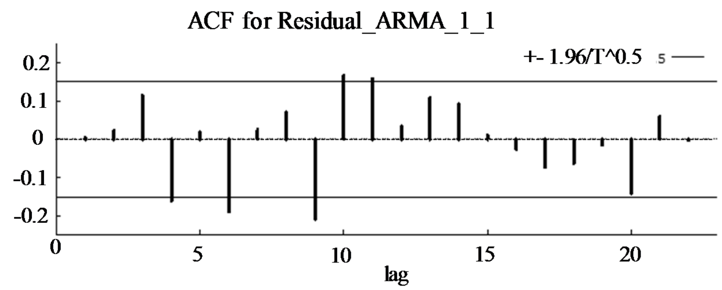
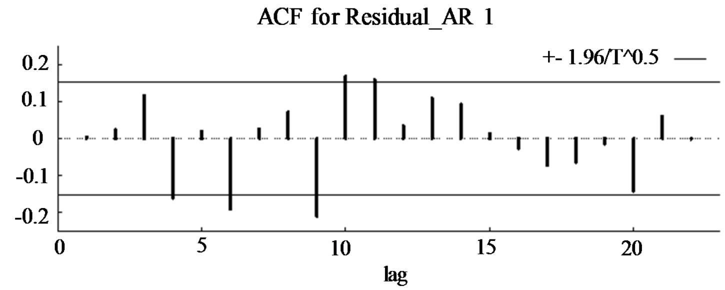


Fig. 7 Results of fruit fly population projections in 2020–2023: (A) continuous monthly population dynamics; (B) discrete monthly dynamics of population

Table 7 Remaining autocorrelation function (ACF) plots

Model	Plot ACF remaining	White noise
ARIMA (1, 0, 3)		Yes
ARIMA (1, 0, 2)		No
ARIMA (1, 0, 1)		No
ARIMA (1, 0, 0)		No

ARIMA = auto-regressive integrated moving average.

Table 8 Selection of best model

Model	Akaike information criterion	White noise remaining
ARIMA (1, 0, 3)	2,828.757	Valid
ARIMA (1, 0, 2)	2,835.289	Not valid
ARIMA (1, 0, 1)	2,833.448	Not valid
ARIMA (1, 0, 0)	2,831.448	Not valid

ARIMA = auto-regressive integrated moving average.

Discussion

This study investigated *B. dorsalis* and *B. carambolae* as important pests in a mango plantation in West Java Indonesia. The population of *B. dorsalis* dominated and had become a major pest of the mango trees, while the abundance of *B. carambolae* was lower than that of *B. dorsalis*. These results were consistent with other studies in Asia and Africa because *B. dorsalis* is a cosmopolitan species and it is a major pest of mangoes causing serious production losses (Salmah et al., 2017; Yin et al., 2018; Hossain et al., 2020; Patel et al., 2019; Jayanthi et al., 2021).

The populations of *B. dorsalis* and *B. carambolae* investigated in the current study demonstrated both monthly and yearly abundance dynamics that were influenced by several factors including abiotic factors. Sunshine duration and wind direction had a significant effect on the population dynamics of the two fruit fly species studied.

The fruit fly population started to increase from October to December and then decreased from February to June. The increase in fruit fly abundance from October to December was consistent with the mango fruit development phase (ripening period from October to December). Studies conducted in India also showed the same trend in different months, namely an increase in the population of *B. dorsalis* and *B. zonata* from March to June (Khan and Naveed, 2017). The fruit fly species population tends to increase as fruit ripening begins, indicating that the occurrence of fruit, particularly in the ripening period has a direct effect on fly emergence (Abdel-Galil et al., 2010; Khan and Naveed, 2017; Danjuma et al., 2020). The same trend of population dynamics has been shown by *B. carambolae*. For example, a study in Thailand showed an increasing trend of star fruit fly population from April to May, with flies being found in large numbers on ripe fruit (Danjuma et al., 2015). In the off-season period of mango fruit, the presence of fruit flies can be influenced by several factors, such as the availability of resources in alternative hosts and abiotic factors.

Population studies aim to explain and predict the development of a population. Environmental factors at the study site may affect the population of a species. Abiotic factors, especially air temperature and rainfall, are the among important factors affecting the fruit fly distribution, with temperature influencing the preoviposition period on host fruit, while rainfall and the number of rainy days affect soil moisture which in turn impacts pupae and imago emergence from pupae (Jackson et al., 1998; Ye and Liu, 2007). The current study demonstrated a significant influence between the duration of solar radiation and wind direction. Sunshine duration had a negative effect on the abundance of *B. dorsalis* and *B. carambolae*, while wind direction had a positive effect on the abundance of both species. Wind speed and humidity had negative effects on *B. dorsalis.* The significant influence of wind direction may be related to the direction of origin of fruit fly dispersal. This was supported by the negative effect of wind speed, suggesting that the fruit fly movement is active, occurring at low wind speeds. The results of the current study are in line with research in Myanmar and India on the effect of long sun exposure (Yin et al., 2018; Patel et al., 2019). However, different results have been reported by other studies, such as Khan et al. (2021) whose results showed a positive correlation between the flies caught every month and all climatic factors, including the length of sunlight. Research conducted by Mouly et al. (2017), also produced different results for the effect of wind speed, with a wind speed negatively correlated with fruit fly populations. Thus, a simple linear regression model derived from wind speed can be considered as the best single predictor of changes in fruit fly populations that can be used in management decision making. The results of the current study are important for fruit fly control. In mango plantations, control of fruit flies, for example by using traps, can be maximized when the duration of sun exposure time and wind speed are low. The positions of the traps can be adjusted to the direction of fruit fly arrivals.

The study of the influence of environmental factors on fruit fly populations of *Bactrocera zonata* (Saunders) and *B. dorsalis* (Hendel) in Pakistan, where significant, positive relationships were observed between the occurrence of *B. zonata* and abiotic factors, including minimum and maximum temperature and sunshine hours, while relative humidity and rainfall were negatively correlated with the abundance of *B. zonata* (Khan and Naveed, 2017).

The effect of wind speed on fruit fly populations was reported in the Mediterranean fruit fly species, *Ceratitis capitata* (Wied.), with the population responding positively to both temperature and humidity, while it responded inversely to wind speed and although weather factors affected that population, fruit ripening had an extrusive effect on the population (Ghanim, 2017). Wind speed was also reported to be negatively correlated with pest populations from other orders such as aphids on cowpea (*Vigna unguiculata* (Lin.) Walp (Arvind and Akhilesh, 2015) and the Antestia bug (*Antestiopsis thunbergii* Gmelin) in the Hemiptera:

Pentatomidae on coffee (*Coffea arabica*, Lin.) (Bigirimana et al., 2019). Different results were reported on the effect on the aphid, *L. erysimi* (Kalt.) on mustard (Bavisa et al., 2018) and *Bemisia tabaci* (Gennadius) on tomato (Jha and Kumar, 2017). In these two species, the wind was positively correlated with both populations. The effect of exposure time had a positive correlation with the aphid*, L. erysimi* (Kalt.) on mustard plants (Bavisa et al., 2018), while a negative correlation of exposure time affected *Bactrocera cucurbitae* (Coquillett) on melon (Laskar and Chatterjee, 2010) and *Bemisia tabaci* (Gennadius) on tomatoes (Jha and Kumar, 2017).

In the current study, the three-year projection suggested a fairly high population potential in 2021, even in months when the fruit fly population is usually low (March–July). Projections in 2022 and 2023 showed an increasing trend in populations starting from August to December. The projection results for these three years can be applied for more systematic management of fruit flies. The months when fruit flies begin to increase (August and September) would be the best time to take preventive actions.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The Dean of the Faculty of Agriculture, Universitas Padjadjaran authorized the research.

References

Abdel-Galil, F.A., Amro, M.A., Abdel-Moniem A.S.H., El-Fandary, O.O. 2010. Population fluctuations and interspecific competition between Tephritid flies attacking fruit crops in the New Valley oases, Egypt. Arch. Phytopathol. Pflanzenschutz. 43: 647–659. doi.org/10.1080/03235400802021272

Anwar, M.Y., Lewnard, J.A., Parikh, S., Pitzer, V.E. 2016. Time series analysis of malaria in Afghanistan: using ARIMA models to predict future trends in incidence. Malar. J. 15: 566. doi.org/10.1186/s12936-016-1602-1.

Arvind, K., Akhilesh, K. 2015. Effect of abiotic and biotic factors on incidence of pests and predator in cowpea (*Vigna unguiculata* (L.) walp.). Legum. Res. 38: 121–125. doi.org/10.5958/0976-0571.2015.00020.X

Bana, J.K., Sharma, H., Kumar, S., Singh P. 2017. Impact of weather parameters on population dynamics of oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) under south Gujarat mango ecosystem. J. Agrometeorol. 19: 78–80.

Bavisa, R., Parmar, G.M., Hirapara, M.M., Acharya, M.F. 2018. Population dynamics of mustard aphid, *Lipaphis erysimi* (Kaltenbach) on mustard in relation to different weather parameters. J. Pharmacogn. Phytochem. 7: 394–396

Bigirimana, J., Uzayisenga, B., J. Gut, L.J. 2019. Population distribution and density of *Antestiopsis thunbergii* (Hemiptera: Pentatomidae) in the coffee growing regions of Rwanda in relation to climatic variables. Crop Protec. 122: 136-141. doi.org/10.1016/j.cropro.2019.04.029

Box, G.E., Jenkins, G.M., Reinsel, G.C., Ljung, G.M. 2015. Time series analysis: Forecasting and control. John Wiley & Sons. Hoboken, New Jersey, USA.

Castilho, A.P., Pasinato, J., dos Santos, J.E.V., da Costa, A.E.S., Nava, D.E., de Jesus, C.R., Adaime, R. 2019. Biology of *Bactrocera carambolae* (Diptera: Tephritidae) on four hosts. Rev. Bras. Entomol. 63: 302–307. doi.org/10.1016/j.rbe.2019.09.002

Choudhary, J., Naaz, N., Chandra P., Bikash, D., Sudarshan, M., Shivendra, K. 2014. Field guide for identification of fruit fly species of genus *Bactrocera* prevalent in and around mango orchards. In: Technical Booklets No.: R-43/Ranchi-16. ICAR Research Complex for Eastern Region, Research Centre. Ranchi, India, pp. 1–16.

Danjuma, *S*., *Abdulmaliq*, *S.Y.*, *Abdulhazeez*, *M*., *Mustapha*, *M*. Ndadama, *M*. Ndadama, M. 2020. Annual population structure of the *Bactrocera dorsalis* in Southern Guinea Savannah of Nigeria. Badeggi J. Agric. Res. Environ. 2: 8–16. doi.org/10.35849/BJARE202001006

Danjuma, *S*., *Boonrotpong*, *S*., *Thaochan*, *N*., *Permkam*, *S*., *Satasook*, *C*. 2015. Population dynamics of the carambola fruit fly *Bactrocera carambolae* Drew and Hancock (Diptera: Tephritidae) on guava in Peninsular Thailand. Indian J. Entomol. 77: 290–297. DOI:10.5958/0974-8172.2015.00059.0

Drew, R.A.I., Romig, M.C. 2013. Tropical Fruit Flies (Tephritidae: Dacinae) of South-East Asia: Indomalaya to North-West Australasia. CAB International. Wallingford, UK.

Ghanim, N.M. 2017. Population fluctuations of the Mediterranean fruit fly, *Ceratitis capitata* (Wied.) with respect to some ecological factors in peach orchards. J. Plant Prot. Pathol. 8: 555–559. doi.org/10.21608/JPPP.2017.46606

Hossain, *M.S.*, *Sarkar*, *B.C.*, *Hossain*, *M.M.*, *Mian*, *M.Y.*, *Rajotte*, *E.G.*, *Muniappan*, R., O'Rourke, M.E. 2020. Comparison of biorational management approaches against mango fruit fly (*Bactrocera dorsalis* Hendel) in Bangladesh. Crop Prot. 135: 104807. doi.org/10.1016/j.cropro.2019.05.001

Jackson, *C.G.*, *Long*, *J.P.*, *Klungness*, *L.M.* 1998. Depth of pupation in four species of fruit flies (Diptera: Tephritidae) in sand with and without moisture. J. Econ. Entomol. 91: 138–142. doi.org/10.1093/jee/91.1.138

Jayanthi, P.D.K, Woodcock, C.M., Caulfield, J., Birkett, M.A., Bruce, T.J.A. 2012. Isolation and identification of host cues from mango, *Mangifera indica* that attract gravid female oriental fruit fly, *Bactrocera dorsalis*. J. Chem. Ecol. 38: 361–369. doi.org/10.1007/s10886-012-0093-y

Jha, S.K., Kumar, M. 2017. Effect of weather parameters on incidence of whitefly, *Bemisia tabaci* (Gennadius) on tomato. J. Entomol. Zool. Stud. 5: 304–306.

Khan, M.H., Khuhro, N.H., Awais, M., Asif, M.U., Muhammad, R. 2021. Seasonal abundance of fruit fly, *Bactrocera* species (Diptera: Tephritidae) with respect to environmental factors in guava and mango orchards. Pak. J. Agric. Sci. 34: 266–272. doi.org/10.17582/journal.pjar/2021/34.2.266.272

Khan, R., Naveed, M. 2017. Occurrence and seasonal abundance of fruit fly, *Bactrocera zonata* Saunders (Diptera: Tephritidae) in relation to meteorological factors. Pak. J. Zool. 49: 999–1003. doi.org/10.17582/journal.pjz/2017.49.3.999.1003

Laskar, N., Chatterjee, H. 2010. The effect of meteorological factors on the population dynamics of melon fly, *Bactrocera cucurbitae* (Coq.) (Diptera: Tephritidae) in the foot hills of Himalaya. J. Appl. Sci. Environ. Manage. 14: 53–58. doi.org/10.4314/jasem.v14i3.61466

Leblanc, L., Hossain, M.A., Doorenweerd, C., Ahmed Khan, S., Momen, M., San Jose, M., Rubinof, F. 2019. Six years of fruit fly surveys in Bangladesh: A new species, 33 new country records and discovery of the highly invasive *Bactrocera carambolae* (Diptera, Tephritidae). Zookeys 876: 87–109. doi.org/10.3897/zookeys.876.38096

Marchioro, C.A. 2016. Global potential distribution of *Bactrocera carambolae* and the risks for fruit production in Brazil. PLoS One 11: e0166142. doi.org/10.1371/journal.pone.0166142

Midgarden, D., van Sauers-Muller, A., Godoy, M.J.S., Vayssières, J.F. 2016. Overview of the programme to eradicate *Bactrocera carambolae* in South America. In: Ekesi, S., Mohamed, S., De Meyer, M. (Eds.). Fruit Fly Research and Development in Africa - Towards a Sustainable Management Strategy to Improve Horticulture. Springer. Cham, Switzerland, pp. 705–736.

Mouly, R., Shivananda, T.N., Verghese, A. 2017. Prediction models for *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) base on weather parameters in an organic mango orchard. J. Entomol. Zool. Stud. 5: 345–351.

Patel, D.R., Patel, J.J., Muchhadiya, D.V., Patel, R.B. 2019. Influence of weather parameters on mango fruit fly, *Bactrocera dorsalis* H. J. Entomol. Zool. Stud. 7: 1157–1160.

Pujiastuti, Y., Irsan, C., Herlinda, S., Kartini, L., Yulistin, E. 2020. Diversity and patterns of presence of fruit flies (Diptera: Tephritidae) in South Sumatra Province. J. Indonesia Entomology. 17: 125–135. doi.org/10.5994/jei.17.3.125 [in Indonesian]

Sahetapy, B., Uluputty, M.R., Naibu, L. 2019. Identification of fruit flies (*Bactrocera* spp.) of pepper (*Capsicum annuum* L.) and star fruit (*Averrhoa carambola* L.) plant origins in Salahutu district, Central Maluku regency. Journal of Agriculture 30: 63–74. doi.org/10.24198/agrikultura.v30i2.23659 [in Indonesian]

Salmah, M., Adam, N.A., Muhamad, R., Lau, W.H., Ahmad, H. 2017. Infestation of fruit fly, *Bactrocera* (Diptera: Tephritidae) on mango (*Mangifera indica* L.) in Peninsular Malaysia. J. Fundam. Appl. Sci. 9: 799–812. doi.org/10.4314/jfas.v9i2s.49

Suputa, Cahyaniati, *Kustaryati,* A., *Railan, M.*, *Issusilaningtyas,* U.H., *Mardiasih* W.P. 2006. Guidelines for Identification of Pest Fruit Flies. Directorate General of Horticulture, Jakarta, Indonesia.

Sutantawong, M., Orankanok, W., Enkerlin, W.R., Wornoayporn, V., Cáceres, C. 2004. The sterile insect technique for control of the oriental fruit fly, *Bactrocera dorsalis* (Hendel) in mango orchards of Ratchaburi Province, Thailand. In: Barnes, B.N. (Ed.). Proceedings of the 6th International Symposium on Fruit Flies of Economic Importance. Isteg Scientific Publications. Irene, South Africa, pp. 223–232.

Vargas, R.I., Piñero, J.C., Leblanc, L. 2015. An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific region. Insects 6: 297–318. doi.org/10.3390/insects6020297

Vayssières, J.F., De Meyer, M., Ouagoussounon, M., et al. 2015. Seasonal abundance of mango fruit flies (Diptera: Tephritidae) and ecological implications for their management in mango and cashew orchards in Benin (Centre & North). J. Econ. Entomol. 108: 2213–2230. doi.org/10.1093/jee/tov143

Win, N.Z., Mi, K.M., Oo, T.T., Win, K.K., Park, J., Park, J.K. 2014. Occurrence of fruit flies (Diptera: Tephritidae) in fruit orchards from Myanmar. Korean J. Appl. Entomol. 53: 323–329. doi.org/10.5656/KSAE.2014.06.0.011

Ye, H., Liu, J. 2007. Population dynamics of oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) in Xishuangbanna, Yunnan province, China. Front. Agric. China. 1: 76–80. doi.org/10.1007/s11703-007-0014-y

Yin, N.N., Theint, Y.Y., Myaing, K.M., et al. 2018. Relationship between population fluctuation of oriental fruit fly *Bactrocera dorsalis* Hhendel and abiotic factors in Yezin, Myanmar. J. Life Sci. 12: 141–149. doi.org/10.17265/1934-7391/2018.03.004