mathematics

Review

Mathematical Model for Analyzing the Dynamics of Tungro Virus Disease in Rice: A Systematic Literature Review

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Abstract: One of the main obstacles in rice cultivation is the tungro virus disease caused by *Rice tungro spherical virus* (RTSV) and *Rice tungro bacilliform virus* (RTBV). These viruses are transmitted by green leafhopper (*Nephotettix virescens*) vector, semi-persistently after sucking infected plants. Subsequently, the vectors migrate and suck susceptible plants, but they can be controlled chemically and biologically. Mathematical modeling is one of the tools that can be used to analyze the spread of disease in plants. A literature review was conducted regarding the mathematical model of the spread of tungro virus disease in rice plants with the data sourced from scholarly references available in the dimension database, Google Scholar, and Scopus in 2012–2021. The steps followed include conducting a literature analysis and examining the mathematical model of the transmission of tungro virus disease in rice plants to identify gaps for future research. The results show that since 2016, few studies have analyzed mathematical models of the spread of tungro virus disease in rice plants. This is evident from the data search results, which show that only four articles were acquired through the option of duplication and visualization using *VOSviewer* software.

Keywords: mathematical model; dynamical analysis; optimal control; plant disease; tungro

MSC: 92D30

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1. Introduction

Rice (*Oryza sativa* L.) is one of the food crops that has a crucial position in the economy of Indonesia. It can provide jobs, increase income, and reduce poverty, in addition to playing a crucial role in enhancing food security. However, the challenges experienced by the agricultural sector are very complex, including fluctuating production with very low productivity.

The low productivity is caused by various factors, such as the problem of pests and plant diseases [1,2]. These problems can be caused by bacteria, viruses, fungi, protozoa, and insect pathogens, spread through wind, water, soil, and other disease-carrying vectors [3].

Farmers often encounter Tungro virus disease when cultivating rice. The disease is caused by *Rice tungro spherical virus* (RTSV) and *Rice tungro baciilliform virus* (RTBV). Both viruses can be spread through a green leafhopper (*Nephotettix virescens*) vector semi-persistently after sucking infected plants. They migrate and suck susceptible plants without going through a latency period in the vector body [4–7]. Symptoms can be seen from changes in leaf color, especially on young leaves, which appear yellow-orange starting from the tips, then they become slightly curled, the number of tillers is reduced, and plant growth is stunted. These symptoms usually appear 6–15 days after infection [8–11].

Mathematical modeling is one of the tools used to analyze the spread of disease in plants. Several previous findings have developed many models for the spread of plant diseases. This includes, previous findings have developed many models for the spread of plant diseases, including the among them modeling of vector-borne diseases with direct transmission [12] and one-time delay [13]. In addition, optimal control was sought from the application of roguing, replanting, curative, and preventive treatments [14], as well as the use of botanical fungicides to reduce the number of infected hosts [15,16].

Other mathematical models, such as the spread of fungal diseases, have been carried out by Castle and Giligan [17], who modeled the spread of fungal diseases causing fungicide-dependent spoilage, protection, and infection rates. Meanwhile, Kumar understood the role of fungicide application in fungal diseases with the help of fractional derivatives consisting of memory effect [18].

Anggriani also created a vector-borne model of rice tungro disease by applying insecticide to infected plants [19]. It was then redeveloped by analyzing the effect of using predators to reduce the number of infected plants [20]. Meanwhile, Blas et al. [21] and Blas and David [22] created a model of tungro disease in rice plants by considering the type and characteristics of the virus.

Other research on plant disease models has been conducted, namely a mathematical model of yellow virus diseases in chili that considers the growth phase and the application of entomopathogenic fungus, *Verticillium lecanii* (*V. lecanii*), to control vectors of the diseases [23] and then looked for control of the usage of *V. lecanii* as a factor in determining the dose to be applied [24].

From the previous description, mathematical modeling is essential in controlling the spread of various plant diseases, especially tungro virus in rice plants. However, there are variations between the different models that have been developed previously. This is due to the different assumptions regarding to show the uniqueness of the models. Therefore, reviewing the literature on the mathematical model of the spread of tungro disease proves to be an interesting topic to discuss. The literature review is expected to identify gaps for the development of models and research methods regarding the spread of tungro virus disease in rice plants.

2. Methods

2.1. Data Search Strategy

The literature review focuses on mathematical modeling of the spread of tungro virus disease in rice plants. The data are sourced from scholarly references in the dimension database, Google Scholar, and Scopus in 2012–2021. The keywords used in searching can be seen in Table 1.

Table 1. Search results through the database.

Keyword	Amount of Data From		
	Dimension	**Google Scholar**	**Scopus**
("Stability analysis" OR "Mathematical model" OR "Mathematical modelling" OR "Dynamical Analysis" OR "Dynamical System" OR "Optimal Control")	1,586,304	18,000	723,128
("Stability analysis" OR "Mathematical model" OR "Mathematical modelling" OR "Dynamical Analysis" OR "Dynamical System" OR "Optimal Control") AND ("Plant disease")	3885	3750	34,717
("Stability analysis" OR "Mathematical model" OR "Mathematical modelling" OR "Dynamical Analysis" OR "Dynamical System" OR "Optimal Control") AND ("Plant disease") AND ("Tungro")	38	43	105
("Stability analysis" OR "Mathematical model" OR "Mathematical modelling" OR "Dynamical Analysis" OR "Dynamical System") AND ("Optimal Control") AND ("Plant disease") AND ("Tungro")	14	16	5

2.2. Selection of Relevant Articles

From the results of Table 1, it can be seen that when using the keywords "("Stability analysis" OR "Mathematical model" OR "Mathematical modeling" OR "Dynamical Analysis" OR "Dynamical System") AND ("Optimal Control") AND ("Plant disease") AND ("Tungro")", data were obtained for 35 articles, five from the Scopus database, 16 from the Google Scholar database, and 14 from the Dimension database. Therefore, 20 articles were screened, after duplication. The next step is to filter articles relevant to the research topic. Thirteen papers are suitable based on the relevancy of their titles and abstracts. Meanwhile, seven were excluded as their titles and abstracts did not corresponding to the research topic. All relevant articles in the previous step were screened based on the availability of full papers, but after studying them in detail, only three matched the expected focus of the topic.

From the three articles studied, a backward and forwarding process was carried out by collecting relevant articles. This process was repeated and stopped when the article obtained was from the most recent year, and there are no more citing articles. From this process, four articles were obtained that were relevant to the research topic [19–22], and were used as study material, as seen in Table 2. The screening process was carried out using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow chart, as shown in Figure 1.

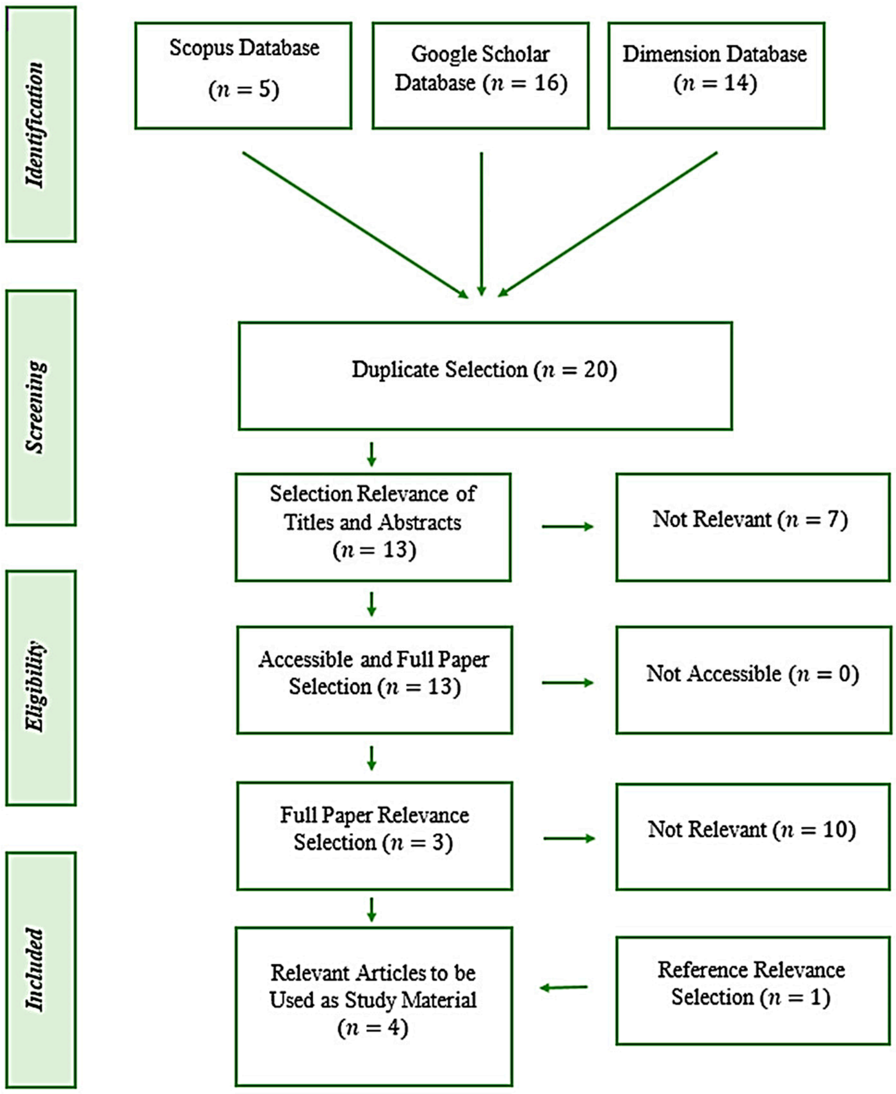

Figure 1. Prisma diagram based on the keywords used.

Table 2. Summary of relevant articles.

No	Author	Purpose and Objectives	Method/Model	Object/Description	Ref.
1.	Castle and Giligan	Make mathematical modeling to consider fungicide dynamics that affect plant pathogens' invasion and persistence.	(1) Model A (Susceptible-Infected) is a conventional model (permanently uses a protector). (2) Model B (Susceptible-Infected-Protected) is an explicit model (allows for spoilage, protection, and fungicide-dependent infection rates).	Fungal disease/full paper is not suitable.	[17]
2	Atallah et al.	Models the dynamic spatial diffusion of disease in vineyards, evaluates nonspatial and spatial control strategies and ranks them based on expected net present values.	Bioeconomic models, agent-based models, dynamic spatial processes, disease control.	Leaf roll disease/inappropriate title.	[25]
3.	Bousset et al.	Consider the interactions between plants, pathogens, the environment, and human actions in space and time to formalize cyclic epidemics.	-	Review article/title irrelevant.	[26]
4.	Blas et al.	Analyze the equilibrium solution, and solve numerically for susceptible rice varieties.	Make a mathematical model of the spread of tungro disease by considering the characteristics of RTSV and RTBV and analyze the model numerically.	Tungro disease in rice plants/paper added and used as a reference paper.	[21]
5.	Papaïx et al.	Study the impact of landscape organization (defined by the proportion of cultivated fields with resistant cultivars and their spatial aggregation) and life-history traits of major pathogens on three disease control steps.	Model: Susceptible-Exposed-Infectious-Removed (SEIR) Method: Statistical analysis.	Epidemiological control/inappropriate title.	[27]
6.	Anggriani et al.	Examine the effect of using insecticides on plants infected with tungro disease in rice plants.	Make the $S_H I_H S_V I_V$ model and use Pontryagin's maximum principle in finding optimal control.	Tungro disease in rice plants/reference paper.	[19]
7.	Blas and David	Analyze the efficiency of the roguing process on land infected with rice tungro disease and pay attention to the types and characteristics of the virus.	Created a rice plant model based on a system of ordinary differential equations to simulate the effect of roguing in controlling the spread of the Tungro virus.	Tungro disease in rice plants/reference paper.	[22]
8.	Jeger et al.	Improve understanding and control of disease through mathematical modeling and analysis.	Modeling Analysis.	Plants in general/full paper are not suitable.	[28]

Table 2. *Cont.*

No	Author	Purpose and Objectives	Method/Model	Object/Description	Ref.
9.	Rimbaud et al.	Develop stochastic models to assess epidemiological and evolutionary outcomes	Stochastic	The pathogen/title is not appropriate.	[29]
10.	Anggriani et al.	Seek optimal control of the use of botanical fungicides.	Create a *SIRXP* model taking into account: (1) Control of infected plants is carried out by preventive treatment to reduce infected plants. (2) Control of infected plants is carried out by preventive treatment to reduce infected plants.	Plant diseases in general/full paper are not suitable.	[15]
11.	Al-Basir et al.	Develop a dynamic model of mosaic disease by considering roguing and insecticides.	Model: $x - y - u - v$ Method: Stability analysis Bifurcation Analysis Using the Pontryagin Maximum Principle.	Mosaic virus on Jatropha plants/full paper is not suitable.	[30]
12.	Amelia et al.	Determining optimal control of the use of *Verticillium lecanii*	Using the Pontryagin Maximum Principle.	Yellow virus disease in red chili plants/whole paper is not suitable.	[24]
13.	Amelia et al.	Seek optimal control of the use of botanical fungicides	Changing the birth rate following a logistic function as the model developed by Anggriani et al. [15]	Plant diseases in general/full paper are not suitable.	[16]
14.	Suryaningrat et al.	Looking for optimal control of the use of insecticides and biological agents in controlling the spread of tungro virus disease	(1) Developed the previous model $(S_H I_H S_V I_V)$ by adding a predator as a green leafhopper controller $(S_H I_H S_V I_V P)$ (2) Consider predators and insecticides. (3) Determine optimal control using Pontryagin's Maximum Principle.	Tungro disease in rice plants/reference paper.	[19]
15.	Anggriani et al.	Determine the optimal control of the roguing and replanting plant disease model that considers curative treatment, preventive treatment, and the combination of curative and preventive treatment.	Using the Pontryagin Maximum Principle.	Plant diseases in general/full paper are not suitable.	[14]

Table 2. *Cont.*

No	Author	Purpose and Objectives	Method/Model	Object/Description	Ref.
16.	Jeger et al.	Review: Epidemiology of Plant Viral Diseases.	Review mathematical models.	Plant virus/inappropriate title.	[31]
17.	El-Sayed et al.	Creating a fractional model for plant disease in two-stage infection	Model: $S-P-E-I-R$ Method: Determine disease-free stability and endemic balance and perform numerical simulations using the fractional Euler method (FEM).	Plants in general/full paper are not suitable.	[32]
18.	Sabir et al.	Introducing a stochastic solver based on Levenberg-Marquardt backpropagation Neural Networks (LMBNNs) for nonlinear host-vector-predator models.	The model used: nonlinear host-vector-predator $S_h - I_h - S_v - I_v - P$ Method: Mean Square Error (MSE), Error Histograms (EHs), and regression/correlation.	Plants in general/irrelevant title.	[33]
19.	Amelia et al.	Analyzes a mathematical model of plant disease that considers the plant growth phase and the application of *Verticillium lecanii*	Performs dynamic analysis on the model that has been created $(S_v I_v S_g I_g S_{BT} I_{BT})$.	Yellow virus disease in red chili plants/whole paper is not suitable.	[23]
20.	Suryaningrat et al.	Completed the host-vector predator system.	Using the DTM and Runge–Kutta methods.	Host-vector- predators/full papers are not suitable.	[34]
21.	Rimbaud et al.	They analyzed 69 modeling studies considering the specific model structure, underlying assumptions, and evaluation criteria.	Review of 69 modeling studies	The review paper/title is not appropriate.	[35]

These keywords are used as the research is limited to developing a mathematical model of tungro virus disease in rice plants, which is dynamically analyzed and uses optimal control theory as a tool to determine the most optimal control that practitioners should carry out.

2.3. Data Analysis

Data analysis consisted of four stages, namely:

1. Reviewing the mathematical model of the spread of tungro virus disease in rice plants. This is necessary to determine the extent to which previous findings have developed the model. Each paper used as a reference is discussed starting with what was analyzed, what assumptions were used, how the model was formed, and what kind of control was carried out;
2. Reviewing the results that have been previously achieved. The results obtained in each paper used as a reference are presented at this stage;
3. Determining the research gap regarding the mathematical model of the spread of tungro virus disease. Each model and analysis carried out in each paper is discussed to obtain a gap that can be used in the development of research models and methods regarding the spread of tungro virus disease in rice plants;
4. Perform statistical analysis to see the development of the model for the spread of tungro virus disease. The development of a model of the spread of tungro virus disease is seen based on how many studies on modeling have been published, since the modeling was carried out, and how it was developed;
5. Performing bibliometric analysis to analyze the novelty, obsolescence, and scientific reference distribution. Mapping the model for the spread of tungro virus disease in rice plants with the help of *VOSViewer* software so that we can see how far the model for the spread of tungro virus disease in rice plants has been developed.

3. Results and Discussion

3.1. Overview of Previous Models

From the results of selecting articles using the keywords "("Stability analysis" OR "Mathematical model" OR "Mathematical modelling" OR "Dynamical Analysis" OR "Dynamical System") AND ("Optimal Control") AND ("Plant disease") AND ("Tungro")", there were 20 selected based on the results of duplication plus one article from the backward and forwarding process. The summary can be seen in Table 2.

After screening, four relevant articles out of the twenty-one are used as reference material. The results show that a dynamic system model for the spread of tungro disease in rice plants developed from the Vector-Borne model has been conducted since 2016 [19–22], as seen in Table 3.

The model developed by Blas et al. in 2016 [21] consisted of eight compartments, equally divided between plant populations, and vector populations. The four compartments of each population were the healthy population, infected with RTSV only, infected with RTBV only, and infected with both (RTSV and RTBV). The infected compartment was distinguished as RTSV alone did not show definite symptoms. In contrast to RTBV-infected plants, they showed dwarfism and moderate discoloration. However, rice plants infected with RTBV and RTSV experienced severe stunting and yellowing [4,36,37].

Rice tungro virus is transmitted exclusively (in a semi-persistent manner and without a latency period) by green leafhoppers, with *Nephotettix virescens* as the primary vector [38]. A vector can feed on plants infected with RTSV to capture and transmit the virus. However, when the planthopper sucks food from rice plants infected with RTBV only, it cannot acquire or transmit the virus. The planthopper can transmit both viruses by sucking the RTSV-infected and RTBV-infected plant [39,40].

Table 3. Previous Tungro Disease Spread Model.

	Formed Models
Model 1 [19]	$\frac{dS_H}{dt} = \pi - \frac{\beta_H b}{N_H} S_H I_V - \mu_H S_H$ $\frac{dI_H}{dt} = \frac{\beta_H b}{N_H} S_H I_V - \mu_H I_H - dI_H$ $\frac{dS_V}{dt} = \eta - \frac{\beta_V b}{N_V} S_V I_H - \mu_V S_V - pS_V$ $\frac{dI_V}{dt} = \frac{\beta_V b}{N_V} S_V I_H - \mu_V I_V - pI_V$
Model 2 [20]	$\frac{dS_H}{dt} = \pi - \frac{\beta_H b}{N_H} S_H I_V - \mu_H S_H$ $\frac{dI_H}{dt} = \frac{\beta_H b}{N_H} S_H I_V - \mu_H I_H - dI_H$ $\frac{dS_V}{dt} = \eta - \frac{\beta_V b}{N_V} S_V I_H - \mu_V S_V - c_V S_V u - \alpha P S_V$ $\frac{dI_V}{dt} = \frac{\beta_V b}{N_V} S_V I_H - \mu_V I_V - c_V I_V u - \alpha P I_V$ $\frac{dP}{dt} = rP\left(1 - \frac{P}{N_P}\right) + \alpha P(S_V + I_V) - Pc_P u$
Model 3 [21]	$\frac{dP_0}{dt} = r(K - N_P) - \frac{\alpha P_0 V_3}{N_P} - \frac{\gamma P_0 V_3}{N_P} - \frac{\tau P_0 V_3}{N_P} - \frac{\beta P_0 V_1}{N_P} - \frac{\sigma P_0 V_2}{N_P} - q_0 P_0$ $\frac{dP_1}{dt} = \frac{\beta P_0 V_1}{N_P} + \frac{\gamma P_0 V_3}{N_P} - \frac{\lambda P_1 V_3}{N_P} - q_1 P_1$ $\frac{dP_2}{dt} = \frac{\tau P_0 V_3}{N_P} + \frac{\sigma P_0 V_2}{N_P} - \frac{\delta P_2 V_3}{N_P} - q_2 P_2$ $\frac{dP_3}{dt} = \frac{\alpha P_0 V_3}{N_P} + \frac{\lambda P_1 V_3}{N_P} + \frac{\delta P_2 V_3}{N_P} - q_3 P_3$ $\frac{dV_0}{dt} = BN_V\left(1 - \frac{N_V}{V}\right) - \frac{\alpha P_3 V_0}{N_P} - \frac{bP_1 V_0}{N_P} + fV_2 - \mu V_0$ $\frac{dV_1}{dt} = \frac{bP_1 V_0}{N_P} - \frac{gP_2 V_1}{N_P} - \mu V_1$ $\frac{dV_2}{dt} = cV_3 - fV_2 - \mu V_2$ $\frac{dV_3}{dt} = \frac{\alpha P_3 V_0}{N_P} + \frac{gP_2 V_1}{N_P} - cV_3 - \mu V_3$
Model 4 [22]	$\frac{dP_0}{dt} = r(K - N_P) - \frac{\alpha P_0 V_3}{N_P} - \frac{\gamma P_0 V_3}{N_P} - \frac{\tau P_0 V_3}{N_P} - \frac{\beta P_0 V_1}{N_P} - \frac{\sigma P_0 V_2}{N_P} - q_0 P_0$ $\frac{dP_1}{dt} = \frac{\beta(1-\rho) P_0 V_1}{N_P} + \frac{\gamma(1-\rho) P_0 V_3}{N_P} - \frac{\lambda(1-\rho) P_1 V_3}{N_P} - q_1(1-\rho) P_1 - \rho P_1$ $\frac{dP_2}{dt} = \frac{\tau(1-\rho) P_0 V_3}{N_P} + \frac{\sigma(1-\rho) P_0 V_2}{N_P} - \frac{\delta(1-\rho) P_2 V_3}{N_P} - q_2(1-\rho) P_2 - \rho P_2$ $\frac{dP_3}{dt} = \frac{\alpha(1-\rho) P_0 V_3}{N_P} + \frac{\lambda(1-\rho) P_1 V_3}{N_P} + \frac{\delta(1-\rho) P_2 V_3}{N_P} - q_3(1-\rho) P_3 - \rho P_3$ $\frac{dV_0}{dt} = BN_V\left(1 - \frac{N_V}{V}\right) - \frac{\alpha P_3 V_0}{N_P} - \frac{bP_1 V_0}{N_P} + fV_2 - \mu V_0$ $\frac{dV_1}{dt} = \frac{bP_1 V_0}{N_P} - \frac{gP_2 V_1}{N_P} - \mu V_1$ $\frac{dV_2}{dt} = cV_3 - fV_2 - \mu V_2$ $\frac{dV_3}{dt} = \frac{\alpha P_3 V_0}{N_P} + \frac{gP_2 V_1}{N_P} - cV_3 - \mu V_3$

The assumptions used by Blas et al. [21], in line with Zang and Holt's [41] research, show that the rate of rice cultivation depends on the maximum capacity $r(K - N_p)$, where r is the rate of planting, N_p is the total crop and K is the maximum capacity for planting rice. Illustrations for possible virus transitions and Blas modeling can be seen in Figures 2 and 3.

Figure 2 shows that the population of susceptible plants increased due to the recruitment of plants by $r(K - N_p)$ and decreased due to the transition from susceptible plants to plants infected with RTSV, RTBV, and both. This is due to the infected vectors (both infected with RTSV, RTBV, or both) sucking up susceptible plants at rates of $\alpha,\ \beta,\ \gamma,\ \sigma$, and τ. In addition, the population of susceptible plants decreased due to harvesting at a rate of q_0. Meanwhile, the process of possible transition can be seen in Figure 3. The figure explains that the susceptible plant population interacts with only RTSV-infected vectors so that the susceptible plants undergo a transition to only RTSV-infected plants. On the other hand, a description of each variable and parameter can be seen in Table 4.

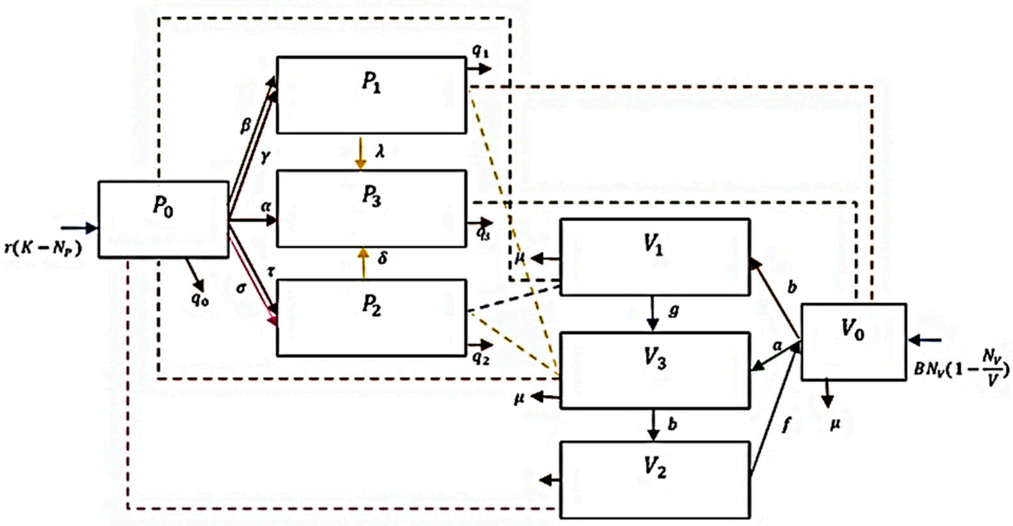

Figure 2. Schematic diagram of the model for the spread of tungro virus disease in rice plants carried out by Blas in 2016 [21].

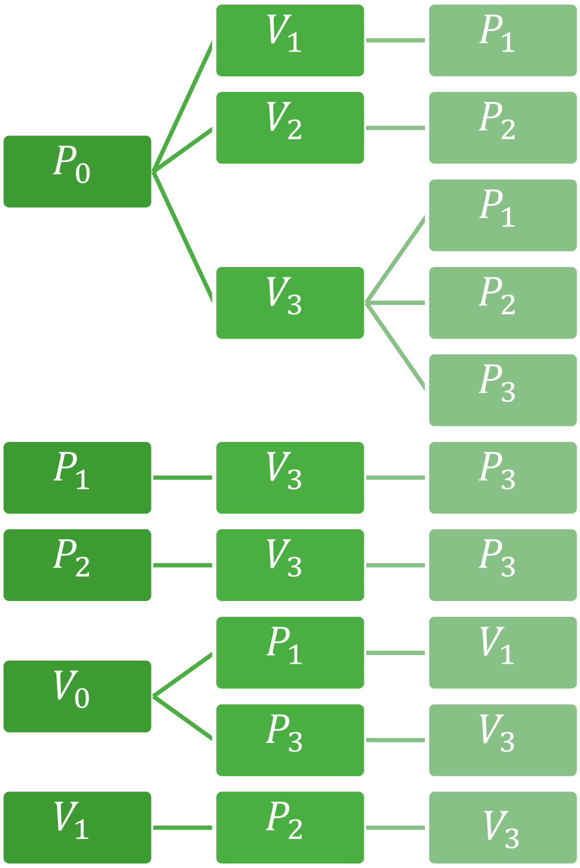

Figure 3. Diagram of possible transitions of plant and vector infections [21].

Table 4. Description of variables [21].

Variable/Parameter	Description
V_0	Healthy Vector Population
V_1	RTSV Infected Vector Population
V_2	RTBV Infected Vector Population
V_3	RTSV + RTBV Infected Vector Population
P_0	Healthy Plants Population
P_1	RTSV Infected Plants Population
P_2	RTBV Infected Plants Population
P_3	RTSV + RTBV Infected Plants Population
α	RTSV + RTBV transmission rate by RTSV + RTBV infected vector in susceptible plants
β	RTSV transmission rate by RTSV Infected vector in susceptible plants
γ	RTSV transmission rate by RTSV + RTBV infected vector in susceptible plants
σ	RTBV transmission rate by RTBV infected vector in susceptible plants
τ	RTBV transmission rate by RTSV + RTBV infected vector in susceptible plants
λ	RTSV + RTBV transmission rate by RTSV + RTBV infected vector in RTSV + RTBV infected plants
δ	RTSV + RTBV transmission rate by RTSV + RTBV infected vector in RTBV infected plants
a	The rate of acquisition of RTSV + RTBV infected plants by susceptible vectors to RTSV + RTBV infected vectors
b	The rate of acquisition of RTSV infected plants by susceptible vectors to RTSV infected vectors
g	The rate of acquisition of RTBV infected plants by RTSV infected vectors to RTSV + RTBV infected vectors

Blas and David [22] developed the previous model [21] to analyze the efficiency of the roguing process on land infected with rice tungro disease. The distribution process in a study conducted in 2017 can be seen in Figure 4 with a roguing effect ρ (representing the percentage of diseased plants removed from the field represented by the green arrow in Figure 4), where $0 \leq \rho \leq 1$.

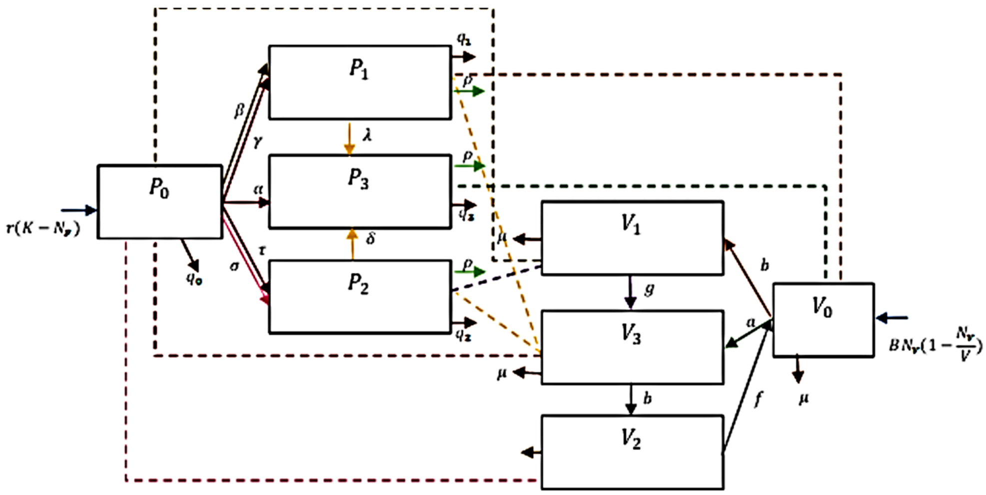

Figure 4. Schematic diagram of the model for the spread of tungro virus disease in rice plants carried out by Blas in 2017 [22].

The following study was conducted by Anggriani et al. in 2017 [19] to analyze the spread of tungro disease based on the SIR (Susceptible–Infected–Recovered) host-vector model [42,43]. Some assumptions used are: plant population is not constant, and growth and death rates are not the same. In addition, new plants are considered healthy, disease transmission occurs as vector insects carry the virus from infected plants, infected plants cannot be cured, and tungro disease can cause death. Insecticide-treated plants are immune to reinfection, regardless of environmental, climate, or weather conditions. The schematic diagram of the spread of tungro disease can be seen in Figure 5, where S_H is a susceptible host plant, I_H is an infected host plant, S_V is a susceptible vector, I_V is an infected vector, N_H is the number of plant populations, N_V is the number of vector populations, π is the rate of plant recruitment, η is the rate of vector recruitment, μ_H is the rate of plant death, μ_V is the mortality vector, β_H is the probability from vector to plant, β_V is the probability from plant to vector, b is the vector suction rate, d is the per capita plant mortality rate, and p is the level of insecticide application.

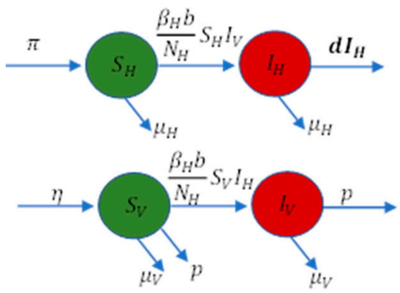

Figure 5. Compartment diagram and flow of disease transmission [19].

Previous research on mathematical modeling for the spread of tungro disease was conducted by Suryaningrat et al. in 2020 [20]. The model created in a previous study [19] was developed by adding predator–prey interactions between vectors and biological agents. The rice plant population into healthy (S_H) and infected (I_H) plants, susceptible (S_V) and infected (I_V) vector populations, and predatory populations (P), where r is the predator birth rate, c_p is the predator death rate due to insecticides, c_v is the rate of vector death due to insecticides, and α is the rate of predation. The schematic diagram and description of each parameter can be seen in Figure 6.

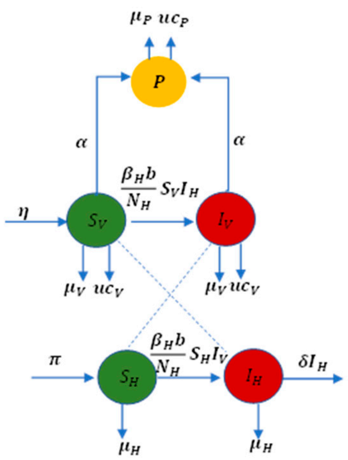

Figure 6. Schematic diagram of the spread of tungro disease in rice plants conducted by Suryaningrat et al. [20].

A "phylogenetic tree" diagram is drawn to represent the relationships between the articles used, as shown in Figure 7. Each branch reflects the model's main characteristics developed in a previous study. For example, the mathematical model of the spread of tungro disease in rice plants is divided into two categories. This includes models for the characteristics of the virus and the similarity between every viral infection.

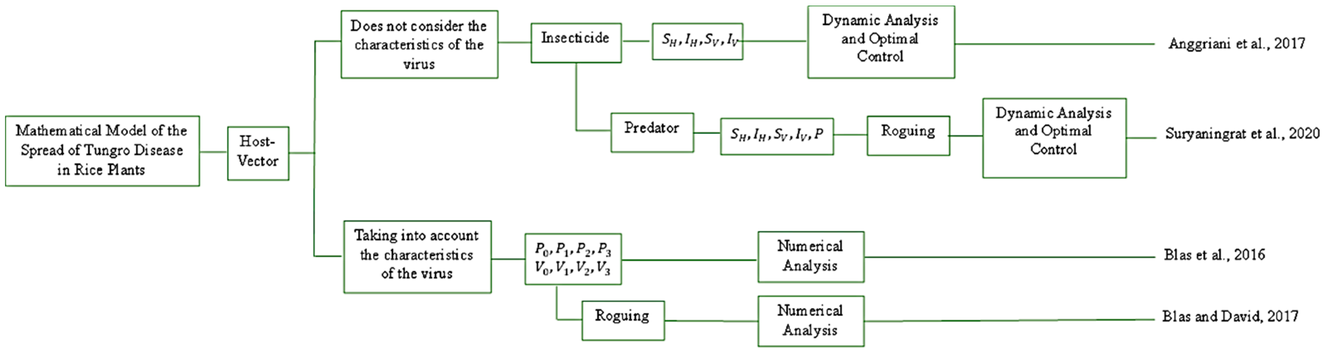

Figure 7. Phylogenetic Tree Diagram Mathematical Model of Tungro Disease Spread in Rice Plants [19–22].

3.2. Results That Have Been Achieved in Previous Studies

From models 1 and 2, the plant population is divided into susceptible plants and those infected with tungro disease. The green leafhopper vector population consists of susceptible and infected vectors. Control is conducted by giving insecticides to infected plants (Model 1) and applying predators and insecticides (Model 2). The two models are solved dynamically, starting from finding the equilibrium point, basic reproduction number, and local stability analysis. In addition, optimal control is also sought using the Pontryagin Maximum Principle.

A model for the spread of tungro disease in rice by considering the characteristics of RTSV and RTBV (Model 3) and the effect of rouging control (Model 4) has also been carried out, but the last two models were analyzed only numerically. Meanwhile, sensitivity and stability analysis should be performed to identify the very influential parameters and determine the stability of the developed model.

3.3. Research Gaps That Might Be Developed

Previous studies have made mathematical models by considering control through rouging, insecticides, and using predators as natural enemies.

The use of insecticides has a quicker capacity to control the spread of tungro disease. However, this application can cause pest and disease resistance, is not environmentally friendly, the price is not economical and can kill natural enemies.

The employment of natural enemies is considered more environmentally beneficial, and the price is relatively affordable, as it is sufficient to plant refugia plants. However, the control process using natural enemies is quite long, hence, when the green leafhopper has exceeded the threshold, further control is needed, such as applying pesticides. This kind of control follows the recommended Integrated Pest Management (IPM) concept, where the application of pesticides is given after reaching the threshold.

Possible development of Models 1 to 4 includes the use of refugia plants and parasitoids, which are considered more environmentally friendly and more economical so that these two controls can be used as consideration for developing a model for the spread of tungro virus disease in rice plants.

The parameters used to model the spread of tungro virus disease in rice plants when performing numerical simulations are only based on assumptions. This is due to the inaccessibility or incompleteness of the required data. Therefore, conducting a sensitivity analysis is essential to identify the parameters that are very influential on the developed model. This is consistent with research the conducted by:

1. Chitnis et al. [44] and Muryawi et al. [45] have analyzed local sensitivity by using partial derivation techniques to determine the parameters of the model influencing disease transmission and prevalence;
2. Blower and Dowlatabadi [46] have performed a sensitivity analysis using Partial Rank Correlation Coefficient (PRCC);

3. Wu et al. [47] conducted a sensitivity analysis using Scatter plots, Sobol Method, Morris Method, Partial Rank Correlation Coefficient (PRCC), and sensitivity heat map method; and
4. Hurint et al. [48] and Rois et al. [49] carried out a sensitivity analysis locally by analyzing the effect of changes in parameter values on the basic reproduction ratio $(\mathcal{R}_0)$.

The previous works primarily studied the stability analysis of the model around the equilibrium point. Therefore, it is also necessary to conduct a global stability analysis of the mathematical model of plant disease spread, such as building the Lyapunov function [12,45,50,51] or using the Volterra–Lyapunov matrix method [52].

3.4. Statistical Analysis

From the keywords used in the data search, 21 articles were obtained, as described in Table 2. After grouping based on the research object, only 19% did modeling on tungro disease, and the other 81% discussed different problems (see Figure 8).

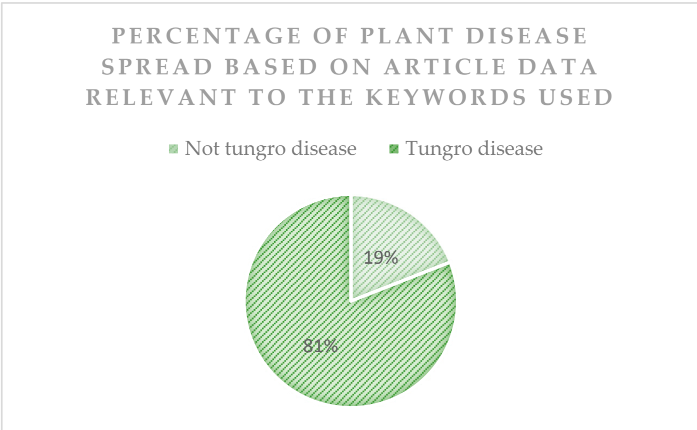

Figure 8. Mathematical modeling percentages on plant diseases.

Figure 9 shows that since 2016, several publications have analyzed mathematical models of the spread of tungro virus disease in rice plants. The most publications occurred in 2017, with as many as two publications. Unfortunately, no articles were published in the next two years, and publications will be available again in 2020. This indicates that research on tungro disease models in rice is scarce.

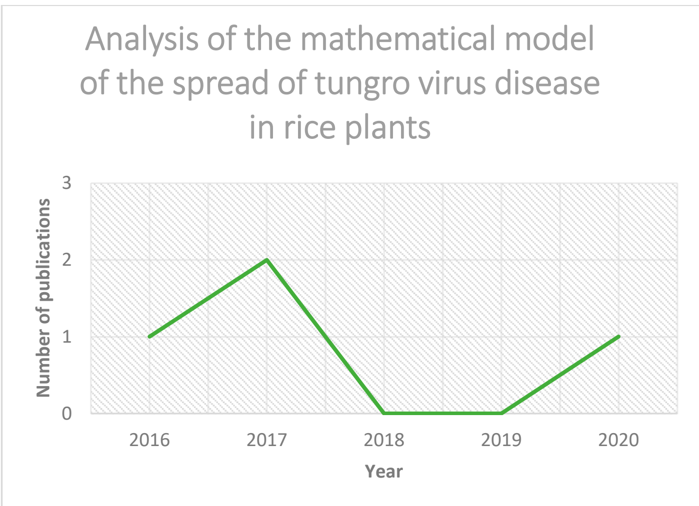

Figure 9. Data on publication of mathematical models of tungro disease.

3.5. Bibliometric Analysis

About 20 articles were relevant to the keywords used as described in Sections 2.2 and 3.1. They were obtained from the duplication selection results and one article was selected based on reference relevance. The results of the visualization of the bibliometric network using the *VOSviewer* software can be seen in Figure 8.

From Figure 10, it can be seen that there are several nodes with different sizes and distances. The size of the node indicates the number of words discussed. The larger the node, the more terms are available in the database. At the same time, the distance from one node to another indicates the strength of the relationship between one word and another. The tungro virus node looks small, and the distance between the "tungro virus" node and the "model" node is quite far. This shows that analysis of the mathematical model of the spread of tungro disease is still rarely conducted.

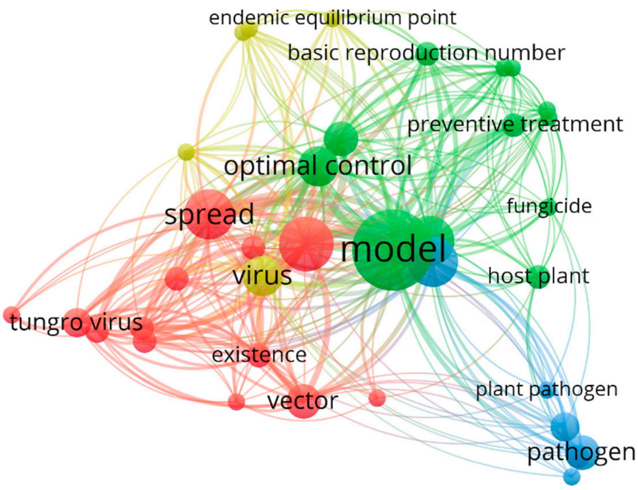

Figure 10. Mapping the topic of the spread of tungro disease in rice plants.

Figure 11 shows no correlation between the node distribution model of the tungro virus and refugia plants, parasitoid utilization, sensitivity analysis, global stability analysis, and software design to predict spread. This means that there is no research on modeling tungro virus disease by considering refugia plants and the use of parasitoids. In addition, the analysis of the mathematical model of the spread of tungro disease has not applied sensitivity analysis, global stability analysis, and software design to predict the spread. However, this analysis is also essential. Therefore, this is an opportunity for further research to develop a model for spreading the tungro virus in rice plants.

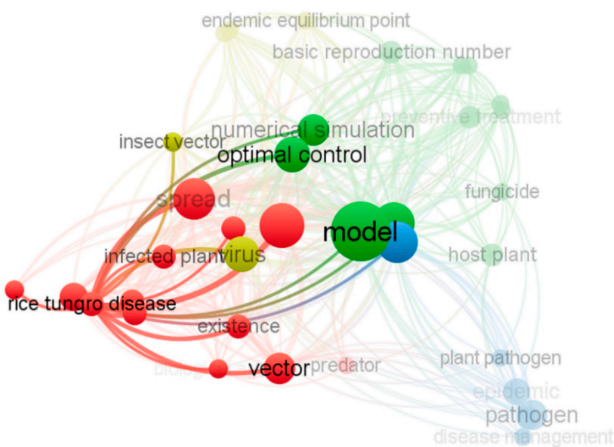

Figure 11. Mapping a mathematical model of the spread of tungro virus in rice plants.

While Figure 12 shows that mathematical modeling of the spread of the tungro virus has been carried out since 2016, it is still rarely conducted, and this can be seen from the node's color and the node's small size. In addition, the four articles used as references were also mapped to visualize the relationship between the two, as shown in Figure 13. The figure shows that the control carried out only considers the use of insecticides, biological agents, and rouging. So that control by considering the planting of refugia plants and the use of parasitoids becomes an opportunity for developing models for spreading tungro virus disease in rice plants.

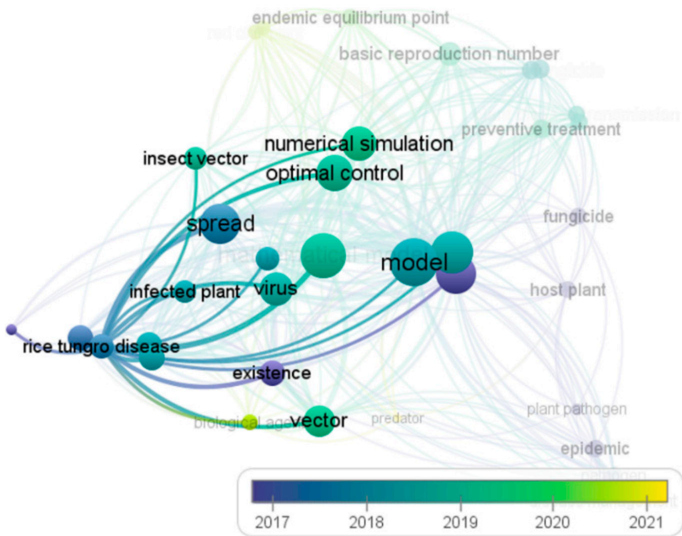

Figure 12. Research mapping on the mathematical model of the spread of tungro virus disease in rice plants.

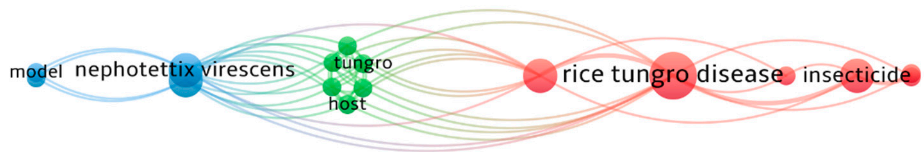

Figure 13. Visualization of linkage of reference articles.

4. Discussion

Research on mathematical modeling of the spread of tungro virus disease in rice plants has been carried out since 2016, but few researchers have conducted such research. This can be seen from the data obtained from the results of a literature study on the dimension database, Google Scholar, and Scopus in 2012–2021, which show there are only four papers available after analysis using the PRISMA method. Of the four papers, the control considered in modeling is limited to using insecticides, rouging, and biological agents. Farmers often carry out control by utilizing the refugia plants and parasitoid, which are considered more environmentally friendly and more economical so that these two controls can be used as consideration for developing a model for the spread of tungro virus disease in rice plants. In addition, the analysis is only limited to finding the equilibrium point, basic reproduction number, local stability analysis, and optimal control, even though other studies, such as sensitivity and global stability analysis, need to be carried out. Furthermore, the model made by previous researchers is continuous, even though rice plants are not continuous, so making a discrete model for the spread of tungro virus disease in rice plants can be considered by future researchers.

5. Conclusions

Mathematical modeling of the spread of the tungro virus in rice plants is rarely conducted. This can be seen from the results of a literature study on the mathematical model of the spread of tungro virus disease in rice plants with data sourced from scholarly references available in the dimension database, Google Scholar, and Scopus in 2012–2021, which were analyzed using PRISMA methods and bibliometric visualization. The results showed that there were only four articles on mathematical modeling of the spread of the tungro virus. Furthermore, the controls carried out by the previous researchers considered rouging, insecticide treatment, and the use of predators as natural enemies in their modeling. Therefore, the use of refugia plants and parasitoids can be considered in future studies to develop a model for spreading the tungro virus in rice plants. In addition, discrete models for the spread of tungro virus disease, global stability, and sensitivity analysis can be used to develop mathematical models for the spread of tungro virus disease in rice plants that future researchers can use.

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