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Implementation of Adomian Decomposition Method for Maize Streak Virus Disease Model to Reduce the Contamination Rate in Maize Plant

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Abstract

In this paper, the Maize Streak Virus disease model which involves the Maize and the Homopteran population is considered. This system of the differential equation is analytically solved by using Adomian Decomposition Method. The analytical results are compared with numerical simulation by assuming certain values for the parameter. Further, the demolishing and contamination rate of contagious and receptive homopteran on receptive and contagious Maize plant $(i_{1,} i_2)$ parameters are analyzed to reduce the contamination rate. In addition, the death rates of contagious maize, receptive homopteran and contagious homopteran (d_1, d_2, d_3) are also discussed to remove the contagious population and make them free from Maize Streak Virus.

Keywords: Maize Streak Virus, Adomian Decomposition Method, Analytical solution, Numerical simulation, contamination rate.

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1. Introduction

Maize is the major source of food, fuel, feed and fibers. Maize is a common food in many places around the world, specifically in sub-Saharan Africa. Provitamin A-biofortified maize crop is used to reduce Vitamin A deficiency in humans. Processed maize flour is used to prepare porridge. Maize *(Zea mays L.)* plant grows in the latitude 58°N to 40°S which is around agroecological areas of the continent Africa. The maize plant is a tall grass that consists of a strong central stalk surrounded by few branches. Maize was brought to African countries by Portuguese traders (Magenya et al., 2020; Maize et al., 2019; Mays, 2011; Mlotha et al., 2015; Shepherd et al., 2010; Society et al., 1923). Maize crop suffers from various diseases. They are brown spots, common rust, downy mildew, head smut, stalk rot, banded leaf, sheath blight, ear rot, northern leaf blight, southern leaf blight and gray leaf spot. Gray leaf spot is caused by *Cercospora zeae maydis.* Northern and Southern leaf blight is due to *Helminthosporium turcicum* and *Helminthosporium maydis.* Banded leaf and sheath blight are because of *Rhizoctonia solani.* Common rust and the brown spot are caused by *Puccinia sorghi* and *Physoderma maydis.* Head smut and ear rot are due to *Sphacelotheca reiliana* and *Aspergillus sp.* Downey mildew is because of *Sclerospora sorghi* (Subedi, 2015; Ward et al., 1999).

This paper deals with Maize Streak virus disease. The severe damage is brought on by Maize Streak Virus-A, one of the 11 different variants which are responsible for the serious damage caused to the maize plant. A family of plant viruses namely *Geminiviridae* is responsible for this major damage in maize plants. These viruses have one strand, circular DNA, and their heads are made up of coat proteins organized in a quasi-icosahedral pattern. Maize streak virus belongs to *Geminiviridae* family and the genus *Mastrevirus.* This disease was at first described as *Mealie Blight, Mealie Yellows* or *Striped leaf disease* in the year 1901 by Claude Fuller. The symptoms include minute circular spots in the leaf which gradually develops into yellow stripes in leaf veins and blade (Shepherd et al., 2010)(Karavina, 2014; Martin & Shepherd, 2009; Reading, 2008; Zhang et al., 2001). This disease is transmitted by homopterans of genus *Cicadulina mbila, Cicadulina Storeyi, Cicadulina bipunctella zeae, Cicadulinalateens* and *Cicadulina parazeae.* In Africa, there are about 18 species of *Cicadulina.* Among these vectors, *Cicadulina mbila* is widely spread and is responsible for transmitting this virus. The head, gut, abdomen, alimentary canal and filter chamber of *Cicadulina mbila* are filled with maize streak virus DNA copies. Once the infected vector species comes in contact with the healthy maize plant, the virus gets transmitted from the salivary gland of the vector when it feeds on the plant by sucking the leaves. Homopterans are controlled by making use of insecticides namely carbosulphan, carbofuran, aldicarb, dimethoate, imidacloprid and endosulphan. Out of these carbofuran and imidacloprid are widely used to control the vector population. Maize streak virus disease can be managed by removing weeds and the contagious crops should be buried as soon as possible (Æ et al., 2009; Bosque-perez, 1999; Karavina, 2014; Reading, 2008).

These are the description of the maize family and the cause of the maize streak virus disease. In section 2, we describe the mathematical model of Maize Streak virus disease as proposed by Haileyesus Tessema Alemeh et.al (Alemneh et al., 2019). In section 3, we will deal with the basic concept and analytical solution of the model using Adomian Decomposition method. In Section 4, results and discussions of the various model parameters are compared with analytical and numerical simulations of the maize streak virus diseases.

2. MODEL FORMULATION AND DESCRIPTION

Haileyesus Tessema Alemneh et al. proposed the disease model for the transmission dynamics of the maize streak virus (Alemneh et al., 2019). This model consists of two populations, Maize and Homopteran which are further divided into two subclasses namely Receptive and Contagious. Let $R_M(t), C_M(t), R_H(t), C_H(t)$ denote the density of Receptive Maize, Contagious Maize, Receptive Homopteran and Contagious Homopteran. In the absence of infection, the population of maize increases at the rate g and with the environmental transferring efficiency T . When a disease is present, the infectious host population helps the receptive host population move in the direction of the transferring efficiency T . The recruitment rate of receptive homopterans r moves to the contagious subgroup by consuming contagious maize at the rate i_2 . Receptive host plants move to contagious class by contact with contagious homopteran at the rate i_1. The death rate of contagious maize, receptive homopteran and contagious homopteran is given by i_1, i_2, i_3. Half absorbance constants of receptive homopteran with contagious maize and receptive maize with the contagious plant are represented as h_1, h_2. The system of differential equations is given as follows.

$$\frac{dR_M}{dt} = gR_M\left[1 - \frac{R_M + C_M}{T}\right] - \frac{i_1 R_M C_H}{h_1 + R_M}$$

$$\frac{dC_M}{dt} = \frac{i_1 R_M C_H}{h_1 + R_M} - d_1 C_M$$

$$\frac{dR_H}{dt} = r - \frac{i_2 C_M R_H}{h_2 + C_M} - d_2 R_H$$

$$\frac{dC_H}{dt} = \frac{c i_2 C_M R_H}{h_2 + C_M} - d_3 C_H \tag{2.1}$$

The initial conditions are $R_M(0) = R_{M0} \geq 0,\ C_M(0) = C_{M0} \geq 0,\ R_H(0) = R_{H0} \geq 0,\ C_H(0) = C_{H0} \geq 0$.

The list of parameters is described in the following table.

Symbol	**Meaning**
$R_M(t)$	The density of Receptive Maize
$C_M(t)$	The density of Contagious Maize
$R_H(t)$	The density of Receptive Homopteran
$C_H(t)$	The density of Contagious Homopteran
g	The intrinsic growth rate of maize
T	Transferring efficiency
h_1	Half absorbance rate of Receptive maize with Contagious plant

Symbol	Meaning
h_2	Half absorbance rate of Receptive Homopteran with Contagious maize plant
r	The recruitment rate of Receptive Homopteran
c	The conversion rate of Contagious Homopteran
i_1	Demolishing and contamination rate of Contagious Homopteran on Receptive Maize plant
i_2	Demolishing and contamination rate of Receptive Homopteran on Contagious Maize plant
d_1	The death rate of Contagious maize
d_2	The death rate of Receptive Homopteran
d_3	The death rate of Contagious Homopteran

Table 1: List of Parameters

3. MODEL SOLUTION THROUGH ADOMIAN DECOMPOSITION METHOD

3.1. Basic Concept of Adomian Decomposition Method

The above differential equation is divided into linear and non-linear terms in the Adomian Decomposition Method. The linear operator that represents the linear term of the equation is inverted and then applied to the given equation. The non-linear term is decomposed into a series which is termed as Adomian polynomials. The result creates a series whose terms are defined by the Adomian polynomials' recurrence relationship. Many mathematical models have been solved using Adomian decomposition method in various fields of science (Adomian, 1990, 1994; Biazar, n.d.; Mak et al., 2019; Rach, 1996; The et al., 1914). The basic concept of this method is given as follows:

A non-linear differential equation of the form,

$$F(t, y(t)) = f(t) \tag{3.1}$$

is considered. Here F represents the non-linear differential operator and y, f are functions of t. In operator form (3.1) becomes,

$$Ly + Ny + Ry = f \tag{3.2}$$

where L, N and R represents the linear, non-linear and remaining linear operator of F.

When we apply (3.2) by the inverse operator L^{-1}, we get

$$L^{-1}Ly = L^{-1}f - L^{-1}Ry - L^{-1}Ny \tag{3.3}$$

Here L^{-1} represents integration. Equation (3.3) becomes

$$y(t) = g(t) - L^{-1}Ry - L^{-1}Ny \tag{3.4}$$

where $g(t)$ represents the function that is obtained while integrating f. The unknown function $y(t)$ is selected as an infinite series,

$$y(t) = \sum_{n=0}^{\infty} y_n(t) \tag{3.5}$$

The rest of the terms are determined by the recurring relationship. The non-linear term is broken down into a set of polynomials called Adomian polynomials, which are shown as:

$$Ny(t) = \sum_{n=0}^{\infty} A_n \tag{3.6}$$

where A_n is given by,

$$A_n = \frac{1}{n!}\frac{d^n}{d\lambda^n} Ny(\lambda)|_{\lambda=0} \tag{3.7}$$

Applying (3.5) and (3.6) in (3.4), we get,

$$\sum_{n=0}^{\infty} y_n = g(t) - L^{-1}\sum_{n=0}^{\infty} Ry_n - L^{-1}\sum_{n=0}^{\infty} A_n \tag{3.8}$$

Expanding the series in L.H.S, we obtain,

$$y_0 + y_1 + \ldots + y_{n+1} = g(t) - L^{-1}\sum_{n=0}^{\infty} Ry_n - L^{-1}\sum_{n=0}^{\infty} A_n \tag{3.9}$$

The recurring relationship is given by,

$$y_0 = g(t) \tag{3.10}$$

$$y_{n+1} = - L^{-1}\sum_{n=0}^{\infty} Ry_n - L^{-1}\sum_{n=0}^{\infty} A_n \tag{3.11}$$

Thus Adomian Decomposition Method produces a series that is absolutely and uniformly convergent.

3.2. Computation using Adomian Decomposition Method

Using the Adomian Decomposition Method, the system of non-linear differential equations defined in equation (2.1) is solved. Let us define the operator $L = \frac{d}{dt}$, then the system of equations becomes,

$$\begin{aligned}
L_{R_M} &= gR_M\left(1 - \frac{R_M + C_M}{T}\right) - \frac{i_1 R_M C_H}{h_1 + R_M} \qquad (3.12)\\
L_{C_M} &= \frac{i_1 R_M C_H}{h_1 + R_M} - d_1 C_M\\
L_{R_H} &= r - \frac{i_2 C_M R_H}{h_2 + C_M} - d_2 R_H\\
L_{C_H} &= \frac{c i_2 C_M R_H}{h_2 + C_M} - d_3 C_H
\end{aligned}$$

The inverse operator $L^{-1} = \int_0^t (.)\,dt$ is used to solve the aforementioned equations on both sides, then we get,

$$\begin{aligned}
L^{-1}L_{R_M} &= L^{-1}\left[gR_M\left(1-\frac{R_M+C_M}{T}\right)\right]-L^{-1}\left[\frac{i_1 R_M C_H}{h_1+R_M}\right]\\
L^{-1}L_{C_M} &= L^{-1}\left[\frac{i_1 R_M C_H}{h_1+R_M}\right]-L^{-1}\left[d_1 C_M\right]\\
L^{-1}L_{R_H} &= L^{-1}[r]-L^{-1}\left[\frac{i_2 C_M R_H}{h_2+C_M}\right]-L^{-1}\left[d_2 R_H\right]\\
L^{-1}L_{C_H} &= L^{-1}\left[\frac{ci_2 C_M R_H}{h_2+C_M}\right]-L^{-1}\left[d_3 C_H\right]
\end{aligned} \tag{3.13}$$

Then we decompose $R_M(t), C_M(t), R_H(t), C_H(t)$ into an infinite number of terms.

$$R_M(t)=\sum_{n=0}^{\infty} R_{Mn}\ ,C_M(t)=\sum_{n=0}^{\infty} C_{Mn}\ ,R_H(t)=\sum_{n=0}^{\infty} R_{Hn}\,,C_H(t)=\sum_{n=0}^{\infty} C_{Hn} \tag{3.14}$$

The non-linear terms are represented by Adomian polynomials.

$$R_M{}^2=\sum_{n=0}^{\infty} A_n\,,R_M C_M=\sum_{n=0}^{\infty} B_n\,,\frac{R_M C_H}{h_1+R_M}=\sum_{n=0}^{\infty} C_n\,,\frac{C_M R_H}{h_2+C_M}=\sum_{n=0}^{\infty} D_n \tag{3.15}$$

The Adomian polynomials are derived as follows:

$$\begin{aligned}
&A_0=R_{M0}{}^2\\
&A_1=2R_{M0}R_{M1}\\
&\vdots\\
&B_0=R_{M0}C_{M0}\\
&B_1=R_{M0}C_{M1}+R_{M1}C_{M0}\\
&\vdots\\
&C_0=\frac{R_{M0}C_{H0}}{h_1+R_{M0}}\\
&C_1=\frac{R_{M1}C_{H0}}{h_1+R_{M0}}+\frac{R_{M0}C_{H1}}{h_1+R_{M0}}-\frac{R_{M0}C_{H0}R_{M1}}{(h_1+R_{M0})^2}\\
&\vdots\\
&D_0=\frac{C_{M0}R_{H0}}{h_2+C_{M0}}\\
&D_1=\frac{C_{M1}R_{H0}}{h_2+C_{M0}}+\frac{C_{M0}R_{H1}}{h_2+C_{M0}}-\frac{C_{M0}R_{H0}C_{M1}}{(h_2+C_{M0})^2}\\
&\vdots
\end{aligned} \tag{3.16}$$

Substituting the results of equation (3.14) to (3.16) in (3.13) we get,

$$R_M(t)-R_M(0)=L^{-1}\left[g\sum_{n=0}^{\infty}R_{Mn}\right]-L^{-1}\left[g\left(\frac{\sum_{n=0}^{\infty}A_n+\sum_{n=0}^{\infty}B_n}{T}\right)\right]-L^{-1}\left[i_1\sum_{n=0}^{\infty}C_n\right]$$

$$C_M(t)-C_M(0)=L^{-1}\left[i_1\sum_{n=0}^{\infty}C_n\right]-L^{-1}\left[d_1\sum_{n=0}^{\infty}C_{Mn}\right]$$

$$R_H(t)-R_H(0)=L^{-1}[r]-L^{-1}\left[i_2\sum_{n=0}^{\infty}D_n\right]-L^{-1}\left[d_2\sum_{n=0}^{\infty}R_{Hn}\right]$$

$$C_H(t)-C_H(0)=L^{-1}\left[ci_2\sum_{n=0}^{\infty}D_n\right]-L^{-1}\left[\mu_3\sum_{n=0}^{\infty}C_{Hn}\right]$$

(3.17)

Expanding the series we get,

$R_{M0} + R_{M1} + R_{M2} + \ldots = R_M(0) + L^{-1}[g(R_{M0} + R_{M1} + R_{M2} + \ldots)] - L^{-1}[g(\frac{(A_0 + A_1 + \ldots) + (B_0 + B_1 + \ldots)}{T})]$

$C_{M0} + C_{M1} + C_{M2} + \ldots = C_M(0) + L^{-1}[i_1(C_0 + C_1 + \ldots)] - L^{-1}[d_1(C_{M0} + C_{M1} + C_{M2} + \ldots)]$

$R_{H0} + R_{H1} + R_{H2} + \ldots = R_H(0) + L^{-1}[r] - L^{-1}[i_2(D_0 + D_1 + \ldots)] - L^{-1}[d_2(R_{H0} + R_{H1} + R_{H2} + \ldots)]$

$C_{H0} + C_{H1} + C_{H2} + \ldots = C_H(0) + L^{-1}[ci_2(D_0 + D_1 + \ldots.)] - L^{-1}[d_3(C_{H0} + C_{H1} + C_{H2} + \ldots)]$

(3.18)

Comparing the like terms of equation (3.18), we get,

$$\begin{aligned}
&R_{M0}=R_M(0)\\
&R_{M1}=L^{-1}[gR_{M0}]-L^{-1}\left[g\left(\frac{A_0+B_0}{T}\right)\right]-L^{-1}[i_1C_0]\\
&R_{M2}=L^{-1}[gR_{M1}]-L^{-1}\left[g\left(\frac{A_1+B_1}{T}\right)\right]-L^{-1}[i_1C_1]\\
&\vdots
\end{aligned} \qquad (3.19)$$

$$\begin{aligned} C_{M0} &= C_M(0) \\ C_{M1} &= L^{-1}\left[i_1 C_0\right] - L^{-1}\left[d_1 C_{M0}\right] \\ C_{M2} &= L^{-1}\left[i_1 C_1\right] - L^{-1}\left[d_1 CM_1\right] \\ &\vdots \end{aligned} \tag{3.20}$$

$$\begin{aligned} R_{H0} &= R_H(0) + L^{-1}\left[r\right] \\ R_{H1} &= -L^{-1}\left[i_2 D_0\right] - L^{-1}\left[d_2 R_{H0}\right] \\ R_{H2} &= -L^{-1}\left[i_2 D_1\right] - L^{-1}\left[d_2 R_{H1}\right] \\ &\vdots \end{aligned} \tag{3.21}$$

$$\begin{aligned} C_{H0} &= C_H(0) \\ C_{H1} &= L^{-1}\left[ci_2 D_0\right] - L^{-1}\left[d_3 C_{H0}\right] \\ C_{H2} &= L^{-1}\left[ci_2 D_1\right] - L^{-1}\left[d_3 C_{H1}\right] \\ &\vdots \end{aligned} \tag{3.22}$$

Evaluating the inverse operator L^{-1} from equations (3.19) to (3.22), we get the required solution.

$R_{M0} = R_M(0)$

$R_{M1} = gR_{M0}\, t - g\left[\frac{R_{M0}^2 + R_{M0}C_{M0}}{T}\right]t - i_1\left[\frac{R_{M0}C_{H0}}{h_1+R_{M0}}\right]t$

$$\begin{aligned} R_{M2} = {} & g\left[gR_{M0} - g\left(\frac{R_{M0}^2 + R_{M0}C_{M0}}{T}\right) - i_1\left(\frac{R_{M0}C_{H0}}{h_1 + R_{M0}}\right)\right]\frac{t^2}{2} \\ & - g\left[\frac{2R_{M0}\,R_{M1} + R_{M0}C_{M1} + R_{M1}C_{M0}}{T}\right]t - i_1\left[\frac{R_{M1}C_{H0}}{h_1 + R_{M0}} \right. \\ & \left. + \frac{R_{M0}C_{H1}}{h_1 + R_{M0}} - \frac{R_{M0}C_{H0}R_{M1}}{(h_1 + R_{M0})^2}\right]t \end{aligned}$$

(3.23)

$$C_{M0} = C_M(0)$$
$$C_{M1} = i_1\left[\frac{R_{M0}C_{H0}}{h_1 + R_{M0}}\right]t - d_1C_{M0}t$$
$$C_{M2} = i_1\left[\frac{R_{M1}C_{H0}}{h_1+R_{M0}} + \frac{R_{M0}C_{H1}}{h_1+R_{M0}} - \frac{R_{M0}C_{H0}R_{M1}}{(h_1+R_{M0})^2}\right]t - d_1\left[i_1\left(\frac{R_{M0}C_{H0}}{h_1+R_{M0}}\right) - d_1C_{M0}\right]\frac{t^2}{2} \vdots \tag{3.24}$$

$$R_{H0} = R_H(0) + rt$$
$$R_{H1} = -i_2\left[\frac{C_{M0}R_{H0}}{h_2 + C_{M0}}\right]t - d_2R_{H0}t$$
$$R_{H2} = -i_2\left[\frac{C_{M1}R_{H0}}{h_2 + C_{M0}} + \frac{C_{M0}R_{H1}}{h_2 + C_{M0}} - \frac{C_{M0}R_{H0}C_{M1}}{(h_2 + C_{M0})^2}\right]t - d_2\left[-i_2\left(\frac{C_{M0}R_{H0}}{h_2 + C_{M0}}\right) - d_2R_{H0}\right]\frac{t^2}{2}$$
$$\vdots \tag{3.25}$$

$$C_{H0} = C_H(0)$$
$$C_{H1} = ci_2\left[\frac{C_{M0}R_{H0}}{h_2 + C_{M0}}\right]t - d_3C_{H0}t$$
$$C_{H2} = ci_2\left[\frac{C_{M1}R_{H0}}{h_2 + C_{M0}} + \frac{C_{M0}R_{H1}}{h_2 + C_{M0}} - \frac{C_{M0}R_{H0}C_{M1}}{(h_2 + C_{M0})^2}\right]t - d_3\left[ci_2\left(\frac{C_{M0}R_{H0}}{h_2 + C_{M0}}\right) - d_3C_{H0}\right]\frac{t^2}{2}$$
$$\vdots \tag{3.26}$$

Thus the required analytical solution is,

$$R_M(t) = R_{M0} + R_{M1} + R_{M2} + \cdots$$
$$C_M(t) = C_{M0} + C_{M1} + C_{M2} + \cdots$$
$$R_H(t) = R_{H0} + R_{H1} + R_{H2} + \cdots$$
$$C_H(t) = C_{H0} + C_{H1} + C_{H2} + \cdots$$

By assigning certain numerical values to the parameters,

$g = 0.5, r = 0.01, c = 0.3, T = 1000, d_1 = 0.4, d_2 = 0.6, d_3 = 0.8,$

$i_1 = 0.09, i_2 = 0.2, h_1 = 0.4 and h_1 = 0.02$

we get the solution as follows:

$$R_M(t) = 5. + 2.477500000\ t + .5911071269\ t^2 - 0.4975124378\ t^3$$
$$C_M(t) = 4. - 1.591666667\ t + .3285635419\ t^2 - 0.1616915423\ t^3$$
$$R_H(t) = 3. - 2.387014925\ t + 1.010209747\ t^2 - 0.1757104783\ t^3 - 0.5970149253\ t^4$$
$$C_H(t) = 0.1 - 0.5428629242\ t^2 + 0.991044776\ t - 0.4781997969\ t^3$$

4. RESULTS AND DISCUSSIONS

The analytical solution for the maize streak virus disease model from equation (3.23) to (3.26) is compared with numerical simulation to produce effective results. Here the initial conditions of the model are $R_M(0)=5, C_M(0)=4, R_H(0)=3, C_H(0)=0.1$. We analyze each parameter involved by assuming certain values of the parameter and keeping other variables fixed. The graphs which are obtained through Matlab software give us a clear understanding of the slope in the system of differential equations.

Figure 1 represents the comparison of analytical and numerical simulation of (3.23). From figure 1 we can see that, with the increase in the intrinsic growth rate of maize g, the rate of the density of the Receptive Maize population $R_M(t)$ increases concerning time. The other parameters like transferring efficiency T, half absorbance rate of receptive maize with contagious plant h_1 & demolishing and contamination rate of contagious homopteran on receptive maize plant i_1 are kept constant.

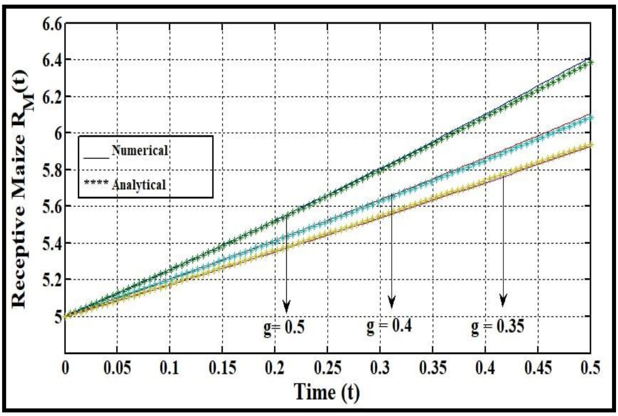

Figure 1

Figure 1 Graphs representing the slope of Receptive maize concerning time for the varying values of the intrinsic growth rate of maize g . The analytical solution is depicted by the star (***) and the solid line (___) indicates numerical simulation accordingly.

Table representing the analytical and numerical value of $R_M(t)$, with respect to the parameter (The intrinsic growth rate of maize g), at time $t = 0.1 \, and \, 0.5$, while other parameters $T = 1000, \; i_1 = 0.09, h_1 = 0.4$ are kept fixed.

Time	Analytical solution of $R_M(t)$			Numerical solution of $R_M(t)$		
	$g = 0.5$	$g = 0.4$	$g = 0.35$	$g = 0.5$	$g = 0.4$	$g = 0.35$
$t = 0.1$	5.254	5.199	5.173	5.256	5.204	5.178
$t = 0.5$	6.386	6.009	5.862	6.414	6.105	5.938

Table 2: Analytical and numerical solution of $R_M(t)$ versus time.

Figure 2(a) & 2(b) determines the comparison between the analytical and numerical simulation of (3.24). From figure (2(a)), we can note that with the rising value of the death rate of contagious maize d_1, the slope of infectious maize $C_M(t)$ with respect to time decreases. Here the half absorbance rate of receptive maize with contagious plants h_1 & demolishing and contamination rate of contagious homopteran on receptive maize plants i_1 are fixed.

From figure (2(b)) we observe that for higher values of demolishing and contamination rate of contagious homopteran on receptive maize plant i_1, the slope of infectious maize $C_M(t)$ with respect to time decreases slowly. Other parameters, the death rate of contagious maize d_1 & half absorbance rate of receptive maize with the contagious plant h_1 are unchanged.

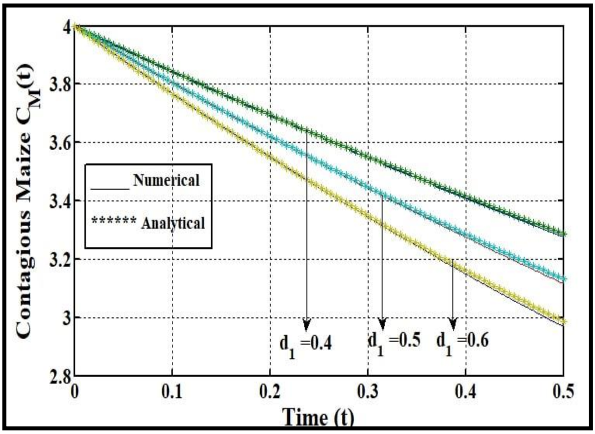

Figure 2(a)

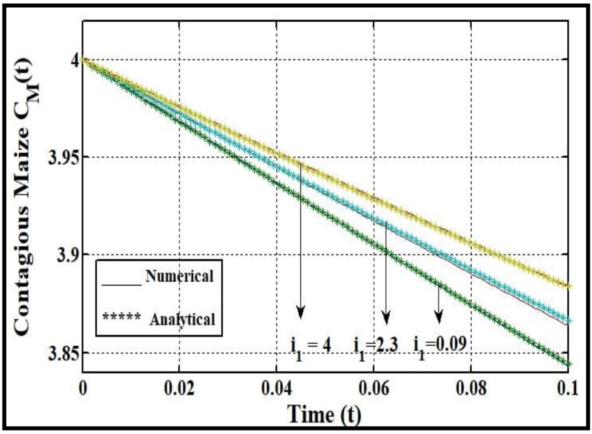

Figure 2(b)

Figure 2(a) and 2(b) Graphs representing the slope of Infectious maize with respect to time for different values of the death rate of Contagious maize d_1 (Figure 2(a)), demolishing and contamination rate of Contagious Homopteran on Receptive maize plant i_1 (Figure 2(b)). The analytical solution is depicted by the star (***) and the solid line (___) indicates numerical simulation accordingly.

Table representing the analytical and numerical value of $C_M(t)$, with respect to the parameter (The death rate of contagious maize d_1), at time $t = 0.1 \, and \, 0.5$, while the other parameter $i_1 = 0.09, h_1 = 0.4$ are kept fixed.

Time	Analytical solution of $C_M(t)$			Numerical solution of $C_M(t)$		
	$d_1 = 0.4$	$d_1 = 0.5$	$d_1 = 0.6$	$d_1 = 0.4$	$d_1 = 0.5$	$d_1 = 0.6$
$t = 0.1$	3.844	3.807	3.769	3.843	3.804	3.766
$t = 0.5$	3.286	3.168	3.023	3.286	3.131	2.968

Table 3: Analytical and numerical solution of $C_M(t)$ versus time.

Table representing the analytical and numerical value of $C_M(t)$, with respect to the parameter (Demolishing and contamination rate of Contagious Homopteran on Receptive Maize plant i_1), at time $t = 0.02$ *and* 0.1, while the other parameter $d_1 = 0.4, h_1 = 0.4$ are kept fixed.

Time	Analytical solution of $C_M(t)$			Numerical solution of $C_M(t)$		
	$i_1 = 4$	$i_1 = 2.3$	$i_1 = 0.09$	$i_1 = 4$	$i_1 = 2.3$	$i_1 = 0.09$
$t = 0.02$	3.978	3.973	3.968	3.975	3.972	3.968
$t = 0.1$	3.950	3.904	3.845	3.884	3.864	3.844

Table 4: Analytical and numerical solution of $C_M(t)$ versus time.

Figure (3(a)) and (3(b)) expresses the comparison of analytical and numerical solution of (3.25). From figure (3(a)) we can conclude that for greater values of the death rate of receptive homopterans d_2, the rate of Receptive Homopteran $R_H(t)$ falls rapidly. The recruitment rate of receptive homopteran r, half absorbance rate of receptive homopteran with contagious maize plant h_2 & demolishing and contamination rate of receptive homopteran on contagious maize plant i_2 are kept constant.

From figure (3(b)) we can define that for bigger values of demolishing and contamination rate of receptive homopteran on contagious maize plant i_2, the rate of receptive homopteran $R_H(t)$ decreases with respect to time. The death rate of receptive homopteran d_2, recruitment rate of receptive homopteran r & half absorbance rate of receptive homopteran with contagious maize plant h_2 are kept fixed.

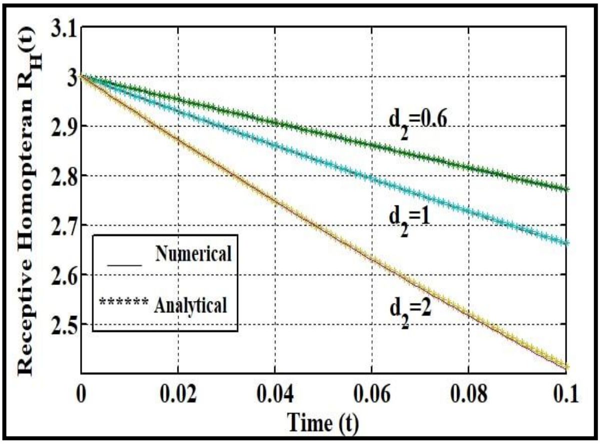

Figure 3(a)

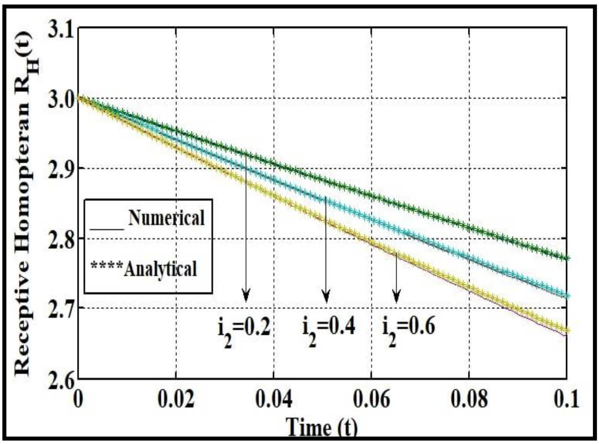

Figure 3(b)

Figure 3(a) and 3(b) Graphs representing the slope of Receptive Homopteran with respect to time for the death rate of Receptive Homopteran d_2 (Figure3(a)), demolishing and contamination rate of Receptive Homopteran on Contagious maize plant i_2 (Figure 3(b)). The analytical solution is depicted by the star (***) and the solid line (___) indicates numerical simulation accordingly.

Table representing the analytical and numerical value of $R_H(t)$, with respect to the parameter (The death rate of receptive homopteran

d_2), at time $t = 0.02$ *and* 0.1 , while the other parameter $r = 0.01, i_2 = 0.2, h_2 = 0.02$ are kept fixed.

Time	Analytical solution of $R_H(t)$			Numerical solution of $R_H(t)$		
	$d_2 = 0.6$	$d_2 = 1$	$d_2 = 2$	$d_2 = 0.6$	$d_2 = 1$	$d_2 = 2$
$t = 0.02$	2.953	2.929	2.871	2.952	2.928	2.870
$t = 0.1$	2.771	2.663	2.413	2.769	2.663	2.407

Table 5: Analytical and numerical solution of $R_H(t)$ versus time.

Table representing the analytical and numerical value of $R_H(t)$, with respect to the parameter (Demolishing and contamination rate of Receptive Homopteran on Contagious Maize plant i_2) , at time $t = 0.02$ *and* 0.1 , while the other parameter $r = 0.01, d_2 = 0.6, h_2 = 0.02$ are kept fixed.

Time	Analytical solution of $R_H(t)$			Numerical solution of $R_H(t)$		
	$i_2 = 0.2$	$i_2 = 0.4$	$i_2 = 0.6$	$i_2 = 0.2$	$i_2 = 0.4$	$i_2 = 0.6$
$t = 0.02$	2.953	2.941	2.929	2.952	2.940	2.929
$t = 0.1$	2.771	2.718	2.668	2.771	2.718	2.660

Table 6: Analytical and numerical solution of $R_H(t)$ versus time.

Figure (4(a)) and (4(b)) describes the comparison between the analytical and numerical simulation of equation (3.26). From figure (4(a)), we can understand that for higher values of demolishing and contamination rate of receptive homopteran on contagious maize plants i_2 , the rate of contagious homopteran $C_H(t)$ increases slowly with respect to time. Other parameters like the conversion rate of contagious homopteran c, half absorbance rate of receptive homopteran with contagious maize plant h_2 and death rate of contagious homopteran d_3 are kept constant.

Figure (4(b)) denotes that for increasing values of death rate of contagious homopteran d_3 , the rate of contagious homopteran

$C_H(t)$ decreases slowly with respect to time. Demolishing and contamination rate of receptive homopteran on contagious maize plant i_2, the conversion rate of contagious homopteran b and half absorbance rate of receptive homopteran with contagious maize plant C is fixed.

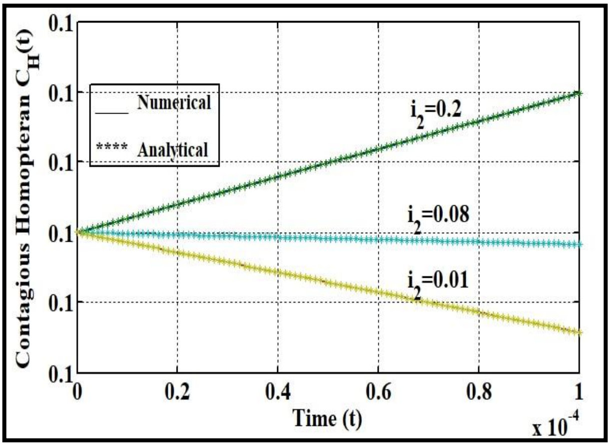

Figure 4(a)

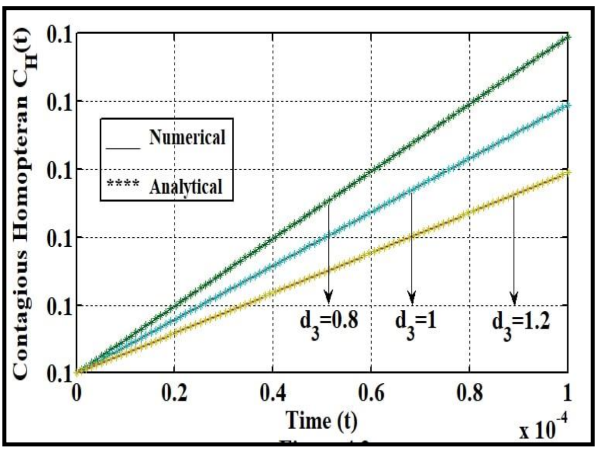

Figure 4(b)

Figure 4(a) and 4(b) Graphs representing the slope of Contagious Homopteran with respect to time for demolishing and contamination rate of Receptive Homopteran on Contagious maize plant i_2 (Figure 4(a)), the death rate of Contagious Homopteran d_3

(Figure 4(b)). The analytical solution is depicted by the star (***) and the solid line (___) indicates numerical simulation accordingly.

Table representing the analytical and numerical value of $C_H(t)$, with respect to the parameter (Demolishing and contamination rate of Receptive Homopteran on Contagious Maize plant i_2), at time $t = 0.2\times10^{-4}$ *and* 1×10^{-4}, while the other parameter $c = 0.3,\ h_2 = 0.02, d_3 = 0.8$ are kept fixed.

Time	Analytical solution of $C_H(t)$			Numerical solution of $C_H(t)$		
	$i_2 = 0.2$	$i_2 = 0.08$	$i_2 = 0.01$	$i_2 = 0.2$	$i_2 = 0.08$	$i_2 = 0.01$
$t = 0.2\times10^{-4}$	0.100	0.100	0.100	0.100	0.100	0.100
$t = 1\times10^{-4}$	0.100	0.100	0.100	0.100	0.100	0.100

Table 7: Analytical and numerical solution of $C_H(t)$ versus time.

Table representing the analytical and numerical value of $C_H(t)$, with respect to the parameter (The death rate of Contagious Homopteran d_3), at time $t = 0.2\times10^{-4}$ *and* 1×10^{-4}, while the other parameter $i_1 = 0.09, h_1 = 0.4$ are kept fixed.

Time	Analytical solution of $C_H(t)$			Numerical solution of $C_H(t)$		
	$d_3 = 0.8$	$d_3 = 1$	$d_3 = 1.2$	$d_3 = 0.8$	$d_3 = 1$	$d_3 = 1.2$
$t = 0.2\times10^{-4}$	0.100	0.100	0.100	0.100	0.100	0.100
$t = 1\times10^{-4}$	0.100	0.100	0.100	0.100	0.100	0.100

Table 8: Analytical and numerical solution of $C_H(t)$ versus time.

The MATLAB code to obtain the numerical solution for the system of the differential equations is as follows:

```
function main1

options=odeset('RelTol',1e-6,'Stats','on');

X0=[5;4;3;0.1];

tspan=[0,0.5];
```

```
tic
[t,X]=ode45(@TestFunction,tspan,X0,options);
toc
figure
hold on
plot (t, X(:, 1));grid;
%plot (t, X(:, 2));grid;
%plot (t, X(:, 3));grid;
%plot (t, X (:, 4));grid;
return
function[dx_dt]=TestFunction(t,x)
g=0.5; i1=2; h1=0.4; T=1000; d1=0.4; d2=0.6; d3=0.8; i2=0.2; h2=0.02;
r=0.01; c=0.3;
dx_dt(1) = (g*x(1)*(1-((x(1)+x(2))/T)))-((i1*x(1)*x(4))/(h1+x(1)));
dx_dt(2) = ((i1*x(1)*x(4))/(h1+x(1)))-(d1*x(2));
dx_dt(3) = r-((i2*x(2)*x(3))/(h2+x(2)))-(d2*x(3));
dx_dt(4) = ((c*i2*x(2)*x(3))/(h2+x(2)))-(d3*x(4));
dx_dt = dx_dt';
```


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6. CONFLICT OF INTEREST

Both authors affirm that they have no competing interests.

7. CONCLUSION

Thus, the analytical solution of Maize streak virus disease is successfully compared with numerical simulation for various parameters and is represented in graphical figures. We can conclude that if the demolishing and contamination rate of Contagious Homopteran on the Receptive Maize plant $i_1 \leq 0.09$, then the contamination rate reduces in the contagious maize population. If demolishing and contamination rate of Receptive Homopteran on Contagious Maize plant is $i_2 \leq 0.01$, then the density of the contagious homopteran population is reduced. Finally, if the death rate of the contagious homopteran $d_3 \leq 0.8$, then the contagious homopteran population dies faster and the maize plant can be free from the maize streak virus.

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