REVIEW ARTICLE • OPEN ACCESS

Study of mathematical modeling for plant disease transmission: a systematic literature review during 2012-2022

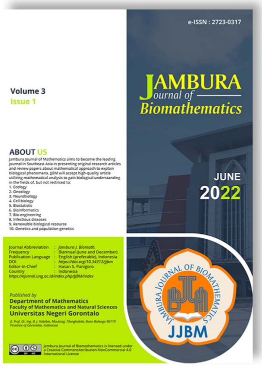
Sanubari Tansah Tresna, Nursanti Anggriani, and Asep Kuswandi Supriatna

Volume 4, Issue 1, Pages 1–14, June 2023

Received 17 January 2023, Revised 23 January 2023, Accepted 24 January 2023, Published Online 6 April 2023

To Cite this Article : S. T. Tresna, N. Anggriani, A. K. and Supriatna,"Study of mathematical modeling for plant disease transmission: a systematic literature review during 2012-2022", *Jambura J. Biomath*, vol. 4, no. 1, pp. 1–14, 2023, *https://doi.org/10.34312/jjbm.v4i1.18443*

JOURNAL INFO • JAMBURA JOURNAL OF BIOMATHEMATICS



Homepage	:	http://ejurnal.ung.ac.id/index.php/JJBM/index
Journal Abbreviation	:	Jambura J. Biomath.
Frequency	:	Biannual (June and December)
Publication Language	:	English (preferable), Indonesia
DOI	:	https://doi.org/10.34312/jjbm
Online ISSN	:	2723-0317
Editor-in-Chief	:	Hasan S. Panigoro
Publisher	:	Department of Mathematics, Universitas Negeri Gorontalo
Country	:	Indonesia
OAI Address	:	http://ejurnal.ung.ac.id/index.php/jjbm/oai
Google Scholar ID	:	XzYgeKQAAAAJ
Email	:	editorial.jjbm@ung.ac.id

Jambura Journal of Biomathematics, Volume 4, Issue 1, Pages 1–14, June 2023 https://doi.org/10.34312/jjbm.v4i1.18443

Review Article

Check for updates

Study of mathematical modeling for plant disease transmission: a systematic literature review during 2012-2022

Sanubari Tansah Tresna[1], **Nursanti Anggriani**[2,*], **and Asep Kuswandi Supriatna**[2]

[1]*Magister Program of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Indonesia*
[2]*Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Indonesia*

ARTICLE HISTORY
Received 17 January 2023
Revised 23 January 2023
Accepted 24 January 2023
Published 6 April 2023

KEYWORDS
bibliometric analysis
mathematical model
plant disease
prisma method

ABSTRACT. *Many models representing disease transmission have been constructed and analyzed mathematically. However, literature studies on the mathematical models for plant disease transmission are more sparse than for disease transmission in humans. This study aims to obtain information about the research conducted and find room for developing the model, including mathematical analysis, intervention used, and biological factors considered. We employ a Systematic Literature Review (SLR) to explore all of the studies on plant disease transmission modeling collected from four digital databases. First, the JabRef reference manager helps conduct the inclusion and exclusion processing. Then, we obtain 60 selected articles that passed the criterion. Next, the VOSviewer application is resulting a bibliometric analysis of the database containing chosen articles. Finally, we classify the model constructed based on the system used and elaborate on the intervention used. The results show that the existing researcher clusters are not linked to each other, and the models only consider usual interventions such as roguing and insecticide spraying. Hence, there is much room to build collaboration between the researcher and develop models for plant disease transmission by considering the other various intervention and biological factors in the model to improve further.*

1. Introduction

Plants are the survival foundation for all creatures, including humans and animals. One major problem in the field of crops around the world is plant disease, which causes health, social, and economic impacts [1]. Many plant diseases possibly affect crop fields, such as Huanglongbing or Citrus greening disease [2–4], Rice tungro virus [5, 6], Maize streak virus [7, 8], and Cocoa black pod disease [9]. Plant disease transmission is well known as considered host-vector disease transmission. It is caused by the fact that the disease is usually transmitted by an insect population, which is known as a vector in the disease transmission field. The study of plant disease transmission through a mathematical model is exciting and needed to achieve better crop yields by considering preventive and control strategies in the model.

The study of plant diseases is interesting because there are often difficulties in supplying agricultural products, such as corn, rice, and soybeans. The disease causes the plant to experience growth disorders so that crop yields are not achieved or even crop failure when the transmission is controlled. Therefore, this study also interests epidemiologists in establishing acceptable and effective mechanisms to prevent the disease and apply control strategies [1, 10]. This is because epidemiological information is important in developing effective integrated disease management (IDM). It involves selecting and applying preventive and control strategies that minimize losses and maximize profits. IDM comprises chemical, biological, and cultural tactics to prevent and suppress the impact of the disease on plants and the environment [11]. The frequent interventions to prevent and control the disease with IDM are rouging, replanting, and injecting nutrients. At the same time, there are still more methods, such as controlling the pH of water, soil humidity, and air temperature, to prevent the disease infection. Furthermore, there is a convenient method for controlling the disease known as integrated pest management (IPM). In the IPM method, the interventions aim to prevent and control the disease by suppressing the vector population and considering the stability of the ecosystem in nature. This method is generally conducted by spraying insecticide or bio-insecticide suitable for controlling the disease and managing the impact of the intervention on the environment. Moreover, the IPM's goal can be achieved by spreading a predator population against the vector population to minimize the use of chemical material. The authors in [12] explained that IPM aimed to optimize the collective effect caused by disease control by interpreting the interactions and strategy formulation.

A mathematical model is helpful for studying disease transmission and population dynamics to understand the complex system, including human, animal, and plant, also improve the strategies of health control [13]. This approach tests and compares different interventions to prevent and control the disease interpreted by parameter values. A mathematical model for studying plant disease transmission is usually developed as a host-vector model. It was built to explain, describe, analyze, and predict the severity of disease spread [11]. Moreover, a mathematical model investigates various interventions to determine whether the dis-

*Corresponding Author.

Email : *nursanti.anggriani@unpad.ac.id* (N. Anggriani)
Homepage : http://ejurnal.ung.ac.id/index.php/JJBM/index / E-ISSN : 2723-0317

ease spread is controlled through numerical simulations. Formulating a host-vector model for a plant disease requires acceptable assumptions regarding the mechanism of disease spread and the other factors considered in the research [14]. The history of a mathematical model for plant disease transmission was studied in [15–17].

Many studies on the host-vector model for plant disease problems were conducted using various plants as objects. Different plants are used as objects in plant disease transmission modeling, including paddy [5, 18], banana [19, 20], maize [7, 8], cassava [21, 22], and trees in forest ecosystems [23]. The models for plant disease transmission are usually developed as a compartmental model in an autonomous system by considering interventions such as roguing [24, 25], replanting [26, 27], nutrient injection [3], and using insecticide [28, 29] also bio-insecticide [6]. Moreover, authors in [30, 31] built a compartmental model in a non-autonomous system to study plant disease by considering factors in disease transmission phenomenon that change over time to obtain more realistic models. The mathematical model for plant disease transmission seemed to develop over time. However, a literature study is a need conducted to confirm its development. In addition, our study aims to explore the possibility of model development by considering any other intervention or biological factor, also the development of mathematical analysis conducted in research. Hence, this research finding is valuable and helpful as a reference for deciding the development direction of this study field.

This review article analyzed mathematical models for plant disease transmission from 60 selected papers. A dataset was created containing the content and information of articles collected from four digital library databases. The dataset was processed using the PRISMA method to select and classify the proper article with this study term. The study recapped and obtained various insights about the disease spread in a crop field and factors that are considered related to the developed model. The development of a mathematical model for plant disease transmission could be analyzed by many kinds of plants objected to in studies and various interventions conducted over time. The bibliometric analysis using VOSviewer was undertaken to analyze the connection between co-authorship-author and co-occurrence-word in the built dataset. Moreover, a specific relationship between some selected words and other words is figured out that generally represents the research scope in a study. A conclusion was presented to explain the complete result of the systematic literature review and the possibility of developing a plant disease transmission model for further research.

2. Materials and Methods

In this section, we provide a simple explanation of the relationship between plant diseases and mathematical modeling. Then, the materials and methods were elaborated, including the data search strategy, the PRISMA method, and bibliometric analysis.

2.1. The Relationship between Plant Disease and Mathematical Modeling

Plant disease is the interaction results between the host, insect, and environment that interrupts their vital function [32]. A simultant combination of these three factors caused the occurrences of any disease in any agricultural area. An example is the lack of favorable weather for mildew development, such as air temperature and leaf wetness. For illustration, if there are infectious hosts in a growing area, but the weather is not supporting the infection process and the relationship of parasitism, then the plant-pathogen relationship leads to incompatible interaction disease development [33].

Plant diseases are grouped due to the nature of their causal hosts and their respective parasitism relationship to cause related symptoms from the interaction of host-pathogen. Hence, a plant's disease occurrence is always caused by microorganisms such as bacteria, fungi, nematodes, and viruses [33]. A disease of infectious nature is the result of interaction between the host and the insect. It spreads when the plants are eaten by infected insects that eat an infected host before [34]. Generally, its transmission phenomenon can be seen as a disease that spreads in the human population transmitted by insect populations as a disease-carrying vector, such as dengue, schistosomiasis, rabies, etc. Therefore, the plant disease transmission phenomenon is well known as host-vector transmission.

Mathematical modeling is the field of mathematics that studies any possible phenomenon in nature by interpreting it into mathematical equations. In plant disease transmission cases, its phenomenon can be studied by introducing ordinary differential equations. It is one of the differential equation types other than partial, fractional, and stochastic differential equations. In general, the differential equation system is classified due to the use of the parameter type. There are two types of parameters, namely time-dependent and non-time-dependent parameters. These types caused the differential equations for representing a disease transmission to be classified as autonomous and non-autonomous systems.

In an autonomous system, a model is constructed with non-time-dependent parameters. Whereas environmental influences in plant disease transmission cases mostly fluctuate over time. Therefore, it needs a lot of assumptions to develop the model, resulting in a model lacking reality. In order to improve the quality by considering the fluctuating environmental factor, a model must be a non-autonomous system. The parameter used in non-autonomous is interpreted as a time-dependent function. The function is constructed to suit the natural condition. Therefore, the developed model is able to represent disease transmission as a result of plant-insect interaction in a better form and more realistic. For example, an autonomous system that is introduced in [35] is rewritten as follows:

$$\begin{aligned}\frac{dS}{dt} &= -\beta SI\\ \frac{dI}{dt} &= \beta SI - \gamma I\\ \frac{dR}{dt} &= \gamma I\end{aligned} \tag{1}$$

The above equation shows a simple disease transmission model in an autonomous system with $S(t)$ and $I(t)$ defined each as susceptible and infectious sub-populations at time t. Given that γ is the recovery rate. In the model, the disease transmission rate is denoted by β and is assumed to be a non-time-dependent

Table 1. The number of published articles from four digital library databases with four keyword sets

Dataset	Keywords	Dimension	Google Scholar	Science Direct	Scopus
Dataset 1	A	1177883	18200	222577	205957
Dataset 2	A AND B	88874	16900	8802	6679
Dataset 3	A AND B AND C	8888	5020	1103	102
Dataset 4	A AND B AND C AND D	192	56	10	2

parameter. The model in eq. (1) is able to study plant disease transmission in case it spreads directly. For example, the article in [18] studies direct disease transmission in the plant population. In order to represent the vector-borne disease, the researcher has to consider susceptible and infectious sub-populations for each plant and vector population. It may suit if the transmission has not happened seasonally, but it is incompatible with some seasonal diseases. For example, dengue and malaria are the cases that will increase significantly in the rainy season related to the mosquito life cycle as a vector in the disease transmission process [36–38]. Therefore, the transmission rate β can be set as a time-dependent parameter $\beta(t)$. Then, eq. (1) changes to eq. (2), as follows:

$$\begin{aligned}\frac{dS}{dt} &= -\beta(t)SI\\ \frac{dI}{dt} &= \beta(t)SI-\gamma I\\ \frac{dR}{dt} &= \gamma I\end{aligned} \tag{2}$$

The system (2) is well-known as a mathematical model in a non-autonomous system. The use of time-dependent parameters in a model results in a better approach to representing the disease spread phenomenon. The authors in [39] explain that the non-autonomous system is so relevant in real life and gives a more realistic model in order to represent disease transmission. The term that changes a non-time-dependent parameter to a time-dependent one also prevails for representing a biological factor in the plant disease spreading process.

2.2. Data Search Strategy

This study began by determining sets of keywords used to search for published articles in four selected digital library databases, such as Dimensions, Google Scholar, Science Direct, and Scopus. For instance, the first set of keywords used to search publications related to mathematical modeling was ("Mathematical Model") OR ("Mathematical Modeling"). The collected articles are limited based on the year of publication from 2012 to 2022. Moreover, the study only collected articles written in English and published or final peer-reviewed articles accepted for publication.

Data collection from Dimension, Science Direct, and Dimensions databases were conducted with some keywords used for the "title, abstract, and keywords." The keywords are only used in the title in the Google Scholar database since this database does not provide processing search using abstracts specifically. The first search was to find all articles about a mathematical model. The search obtained 1177883 articles from Dimension, 18200 articles from Google Scholar, 222577 articles from Science Direct, and 205957 articles from Scopus. Other keyword sets were applied, including ("Epidemic") OR ("Epidemiology"), ("Dynamical System"), and ("Plant Disease") in each step of the article search. All of the keywords are selected due to the need for this literature review and for further research in this field. We chose general words to reach more articles in order to obtain the well-represented articles in this study field. Then, we combined the keywords to obtain the proper articles with our search. This was conducted since, without combination, the keywords search results show articles are too much and not focused on this research aim. The search results from four filtering processes were served on the four databases in Table 1. The alphabets symbolize the set of keywords, and the "Keywords" column in Table 1 represents the following keywords:

- Keywords A : ("Mathematical Model") OR ("Mathematical Modeling")
- Keywords B : ("Epidemic") OR ("Epidemiology")
- Keywords C : ("Dynamical System")
- Keywords D : ("Plant Disease")

2.3. The PRISMA Method

A systematic literature review is a method that makes it possible to gather pertinent data about a specific subject that meets the pre-established eligibility requirements. There are several methods to conduct this study, such as SALSA, PRISMA, PSALSAR, and PICOC [40]. In this study, the method used is the Preferred Reporting Item for Systematic Review and Meta-Analyses, known as the PRISMA method. This method is a procedure for resulting in articles suitable to study by conducting some selection processes. This process is elaborated in the following step [41]:

- Step 1 : Identification is collecting related articles from databases and removing duplicated articles.
- Step 2 : Screening is a process to select articles that pass the criterion terms. This step allows the researcher to determine suitable criteria for obtaining relevant articles for the conducted studies. Generally, it is separated into some steps as researchers needs.
- Step 3 : Collect suitable studies into one new database to conduct further analysis more easily.

Authors in [42] explain that the PRISMA method is an analysis conducted to identify elements of articles included in a database. It is a brief review of the questions used to obtain insights into the study topics through identification, selection, and critical assessments of the relevant literature, such as the above-elaborated steps.

The selection processes were classified into semi-automatic and manual stages. The semi-automatic selection was conducted to check the existence of duplicate articles in a database against other databases. The Scopus database is a reference for checking the possibility of duplication on the whole articles in Dimension, Google Scholar, and Science Direct databases. First, the search results data from each database is stored in a BIB file. Then, the first selection process is conducted using open-source software called JabRef by uploading the saved BIB files, which aim to produce unique articles in a combined database. In addition, the JabRef app helps the researcher classify the articles concerning the selection criteria by manually marking the passed article in each selection process. For instance, the researcher may add a "star" column beside the "article title" column as a mark and add the number of stars in the column for related articles in each selection. The software details and how to run it can be accessed at this link `JabRef`. Therefore, this application is very helpful in carrying out the inclusion-exclusion process by counting stars representing the article's level of suitability. This study found 36 articles in Dimension and 20 in Google Scholar that have been identified as duplications of articles in the Scopus and Science Direct combination database due to no duplicate articles in Science Direct against Scopus. Finally, 204 unique articles were collected from four databases without redundant articles and stored as a RIS file format to conduct bibliometric analysis using VOSviewer. The manual selection is a process to determine the relevant articles for this study. This stage was divided into two steps, including (1) determining the relevance of the "title, abstract, and keywords" of an article and (2) conducting a brief review of the entire article's contents.

All the relevant articles for tremendous understanding are divided into two classes based on the system used, autonomous and non-autonomous systems. The whole article was explored to gain information about the authors and the year of publication. This study briefly explained the constructed model in a selected article due to the most cited and one of the latest articles in the dataset. Additionally, the interventions used in the study were identified to track the model development by considering the factors that affect the disease transmission phenomenon. The articles' findings were summarized to share insights and the possibility of model development for further studies.

2.4. *Bibliometric Analysis*

The bibliometric analysis was conducted for 60 selected articles for massive understanding. The sixty articles selected for the analysis are accessible articles that study plant disease using ordinary differential equations. All of it explains how the disease transmits at the population level. This analysis method is frequently implemented in literature studies to gain bibliographic mapping of the publications. It could cover a list of keywords, authors, national or subject bibliographies, or other specialized subject patterns [43]. The bibliometric analysis used the VOSviewer computer software application. The VOSviewer is open-source software that obtains a mapping due to bibliometric analysis [44]. VOSviewer visualizes the links between different nodes in a network image. The analysis using this app is conducted by saving the new database containing related articles and following the procedure in [44]. The software details and how to run it can be accessed at this link `VOSViewer`.

3. Results and Discussion

This section presents the bibliometric analysis results by network visualizations and findings of the systematic literature review using the PRISMA method.

3.1. *Results of PRISMA Method*

The selection of articles based on the relevance "title, abstract, and keywords" in Dataset 4 resulted in 136 relevant articles for full paper selection. A skimming method was used to study all 136 articles to summarize the main content containing the type of model developed and its explanation. This study selected the relevant article related to a specific criterion. Articles were identified as compatible studies for tremendous understanding if the authors develop a compartmental model in an ordinary differential equations system using autonomous and non-autonomous systems. A compartmental model is constructed by dividing a population into some sub-populations denoted by symbols that usually mean the description of the condition, respectively. The study obtained 60 articles suitable to the terms for tremendous understanding. The selection process was determined using the flow chart of the PRISMA method shown in Figure 1.

Figure 1 shows that some articles were eliminated due to the title, abstract, and keywords used in an article being irrelevant to the terms. In case the article's title, abstract, and keywords are relevant to the terms, the study explained why they should be excluded from the selection process. First, all the articles that passed the relevance title, abstract, and keywords were skimmed through to determine the suitability of the article contents with the terms to be discussed to achieve the goal of this study. The results showed that several articles did not contain the content under study. For instance, articles in [45] study the plant disease phenomenon but do not discuss how the disease spreads. Authors of articles in [46–48] researched plant disease based on image processing to detect disease but did not study its transmission. The references in [49–51] explain plant disease transmission, especially for Mosaic disease, but developed the model in a fractional differential equations system. The other articles in [52, 53] studied plant disease transmission using a compartmental model but must be excluded due to the developed model constructed in a partial differential equations system. Although several articles contain a differential equations system to represent the disease phenomenon, it remains eliminated because the authors do not study the transmission and explain more effects on the individual plant, such as in [45]. The final selection result obtained 60 compatible articles for massive understanding.

The bibliometric analysis results were presented using the network, overlay, and density visualization. The analysis was conducted in two scopes, including co-authorship-author and co-occurrence-word.

3.1. *Visualization of the Co-Authorship-Author Connection*

The analysis of the co-authorship author was conducted by determining the relationship among the authors. The VOSviewer conducts an overview of the connection of the co-authorship author from the menu. The study analyzed the relationship between authors with one published article that would appear in the analysis result. It means that all passed papers in the

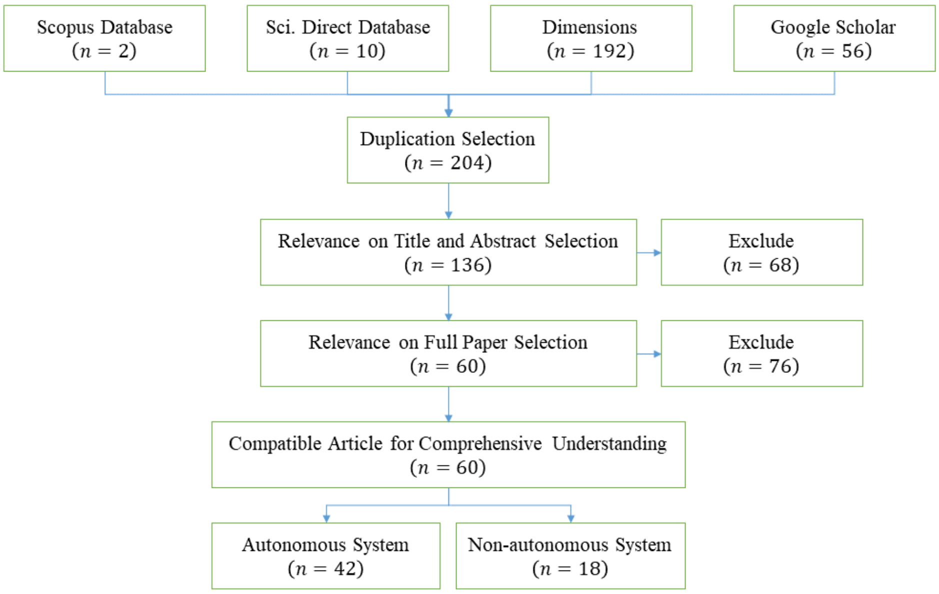


Figure 1. The flow chart of the PRISMA method.

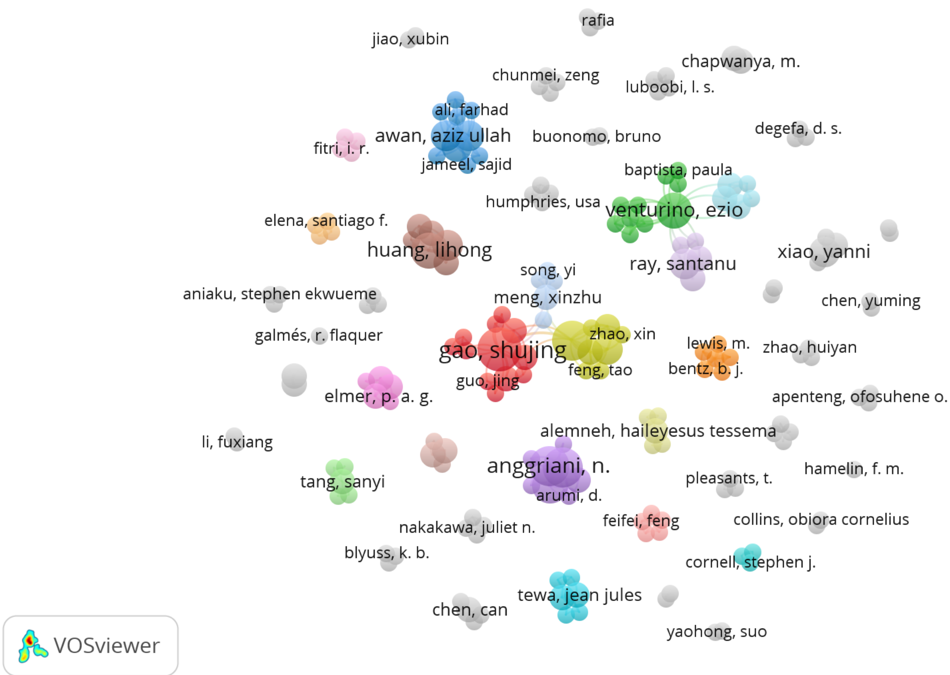


Figure 2. Network visualization of the co-authorship-author connection.

dataset are analyzed. Therefore, VOSviewer performed 192 authors names divided into 47 clusters, as shown in Figure 2. The clusters represent each author's team that frequently conducted studies together. The result showed that the most productive authors studying plant disease transmission using a mathematical model were Gao, S with six publications, Anggriani, N and Istifadah N with five each, and Huang, L with four published articles.

The bibliometric analysis is also resulting mapping for overlay and density visualizations. The overlay visualization shows the year with the most publication of each author. In contrast, the density visualization represents how an author influences the scope of the study for the other authors. The overlay and density visualization are shown in Figures 3 and 4, respectively.

3.1. Visualization of the Co-Occurrences-Word Connection

The analysis for the Co-Occurrence-Word connection is aimed at investigating the frequent words used in all passed articles. The VOSviewer also has a supportive feature to conduct

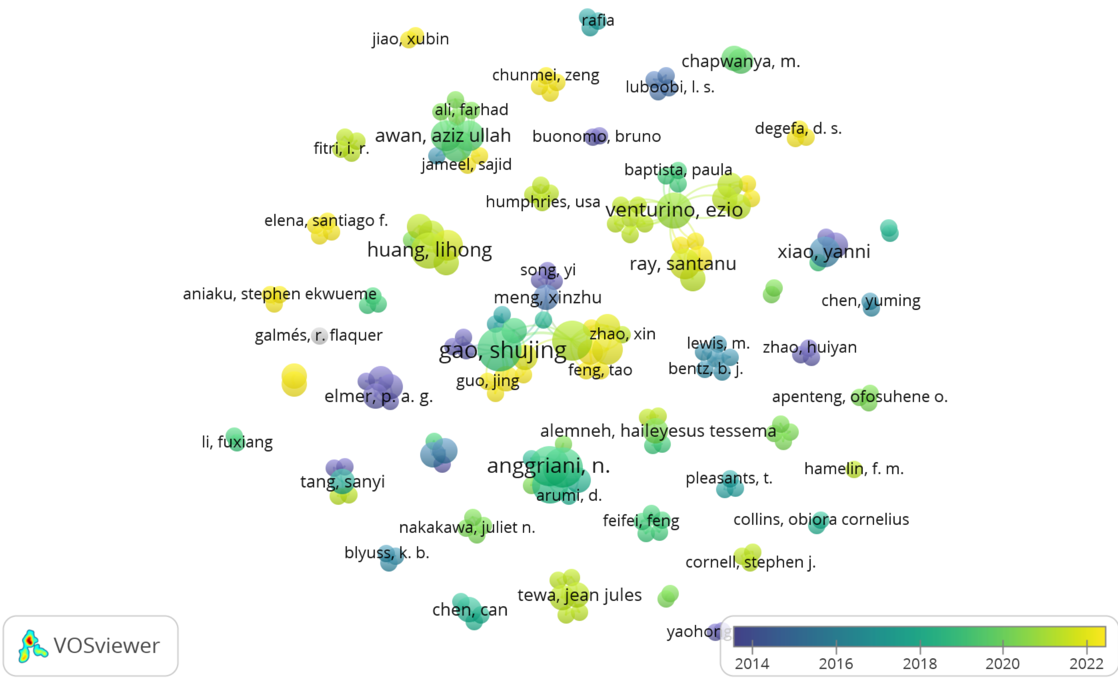


Figure 3. Overlay visualization of the co-authorship-author connection.

Figure 4. Density visualization of the co-authorship-author connection.

an exploration of the co-occurrence-word relationship. First, the minimum occurrences number of a word in an article is decided based on recommendations from the VOSviewer system, which is ten times. Therefore, VOSviewer performed 28 words, but only 16 words passed the threshold recommended by the system at 60% most relevant to the terms. The words obtained were divided into two clusters interpreting the word classification due to their frequency of use relation. The finding shows that the most often words used in Dataset 4 are "model," "analysis," and "plant," which are used 74, 25, and 32 times, respectively. In contrast, the sparsest words that are used are "infected plant," "analytical result," and "huanglongbing," that used ten times each. The most relevant words to the Dataset 4 were "infected plant," "model," and "number," which scored 2.52, 1.91, and 1.36, respectively,

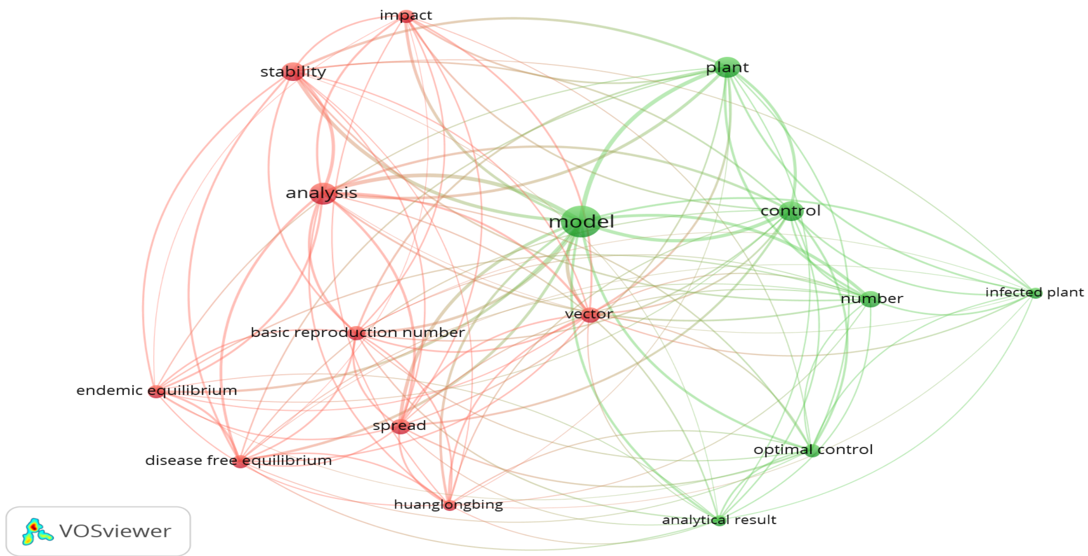


Figure 5. Network visualization of the co-occurrence-word connection.

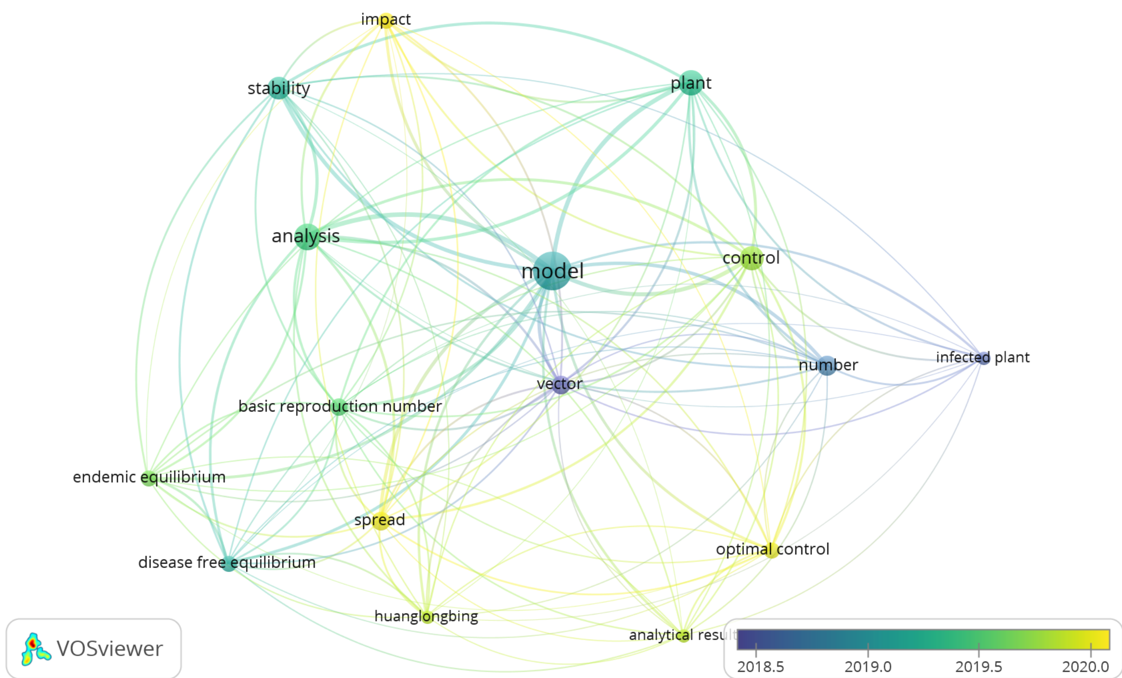


Figure 6. Overlay visualization of the co-occurrence-word connection.

whereas the "basic reproduction ratio" only scored 0.34. The visualization of the co-occurrence-word connection is shown in Figure 5. Moreover, the study investigated the one-color line that connected two words representing the inner cluster relation. The line with gradation color represents the relation between two words in different clusters. In case the words "infected plant" and "endemic equilibrium" looked in another cluster and there is no line that connected the words means that they have no direct connection.

The bibliometric analysis is also resulting the overlay and density visualization for co-occurrence-word connection. The overlay visualization shows the frequently used words in articles based on the publication year. The density visualization represents the words representing the dominant content or scope in the whole passed article. The overlay and density visualization is shown in Figures 6 and 7.

3.2. Results of Systematic Literature Review

One of the earlier articles that contained a transmission model for plant disease phenomenon divided plant and vector populations into three sub-populations each [54]. The model was constructed using a differential equations system in an au-

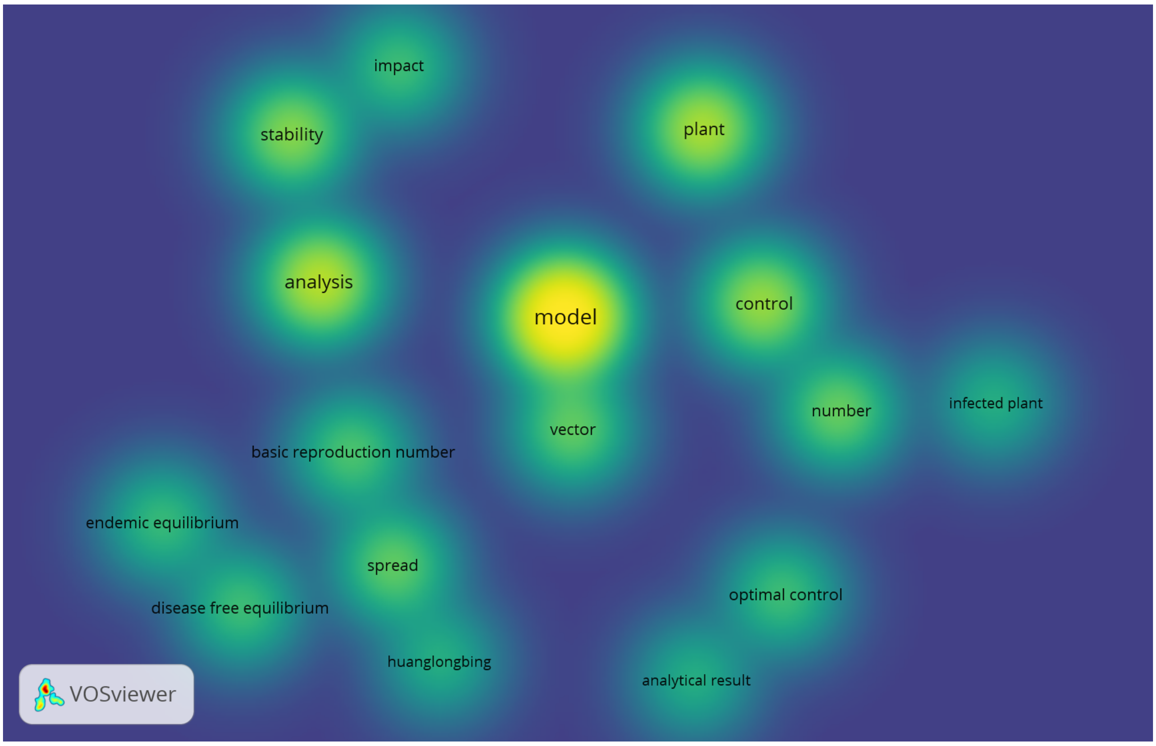


Figure 7. Density visualization of the co-occurrence-word connection.

tonomous system, where the value of the parameter used does not change over time. The authors considered a latent period of infected plant and vector and conducted parameter estimating. Additionally, they claim that the developed model could answer why the disease does not become extinct and is used to explore other natural aspects.

The study explored all articles that contained a compartmental model using an ordinary differential equations system. It elaborated on all the articles identified, such as the authors with published time represented by citation number, cited by, the plants, the data type used, whether the model was analyzed mathematically, and the intervention used. The article's exploration is divided based on the system used, including the autonomous system (see Table 2) and the non-autonomous system (see Table 3). These aimed to perform the identity of the whole article and obtain essential information for further exploration.

The essential information of 60 articles has been elaborated on and is available to use for further work. Published articles in [1] and [10] are the most cited in the autonomous system at 43 times each, whereas in the non-autonomous system, the article in [18] is the most cited at 14 times. Somehow, there are still articles that remain not been referenced, including the articles in [57, 78, 82]. Some possibilities caused an article has not been used as a reference, including the latest publication time, the model in the article frequently explored, and the findings not being followed up by the other studies.

Studies on transmission modeling have examined many diseases in various plants. Plants that produce food materials, such as rice [18, 54] and maize [8, 28], are the types of plants that are frequently explored in this research. Articles in [4, 65, 73, 81] studied the plant disease problem in orange plants, the most investigated problem in selected articles. Other than agricultural, several diseases on trees, such as pine [29, 60, 62], olive [61, 85], and palm [77], are studied. The various plants discussed in the articles indicate a mathematical model development and exploration activity.

A transmission model for plant disease phenomenon contained in almost every publication was analyzed using mathematical theories. Only 3 out of 60 articles did not analyze the model contained mathematically. Analyzing the model aimed to check the solution positivity, solution boundedness, and equilibrium points with their local and global stability [26, 28, 55, 56, 83]. The analysis procedure conducted on the model in the non-autonomous system is different and more complicated than in the autonomous system. For example, the articles in [26, 30] needed a Brouwer fixed point theorem and LaSalle's invariance theorem to determine the equilibrium points and their stability. The primary reproduction ratio is a parameter used to determine the endemicity level of disease and was always constructed in every analyzed article. Bifurcation is another analysis conducted to investigate the condition where the basic reproduction ratio is equal to one ($\Re_0 = 1$), representing that the disease is endemic and non-endemic. Bifurcation analysis has several approaches, including forwarding [28, 57], backward [73, 88], and Hopf bifurcation [70, 85] were figured out in their reports.

The optimal control theory was used to obtain the optimal intervention considering some constraints [89]. This theory allows the researcher to get optimal results through efforts by considering intervention costs and bounded resources. In the plant disease problem, the costs for conducting the interventions, such as insecticide and injecting more nutrients into the plants, were the most explored in the articles. The optimal control exploration for the plant disease transmission model is ably conducted in the autonomous system [61, 62] and non-autonomous system

Table 2. List of Eligible Studies Involving Autonomous System

Ref.	Cited by	Plant	Data Type	Analysis	Interventions
[55]	0	Orange	Estimated	Yes	Quarantine
[56]	1	Potato	Secondary	Yes	Roguing
[22]	1	Cassava	Estimated	Yes	Resistant Plant Used, Reducing Pathogens
[57]	0	Not-Specified	Simulation	Yes	Insecticide
[27]	7	Maize	Secondary	Yes	Insecticide, Quarantine
[58]	11	Orange	Secondary	Yes	Insecticide, Roguing, Adding Nutrient to Plant
[59]	5	Cassava	Simulation	Yes	Cleaning Seed
[60]	2	Pine	Simulation	Yes	Insecticide, Roguing
[61]	12	Olive	Secondary	Yes	-
[9]	6	Cocoa	Estimated	Yes	Treatment
[62]	5	Pine	Simulation	Yes	Roguing
[63]	8	Not Specified	Simulation	Yes	Roguing
[64]	8	Not Specified	Simulation	Yes	-
[19]	1	Banana	Secondary	Yes	Roguing
[3]	10	Orange	Estimated	Yes	Insecticide, Roguing, Adding Nutrient to Plant
[6]	7	Paddy	Simulation	Yes	-
[7]	4	Maize	Secondary	Yes	-
[28]	17	Maize	Secondary	Yes	-
[65]	5	Orange	-	Yes	-
[66]	26	Cassava	Simulation	Yes	Insecticide, Roguing
[67]	3	Paddy	Simulation	Yes	Roguing, Curative
[4]	12	Orange	Secondary	Yes	Roguing
[5]	10	Paddy	Simulation	Yes	-
[68]	9	Apple	Simulation	Yes	Roguing
[69]	3	Not Specified	Simulation	Yes	Roguing
[70]	6	Not Specified	Secondary	Yes	-
[8]	3	Maize	Estimated	Yes	Resistant Plant Used
[71]	14	Paddy	Simulation	Yes	Roguing, Curative
[23]	2	Pine	Simulation	No	-
[72]	6	Not Specified	Simulation	Yes	-
[73]	12	Orange	Secondary	Yes	Roguing
[74]	4	Not Specified	-	Yes	Roguing
[29]	16	Pine	Simulation	Yes	Insecticide
[25]	13	Not Specified	-	Yes	-
[20]	13	Banana	Estimated	Yes	Insecticide
[10]	43	Not Specified	Simulation	Yes	-
[75]	13	Not Specified	Estimated	No	Elicitor
[11]	9	Not Specified	Secondary	Yes	Roguing
[1]	43	Not Specified	Simulation	Yes	Roguing
[24]	20	Not Specified	Simulation	Yes	Roguing
[76]	11	Not Specified	Simulation	Yes	-
[77]	0	Palm	Secondary	Yes	Treatments

Table 3. List of Eligible Studies Involving Non-Autonomous System

Ref.	Cited by	Plant	Data Type	Analysis	Interventions
[78]	0	Not Specified	Secondary	Yes	Roguing
[21]	5	Cassava	Estimated	Yes	Roguing
[79]	2	Potato	Simulation	Yes	-
[80]	1	Banana	Secondary	Yes	-
[18]	14	Paddy	Estimated	No	-
[81]	4	Orange	Estimated	Yes	Vaccination
[82]	0	Banana	Secondary	Yes	Roguing
[26]	5	Not Specified	Simulation	Yes	Roguing
[83]	2	Not Specified	Simulation	Yes	Roguing
[84]	11	Not Specified	Secondary	Yes	-
[31]	11	Not Specified	Simulation	Yes	Insecticide
[30]	3	Not Specified	Simulation	Yes	-
[85]	1	Olive	Simulation	Yes	-
[13]	5	Not Specified	Simulation	Yes	-
[86]	13	Not Specified	Estimated	Yes	-
[87]	13	Not Specified	Simulation	Yes	Roguing
[88]	9	Not Specified	Simulation	Yes	-
[2]	11	Orange	Estimated	Yes	-

[31, 81].

The models for plant disease transmission were constructed by conducting various interventions to control the spread and suppress the risk of infection. Roguing is the most used intervention to suppress the possibility of disease transmission [14, 59, 74, 75]. Roguing is conducted by removing the infected plants to stop the transmission through vectors. The other interventions usually used to prevent the disease's spread are adding nutrients to plants and applying insecticides. Conducting nutrient injection is one of the actions to avoid the infection because the resistance plant increases [3, 58, 75]. In comparison, applying insecticides is usually used to suppress the number of infected or susceptible vectors [13, 22, 76]. This intervention is better used if the infection happens, considering its side effects on the environment. Numerical simulations were conducted to confirm the analysis results. In addition, the simulation with changing the value of the selected parameter is explored to figure out the long-term behavior of the disease phenomenon. However, the parameter value in the simulation mainly uses simulation data and secondary data due to limited data availability. Only eight articles in autonomous systems confirm this limitation, and six in the non-autonomous system estimate the parameter value based on data obtained to conduct the numerical simulation.

Two articles were picked based on special criteria in the following subsections. The constructed models and research scope were elaborated to explain why the article was selected for more exploration and the possibility for further development.

3.2. The Article with the Model Constructed in the Autonomous System

The study explored the whole content in [10] because the article contained a transmission model in the autonomous system and was the most used as a reference in articles including [66, 90–92]. For instance, the authors in the article [90] developed the model in [10] into a delay differential equation system for covering the latent period process such as in transition from susceptible to infected plant or vectors since the identification in this infection process is hard to interpret by an equation. It represents that the article content is constructive for other researchers. In addition, the constructed model seemed to leave much room for development to obtain a better model. The further consideration in this decision is publication time because publication in [1] is also frequently used as a reference. The constructed model is identified and rewritten in the following equations (see eq. (3)) with the parameter used description in Table 4.

$$
\begin{aligned}
\frac{dS(t)}{dt} &= f(S(t), I(t)) - \mu S(t) \\
&\quad - \left(\frac{\beta_p Y(t)}{1+\alpha_p Y(t)} + \frac{\beta_s I(t)}{1+\alpha_s I(t)}\right) S(t) \\
\frac{dI(t)}{dt} &= \left(\frac{\beta_p Y(t)}{1+\alpha_p Y(t)} + \frac{\beta_s I(t)}{1+\alpha_s I(t)}\right) S(t) \\
&\quad - (r+\mu+\gamma) I(t) \\
\frac{dR(t)}{dt} &= \gamma I(t) - \mu R(t) \\
\frac{dX(t)}{dt} &= \Lambda - \frac{\beta_i I(t) X(t)}{1+\alpha_i I(t)} - mX(t) \\
\frac{dY(t)}{dt} &= \frac{\beta_i I(t) X(t)}{1+\alpha_i I(t)} - mY(t)
\end{aligned}
\tag{3}
$$

Note that $f(S(t), I(t)) = \mu K(t) + rI(t)$.

The model in eq. (3) was developed by considering two creature populations: plant and vector. First, the plant population (K) is divided into susceptible (S), infected (I), and recovered (R) sub-populations. The vector population was divided into susceptible (X) and infective (Y) sub-populations. By investigating the parameter representing the factor considered in this study, no one intervention was identified to control the disease. There are many possibilities to make the model better and more realistic. However, the author analyzed the model comprehensively, including the existence of solutions and equilibrium points with their local and global stability also tried to introduce the possibility of a periodic solution existence. The findings in this study show that disease transmission is influenced mainly by $\beta_i, \beta_p, \beta_s$ and m. Therefore, it is important to pay more attention to decreasing the infection rates and increasing the removal vectors rate to control the disease. The article was mainly used as a reference due to its contents. This confirms that the model remains much room for development by considering intervention to prevent and control the disease spread. Therefore, the analysis results could be a basis for further studies.

3.2. The Article with the Model Constructed in the Non-Autonomous System

The study explored the whole content in [78] because the article contained a transmission model in the non-autonomous system and is more suitable for the disease spread phenomenon. Although the article in [18] is the most often used as a reference, the contents do not precisely describe the phenomenon since the authors don't describe disease transmission as a vector-host model and represent that the disease spread directly between plants. The constructed model in the selected article was identified and rewritten in the following equations with the parameter used description in Table 5.

$$
\begin{aligned}
\frac{dX(t)}{dt} &= r - k_1 X(t)V(t) - gX(t) \\
\frac{dY(t)}{dt} &= k_1 X(t)V(t) - gY(t) - \alpha(t)Y(t) \\
\frac{dU(t)}{dt} &= b(U(t)+V(t))\left(1 - \frac{U(t)+V(t)}{m(X(t)+Y(t))}\right) \\
&\quad - k_2 U(t)Y(t) - cU(t) \\
\frac{dV(t)}{dt} &= k_2 U(t)Y(t) - cV(t)
\end{aligned}
\tag{4}
$$

The model in eq. (4) was developed by considering two creature populations: plant and vector. First, the plant population was divided into susceptible and infected sub-populations. The vector population was also divided into susceptible and infective sub-populations. The authors consider intervention to reduce infected plants in the model, namely roguing, represented by a time-dependent parameter. It caused the model to be categorized as a non-autonomous model. There are still many possibilities to make the model better by considering more biological factors represented by time-dependent parameters to obtain a better approach to the actual situation. For example, further research must consider a time-dependent parameter for infection rate since the virus transmission is affected by environmental factors that change over time. However, the author analyzed the model comprehensively, including the existence of periodic solutions and equilibrium points with their local and global stability through the LaSalle's invariance theorem. The main findings of this study show that the infected populations, both plant and vec-

Table 4. Parameter description in [10]

Parameters	Descriptions
β_i	The infection rate in vector population
β_p	The infection rate in plant population through vector bites
β_s	The infection rate in plant population directly
α_i	The level of infection saturates
α_p	The level of infection saturates
α_s	The level of infection saturates
γ	Recovery rate
μ	Plant natural death rate
Λ	Vector natural recruitment rate
m	Vector natural death rate
r	Mortality of disease infected

Table 5. Parameter description in [78]

Parameters	Descriptions	Units
r	Rate of replanting	day^-1
α	Rate of roguing	day^-1
g	Rate of harvesting	day^-1
m	Carrying capacity of the plant population	day^-1
b	Vector natural birth rate	day^-1
c	Vector natural death rate	day^-1
k_1	Rate of infection	$vector^-1day^-1$
k_2	Rate of acquistion	$vector^-1day^-1$

tor, are eradicated if the cultural control strategy, such as roguing, is conducted frequently. The model could still develop by considering various interventions and applying optimal control theory to obtain the optimal solution due to the resource limitations and expand the research scopes.

3.3. Discussion

The development of mathematical modeling for plant disease transmission is mostly studied in autonomous systems. Based on Tables 1 and 2, 60 articles study disease transmission using an ordinary differential equation system. Various plants are set to be an object in the research due to the different ways of transmission, such as direct and indirect transmission. The data type used to validate the model and obtain the population dynamics in the system is mostly secondary data referenced to some articles. It is confirmed by the finding that only 33.3% of selected articles conducting data processing based on the primary data to obtain the parameter's value. It is necessary to use the primary data related to the object of the research intention to obtain more appropriate behavior. Whereas the analysis conducted on the research in this field is well-presented.

For instance, the model analysis in [10] and [78] is well-conducted to obtain the biological meaning and explain the phenomenon using mathematical insights. However, the researchers still use primary data to validate the model and obtain a long-term behavior prediction of the disease spread phenomenon. In addition, both models do not construct with considering any intervention to prevent or control the disease spread. Therefore, the models remain much room for development in further studies with considering intervention and using primary data for simulation.

To study the impact of an intervention to control the disease, researchers in this field mostly consider roguing, especially in constructing models in the non-autonomous system. At the same time, represented by 22 articles, which is about 36.6%, that do not consider any intervention to prevent and control the disease, the model is only used to express the disease transmission phenomenon. In addition, most intervention considered in the model, such as roguing, applying insecticide, and adding nutrients, is common and usual. This means that many scopes remain and are possibly considered in further research to prevent and control the disease, including studying the photosynthesis effect on the plant cycle, soil moisture level, water pH level, and spreading the predator to control the vector population, etc.

4. Conclusion

This study performed a systematic literature review to explore the development of a mathematical model for plant disease transmission. It collected 204 unique articles from four databases: Dimensions, Google Scholar, Science Direct, and Scopus. Publication time is one filter that is applied in search processes, which is from 2012 to 2022. After conducting selection processes by including and excluding criteria, 60 articles were found suitable for this study. The whole passed article contained a compartmental-based model to represent the disease spread phenomenon.

The collected articles mainly explain the model's analysis using a mathematical theory, especially dynamical theory, such as examining the equilibrium point, analyzing its local or global stability, and bifurcation. However, few articles use primary data to perform numerical simulations and apply optimal control theory. The interventions, plant kinds, and data types used are shown in Tables 1 and 2. Studies on a mathematical model for plant disease transmission is highly possible to develop based on the elaboration and explanation in this article. Further study could be conducted with a new collaboration between inter-cluster researchers. We believe that the development of mathematical modeling for plant disease transmission will be more significant and comprehensive by considering other interventions and biological factors. In addition, it allows the research to produce more mathematical insights for further development through analysis, such as sensitivity analysis and applying more optimal control theory to consider the limitation of resources. Furthermore, the study of obtaining and processing primary data is needed to get a more realistic simulation that allows the results to be used as a prediction and not only to study its long-term behavior.

Author Contributions. **Sanubari Tansah Tresna:** Conceptualization, methodology, formal analysis, software, investigation, resources, writing—original draft preparation, and visualization. **Nursanti Anggriani:** Conceptualization, validation, writing—review and editing, supervision, project administration, and funding acquisition. **Asep Kuswandi Supriatna:** Conceptualization, validation, writing—review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

Acknowledgement. Authors are thankful the Indonesian Ministry of Education, Culture, Research, and Technology for a Master Thesis Research Project in 2022.

Funding. This research was funded by the Indonesian Ministry of Education, Culture, Research, and Technology for a Master Thesis Research Project in 2022, grant number 1318/UN6.3.1/PT.00/2022. The APC was funded by Universitas Padjadjaran.

Conflict of interest. The authors declare no conflict of interest.

Data availability. Not applicable.

References

[1] T. Zhao, Y. Xiao, and R. J. Smith, "Non-smooth plant disease models with economic thresholds," *Mathematical Biosciences*, vol. 241, no. 1, pp. 34–48, 2013. DOI: 10.1016/j.mbs.2012.09.005

[2] J. Wang, S. Gao, Y. Luo, and D. Xie, "Threshold Dynamics of a Huanglongbing Model with Logistic Growth in Periodic Environments," *Abstract and Applied Analysis*, vol. 2014, pp. 1–10, 2014. DOI: 10.1155/2014/841367

[3] F. Zhang, Z. Qiu, B. Zhong, T. Feng, and A. Huang, "Modeling Citrus Huanglongbing transmission within an orchard and its optimal control," *Mathematical Biosciences and Engineering*, vol. 17, no. 3, pp. 2048–2069, 2020. DOI: 10.3934/mbe.2020109

[4] S. Gao, D. Yu, X. Meng, and F. Zhang, "Global dynamics of a stage-structured huanglongbing model with time delay," *Chaos, Solitons & Fractals*, vol. 117, pp. 60–67, 2018. DOI: 10.1016/j.chaos.2018.10.008

[5] N. Anggriani, M. Ndii, D. Arumi, N. Istifadah, and A. Supriatna, "Mathematical model for plant disease dynamics with curative and preventive treatments," in *AIP Conference Proceedings*, vol. 2043, no. 1. AIP Publishing LLC, 2018, p. 020016. DOI: 10.1063/1.5080035

[6] W. Suryaningrat, N. Anggriani, A. Supriatna, and N. Istifadah, "The optimal control of rice tungro disease with insecticide and biological agent," in *AIP Conference Proceedings*, vol. 2264, no. 1. AIP Publishing LLC, 2020, p. 040002. DOI: 10.1063/5.0023569

[7] K. M. Putri *et al.*, "A maize foliar disease mathematical model with standard incidence rate," in *IOP Conference Series: Materials Science and Engineering*, vol. 546, no. 5. IOP Publishing, 2019, p. 052085. DOI: 10.1088/1757-899X/546/5/052085

[8] O. C. Collins and K. J. Duffy, "Optimal control of foliar disease dynamics for multiple maize varieties," *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, vol. 68, no. 5, pp. 412–423, 2018. DOI: 10.1080/09064710.2017.1416156

[9] B. Oduro, O. O. Apenteng, and H. Nkansah, "Assessing the effect of fungicide treatment on cocoa black pod disease in ghana: Insight from mathematical modeling," *Statistics, Optimization & Information Computing*, vol. 8, no. 2, pp. 374–385, 2020. DOI: 10.19139/soic-2310-5070-686

[10] R. Shi, H. Zhao, and S. Tang, "Global dynamic analysis of a vector-borne plant disease model," *Advances in Difference Equations*, vol. 2014, no. 1, pp. 1–16, 2014. DOI: 10.1186/1687-1847-2014-59

[11] Z. Zhonghua and S. Yaohong, "Stability and sensitivity analysis of a plant disease model with continuous cultural control strategy," *Journal of Applied Mathematics*, vol. 2014, 2014. DOI: 10.1155/2014/207959

[12] J. A. Stenberg, "A conceptual framework for integrated pest management," *Trends in plant science*, vol. 22, no. 9, pp. 759–769, 2017. DOI: 10.1016/j.tplants.2017.06.010

[13] M. Chapwanya and Y. Dumont, "On crop vector-borne diseases. impact of virus lifespan and contact rate on the traveling-wave speed of infective fronts," *Ecological Complexity*, vol. 34, pp. 119–133, 2018. DOI: 10.1016/j.ecocom.2017.08.002

[14] F. Brauer, "Mathematical epidemiology: past, present, and future. infectious disease modelling. 2, 113–127 (2017). DOI: 10.1016/j.idm.2017.02.001

[15] M. Jeger, F. Van Den Bosch, L. Madden, and J. Holt, "A model for analysing plant-virus transmission characteristics and epidemic development," *Mathematical Medicine and Biology: A Journal of the IMA*, vol. 15, no. 1, pp. 1–18, 1998. DOI: 10.1093/imammb/15.1.1

[16] M. Jeger *et al.*, "Theory and plant epidemiology." *Plant Pathology*, vol. 49, no. 6, pp. 651–658, 2000. DOI: 10.1046/j.1365-3059.2000.00522.x

[17] F. Van den Bosch, N. McRoberts, F. Van den Berg, and L. Madden, "The basic reproduction number of plant pathogens: matrix approaches to complex dynamics," *Phytopathology*, vol. 98, no. 2, pp. 239–249, 2008. DOI: 10.1094/PHYTO-98-2-0239

[18] S. Kirtphaiboon, U. Humphries, A. Khan, and A. Yusuf, "Model of rice blast disease under tropical climate conditions," *Chaos, Solitons & Fractals*, vol. 143, p. 110530, 2021. DOI: 10.1016/j.chaos.2020.110530

[19] M. G. Amorocho and A. M. Loaiza, "A theoretical model for the prevention of banana moko (musa aab simmonds)," *F1000Research*, vol. 9, 2020. DOI: 10.12688/f1000research.27373.2

[20] B. Nannyonga, L. S. Luboobi, P. Tushemerirwe, and M. Jabłońska-Sabuka, "Using contaminated tools fuels outbreaks of Banana Xanthomonas wilt : An optimal control study within plantations using Runge–Kutta fourth-order algorithms," *International Journal of Biomathematics*, vol. 08, no. 05, p. 1550065, 2015. DOI: 10.1142/S1793524515500655

[21] M. Chapwanya and Y. Dumont, "Application of mathematical epidemiology to crop vector-borne diseases: the cassava mosaic virus disease case," in *Infectious Diseases and Our Planet*. Springer, 2021, pp. 57–95. DOI: 10.1007/978-3-030-50826-5_4

[22] I. S. Onah, S. E. Aniaku, and O. M. Ezugorie, "Analysis and optimal control measures of diseases in cassava population," *Optimal Control Applications and Methods*, 2022. DOI: 10.1002/oca.2901

[23] G. Wake, N. Williams, and T. Pleasants, "A dynamical systems model for polycyclic foliar forest pathogens," *ANZIAM Journal*, vol. 59, pp. C1–C14, 2017. DOI: 10.21914/anziamj.v59i0.12625

[24] T. Zhang, X. Meng, Y. Song, and Z. Li, "Dynamical analysis of delayed plant disease models with continuous or impulsive cultural control strategies," in *Abstract and applied analysis*, vol. 2012. Hindawi, 2012. DOI: 10.1155/2012/428453

[25] G. Neofytou, Y. Kyrychko, and K. Blyuss, "Time-delayed model of immune response in plants," *Journal of theoretical biology*, vol. 389, pp. 28–39, 2016. DOI: 10.1016/j.jtbi.2015.10.020

[26] W. Li, L. Huang, Z. Guo, and J. Ji, "Global dynamic behavior of a plant disease model with ratio dependent impulsive control strategy," *Mathematics and Computers in Simulation*, vol. 177, pp. 120–139, 2020. DOI: 10.1016/j.matcom.2020.03.009

[27] H. T. Alemneh, A. S. Kassa, and A. A. Godana, "An optimal control model with cost effectiveness analysis of maize streak virus disease in maize plant," *Infectious Disease Modelling*, vol. 6, pp. 169–182, 2021. DOI: 10.1016/j.idm.2020.12.001

[28] H. T. Alemneh, O. D. Makinde, and D. Mwangi Theuri, "Ecoepidemiological model and analysis of msv disease transmission dynamics in maize plant," *International Journal of Mathematics and Mathematical Sciences*, vol. 2019, 2019. DOI: 10.1155/2019/7965232

[29] A. U. Awan, M. Ozair, Q. Din, and T. Hussain, "Stability analysis of pine wilt disease model by periodic use of insecticides," *Journal of Biological Dynamics*, vol. 10, no. 1, pp. 506–524, 2016. DOI: 10.1080/17513758.2016.1225828

[30] R. Anguelov, R. Bekker, and Y. Dumont, "Bi-stable dynamics of a host-pathogen model," *BIOMATH*, vol. 8, no. 1, 2019. DOI: 10.11145/j.biomath.2019.01.029

[31] B. M. Chen-Charpentier and M. Jackson, "Direct and indirect optimal control applied to plant virus propagation with seasonality and delays," *Journal of Computational and Applied Mathematics*, vol. 380, p. 112983, 2020. DOI: 10.1016/j.cam.2020.112983

[32] L. J. Francl, "The disease triangle: a plant pathological paradigm revisited,"

The Plant Health Instructor, vol. 10, 2001. DOI: 10.1094/PHI-T-2001-0517-01

[33] V. Bischoff, K. Farias, J. P. Menzen, and G. Pessin, "Technological support for detection and prediction of plant diseases: A systematic mapping study," *Computers and Electronics in Agriculture*, vol. 181, p. 105922, 2021. DOI: 10.1016/j.compag.2020.105922

[34] F. U. Rehman, M. Kalsoom, M. Adnan, N. Naz, T. Ahmad Nasir, H. Ali, T. Shafique, G. Murtaza, S. Anwar, and M. A. Arshad, "Soybean mosaic disease (smd): a review," *Egyptian Journal of Basic and Applied Sciences*, vol. 8, no. 1, pp. 12–16, 2021. DOI: 10.1080/2314808X.2021.1881245

[35] W. O. Kermack and A. G. McKendrick, "A contribution to the mathematical theory of epidemics," *Proceedings of the royal society of london. Series A, Containing papers of a mathematical and physical character*, vol. 115, no. 772, pp. 700–721, 1927. DOI: 10.1098/rspa.1927.0118

[36] F. Coutinhoa, M. Burattinia, L. Lopeza, and E. Massada, "Threshold conditions for a non-autonomous epidemic system describing the population dynamics of dengue," *Bulletin of mathematical biology*, vol. 68, no. 8, pp. 2263–2282, 2006. DOI: 10.1007/s11538-006-9108-6

[37] K. F. Nipa, S. R.-J. Jang, and L. J. Allen, "The effect of demographic and environmental variability on disease outbreak for a dengue model with a seasonally varying vector population," *Mathematical Biosciences*, vol. 331, p. 108516, 2021. DOI: 10.1016/j.mbs.2020.108516

[38] M. Li and H. Zhao, "Dynamics of a dengue fever model with vertical transmission and time periodic in spatially heterogeneous environments," *Mathematical Methods in the Applied Sciences*, vol. 44, no. 14, pp. 11 350–11 375, 2021. DOI: 10.1002/mma.7496

[39] J. Yang and X. Wang, "Existence of a nonautonomous sir epidemic model with age structure," *Advances in Difference Equations*, vol. 2010, no. 1, p. 212858, 2010.

[40] W. Mengist, T. Soromessa, and G. Legese, "Method for conducting systematic literature review and meta-analysis for environmental science research," *MethodsX*, vol. 7, p. 100777, 2020. DOI: 10.1016/j.mex.2019.100777

[41] E. Stovold, D. Beecher, R. Foxlee, and A. Noel-Storr, "Study flow diagrams in cochrane systematic review updates: an adapted prisma flow diagram," *Systematic reviews*, vol. 3, no. 1, pp. 1–5, 2014. DOI: 10.1186/2046-4053-3-54

[42] D. Moher, A. Liberati, J. Tetzlaff, D. G. Altman, and P. Group*, "Preferred reporting items for systematic reviews and meta-analyses: the prisma statement," *Annals of internal medicine*, vol. 151, no. 4, pp. 264–269, 2009. DOI: 10.7326/0003-4819-151-4-200908180-00135

[43] O. Ellegaard and J. A. Wallin, "The bibliometric analysis of scholarly production: How great is the impact?" *Scientometrics*, vol. 105, no. 3, pp. 1809–1831, 2015. DOI: 10.1007/s11192-015-1645-z

[44] V. E. NJ and W. L., "Manual for vosviewer version 1.5.2," *Leiden: The Netherlands*, 2012

[45] M. J. Jeger and M. Pautasso, "Plant disease and global change: the importance of long-term data sets," *New Phytologist*, vol. 177, no. 1, pp. 8–11, 2008. DOI: 10.1111/j.1469-8137.2007.02312.x

[46] S. D. Khirade and A. Patil, "Plant disease detection using image processing," in *2015 International conference on computing communication control and automation*. IEEE, 2015, pp. 768–771. DOI: 10.1109/ICCUBEA.2015.153

[47] D. Palma, F. Blanchini, and P. L. Montessoro, "A system-theoretic approach for image-based infectious plant disease severity estimation," *PloS one*, vol. 17, no. 7, p. e0272002, 2022. DOI: 10.1371/journal.pone.0272002

[48] S. P. Mohanty, D. P. Hughes, and M. Salathé, "Using deep learning for image-based plant disease detection," *Frontiers in plant science*, vol. 7, p. 1419, 2016. DOI: 10.1371/journal.pone.0272002

[49] S. Liu, M. Huang, and J. Wang, "Bifurcation control of a delayed fractional mosaic disease model for jatropha curcas with farming awareness," *Complexity*, vol. 2020, 2020. DOI: 10.1155/2020/2380451

[50] M. Vellappandi, P. Kumar, V. Govindaraj, and W. Albalawi, "An optimal control problem for mosaic disease via caputo fractional derivative," *Alexandria Engineering Journal*, vol. 61, no. 10, pp. 8027–8037, 2022. DOI: 10.1016/j.aej.2022.01.055

[51] P. Kumar, V. S. Erturk, and H. Almusawa, "Mathematical structure of mosaic disease using microbial biostimulants via caputo and atangana–baleanu derivatives," *Results in Physics*, vol. 24, p. 104186, 2021. DOI: 10.1016/j.rinp.2021.104186

[52] M. Jablonska-Sabuka, R. Kalaria, and T. Kauranne, "A dynamical model for epidemic outbursts by begomovirus population clusters," *Ecological Modelling*, vol. 297, pp. 60–68, 2015. DOI: 10.1016/j.ecolmodel.2014.11.008

[53] W. Suryaningrat, N. Anggriani, and A. K. Supriatna, "Mathematical analysis and numerical simulation of spatial-temporal model for rice tungro disease spread," *Commun. Math. Biol. Neurosci.*, vol. 2022, pp. Article–ID, 2022. DOI: 10.28919/cmbn/7160

[54] F. Nakasuji, S. Miyai, H. Kawamoto, and K. Kiritani, "Mathematical epidemiology of rice dwarf virus transmitted by green rice leafhoppers: a differential equation model," *Journal of applied ecology*, pp. 839–847, 1985. DOI: 10.2307/2403233

[55] Y. Liu, C. Zeng, J. Guo, and Z. Liao, "Global dynamics of a new huanglongbing transmission model with quarantine measures," *Applied Mathematics*, vol. 13, no. 1, pp. 1–18, 2022. DOI: 10.4236/am.2022.131001

[56] D. Degefa, O. Makinde, and D. Temesgen, "Modeling potato virus y disease dynamics in a mixed-cropping system," *International Journal of Modelling and Simulation*, vol. 42, no. 3, pp. 370–387, 2022. DOI: 10.1080/02286203.2021.1919818

[57] S. Adhurya, F. A. Basir, and S. Ray, "Stage-structure model for the dynamics of whitefly transmitted plant viral disease: an optimal control approach," *Computational and Applied Mathematics*, vol. 41, no. 4, pp. 1–22, 2022. DOI: 10.1007/s40314-022-01864-9

[58] F. Zhang, Z. Qiu, A. Huang, and X. Zhao, "Optimal control and cost-effectiveness analysis of a huanglongbing model with comprehensive interventions," *Applied Mathematical Modelling*, vol. 90, pp. 719–741, 2021. DOI: 10.1016/j.apm.2020.09.033

[59] F. Hamelin, B. Bowen, P. Bernhard, and V. Bokil, "Optimal control of plant disease epidemics with clean seed usage," *Bulletin of mathematical biology*, vol. 83, no. 5, pp. 1–24, 2021. DOI: 10.1007/s11538-021-00872-w

[60] M. Ozair, T. Hussain, K. A. Abro, S. Jameel, and A. U. Awan, "Role of pine wilt disease based on optimal control strategy at multiple scales: A case study of korea," *Journal of Biosciences*, vol. 46, no. 4, pp. 1–16, 2021. DOI: 10.1007/s12038-021-00208-9

[61] M. Brunetti, V. Capasso, M. Montagna, and E. Venturino, "A mathematical model for xylella fastidiosa epidemics in the mediterranean regions. promoting good agronomic practices for their effective control." *Ecological Modelling*, vol. 432, p. 109204, 2020. DOI: 10.1016/j.ecolmodel.2020.109204

[62] M. Ozair, T. Hussain, A. U. Awan, A. Aslam, R. A. Khan, F. Ali, and F. Tasneem, "Bio-inspired analytical heuristics to study pine wilt disease model," *Scientific Reports*, vol. 10, no. 1, pp. 1–15, 2020. DOI: 10.1038/s41598-020-60088-1

[63] W. Li, L. Huang, and J. Wang, "Dynamic analysis of discontinuous plant disease models with a non-smooth separation line," *Nonlinear Dynamics*, vol. 99, no. 2, pp. 1675–1697, 2020. DOI: 10.1007/s11071-019-05384-w

[64] S. Ray and F. Al Basir, "Impact of incubation delay in plant–vector interaction," *Mathematics and Computers in Simulation*, vol. 170, pp. 16–31, 2020. DOI: 10.1016/j.matcom.2019.09.001

[65] J. Wang, F. Feng, Z. Guo, H. Lv, and J. Wang, "Threshold dynamics of a vector-borne epidemic model for huanglongbing with impulsive control," *Applied Mathematics*, vol. 10, no. 4, pp. 196–211, 2019. DOI: 10.4236/am.2019.104015

[66] V. A. Bokil, L. Allen, M. J. Jeger, and S. Lenhart, "Optimal control of a vectored plant disease model for a crop with continuous replanting," *Journal of Biological Dynamics*, vol. 13, no. sup1, pp. 325–353, 2019. DOI: 10.1080/17513758.2019.1622808

[67] N. Anggriani, M. Ndii, N. Istifadah, and A. Supriatna, "Disease dynamics with curative and preventive treatments in a two-stage plant disease model," in *AIP Conference Proceedings*, vol. 2043, no. 1. AIP Publishing LLC, 2018, p. 020010. DOI: 10.1063/1.5080029

[68] C. Chen, C. Li, and Y. Kang, "Modelling the effects of cutting off infected branches and replanting on fire-blight transmission using filippov systems," *Journal of theoretical biology*, vol. 439, pp. 127–140, 2018. DOI: 10.1016/j.jtbi.2017.11.017

[69] C. Chen and X. Chen, "Rich sliding motion and dynamics in a filippov plant-disease system," *International Journal of Bifurcation and Chaos*, vol. 28, no. 01, p. 1850012, 2018. DOI: 10.1142/S0218127418500128

[70] J. Liu and T. Zhang, "Stability and hopf bifurcation analysis of a plant virus propagation model with two delays," *Discrete Dynamics in Nature and Society*, vol. 2018, 2018. DOI: 10.1155/2018/7126135

[71] N. Anggriani, M. Mardiyah, N. Istifadah, and A. Supriatna, "Optimal control issues in plant disease with host demographic factor and botanical fungicides," in *IOP conference series: Materials Science and Engineering*, vol. 332, no. 1. IOP Publishing, 2018, p. 012036. DOI: 10.1088/1757-899X/332/1/012036

[72] M. Rafiq, A. Raza *et al.*, "Numerical modeling of transmission dynamics of vector-borne plant pathogen," in *2017 14th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*. IEEE, 2017, pp. 214–219. DOI: 10.1109/IBCAST.2017.7868057

[73] L. Luo, S. Gao, Y. Ge, and Y. Luo, "Transmission dynamics of a huanglongbing model with cross protection," *Advances in Difference Equations*, vol. 2017,

no. 1, pp. 1–21, 2017. DOI: 10.1186/s13662-017-1392-y

[74] Y. Chen and J. Yang, "Global stability of an sei model for plant diseases," *Mathematica Slovaca*, vol. 66, no. 1, pp. 305–311, 2016. DOI: 10.1515/ms-2015-0137

[75] N. S. A. Latif, G. C. Wake, T. Reglinski, and P. A. Elmer, "Modelling induced resistance to plant diseases," *Journal of theoretical biology*, vol. 347, pp. 144–150, 2014. DOI: 10.1016/j.jtbi.2013.12.023

[76] R. Anguelov, J. Lubuma, and Y. Dumont, "Mathematical analysis of vector-borne diseases on plants," in *2012 IEEE 4th international symposium on plant growth modeling, simulation, visualization and applications*. IEEE, 2012, pp. 22–29. DOI: 10.1109/PMA.2012.6524808

[77] H. H. Mustafa, N. A. Samat, Z. Mohamed, and F. A. Kassim, "Stage progression model for soil-borne plant disease in oil palm plantation," *Journal of Xi'an Shiyou University*, vol. 15, no. 1, pp. 53–64, 2021

[78] G. Qiu, S. Tang, and M. He, "Analysis of a high-dimensional mathematical model for plant virus transmission with continuous and impulsive roguing control," *Discrete Dynamics in Nature and Society*, vol. 2021, 2021. DOI: 10.1155/2021/6177132

[79] R. Atlihan, N. F. Britton, S. Demir, A. Papasidero, M. R. Risvanli, M. Seminara, and E. Venturino, "Can symbiotic fungi protect plants from insect pests? a simple mathematical model," *Computational and Mathematical Methods*, vol. 3, no. 6, p. e1121, 2021. DOI: 10.1002/cmm4.1121

[80] F. P. Agouanet, I. Tankam-Chedjou, R. M. Etoua, and J. J. Tewa, "Mathematical modelling of banana black sigatoka disease with delay and seasonality," *Applied Mathematical Modelling*, vol. 99, pp. 380–399, 2021. DOI: 10.1016/j.apm.2021.06.030

[81] Y. Luo, F. Zhang, Y. Liu, and S. Gao, "Analysis and optimal control of a huanglongbing mathematical model with resistant vector," *Infectious Disease Modelling*, vol. 6, pp. 782–804, 2021. DOI: 10.1016/j.idm.2021.05.004

[82] J. N. Nakakawa, J. Y. Mugisha, M. W. Shaw, and E. Karamura, "Banana xanthomonas wilt dynamics with mixed cultivars in a periodic environment," *International Journal of Biomathematics*, vol. 13, no. 01, p. 2050005, 2020. DOI: 10.1142/S1793524520500059

[83] W. Li, L. Huang, and J. Wang, "Global dynamics of filippov-type plant disease models with an interaction ratio threshold," *Mathematical Methods in the Applied Sciences*, vol. 43, no. 11, pp. 6995–7008, 2020. DOI: 10.1002/mma.6450

[84] F. Al Basir, S. Adhurya, M. Banerjee, E. Venturino, and S. Ray, "Modelling the effect of incubation and latent periods on the dynamics of vector-borne plant viral diseases," *Bulletin of Mathematical Biology*, vol. 82, no. 7, pp. 1–22, 2020. DOI: 10.1007/s11538-020-00767-2

[85] P. Baptista, I. M. Bulai, T. Gomes, and E. Venturino, "Modeling the interactions among phythopatogens and phyllosphere microorganisms for the biological disease control of olea europaea l." *Mathematical biosciences*, vol. 308, pp. 42–58, 2019. DOI: 10.1016/j.mbs.2018.12.002

[86] V. Krivan, M. Lewis, B. J. Bentz, S. Bewick, S. M. Lenhart, and A. Liebhold, "A dynamical model for bark beetle outbreaks," *Journal of Theoretical Biology*, vol. 407, pp. 25–37, 2016. DOI: 10.1016/j.jtbi.2016.07.009

[87] T. Zhao and Y. Xiao, "Plant disease models with nonlinear impulsive cultural control strategies for vegetatively propagated plants," *Mathematics and Computers in Simulation*, vol. 107, pp. 61–91, 2015. DOI: 10.1016/j.matcom.2014.03.009

[88] B. Buonomo and M. Cerasuolo, "Stability and bifurcation in plant–pathogens interactions," *Applied Mathematics and Computation*, vol. 232, pp. 858–871, 2014. DOI: 10.1016/j.amc.2014.01.127

[89] S. Lenhart and J. T. Workman, *Optimal control applied to biological models*. Chapman and Hall/CRC, 2007. DOI: 10.1201/9781420011418

[90] B. M. Chen-Charpentier and I. Diakite, "A mathematical model of bone remodeling with delays," *Journal of computational and applied mathematics*, vol. 291, pp. 76–84, 2016. DOI: 10.1016/j.cam.2014.11.025

[91] M. J. Jeger, "The epidemiology of plant virus disease: Towards a new synthesis," *Plants*, vol. 9, no. 12, p. 1768, 2020. DOI: 10.3390/plants9121768

[92] M. Jackson and B. M. Chen-Charpentier, "Modeling plant virus propagation with delays," *Journal of Computational and Applied Mathematics*, vol. 309, pp. 611–621, 2017. DOI: 10.1016/j.cam.2016.04.024