



Predictive results of tobacco budworms and whiteflies causing the tobacco in Vietnam based on weather and climate in the 2024 season

Nguyen Van Chin^a, Nguyen Van Van^a, Pham Ha Thanh^b, Nguyen Quoc Tuan^b, and Nguyen Nam Giang^a

^aVietnam Tobacco Institute, ^bVietnam National Tobacco Corporation

Corresponding author: chinvtl@gmail.com

Volume 6, Issue 15, Sep 2024

Received: 15 July 2024

Accepted: 25 Aug 2024

Published: 05 Sep 2024

doi: [10.48047/AFJBS.6.15.2024.5154-5169](https://doi.org/10.48047/AFJBS.6.15.2024.5154-5169)

ABSTRACT

Tobacco budworms and whiteflies are the major pests in tobacco growing areas of Vietnam. Whiteflies do not only cause direct damage but transmit the Begomovirus to the tobacco plant. To control insectpests in tobacco plants, Vietnam Tobacco Institute has built a predictive model based on the Skybit, Fuzz and Degree Day models that run on Excel software. Based on the interaction between the insectpests, environmental conditions, tobacco plants, etc give forecast results and advise the best control. The results showed the accuracy of predict the budworms and whiteflies reached a range of 83.3 - 91.7% in Cao Bang, Gia Lai, Tay Ninh region, and the whiteflies in Cao Bang up 100%, and was similar to 2023. The degree day model had low accuracy when predict the whiteflies and aphids causing tobacco in Tay Ninh, and was the same in 2023. The accuracy of the prediction lowed when the temperature was higher than the Topt and TU. The predictive model with degree day was high accurate when the temperature was little change and within the growing temperature levels of insects. Based on the predictive results, we gave the best methods to effectively control the insect pests to damage, reduced the use of pesticides compared to years ago, increased yield and quality, and income for the farmers. In 2024, we effectively prevented the whiteflies, aphids and curl-top disease outbreak strongly in Lang Son and Gia Lai. This model gave the high predictive accuracy for the most insectpests on the tobacco plants.

Keywords: *The tobacco budworms, whiteflies, Forecast model, and Tobacco*

1. Introduction

Tobacco is an important economic crop in many countries around the world. Major tobacco producing countries around the world include China, India, Brazil, etc. Like many economic crops, tobacco is subjected to damage by several species of insect pests from the greenhouse to the field stage. Some major harmful species are tobacco aphids, black cutworms, budworms, hornworms, thrips (PA. Edde, 2018). In Vietnam, tobacco plants are mainly transplanted in Cao Bang, Bac Kan, Lang Son, Gia Lai, and Tay Ninh provinces, with an annual area of over 5,500 ha, and damage by many species of insects and diseases, such as tobacco aphids, budworms, whiteflies, powdery mildew, etc. According to plant protection experts, every year in Vietnam, the yield loss due to insect pests estimates from 10 - 30%. The tobacco budworm (*Heliothis virescens*) is an important pest in tobacco-growing countries worldwide. In 2006, in Georgia, USA, the tobacco budworms caused damage of about 2.229 million USD, with prevention costs of 1.308 million USD and damage caused by 0.921 million USD (McPherson, R.M, 2006). *Bemisia tabaci* belongs to Homoptera, Aleyrodidae and Bemisia, is one of the most important agricultural pests in the world, is widely distribution in more than 90 countries and regions in the world. In Beijing, China, *Bemisia tabaci* causes severe damage to tomatoes, eggplants, cucumbers, melons and zucchini, with more than 70% of the loss of production (Shunxiao Liu et al., 2020). In addition to direct damage, *Bemisia tabaci* transmits viruses (David W. Onstad, 2014). In Vietnam, *Bemisia tabaci* is a vector transmitting the Begomovirus causing damage on tobacco plants.

Currently, many countries in the world have used weather data to forecast pests and diseases of many crops. Some popular forecasting models are the Skybit, Degree Days (DD), and the Fuzzy logic model. Forecast result have an accuracy of up to 85% for pests (Ching-Ju Chen et al., 2012), 75 - 95% for insects on rice in India (Vennila S et al., 2016), 81.6 - 89.9% for fungi (Fatthy Amir, 2016). Skybit model used weather data to predict the diseases and insects such as apples, carrots, tomatoes (Matthew Wallhead et al., 2017; Joe Russo, 2000; Joe Russo et al., 2002). Predicting by degree days: Insects are cold-blooded animals, and the temperature plays an important role for their growth. Each insect has a temperature threshold for its development, such as base development temperature (Tbase), upper development temperature (TU), and optimum temperature level (Topt). Development of insects can not occur when temperatures are below Tbase or above TU. The fuzzy logic model has applied to forecast insect pests based on weather conditions. The activity of organisms only happens when proper temperature and humidity levels (Vidita Tilva et al., 2013). In recent years, Vietnam Tobacco Institute has built a forecast model based on the Skybit, Fuzzy, and Degree-days models, and is run on Excel software (Nguyen Van Chin et al., 2021 - 2023). The forecast result of these models helped us give the best control, with the accuracy from 83.4 - 91.7% (Nguyen Van Chin et al., 2023). In 2024 crop season, we continue to use this model to predict tobacco budworms and whiteflies in Vietnam.

2. Materials and Methods

2.1. Forecast Areas: Predict insects for three the tobacco growing regions, including Cao Bang, Gia Lai, and Tay Ninh. Cao Bang region is in Northern mountain, Gia Lai region: Central Highlands, and Tay Ninh following the South of Vietnam.

Forecast objects: Some main organisms cause the tobacco plants in Vietnam, such as tobacco budworms (*Helicoverpa assulta*) and Whiteflies (*Bemisia tabaci* (G.).

2.2. Forecast time and the growing stage of tobacco: Cao Bang region: From December 2023 to May 2024, Tay Ninh and Gia Lai: December 2023 to April 2024, corresponding to the transplanting to harvesting time. The weather of Cao Bang: December 2023 to March 2024 usually occurs cool, deep cold, and harmful cold; April to June 2024: The rainy season, hot sun, and high humidity. The weather of Gia Lai and Tay Ninh: Two distinct seasons are the rainy and dry seasons. The rainy season usually starts from May to the end in October, and the dry season is from November to April of the following year. The tobacco growing season is in the dry season, with hot sun, low humidity, and little rain.

2.3. Weather data for the forecast: Weather forecast data for the fifteen days and months in Cao Bang, Gia Lai, and Tay Ninh regions in 2024 selects from weather forecast websites, such as Myweather2.com, Tutiempo.net, Myforecast.com, and Vietnam National Center for Hydrometeorological Forecasting. The weather data from these websites is high accuracy for tobacco growing regions of Vietnam.

2.4. Forecast methods: Our predictive model is built based on the Skybit, Fuzzy, and degree day models, and runed on Excel software with input data, such as insect pest information, weather information, and forecastive levels of the insects. In this model, we use the IF function in Excel software to determine the correlation between weather factors and the biological characteristics of insects. To give the final forecast and advise control methods, we based on the surveying results, history field, varieties, crop rotation, stages growth of tobacco, and the predictive experience. Predictive levels of insects: 0: No active; 1: Active and negligible damage; 2: Active and light damage; 3: Active and moderate; 4: Strong action and severe damage.

The formula for calculating degree day (DD): $DD = (T_{max} + T_{min})/2 - TL$. If $DD < 0$: $0^{\circ}D$; $TU, TL < TL$ and $TU, TL > TU$: $0^{\circ}D$; $T_{max} > TU$: $T_{max} = TU$; $T_{max} < TU$ and $T_{min} > TL$: $T_{tb} - TL$ (Michigan State University, University of Illinois, and the University of California). Accurate of predict (A. Ghobakhlou et al., 2015) = $\{(\sum \text{Accurate predict times})/(\sum \text{Predict times})\} * 100$.

Insect information

T	Temperature levels for the growth and development of insect (T_{base} , TU , T_{opt}).
DD	Degree days of insect (Frank Zalom et al., 1983).
ADD	Accumulated degree days of insect
RH	Relative humidity for the growth and development of insect
RHmin	Low relative humidity for the growth and development of insect
RH max	High relative humidity for the growth and development of insect
P	Predict the daily severe rating of insect from 0 (no damage) to 4 (severe damage)
T_{max}	Daily maximum Temperature.
T_{min}	Daily minimum Temperature.
T_{avg}	Daily average temperature
Prec	Daily precipitation
RD	Number of rainy days
RH	Daily average Relative humidity.
RHmin	Daily low relative humidity
RHmax	Daily high relative humidity
LW	The total number of leaf wetness hours per a day.
Weather	Cloud, overcast, rainy, sunny, wind

Levels to forecast the insects

IF function: IF (Humidity is dry) and (Temperature is very low) and (compared to growth conditions of pests) then (Insect is no active);
IF function: IF (Humidity is dry) and (Temperature is too high) and (compared to growth conditions of pests) then (Insect is no active);
.....;
IF function: IF (Humidity is too high) and (Temperature is optimal) and (Leaf wetness/many water drops on leaves in a long time) and (compared to growth conditions of insect) then (Insect is action, but is dead a lot);
IF function: IF (Humidity is an optimal level) and (Temperature is optimum) and (Leaf wetness duration is very short or no leaf wetness) and (compared to growth conditions of insect) then (Insect is strong action and can cause severe damage).

3. Results and discussion

3.1. Biological characteristics of the tobacco budworms and whiteflies

Insect development is closely dependent on weather conditions, especially the temperature and relative humidity. Insect population strongly develop when weather conditions are optimal and natural enemies are few or destroyed. Weather factors affect the abundance, distribution, and the growth rate of insects. The relative humidity also affects insect activity, especially the ability to moult (Khan MMH, 2019). Rain is a factor affecting insect activity in the field. Heavy rain and prolonged rain days cause insect death and limit the fly ability of adults, mate, and reproduce, leading to a sharp decrease in pest population (Ge, F et al., 2003; Li Z et al., 2016). Prolonged rain days increases relative humidity, soil moisture and field humidity, leading to an increase in the rate of parasitized insects and the mortality rate of pupae, larvae, and adults (Chen. F et al., 2003).

Tobacco budworms only develop in the temperature range of 13.3 - 33°C and relative humidity of 50 - 90%, and thrive at the optimal temperature range: 21 - 24°C for larvae and 21 - 27°C for adult, egg, mate, reproduce, and optimal relative humidity is from 80 to 85%. They are inactive when the temperature is below 13.3°C and above 33°C. Tobacco budworms decreases in relative humidity below 63% and temperature: 20 - 21°C, the mortality rate of larvae is up of 96.15%, and most of the pupae do not moult to adulthood. The mortality rate of the first - second instars ranges from 82 to 83% at temperature range of 29 - 30°C and relative humidity of 80 - 81% (Nguyen Van Chin, 2021; 2023). To complete their life cycle from egg to adult stage, the accumulated degree day of the tobacco budworms needs to be 413.3°D, the lower temperature threshold (Tbase): 13.3°C and the upper temperature threshold (TU): 33°C (Butler GD et al., 1976). When the temperature is below or above the biological threshold, the tobacco budworms do not complete its life cycle and do not appear in the tobacco field. Whiteflies develop in the temperature range of 15 - 33°C and relative humidity from 31 - 95%, but the best optimal is from 20 - 25°C and relative humidity: 65 - 75%. When the temperature is above 33°C or below 15°C, whiteflies can not complete their life cycle and die a lot. The whitefly population decreases when the temperature is above 27°C and decreases severely when the temperature is above 32°C or low 15°C. Heavy rain strongly reduces the density of whiteflies in the field (H. Gamarra et al., 2016). According to Le Thi Tuyet Nhung, 2014, whiteflies develop suitably in temperature levels from 24 to 25°C, a fecundity: 25°C, relative humidity: 64%, and decreases strongly when the temperature is above 33°C. Shunxiao Liu et al., 2020, whiteflies thrive at a temperature of 22°C and relative humidity: 65 - 75%. The whiteflies are not active when relative humidity is below 31%. Whiteflies develop in the temperature range from 13.07 to 32°C. Outside this range, whiteflies' activity is delayed. To complete their life cycle from egg to adult, they have to accumulate degree day about 317.3°D (University of California, 2024 and N Zandi Sohani et al., 2007)

Table 1. The growing conditions of tobacco budworms and whiteflies

Insect information	Predict levels				
	0	1	2	3	4
Tobacco budworm					
The growing temperatures level of egg, adult, mate, pupa, and reproduce (°C)	<13,3 ≥ 33	13,3 - < 18 > 30 - < 33	18 - < 21 > 27- ≤ 30	21 - 27	21 - 27
The growing temperatures level of larvae (°C)	<13,3	13,3 - < 18 > 30 - < 33	18- <2 2 >24 -< 30	22 - 24	22 - 24
If T ≥ 30°C, mortality rate of the one instar larvae is up to 82.76; The most budworms enter diapause at T < 15°C, T > 33°C [Nguyen Van Chin, 2011; 2023].					
The growing relative humidity level (%)	50	60	>60 - < 75 > 90 - 100	75- < 80 > 85 - ≤ 90	80 - 85
If RH ≤ 63%, mortality rate of larvae is up 96.15%; most pupae can not mature [Nguyen Van Chin, 2011; 2023] ADD (egg - adult): 413.3°D, low development temperature (Tbase): 13.3°C, and upper development temperature (TU): 33°C (Butler et al., 1976 and UC IPM Phenology Model Database - University of California).					
Whitefly					
The growing temperatures level (°C)	≤ 15 > 33	15 - < 18 30 - ≤ 33	18 - < 20 > 25, < 30	20 - 25	20 - 25
The growing relative humidity level (%)	≤ 31	31 - 50 90 - 100	> 50, < 65	> 75, < 90	65 - 75
ADD of one life circle: 317.3°D, Tbase: 13.07°C and TU: 32°C (N Zandi Sohani et al., 2007 and UC IPM Phenology Model Database - University of California)					
If T < 15°C, T > 33°C, whiteflies can not complete their life circle; T = < 12 -15°C, T > 33°C: mortality rate of developmental stages of tobacco budworm is high. The survival rate of budworms is the best high at 20°C, and the best high reproduce is at 25°C. Whitefly population lightly reduces when temperature > 27°C and severely reduces when 32°C < T < 15°C. Little rain and low relative humidity suit the developmental whitefly population (H. Gamarra et al., 2016). Le Thi Tuyet Nhung, 2014, the optimal temperature level for the whitefly is 24 - 25°C, good fertility: 25°C, and the optimal relative humidity: 64%. Whitefly population decreases when T ≥ 29°C and strongly reduces: T > 33°C. Shunxiao Liu et al., 2020, they develop the best in 22°C and RH = 65 - 75%, when RH ≤ 31%, all whiteflies die.					

3.2. Forecast the tobacco budworms causing damage in Vietnam

3.2.1. Forecast the tobacco budworms in Cao Bang region

- Forecast the tobacco budworms by Degree day

Insects are cold-blooded animals, so temperature plays an important role in their growth and development. Each insect species has a development temperature threshold (T_{base} and T_U), and they cannot function when the temperature is below or above this threshold. The Degree day of insects is calculated by the effective development temperature of each day of insects, thereby determining the possibility of the appearance of the developmental stages, life cycle and peak population time of insects.

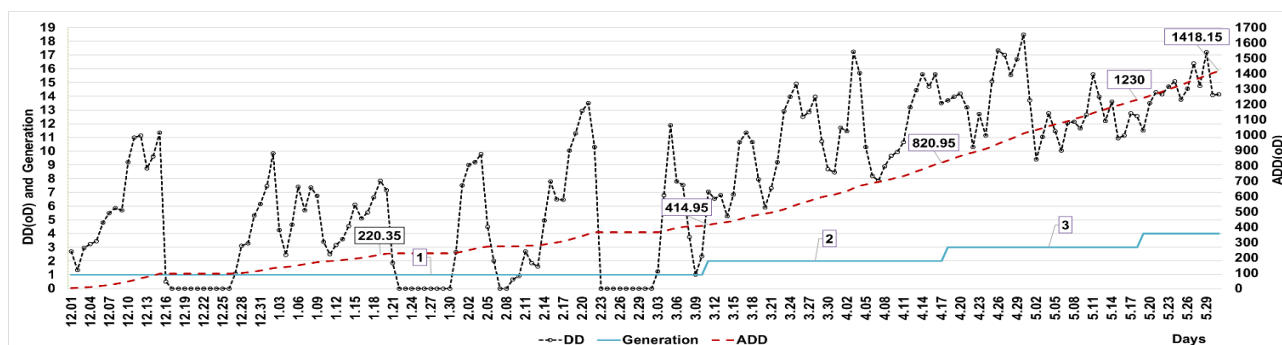


Figure 1. Predict the generations of tobacco budworms with growing degree day from 12/2023 to 5/2024 in Cao Bang province

To complete the life cycle, the accumulated degree day of budworms needs to be 413.3. Based on the degree day in Figure 1, accumulated degree day of budworms from December 1, 2023 to May 30, 2024, reached 1418.15 $^{\circ}$ D, corresponding to 3 - 4 generations in the field. In the quick development tobacco stage, from December 10, 2023 to March 15, 2024, only had 1 generation. Special some days, December 16 - 28, 2023; January 21 - 30, February 7 - 12, and February 23 - March 3, 2024 had DD < 0, leading to the budworms being inactive or dying a lot. From the flowering stage onwards was not suitable for the budworms to cause damage, from March 15 to May 30, 2024, there were up to 3 generations in the field. From the above analysis results, the forecast tobacco budworm appeared less (<5%) and caused insignificant to slight damage in Cao Bang region.

- Forecast the tobacco budworms by weather and climate conditions

Abiotic factors, such as temperature, humidity, photoperiod, wind speed and rainfall play an important role in determining the distribution and population dynamics of insects and the development cycle of each individual (Pellegrino AC et al., 2013). In that, the temperature, relative humidity and rainfall have the strongest impact. Based on the interaction between weather and climate factors, biological characteristics of insects and the development stages of tobacco plants, forecast the tobacco budworms in the Cao Bang region from December 2023 to May 2024 was showed in Figure 2.

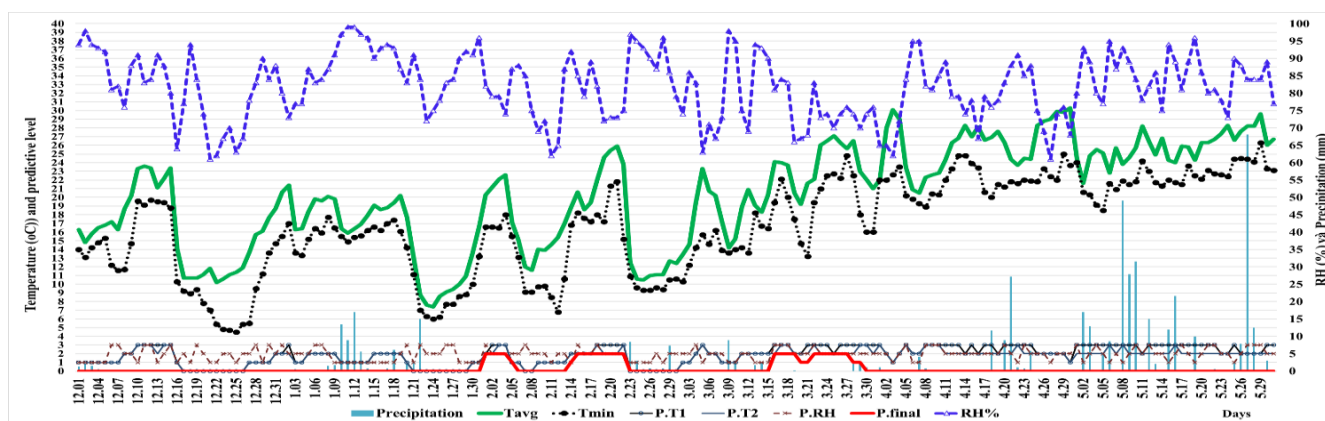


Figure 2. Predict the growth, development and damage of tobacco budworms with weather and climate from 12/2023 to 5/2024 in Cao Bang province

From December, 2023 to January, 2024, forecast the tobacco budworm did not appear or appear very little (scattered) in the fields. During this period, Cao Bang region, as well as the northern tobacco growing provinces had cold, deep cold and harmful cold weather conditions, with an average temperature of 15.8 $^{\circ}$ C and close to the low temperature threshold of budworms (T_{base} = 13.3 $^{\circ}$ C), the maximum temperature was 19.9 $^{\circ}$ C and the minimum temperature was 12.5 $^{\circ}$ C. In particular, from

December 16 - 28, 2023 (15 days) and January 21 - 31, 2024 (11 days) had average temperatures below the Tbase, with Tavg from 9.87 to 11.8°C, Tmax: 12.5°C and Tmin: 7.3°C (4.5 - 10.3°C), leading to tobacco budworms ceasing function, diapausing, and dying a lot. Relative humidity also affected the development of budworms in the field. Monitoring results showed that most days (making up more than 82%) from December 2023 to January 2024 had high relative humidity, ranging from 84 - 100% and many days above 90%, leading to limiting the ability of adults to fly and mate, and increasing the mortality rate of the larvae, adults, and pupae due to parasitism and waterlogging or leaf's wet/water drops. Heavy rain and rain prolonging many days in December 2023 and January 2024 significantly reduced the budworm population in the field, and effectively killed the adults, larvae and pupae. Specifically, in December 2023, there were 07 days of continuous light rain; January 2024, there were 16 days of rain with 06 days having moderate to heavy rain (5.6 - 17.0 mm).

From February to March, 2024, the forecast budworms occurred less (< 5%) and caused insignificant to light damage in Cao Bang region. During this period, the weather gradually warmed up, but many days had deep cold, harmful cold and frost, and continuous drizzle and heavy rain to limit the growth of insects. The average temperature in February 2024 was about 16.8°C and the minimum temperature was 13.5°C, equivalent to Tbase (13.3°C). In March 2024, the average temperature was 20.8°C, and the minimum temperature was 16.9°C. In particular, February 6 - 12, 2024 (6 days), February 23 - March 3, 2024 (10 days) and March 9 - 10, 2024 (2 days) had average temperatures equivalent to or below the Tbase, with the corresponding Tavg: 13.5°C and Tmin: 9.5°C; Tavg: 11.9°C and Tmin: 10.5°C; Tavg: 14.7°C and Tmin: 13.8°C, leading to inhibiting/restraining the development of insects. Rainfall and number of rainy days significantly impacted the budworms. In February and March 2024, there were 16 rainy days, with 11 days appearing drizzle and 05 days accruing moderate to heavy rain, with rainfall from 4 - 9 mm on February 23 - 24 and 29, March 9 and 18. So, with the temperature, precipitation and number of rainy days in February and March 2024 were not favourable for budworms to develop, while the average humidity (80 - 82%) and the tobacco plants were optimal for their growth.

From April to May, 2024, forecast the budworms did not damage on the tobacco plants. Because, tobacco plants were cutting top off and harvested, and it was rainy many days, leading to no favourable for the budworms to develop. In April 2024, there were 10 rainy days, with 05 days of moderate to heavy rain (April 7, 18, 20 - 21, 24), with rainfall from 5 - 27 mm. In May 2024, the rainfall increased sharply, reaching 310 mm, with 18 days of heavy rain with a daily average rainfall of over 10 mm.

The assessable results of the influence of weather and climate on the emergence and damage of budworms were consistent with the studies of many authors. The research results concluded that budworms were sexually inactive when the temperature was below 15°C and died when the temperature was below the Tbase (13.3°C) (Mironidis, G et al., 2012). Heavy rain and rainy many days with rainfall above 5 mm increased relative humidity and soil moisture, which raised the mortality rate of larvae (Ge, F et al., 2003), pupae and adults (Chen, F.J et al., 2003), and strongly reduced the ability of adults to fly, mate and reproduce (Li Z et al., 2016). Heavy rains sharply decreased the budworm population in the field. Because the larvae, adults, and eggs were killed a lot by washing away, immersion in water and infective disease, and pupae were killed in wet soil condition (Gullan et al., 2005). The pupae remained in a sexual diapause state for about 20 months when the temperature was below 18°C (Phillips, J. R et al., 1966), and the reproductive capacity of insects reduced when the temperature was below 20°C and strongly decreased when the temperature was below 15°C (Noor-ul-Ane, M et al., 2018). The mortality rate of adults was high when there was heavy rain and strong wind.

Based on the degree day, weather and climate factors, forecast budworms caused insignificant to slight damage in Cao Bang region in 2024. Compared to the surveying results, budworms caused light damage, with the highest damage rate on February 30, 2024 at 3.1% and other periods with damage rates from 0.0 - 1.6%. The forecast results of budworms in Cao Bang region had an accuracy of 91.7%. Advice on control methods: Continue to investigate the budworms in the field. It only controlled by the handicraft methods and used pesticides when the damage rate was from 5 to 10%.

3.2.2. Forecast the tobacco budworms in Gia Lai region

- *Forecast the tobacco budworms by Degree day*

The growing degree day of budworms is accumulated from the planting stage to the end of harvest. The budworms complete their life cycle, from the egg to the adult when the ADD reaches 413.3°D. Results in Figure 3 showed the ADD of budworms in the Gia Lai region reached 1,648.8°D, corresponding to 4 generations in the field. The ADD from the planting stage to before the cutting the top off one week, from December 10, 2023 to February 15, 2024 accumulated 673°D, corresponding to 1.5 generations. From February 15, 2024 to completing the harvest stage was 2.5 generations. So, based on the number of generations in the field, predict the budworms appeared rarely (<5%) and caused insignificant to slight damage in Gia Lai region.

- Forecast the tobacco budworms by weather and climate conditions

Based on the weather, climate conditions, and the development stages of tobacco plants in the Gia Lai region, the forecast the budworms caused insignificant to slight damage. In the season 2024 (Figure 4), relative humidity was low, ranging from 45 - 75%, an average of 67.4% that was little suitable for budworms to develop strongly. Because the eggs, larvae and pupae were difficult to moult when the relative humidity was lower than 63%. In addition, the daytime temperature was high (30 - 31°C), the strong sunlight intensity (7 - 9 hours of sunlight/day), and the low relative humidity made insects stressed due to dehydration or heat shock (Romoser., et al., 1998).

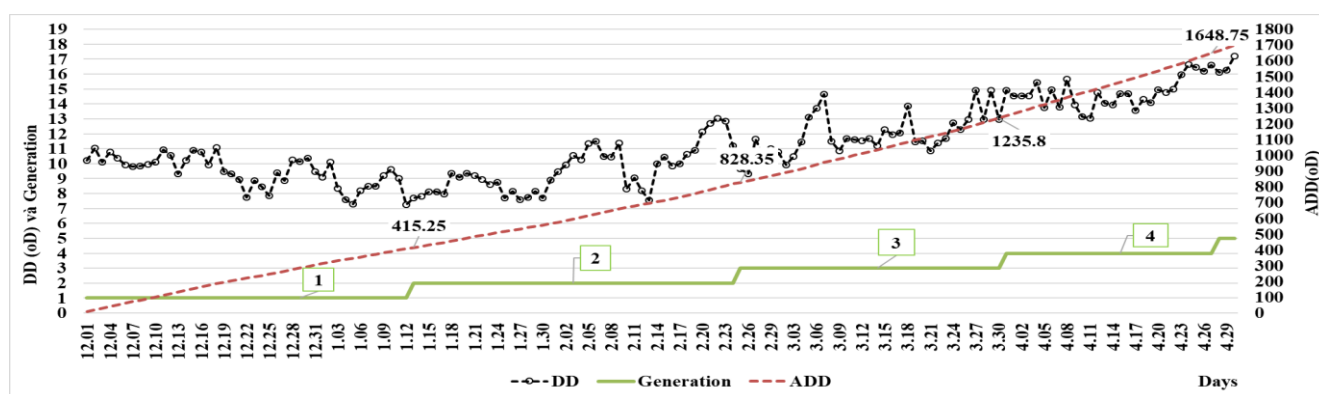


Figure 3. Predict the generations of tobacco budworms with growing degree day from 12/2023 to 4/2024 in Gia Lai region

Based on the degree day, weather and climate conditions in Gia Lai, forecast the budworms appeared less (<5%) and caused insignificant to slight damage. Compared to the surveying results, the budworms caused slight damage on January 30, 2024 with the highest damage rate of 2.7%, and caused insignificant damage in other periods (0.0 - 1.3%). The forecast results of the budworms in Gia Lai were an accuracy of about 83.3%. Advice on control methods: Continue to investigate the budworms in the field. It only controlled by handicraft methods and used pesticides when the damage rate was from 5 to 10%.

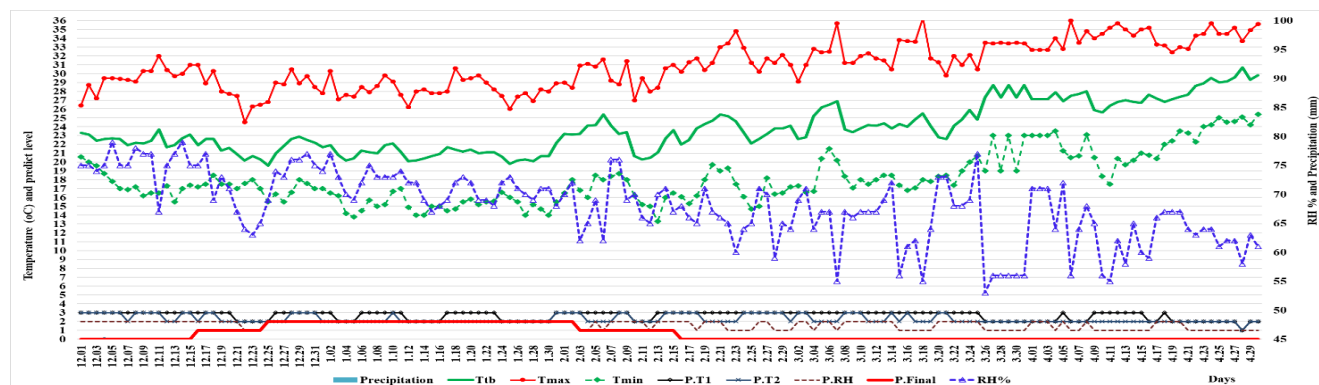


Figure 4. Predict the growth, development and damage of tobacco budworms with weather and climate from 12/2023 to 4/2024 in Gia Lai region

3.2.3. Forecast the tobacco budworms in Tay Ninh region

- Forecast the tobacco budworms with Degree day

The forecast results in Figure 5 showed the ADD from December 2023 to April 2024 of the budworms in the Tay Ninh area reached 2,446°D and corresponded to about 5 - 6 generations in the field. In the stage from the transplanting to before flowering one week (February 15, 2024), ADD of budworms accumulated 1.234°D, corresponding to 3 generations. From the cutting the top off stage to the end of the harvest accumulated 1.212°D, corresponded to 2 - 3 generations. Based on the number of generations in the field, the forecast the budworms caused moderate damage in the Tay Ninh region.

- Forecast the tobacco budworms with weather and climate conditions

The tobacco growing Tay Ninh region had high temperature, low relative humidity, and strong light intensity, especially the many days in February, March and April having hot sun and intense sunshine to inhibit the growth of the budworms (Figure 6). In addition, the hot sun weather caused wilt symptoms of top leaves of the PVH2343 tobacco variety in March and April 2024 to reduce the ability of the budworms to eat. For example, the average temperature in the 2024 crop season was about 30°C and above the best optimal temperature (Topt) of the budworms (22 - 24°C); the highest daily average temperature was 35.8°C and above TU; and the lowest daily average temperature was 26°C and above Topt. The average relative humidity of the Tay Ninh region was low, with an average of 63 - 65%, and the lowest daytime humidity ranged from 31 - 45% to limit the growth of budworms. When relative humidity was lower than 63%, the mortality rate of budworms was very high. Combined the number of sunshine hours (9 - 9.5 hours/day), low humidity and high temperature made insects quickly stressed due to dehydration and heat shock, and the budworms died a lot.

Our studies were consistent with the research results of Romoser et al., 1998 and Nguyen Van Chin, 2021, high temperature and low humidity caused stress for the budworms due to dehydration and heat shock. When the temperature was higher than 33°C, larvae and pre-pupa were diapaused because they were sensitive to high temperatures and heat (Liu Z et al., 2016 and Liu, Z. D et al., 2004). Reproducing capacity was reduced, and the mortality rate was highest when the temperature was above 35°C (Noor-ul-Ane, M et al., 2018). Relative humidity strongly affected the development of insect pests. Dry weather and relative humidity below 65% were not optimal for the budworms to develop because they affected the water balance in the insect's body. Relative humidity affected the water balance in the host plant and impacted the feeding ability of insects (Qin, J. D, 1964). Low humidity made the shell of eggs hard, so it was difficult for larvae to bite the shell and get out, reduced the vitality of larvae, and ability to cause of insects (Jin, C. X, 1979). Dry soil had a good effect on preventing the outbreak of adult density in the field (Johnson, S.N et al., 2010) because the pupae were difficulty moulting/prolonging the diapause. Pupae did not moult to adulthood when the soil humidity was below 60% (Trottier R et al., 1979).

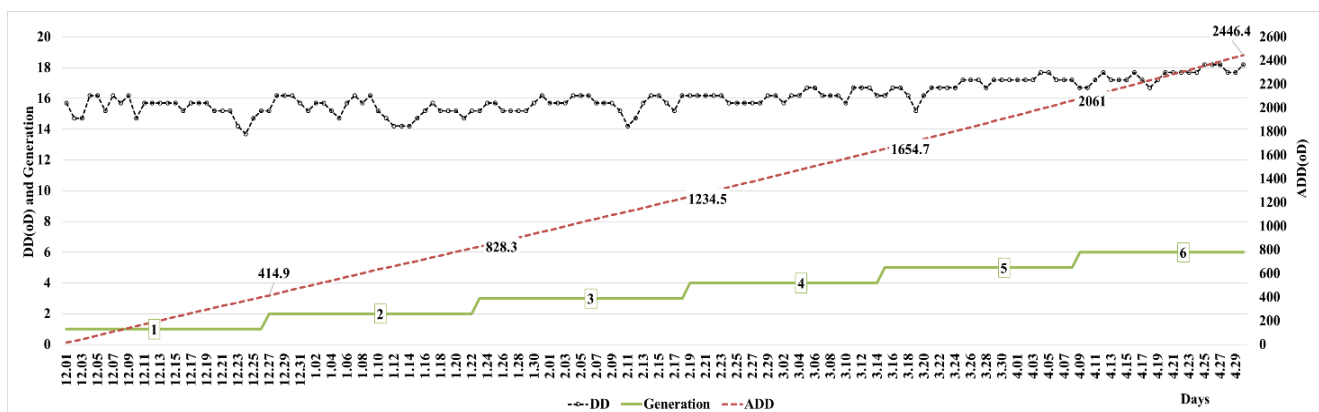


Figure 6. Predict the growth, development and damage of tobacco budworms with weather and climate from 12/2023 to 4/2024 in Tay Ninh region

In the 02 forecast models, the forecast model with the degree day had a lower level of accuracy than the forecast model with weather and climate. This study was similar to our research result in 2023 and was the same the J.A. Davis et al., 2006, Elliott et al., 1989, Tamaki et al., 1982 and Newman, 2005: High temperature did no correlation to insect population development. The growth of insects, fertility and longevity slowed down when the temperature was higher than the optimal temperature levels.

Based on the weather and climate, the forecast the budworms appeared less (< 5%) and caused insignificant damage in Tay Ninh region. Compared to the surveying results, the budworms caused insignificant damage from December 31, 2023 to January 15, 2024, with the highest damage rate of 0.4%. Other stages, the budworms rarely appeared. The degree day model had low accuracy with budworms in Tay Ninh region. The accuracy of predict the tobacco budworms reached 91.6%. Advice on control methods: Continue to investigate the tobacco budworms in the field. It only controlled by handicraft methods and did not use pesticides to spray the control.

3.3. Forecast the whiteflies causing damage in Vietnam

3.3.1. Forecast the whiteflies in Cao Bang region

- Forecast the whiteflies with the growing degree day

The forecast results in Figure 7 showed the accumulated degree day of whiteflies from December 2023 to May 2024 reached 1262.6°D, corresponding to 4 - 5 generations in the field. From the transplanting time to a week before tobacco plants occurring buds only one generation appeared. From the stage of the plants occurring buds to the end of season appeared 3 - 4 generations. The whiteflies appearing in one generation in this stage was from December 16 - 28, 2023, January 21 - 30, 2024, and February 7 - 12, 2024 had too low temperature levels, and $DD \leq 0$, leading to insects not accumulating degree day or insects stopping the growth or dying a lot. Based on the number of generations in the field, the prediction of whiteflies caused insignificant damage in the Cao Bang region.

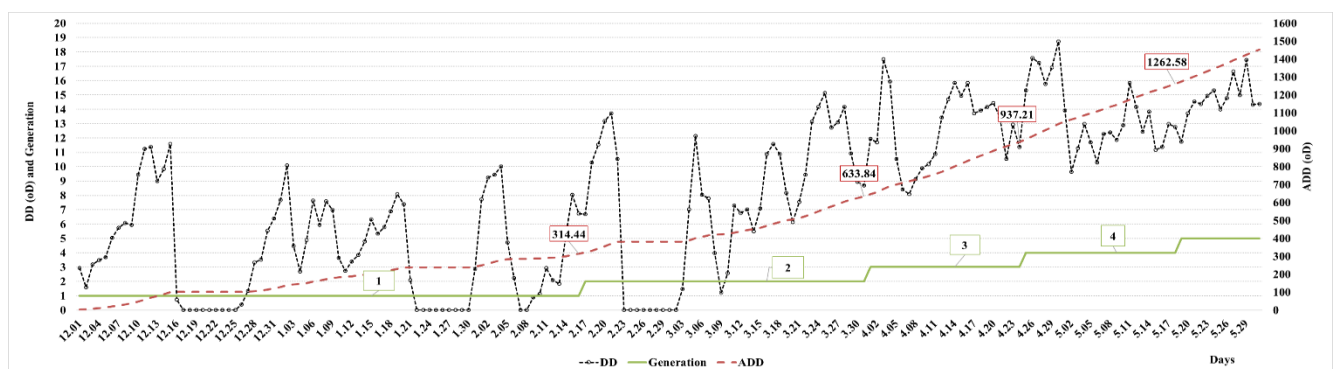


Figure 7. Predict the generations of whiteflies with growing degree day from 12/2023 to 5/2024 in Cao Bang region

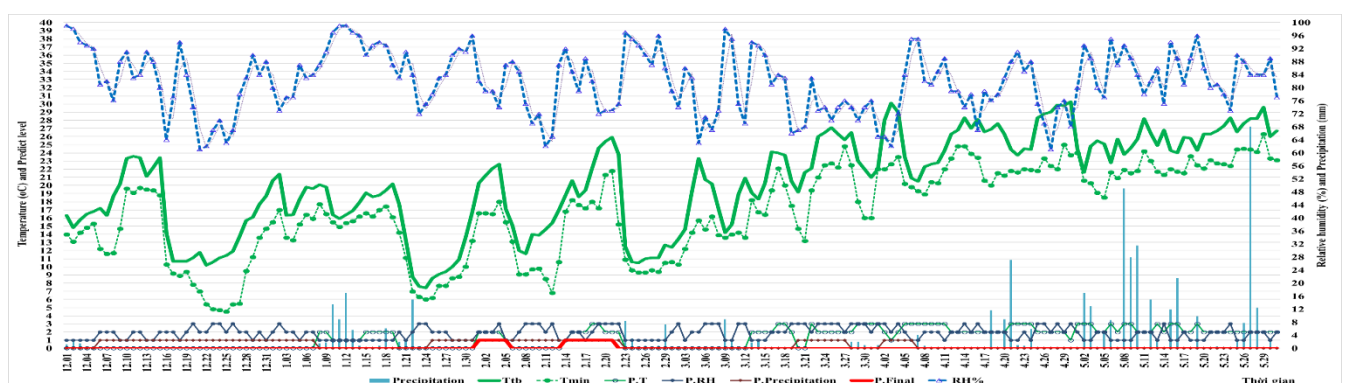


Figure 8. Predict the growth, development and damage of whiteflies with weather and climate from 12/2023 to 5/2024 in Cao Bang region

- Predict the growth, development and damage of whiteflies with weather and climate

Based on the weather and climate conditions in Cao Bang in Figure 8, forecast the whiteflies did not appear/appear a little in the field. The forecast results of insects causing the tobacco were as follows:

From December, 2023 to February 15, 2024, the whiteflies did not appear in the field. During this period, the daily average temperature was low, with frequently appearing cold, deep cold, and damaging cold to inhibit the development or kill the whiteflies, with an average temperature of 16.0°C, nearly equal to Tbase (13.03°C) and the lowest temperature for the whiteflies completing their life cycle was 15°C (TL2). The the best minimum temperature was 12.6°C, below the Tbase and TL2. In particular, December 16 - 26, 2023; January 22 - 30, 2024; and February 7 - 9, 2024 had an average temperature below the Tbase, respectively 11.2°C (4.5 - 9.5°C); 9.9°C (6 - 10°C) and 12.5°C (6.8 - 13.1°C), lead to whiteflies being inactive, diapause or death a lot due to heat shock. On the other hand, December 2023 to January 2024, Cao Bang region had prolonged rain days, drizzle, and high relative humidity, especially from January 8 - 22, 2024 had continuous rain with rainfall ranging from 0.25 - 17.02 mm, in that, January 10 - 13, 18, and 20 - 22, there was moderate to heavy rainfull (3 - 17.02 mm) which effectively washed away the whiteflies population; limited their ability to fly, mate, and reproduce; and increasing the mortality rate of adults and larvae due to infective disease.

From February 16 to May 30, 2024, the average temperature was 23.3°C and within the best suitable temperature range (20 - 25°C) for whiteflies to develop and reproduce. However, this period had high humidity and many days of continuous rain, which was not optimal for the growth of whiteflies. For examle, February 23 to March 31, 2024, Cao Bang region had 14 rainy days, with 06 days having moderate to heavy rain (3 - 9 mm); April: 09 rainy days, with 05 days having heavy to too heavy rain (5 - 27 mm); May 2024 had 18 rainy days, with 16 days having heavy to too heavy rain, with rainfall from 7 - 98 mm. Heavy rain and prolonged rain days effectively washed away the most of adults and larvae, and pupae were died a lot in wet soil conditon. On the other hand, from March 30, 2024 onwards, tobacco plants have been cutting the top off and harvested to be not optimal for whiteflies to damage. Relative humidity affected the whiteflies. Relative humidity in 2024 was too high, with an average of 82% and higher than the suitable relative humidity threshold of whitefly (65 - 75%), in that, relative humidity of many days was from 87 - 99%, which did not suit for whiteflies to develop, fly, mate and survive. The relative humidity above 85%, and prolonged light rain days increased field humidity and leaf wetness, leading to increasing the death rate of adults, larvae and pupae.

Our research reaults were similar to Gamarra, H et al., 2016 and Nguyen Thi Tuyet Nhung, 2014, the whiteflies thrived in the temperature range of 20 - 25°C and reproduced suitably in the temperature range of 22 - 23°C, especially at 22.5°C. Nguyen Thi Tuyet Nhung, 2014 and QIU Bao-li et al., 2003, the whitefly population decreased slightly when the temperature was below 17°C and decreased sharply when the temperature was below 15°C (Gamarra, H et al., 2016). Heavy rain and prolonged rain days effectively washed away whitefly populations (Shunxiao Liu et al., 2020). At high relative humidity, the lifespan of adults significantly shortened, and the number of eggs of females was reduced strongly (Yang Shaowu et al., 2022).

Based on the growing degree day, weather and climate, forecast the whiteflies did not appear or appeared rarely in the Cao Bang. The surveying results showed whiteflies did not appear in the tobacco field. The accuracy of forecast the whiteflies in Cao Bang was about 100%. Advice on control methods: Continue to investigate the whiteflies and did not use pesticides to control.

3.3.2. Forecast the whiteflies in Gia Lai region

- Forecast the whiteflies with the growing degree day

The 2024 crop season of Gia Lai region had an average temperature of 23.8°C and was optimal for the growth of whiteflies in the field. The accumulated degree day of whiteflies in this time was 1.738,2°D,

corresponding to 6 generations of insects appearing in the field. The stage of the tobacco plant developed quickly and was sensitive to insects appearing in 03 generations. From the stage of cutting the top off to the end of the season, which was not suitable for the whiteflies to damage, 03 insect generations appeared. Based on the number of generations in the field, the forecast whiteflies developed rapidly and caused the moderate to severe damage.

- Predict the whiteflies with weather and climate

The study results in Figure 10 showed the whiteflies developed quickly and could caused severe damage in Gia Lai. Because there were three the most suitable main factors for the development and reproduction of insects, such as optimal environmental conditions, tobacco plants were susceptible to insects, and the source of infection accumulated on host plants in the field, such as cassava, squash, chilli, watermelon, etc. These host plants were grown in the previous season and intercropped with tobacco fields. The detailed forecast of the whiteflies in Gia Lai was as follows:

The environmental conditions from December 2023 to May 2024 were suitable for whiteflies to grow and reproduce (Figure 10). The average temperature in December 2023 was about 22.0°C, January 2024: 20.9°C, February 2024: 23.2°C, March 2024: 24.4°C, and the average temperature of this period was 22.05°C which was the best optimal for growth of whiteflies (20 - 25°C). In addition, the relative humidity was favourable for whiteflies to develop, with the average humidity in December 2023 at 73.4%, January 2024: 71.2%, February 2024: 67.3%, March 2024: 64.2%, and the average humidity of this time was 69.7% within the range of the most optimal humidity levels of whiteflies (65 - 75%).

The amount of rain and the number of rainy days play an important role in determining the density of whiteflies in the field. Heavy rain and prolonged rain days effectively reduced/destroyed/washed out the density of whiteflies. A little rain was good for the whitefly population to develop and spread. In December 2023, there were 05 rainy days, with rainfall < 0.6 mm; January 2024: No rain; February 2024: 01 rainy day (0.5 mm), and in March: 01 rainy day (0.5 mm). From February 16 to April 30, 2024, whiteflies decreased sharply and caused no damage. During this stage, the tobacco plants were cutting the top off, harvested, and aged to be unsuitable for whiteflies to damage, although weather conditions were favourable for whiteflies (temperature of 26.3°C, humidity: 63.5% and little rain).

Our evaluation of climate and weather affecting the development of whiteflies was consistent with many authors in the world. The whiteflies grew and reproduced quickly in the temperature range of 20 - 25°C, especially the reproductive capacity and survival rate of whiteflies were highest at 22.5°C (Nguyen Thi Tuyet Nhung, 2014; Gamarra, H et al., 2016). The whiteflies thrived in dry weather conditions and low relative humidity at ranging from 60 - 75% (Lin, KeJian et al., 2004), 64% (Le Thi Tuyet Nhung, 2014), 65 - 72% (Chaudhuri N et al., 2001), and 65 - 75% (N Zandi Sohani et al., 2007). Little rain was favourable for the whitefly population to grow, and heavy rain over 5 mm strongly reduced the whitefly population (Chaudhuri N et al., 2001).

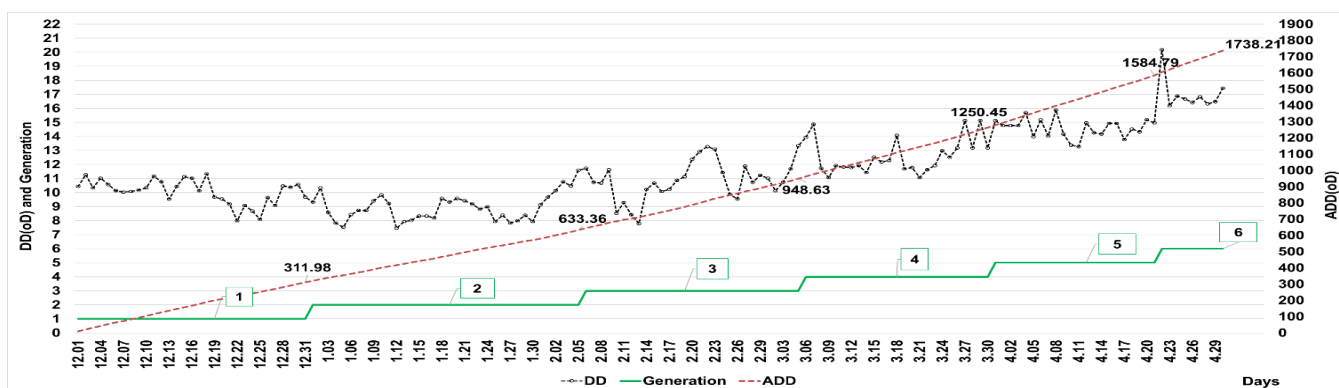


Figure 9. Predict the generations of whiteflies with growing degree day from 12/2023 to 4/2024 in Gia Lai region

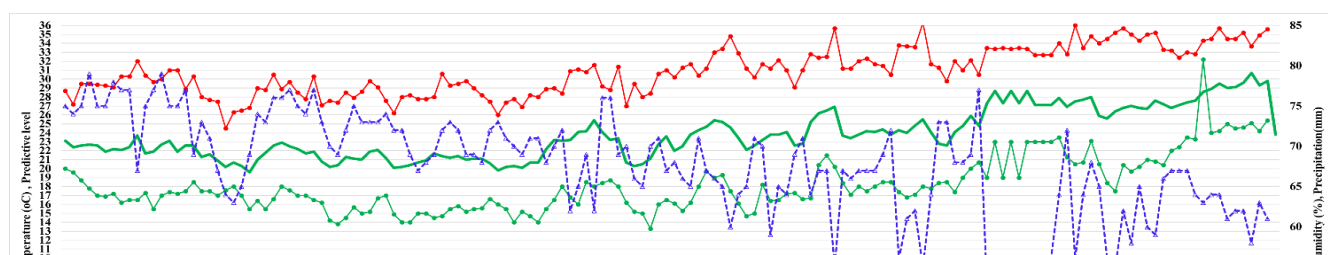


Figure 10. Predict the growth, development and damage of whiteflies with weather, climate from 12/2023 to 4/2024 in Gia Lai region

Based on the growing degree day, weather and climate, predicted the whiteflies developed strongly and could break out into an epidemic in Gia Lai in 2024. The surveying results showed the whiteflies developed strongly on January 15, 2024, with a damage rate of 31.8%, especially in IaPa and Phu Thien districts, Gia Lai province with a damage rate of 100% and the density of whiteflies over 100 individuals/leaf. The accuracy of the forecast the whiteflies in Gia Lai reached 91.7%. Advice on control methods: Investigating the whiteflies in the field and using pesticides to spray. The severely damaged areas, such as IaPa and Phu Thien needed a mixture of Confidor 100SL + Actara 5WP/Confidor 100SL + Angun 5wg to spray, and the single insecticide spray had low effective control. In other areas with light damage, spraying Confidor 100SL or Actara 5WP was high effective control. The controlled result has limited the whiteflies and curl-tip disease to causing severe damage in Gia Lai.

3.3.3. Forecast the whiteflies in Tay Ninh region

- Forecast the whiteflies with the growing degree day

The accumulated degree day of whiteflies in the 2024 crop season in Tay Ninh (Figure 11) took 2412.86°D, correspondingly 08 generations in the field. From the planting stage to the flowering, December 2023 to February 2024, 4 - 5 generations appeared. From the stage of cutting the top off to the end of harvest, there were 3 - 4 generations. Based on the number of generations in the field, forecast the whiteflies developed strongly in Tay Ninh

- Predict the whiteflies with weather and climate

The tobacco growing Tay Ninh region had high temperature, frequent sunshine, intense hot sun, many hours of sunshine with high light intensity, and low relative humidity inhibiting the growth, development and reproduction of whiteflies, leading to a sharply decreasing in the population density in the fields. The detailed forecast of the whiteflies causing damage in Tay Ninh was as follows:

From December, 2023 to February 15, 2024 (Figure 12), forecast whiteflies caused insignificant or light damage. Because the average temperature during this period was too high (30°C), the highest daily temperature was up 34 - 36°C and higher than optimal temperature levels (20 - 25°C) and TU (32°C) of whiteflies to inhibit the growth of them. Relative humidity was low, an average of 68% and the daytime humidity fluctuated from 31 - 45%, which reduced the moult ability of whiteflies.

From February 16 to April 31, 2024, forecast whiteflies did not occur in the field. During this stage, tobacco with cutting the top off and harvesting was not optimal for whiteflies to cause damage. General, the temperature and humidity during this time were not optimal for whiteflies to develop. The average temperature was 31°C, the highest daily temperature was above 36°C, and many days had temperature from 38 - 41°C to affect the biochemical activities of insects, especially harmful to the vitality of larvae and pre-pupa. The daytime relative humidity only ranged from 31 - 45% to restrain the development or cause death of the most phases of whiteflies. The high temperature, low relative humidity, and high light intensity caused the whitefly stress due to water imbalance in the body and heat shock. Those conditions affected the growth and development of tobacco plants, leading to a reduction in the ability of insects to eat. Thus, whiteflies only caused insignificant damage in Tay Ninh.

Our findings were consistent with studies of many authors in the world. Larvae and pre-pupal stages of whiteflies were sensitive to high temperatures and low relative humidity. High temperatures and low humidity caused insects to be stressed due to water imbalance in the body and heat shock (Romoser et

al., 1998; Nguyen Van Chin, 2021). The population and vitality of whiteflies decreased when the temperature increased highly. When the temperature was above 27°C, the whitefly population slightly decreased; > 30°C, the whitefly population decreased sharply (Gamarra, H et al., 2016) and > 32°C, whiteflies did not complete the life cycle and the survival rate of first-instar larvae was low (Shunxiao Liu et al., 2020). Nguyen Duc Khanh et al., 2021, the larval and pre-adult stages were most lethal at 30°C. The mortality rate of eggs was higher than larval mortality. Adult lifespan decreased when the temperature was above 25°C and decreased sharply at 30°C. The egg-laying ability of adults decreased when the temperature was above 27.5°C and decreased sharply at 30°C. Urbano Nava-Camberos et al., 2001, larval development increased gradually from 15°C to 30°C and decreased sharply from 32°C onwards and did not develop at 35°C. Butler et al., 1983, the larvae did not develop when the temperature was above 32.5°C. Chu, D et al., 2012, temperatures below 20°C and above 30°C were not optimal for growth and reproduction, and relative humidity below 50%, whiteflies died a lot.

Our the research results showed the the degree day model was not accuracy for whiteflies and was similar to 2023 in Tay Ninh. According to the research results of J.A. Davis et al., 2006, this model only predicted accurately when the temperature fluctuated low and within the development thresholds of insects, and the most accurately within the suitable threshold of insects to develop. When the temperature changed widely, the accuracy of the forecast was low (J.A. Davis et al., 2006). Elliott and Kieckhefer, 1989, this model was only accurate when the temperature fluctuated from Tbase to Topt. When the temperature exceeded those thresholds, the model did not act and was not proper for predicting. It did not accurately predict the insect population at high temperatures because there was no correlation between temperature and the growth of insect population at high temperatures (Tamaki et al., 1982). When the temperature was above the optimum temperature threshold, the development of insects slowed down, and fecundity and longevity decreased sharply (Newman, 2005).

After 2 years of testing the degree day forecast model, this model had a low accuracy level when forecast the tobacco aphids and whiteflies in Tay Ninh where the temperature was higher than the optimum temperature and upper-temperature threshold; the low accuracy level when the temperature exceeded TU. This model only had one temperature factor to affect insects, however, in natural conditions, the growth, survival, reproduction, and migration of insects were affected by many other factors, such as humidity, rainfall, hours of sunshine, light intensity, crops, etc.

So, predict the whiteflies caused insignificant damage in Tay Ninh. Compared to the surveying results, whiteflies developed strongly on January 15, 2024, with a damage rate of 7.1% and caused insignificant damage. The accuracy of the forecasting model in Tay Ninh was 91.7%. The degree day forecast model was not suitable for predicting whiteflies and tobacco aphids in Tay Ninh. Advice on control methods: Investigating the whiteflies in the field and no use pesticides to sprav the control

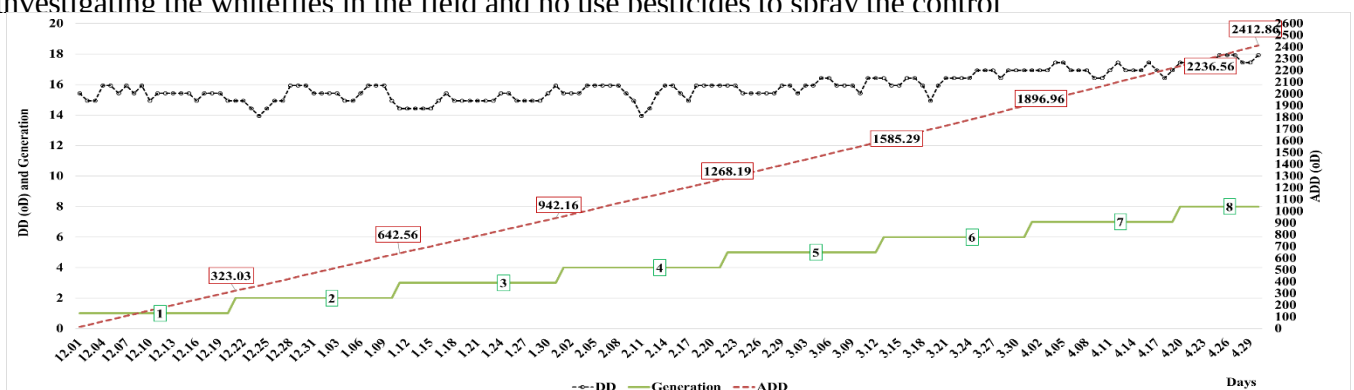


Figure 11. Predict the generations of whiteflies with growing degree day from 12/2023 to 4/2024 in Tay Ninh province

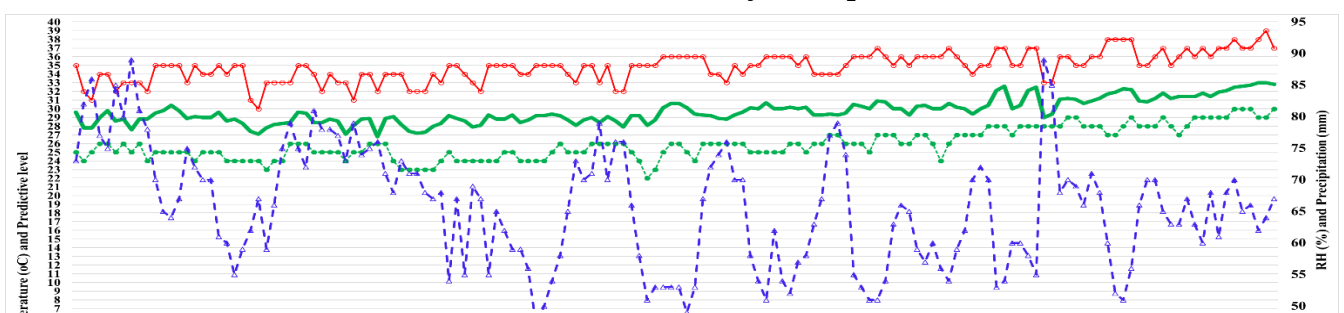


Figure 12. Predict the growth, development and damage of whiteflies with weather, climate from 12/2023 to 4/2024 in Tay Ninh region

4. Conclusion and suggestions

In 2023 - 2024, Vietnam Tobacco Institute have applied the forecast model of insects and diseases based on the degree days, skybit, and Fuzzy models. Predictive results of budworms and whiteflies were the accuracy of 83.3 to 91.7%, and the whiteflies in Cao Bang up 100%. The degree day model had low accuracy when predict the whiteflies, tobacco aphids and budworms in Tay Ninh. Combined the Skybit + Fuzzy + Degree day models gave high effective prediction with the most insectpests on tobacco.

Based on the predictive results, we gave the effectively control methods, reduced the use of pesticides compared to years ago, increased yield and quality, especially prevented the whiteflies, aphids and curl the top disease outbreak strongly in the field.

To encrease the accuracy of forecast with weather and climate, we will continue research and improve this model in the next years.

References

- Noor-Ul-Ane M, Kim DS, Zalucki MP. (2018). Fecundity and Egg Laying in *Helicoverpa armigera* (Lepidoptera: Noctuidae): Model Development and Field Validation. *J Econ Entomol.* 2018 Sep 26;111(5):2208-2216. doi: 10.1093/jee/toy183.
- Fatthy Amir. (2016). Leafwetness duration modelling using adaptive neuro Fuzzy inference system. A thesis submitted to Auckland University of Technology in partial fulfilment of the requirement for the degree of Master of Computer and Information Science. June, 2016.
- Butler, G. D., Jr. and A. G. (1976). Hamilton. Development time of *Heliothis virescens* in relation to constant temperature. *Environmental Entomology*, Volume 5, Issue 4, 1 August 1976, Pages 759-760. <https://doi.org/10.1093/ee/5.4.759>.
- Butler G. D. Jr. Henneberry T. J. Clayton T. E. (1983). *Bemisia tabaci* (Homoptera: Aleyrodidae): development, oviposition and longevity in relation to temperature. *Ann. Entomol. Soc. Am.* 76: 310–313.
- QIU Bao-li, REN Shun-xiang, N.S. MANDOUR, LIN Li. 2003). EFFECT OF TEMPERATURE ON THE DEVELOPMENT AND REPRODUCTION OF *BEMISIA TABACI* B BIOTYPE (HOMOPTERA: ALEYRODIDAE). *Insect Science*. Volume10, Issue1. Pages 43-49.
- Chen, F. J., Zhai, B. P., & Zhang, X. X. (2003). Effects of soil moisture during the pupal stage on population development of cotton bollworm, *Helicoverpa armigera* (Hübner). *Acta Ecologica Sinica*, 23(1), 112-121.
- Chaudhuri N., Deb D.C., Senapati S.K. (2001) Biology and fluctuation of white fly (*Bemisia tabaci* genn.) population on tomato as influenced by abiotic factors under Terai region of West Bengal. *Indian Journal of Agricultural Research*. Volume : 35, Issue : 3 First page: (155) Last page: (160).
- Ching Ju Chen, Yuan-Shuo Li, Chen-Yu Tai, Ying-Cheng Chen, Yueh-Min Huang.(2022). Pest incidence forecasting based on Internet of Things and Long Short-Term Memory Network. *Applied Soft Computing*, Volume 124, 2022, 108895. <https://doi.org/10.1016/j.asoc.2022.108895>
- Chu, D., Tao, Y.L., Zhang, Y.J., Wan, F.H. and Brown, J.K. (2012) Effects of Host, Temperature and Relative Humidity on Competitive Displacement of Two Invasive *Bemisia tabaci* Biotypes [Q and B]. *Insect Science*, 19, 595-603. <https://doi.org/10.1111/j.1744-7917.2011.01500.x>
- Nguyen Van Chin. (2021). Application of The Skybit Model to Forecast the Brown Spot, Frogeye and Powdery Mildew Diseases in Tobacco Based on Weather Data. *Asian Journal of Fundamental and Applied Sciences*. e-ISSN: 2716-5957. Vol. 2, No. 2, 49-56, 2021. <http://myjms.mohe.gov.my/index.php/ajfas>

- Nguyen Van Chin, Nguyen Van Van and Pham Ha Thanh. (2023). Forecast results of some major insects damaging the tobacco plants in Vietnam based on weather conditions. *Eur. Chem. Bull.* 2023, 12 (Regular Issue 6), 229- 241.
- Davis J. A and others. (2006). Effects of High and Fluctuating Temperatures on *Myzus persicae* (Hemiptera: Aphididae), *Environmental Entomology*, Volume 35, Issue 6, 1 December 2006, Pages 1461–1468, <https://doi.org/10.1093/ee/35.6.1461>
- Elliott N.C. Kieckhefer R.W. (1989). Effects of constant and fluctuating temperatures on immature development and age-specific life tables of *Rhopalosiphum padi* (L.). *Can. Entomol.* 121: 131-140.
- PA. Edde. (2018). Principal Insects Affecting Tobacco Plants in the Field. *Contributions to Tobacco Research*. Volume 28. No. October 2018 DOI: 10.2478/cttr-2018-0013.
- Gullan PJ, Cranston PS. (2005). *The Insects: An Outline of Entomology* 3rd edition. London: Blackwell.
- Ghobakhlou A, F. Amir1, J. Whalley and P. Sallis. (2015). Estimation of Leaf Wetness Duration Using Adaptive Neuro-Fuzzy Inference Systems. 21st International Congress on Modelling and Simulation, Gold Coast, Australia, 29 Nov to 4 Dec 2015. www.mssanz.org.au/modsim2015
- Ge, F., Liu, X. H., Ding, Y. Q., Wang, X. Z., & Zhao, Y. F. (2003). Life table of *Helicoverpa armigera* in Northern China and characters of population development in Southern and Northern China. *Chinese Journal of Applied Ecology*, 14(2), 241-245.
- H. Gamarra, N. Mujica, P. Carhuapoma, J. Kreuze, & J. Kroschel. (2016). SWEETPOTATO WHITE FLY, BEMISIA TABACI (GENNADIUS 1989) (BIOTYPE B). Pest Distribution and Risk Atlas for Africa. (<https://cipotato.org/riskatlasforafrica/bemisia-tabaci>)
- Johnson, SN, Gregory, PJ, McNicol, JW, Oodally, Y, Zhang, X and Murray, PJ. (2010). Effects of soil conditions and drought on egg hatching and larval survival of the clover root weevil (*Sitona lepidus*). *Applied Soil Ecology*, 44, 75-79.
- Jin, C. X. (1979). The relations of population dynamics of the armyworm *Leucania separata* Walker to relative humidity and rainfall. *Acta Entomol. Sin.* 22, 404–412.
- Khan M.M.H. (2019). Effect of temperature and relative humidity on the population dynamics of brinjal and tomato infesting whitefly, *Bemisia tabaci*. Jahangirnagar University *J. Biol. Sci.* 8(1): 83-86, 2019.
- Nguyen Duc Khanh, Le Ngoc Anh & Ho Thi Thu Giang. (2021). Effect of Temperature on Life History of *Bemisia Tabaci* (Gennadius) (Homoptera: Aleyrodidae) on Cassava *Manihot Esculenta* Crantz. *VJAS*. 2021; 4(1): 912-920 <https://doi.org/10.31817/vjas.2021.4.1.02>.
- Liu, Z., Xin, Y., Zhang, Y. (2016). Summer diapause induced by high temperatures in the oriental tobacco budworm: ecological adaptation to hot summers. *Sci Rep* 6, 27443 (2016). <https://doi.org/10.1038/srep27443>.
- Liu, Z. D., Gong, P. Y., Wu, K. J., & Li, D. M. (2004). Effects of high temperature on incidence of pupation, summer diapause and pupal weight of the cotton bollworm, *Helicoverpa armigera* (Hübner). *Acta Entomologica Sinica*, 47(1), 14–19.
- Shunxiao Liu, Hao Yu, Vlasenko V.A. (2020). Effect of Different Temperature and Humidity on *Bemisia tabaci*. *Journal of Botanical Research*. Volume 02 | Issue 02 | April 2020. <https://ojs.bilpublishing.com/index.php/jbr>
- Li Z, Zheng YS, Tang BS. (2016). Study on the relationship between precipitation and number of cotton bollworms. *Hubei Agricultural Sciences*. 2016;55(13):3340– 3348.
- McPherson R.M. (2006). Tobacco Insects. Summary of Losses from Insect Damage and Cost of Control in Georgia 2006. The University of Georgia, College of Agriculture and Environmental Sciences, Department of Entomology Special Committee on Insect Surveys and Losses.
- Mironidis, G., & Savopoulou-Soultani, M. (2012). Effects of constant and changing temperature conditions on diapause induction in *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Bulletin of Entomological Research*, 102(2), 139-147. doi:10.1017/S0007485311000484.
- Le Thi Tuyet Nhung. (2014). Research on the composition of the whitebee species *aleyrodidae* (homoptera) and their biological and ecological characteristics, and measures to prevent the tobacco whitebee *bemsisa tabaci gennadius* damages to *solanthica* plants in the Hanoi region. Doctoral thesis in agriculture.Vietnam.
- URBANO NAVA-CAMBEROS, DAVID G. RILEY, AND MARVIN K. HARRIS.(2001). Temperature and Host Plant Effects on Development, Survival, and Fecundity of *Bemisia argentifolii* (Homoptera: Aleyrodidae). *POPULATION ECOLOGY*. Vol. 30, no. 1.

- David W. Onstad. (2014). IPM and Insect Resistance Management. 2014. Insect Resistance Management (Second Edition). Pages 515-532. <https://doi.org/10.1016/B978-0-12-396955-2.00016-3>.
- Phillips, J.R. and L.D. Newsom. (1966). Diapause in *Heliothis zea* and *Heliothis virescens* (Lepidoptera: Noctuidae); *Ann. Entomol. Soc. Am.* 59 (1966) 154–159. DOI: 10.1093/aesa/59.1.154.
- Pellegrino AC, Peñaflor MFGV, Nardi C, Bezner-Kerr W, Guglielmo CG. (2013). Weather Forecasting by Insects: Modified Sexual Behaviour in Response to Atmospheric Pressure Changes. *PLOS ONE* 8(10): e75004. <https://doi.org/10.1371/journal.pone.0075004>.
- Qin, J. D. (1964). Study on water in food and environment for *Mythimna separata* larvae. *Acta Entomologica Sinica*, 13(5), 659–669.
- Joe Russo. (2000). Weather forecasting for IPM. Pages 453-473 in: Emerging Technologies for Integrated Pest Management: Concepts, Research, and Implementation. G. G. Kennedy and T. B. Sutton, eds. *American Phytopathological Society*, St. Paul, MN.
- Joe Russo and Zack, J. W. (2002). Commercialization of Plant Disease Forecasting in the United States. In: Plant Disease Forecasting. E. Park, ed. *Korean Society of Plant Pathology*, Seoul, Korea. In press.
- Romoser, William & Stoffolano, John. (1998). The Science of Entomology, 4th Edition W S Romoser, J G Stoffolano WCB McGraw-Hill, Dubuque, Iowa 1998.
- N. Zandi Sohani, P. Shishehbor and F. Kocheili. (2007). Thermal effect on Biology and life table of *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae). *Pakistan Journal of Biological Sciences* 10(22): 4057-4062,2007.
- Tamaki G. Weiss M.A. Long G.E. (1982). Effective growth units in population dynamics of the green peach aphid (Homoptera: Aphididae). *Environ. Entomol.* 11: 1134–1136.
- Vidita Tilva, Jignesh Patel, Chetan Bhatt. (2013). Weather Based Plant Diseases Forecasting Using Fuzzy Logic. Nirma University International Conference on Engineering (NUICONE). DOI: 10.1109/NUICONE.2013.6780173.
- Vennila S., J Singh, P Wahi, M Bagri, DK Das and M Srinivasa Rao. (2016). Web enabled weather based prediction for insect pests of rice. ICAR-National Research Centre for Integrated Pest Management, New Delhi-110 012 India.50p.
- Trottier, R and Townshend, JL. (1979). Influence of soil moisture on apple maggot emergence, *Rhagoletis pomonella* (Diptera: Tephritidae). *The Canadian Entomologist*, 111, 975–976.
- Matthew Wallhead and Heping Zhu. (2017). Decision Support Systems for Plant Disease and Insect Management in Commercial Nurseries in the Midwest: A Perspective Review. *Journal of Environmental Horticulture* (2017)35(2): 84-92.
- Frank Zalom, Peter Goodell, Lloyd T. (Ted) Wilson, WW Barnett. (1983). Degree-Days, the Calculation and Use of Heat Units in Pest Management: University of California Division of Agriculture and Natural Resources Leaflet 21373.