# Date estimation for the control of avocado (*Persea americana* Mill.) anthracnose (*Colletotrichum* spp.)

**Duran-Peralta, Elisa**[1]; **Huerta-de la Peña, Arturo**[1]; **Acuayte-Valdes, Consuelo**[2]; **Núñez-Tovar, Ramón**[1*]

[1] Colegio de Postgraduados – Campus Puebla. Maestría en Desarrollo e Innovación en Fruticultura Familiar, Bulevar Forjadores de Puebla Núm. 205. Santiago Momoxpan. Municipio de San Pedro Cholula. C.P. 72760, Puebla, México.

[2] Ingeniería en Agronomía-Nova Universitas. Carretera a Puerto Ángel km 34.5, Ocotlán de Morelos, Oaxaca. C.P. 71513. Tel. 55 16086172.

* Correspondence: nunezt@colpos.mx

**ABSTRACT**

**Objective**: To generate a program that estimates the dates or times for the control of avocado anthracnose, based on the meteorological conditions required for the infection, establishment, and development process.

**Design/Methodology/Approach**: An Excel program was developed to estimate temperature (T), relative humidity (RH), dew point (PR), leaf wetness (LW), and probability of precipitation (PoP) and to evaluate, on an hour-per-hour basis, the fulfillment of the climate thresholds required for the establishment and development of *Colletotrichum* spp. The maximum and minimum daily temperature must be determined with an 80% probability of occurrence and the probability of precipitation. This information was obtained from the daily records of the CONAGUA (National Water Commission) weather stations for three avocado-producing municipalities in Puebla during a 16-year period (2007-2022).

**Results**: The resulting program estimates the meteorological variables for the following ten days. The conditions in January were not optimal for the onset and development of avocado anthracnose in the three municipalities of Puebla taken as a case study. On the contrary, June had optimal temperature and relative humidity, as well as a higher probability of precipitation.

**Study Limitations/Implications**: Accurate data on the meteorological conditions of the orchards under study are required to increase efficiency.

**Findings/Conclusions**: The program will help producers to determine application dates, developing a more user-friendly and efficient management proposal for controlling avocado anthracnose.

**Keywords**: weather, Colletotrichum, forecast.

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## INTRODUCTION

Avocado is native to Mexico and Central America (Williams, 1977). The oldest avocado fossils (7,000-years old) were found in a cave in Coxcatlan, Puebla (Smith, 1966). The greatest diversity of both plants and pathogens can be found in this region of the world. This situation is key for genetic improvement or biological control programs. Mexico's main exports include avocado, tomato, berries, tequila, and beer. Mexico supplies 45% of the world export market for avocado (FAOSTAT, 2022). Most of the produce is harvested

from October to February, with a medium offer from March to May and a low production from June to September (Barrientos, 2010). This phenomenon opens a window for sales from states in which avocado production has been recently introduced, including Puebla, Morelos, and the State of Mexico.

Anthracnose is one of the major avocado diseases and it diminishes both the quality and quantity of the production. It has been recorded both before and after the harvest. Determining the weather conditions that contribute to the onset and development of fungi and inputting them into a software enable research teams to verify which dates and conditions are favorable for the onset of the infection process. These results enable a timely decision-making regarding preventive control and the use of biological control, biorational insecticides, or other environmentally-friendly controls that do not involve worked or consumer health.

The *Colletotrichum* and *Glomerella* fungi (in their asexual and sexual phases, respectively) cause the death of flowers, as well as sunblotch, brown spots, purple patches, and other general avocado anthracnose syndromes (Figure 1). The indiscriminate use of agrochemicals to control these fungi has caused the selection of resistant fungus populations. Some products prevent spore germination and inhibit the development of appressoria or haustoria; however, they must be applied at the right time to achieve a good pathogen control. Duran *et al.* (2017) determined the infection thresholds for the

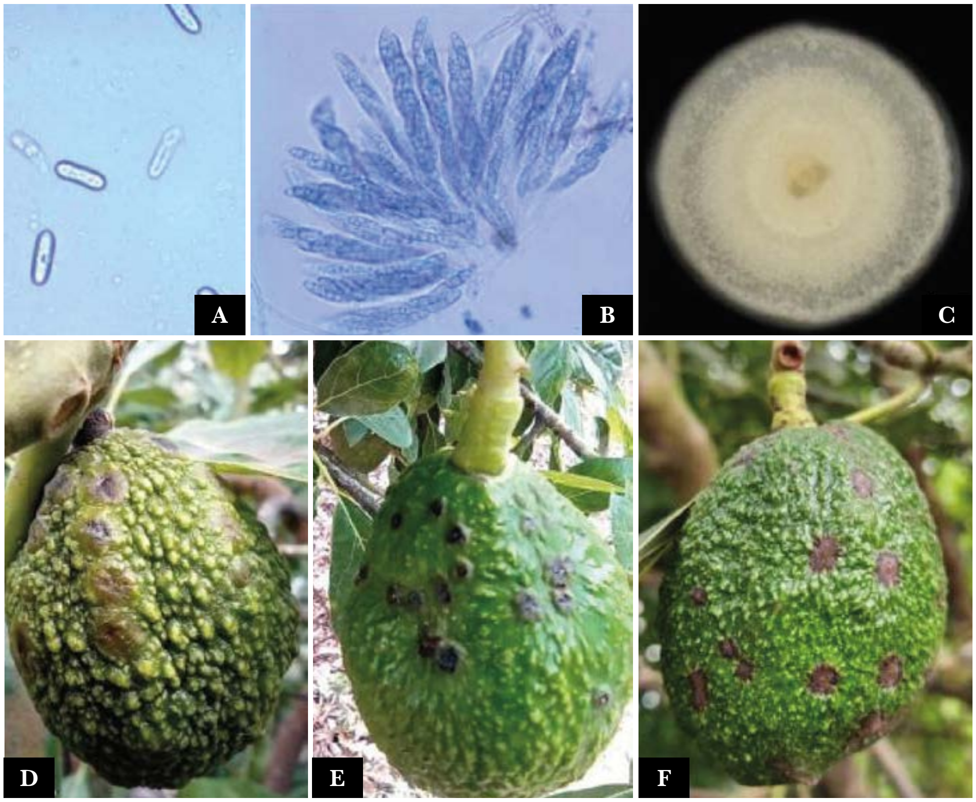


**Figure 1**. A) *Colletotrichum* sp. conidia (A). B) *Glomerella* sp. asci and ascospores. C) *Colletotrichum* sp. colony in a Petri dish. D), E), and F) *Colletotrichum* sp. symptoms in avocado.

onset and development of avocado anthracnose. The aim of this study was to develop a program that estimated the appropriate dates or time for the control of avocado anthracnose, based on the meteorological conditions required for the establishment and development of the disease.

## MATERIAL AND METHODS

An Excel program was developed to estimate temperature (T), relative humidity (HR), precipitation (PR), leaf wetness (LW), and probability of precipitation (PoP) and to evaluate, on an hour-per-hour basis, the fulfilment of the climate thresholds required for the establishment and development of *Colletotrichum* spp. The daily maximum and minimum temperature must be determined with an 80% probability of occurrence and the probability of precipitation. The data were obtained from the daily records of the CONAGUA weather stations from 2007 to 2022 for three avocado-producing municipalities in the state of Puebla: Chilchotla (station 21067), Zacatlán (station 21107), and Atlixco (station 21012). The resulting program estimates the meteorological variables for the following ten days.

Based on the maximum and minimum temperature forecast, the program determined the hourly temperature using the method developed by Linvill (1990) and the relative humidity, dew point, leaf wetness, and precipitation based on their probability of occurrence. Four continuous hours are required to achieve the optimal conditions for the development of anthracnose. When those conditions are met, the program informs, through a written message, that the infection thresholds of *Colletotrichum* spp. in avocado have been exceeded. Based on the optimal conditions for the onset of the infection (Duran-Peralta *et al.*, 2017), the program points out the potential date(s) in which the favorable conditions for the development of the disease will be met.

The method developed by Linvill (1990) was used to determine hourly temperature, based on the minimum and maximum temperature of the day in question and the minimum temperature of the following day.

A lineal function was estimated for the relative humidity, based on the behavior of hourly data of the day in question, using the 2003-2020 records of the CONAGUA weather stations in Atlixco, Chilchotla, and Zacatlan. Relative humidity was estimated with a 79% probability of occurrence, using the following formula:

$$RH = -0.0015 * H4 + 0.0839H3 - 1.3536H2 + 5.1597H1 + 1.131RH$$

Where: RH=relative humidity; $H4$=relative humidity at hour 4; $H3$=relative humidity at hour 3; $H2$=relative humidity at hour 2; $H1$=relative humidity at hour 1.

The dew point was estimated based on the temperature and relative hourly humidity resulting from the following equation:

$$DP = 8RH * 112 + 0.9 * T + 0.1 * T - 112100$$

Where: $DP$=dew point; $T$=temperature in °C; $RH$=relative humidity.

Historical records were consulted to estimate the probability of occurrence (p=0.80) of precipitation (0=no and 1=yes). This information was obtained from the 2007-2022 daily records of the CONAGUA weather stations located in the avocado-producing municipalities of Atlixco, Chilchotla, and Zacatlán.

The leaf wetness criteria were based on the behavior of weather data: a 35 min LW was estimated with precipitation; a 1.2 to 0.7 difference between temperature and dew point was calculated at 50 min LW; an estimated < 07 difference means a 60 min LW; and other data indicated a 0 LW. The hours of solar radiation were estimated with the Witt method (1995), which considers the sunrise time and the latitude of the orchard.

The resulting program was used to estimate the dates in which the optimal conditions for the onset and development of the disease would be fulfilled. The results were compared with the anthracnose symptoms recorded in two avocado orchards in each of the municipalities under study. The data for the evaluation period were arranged per week and input into the R software to determine their correlation coefficient.

## RESULTS AND DISCUSSION

The program forecasts and describes the behavior of the minimum and maximum temperature, dew point, precipitation, relative humidity, and leaf wetness for the following ten days. The conditions were not optimal during January in the orchards from the three municipalities used as study cases; meanwhile, temperature and relative humidity were optimal in June, when rains also recorded a greater probability of occurrence. The program issues an alert every time that the conditions for the onset or development of the fungi are met. In certain times of the year, adequate conditions prevail for a very long time and therefore many alerts are issued in some weeks (Table 1). Risk models based on weather variables can be used to optimize application dates and to reduce to a minimum the number of times that spray should be applied to control the disease (Guzmán-Plazola, 1997).

The Instituto de Investigaciones Agropecuarias (INIA, 2019) developed an information platform which models meteorological data recorded by the INIA automated weather stations in southern Chile, in order to determine favorable conditions for the development of the *P. infestans* infection. This highly-efficient platform has diminished

**Table 1**. Evaluation of the anthracnose detection program in avocado orchards in Atlixco and Chilchotla (2023 production cycle).

| Information | Atlixco | | Chilchotla | |
|---|---|---|---|---|
| | Orchard 1 | Orchard 2 | Orchard 1 | Orchard 2 |
| Evaluation period | 04 april to 20 august | | 28 march to 26 october | |
| First alert | 04-apr | | 28-march | |
| First detection of symptoms | 10-apr | | 3-apr | |
| Numbers of days with alerts | 64 | | 75 | |
| Numbers of days with symptoms | 24 | 22 | 32 | |
| Correlation coefficient | 0.8313 | 0.8135 | 0.8019 | 0.8058 |

the number of applications by 50%, achieving a similar control of the disease than a fixed schedule program (Acuña and Gutiérrez 2019). MELCAST is another alert system based on weather conditions; it is used to control leaf diseases in melons and watermelons, diminishing the application of fungicides by 20% (Egel and Latin, 2012).

Comparing the dates in which the optimal conditions for the onset and development of the disease are met and the dates in which symptoms were recorded in the field resulted in an $R^2$ of 0.83 and 0.81 in Atlixco and an $R^2$ of 0.80 in both orchards in Chilchotla (Table 1). Since Zacatlan has very varied weather conditions and drastic changes were recorded between nearby orchards, the weather data taken from the local weather stations were not considered representative of the evaluated orchards.

Humidity involves relative humidity, leaf wetness, and precipitation (Gillespie and Sentelhas, 2008). Temperature can be evaluated as environmental temperature, soil temperature, plant temperature, and dew point. Studying the relation between meteorological variables and pest and disease development —as a tool to forecast major agricultural events— is part of a comprehensive management (Badnakhe *et al.*, 2018; De Oliveira-Aparecido *et al.*, 2020).

Meteorological models alert producers about potential disease outbreaks; therefore, agrometeorology contributes to the management of diseases (Gillespie and Sentelhas, 2008). Additionally, disease forecasting could favor a lower use of pesticides and reduce their economic and environmental consequences (De Wolf and Isard, 2007). Vizcaino *et al.* (2021) developed a list of fungicides that have been authorized for the control of avocado anthracnose; this list includes active ingredients that have been authorized for their exportation to the USA (Table 2). Producers should alternate between products with different action modes to prevent the selection of resistant populations. Copper fungicides and strobilurins are commonly used to control anthracnose in the field, since they inhibit spore germination; meanwhile, Fluazinam® inhibits mycelial growth and spore germination, but is not effective in the field (Everett *et al.*, 2005). Copper and systemic fungicide mixes are promising treatments for producers whose plants require a healing effect (Vizcaino-Ríos *et al.*, 2021).

This study estimated the dates in which the meteorological requirements for the infection of avocado plants by *Colletotrichum* spp. were met in three municipalities of Puebla. Researching the environmental factors that make up or influence the infection and the disease cycle is essential to understand the onset and establishment of the disease (Evans *et al.*, 1992). The program is a guide for scheduling fungicide applications: However, common sense should also be applied. If the disease exercises a strong pressure on the orchard, the producers should return to the 15-day fungicide application schedule.

## CONCLUSIONS

The system developed in this research describes and forecasts the behavior of minimum and maximum temperature, relative humidity, leaf wetness, dew point, and precipitation for the following ten days. During January, the conditions were not optimal in the orchards evaluated in the three municipalities used as case studies; however,

**Table 2**. List of fungicides recommended for the control of anthracnose in avocado orchards (APEAM, 2020).

| Technical name | Classification for resistance management | |
|---|---|---|
| | Chemical group | Action mode |
| Azoxystrobin | Metoxi-acrilatos | Respiración (C3. Complejo III: citocrom bc1 (ubiquinol oxidasa) on site Qo (gen cyt b) |
| Azufre Elemental | Inorgánicos | Contact action Multi-site |
| Azufre elemental + Oxicloruro de Cobre | Inorgánicas + Sales orgánicas de cobre | Contact action Multi-site |
| Boscalid + Pyraclostrobin | Piridina-carboxamida + Metoxicarbamato | Succinate inhibitor deshidrogenasa + inhibidores de quinone |
| Cyprodinil+Fludioxonil | Anilinopyrimidina + Fenilpirrol | It acts by inhibiting the biosynthesis of metionine +TIt acts in the actúa in y the transport associated to glucose phosphorylation |
| Folpet | M 04 | Contact action Multi-site |
| Fluoxastrobin | Dihidro-dioxazinas | Complejo III del breathing process |
| Cupric Oxide | Sales Inorgánicos de cobre | Contact action Multi-site |
| Copper Hydroxide | Sales Inorgánicos de cobre | Contact action Multi-site |
| Hidróxido Cúprico + Folpet | Sales Inorgánicos + Ftalimidas | Contact Action Multi-site |
| copper oxychloride | Sales inorgánicas de cobre | Contact action Multi-site |
| Cuprous oxide | Inorgánico | Contact action Multi-site |
| Octanoato de Cobre | Inorgánico (electrófilos) | Acción de contacto Multi-sitio |
| Pyraclostrobin | Metoxicarbamato | inhibidores de quinona |
| Propiconazol | Triazoles | ergosterol biosynthesis |
| Copper Sulfate Pentahydrate | Inorganic copper salts | Contact action Multi-site |
| Copper sulphate | Inorganic copper salts | Contact action Multi-site |
| Tiabenzadol | Bencimidazoles | Inhibitors of mitosis and cell division |
| Tribasic Copper Calcium Chloride | Inorgánic | Multi site |
| Thiram | Ditiocarbamatos | It acts on the enzymatic systems, causing an accumulation of pyruvic acid that prevents the germination of spores. |

Source: Table developed by Vizcaino-Ríos *et al.* (2021).

the weather conditions in June were favorable for the onset of the infection and the development of *Colletotrichum* spp. in avocado.

The chemical control of avocado anthracnose involves the application of fungicides that have been authorized by APEAM, the Mexican association of avocado producers, packers, and exporters. The frequency of the application depends of the residual efficacy of fungicides. According to the program, a systemic fungicide can be applied at the moment when the onset of the disease is expected —to diminish the initial inoculum and to delay the start of the pandemic— and a contact fungicide can be applied as a response to anthracnose alerts and when the protective effect of fungicide has ended. Systemic fungicides can be applied at the start of the rainy season, when the program indicates that the environmental factors have been met. Contact products can be applied again after the rainy season is over, on the dates determined by the program and the residual efficacy of fungicides. Determining application dates helps to develop an improvement program for the efficient control of avocado anthracnose. The program can be applied in other avocado-producing zones. The only requirements are the temperature and humidity data for the orchard under study provided by a weather station and an evaluation of the development threshold of the pathogen. The program will help avocado producers to optimize application time, based on temperature and humidity conditions, instead of applying fungicides every 15 days.

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