Journal of Desert and Environmental Agriculture, 4 (2):294-324, 2024 JDEA
DOI: 10.21608/jdea.2024.285530.1051

Article

Monitoring and Early Detection of the Effects of Temperature Stress on Date Palm Root Rot Disease

Khaled Hussein Arafat *

Department of Plant Pathology, Faculty of Agriculture, New Valley University, New Valley Governorate, Kharga City, Egypt

drkhaledarafat@agr.nvu.edu.eg

ORCID: https://orcid.org/0000-0002-9895-4982

Article info.

Received on:26-4-2024

Accepted on: 16-5-2024

Published on: 6-2024

Open Access

Abstract

Date palms are important crop in arid and semi-arid regions because they provide food, income, and cultural significance. However, their cultivation is threatened by diseases such as root rot caused by various fungi. Climate change increases temperature stress, which worsens the severity of root rot. To predict the effects of temperature stress on date palm root rot, modeling techniques are used to simulate the complex relationships between temperature, fungal pathogens, and date palm health. These models enable the prediction of disease outbreaks under different climate scenarios. This study used meteorological data from the National Center for Environmental Information from 1988 to 2019. By analyzing the average air temperature and the severity of pathogenic fungi that cause root rot in date palms, the relationship between these variables was determined. The study took place at Kharga Oasis in New Valley governorate, where average temperatures over 32 years were observed. The influence of temperature stress on date palm root rot depends on factors such as date palm variety, fungal species, and other environmental factors. By integrating temperature monitoring, predictive modeling, and a deep understanding of the correlation between root rot and temperature, an efficient forecasting system can be established. To effectively control date palm root rot, integrated management strategies that include cultural practices, fungicides, and the use of resistant varieties are likely to achieve the best results. This comprehensive approach addresses the various factors that contribute to date palm root rot, promoting sustainability, and protecting this important crop from the threats it faces.

KEYWORDS: Date palm root rot; temperature stress; forecasting model; disease severity; climate change.

ISSN: 2735–4709
https://jdea.journals.ekb.eg/

INTRODUCTION

Kharga Oasis is the largest oasis in Egypt's Western Desert, situated at 25°26′56″ N and 30°32′24″ E. It acts as the governorate's administrative center for the New Valley. Extreme dryness, high summertime daytime temperatures, and notable daily temperature variations define the oasis climate, low relative humidity, and high solar radiation **(Khalil & Gira, 2012)**. The date palm (*Phoenix dactylifera* L.) has played a prominent role in the culture, economy and agriculture of Egypt for thousands of years **(Soomro et al., 2023)**. However, several diseases, such as root rot caused by fungi, viz. *Fusarium* species, *Botryodiplodia theobromae*, *Thielaviopsis paradoxa*, and *Rhizoctonia solani*, present a threat to their cultivation **(Khan et al., 2023; Zakaria, 2023)**. According to previous research **(Alemayehu, 2023; Munier et al., 1973)**, high temperatures, almost no rainfall, and low humidity are the limiting factors for date palm cultivation. Predictive equations or forecast systems are usually constructed on initial levels of the inoculum or vector population or weather parameters. Prediction equations or forecasting systems are often developed based on variables such as the initial inoculum amount, the population of vectors or weather parameters **(Chakrabarti & Mittal, 2023).** These variables are used individually or in combination to develop forecasting systems and equations. The limitations of these systems have been discussed in the literature. **(Qu & Shi, 2023)** suggested that the potential movement of the infection chain from one stage to the next should be considered when predicting disease outbreaks. In addition, machine learning techniques have been explored to improve the predictive capabilities of climate and weather models **(De, et al., 2023).** Disease prediction is a system that allows more accurate prediction of the incidence or severity of a disease. Temperatures play a critical role in influencing plant diseases in temperate regions where there is a significant variation in seasonal and diurnal temperatures. Changes in temperature can directly affect the growth, survival, and reproduction of pathogens, as well as the susceptibility of host plants to disease. Studies have shown that warmer temperatures can increase the incidence and severity of diseases in both agricultural and wild plant systems **(Laine, 2023).** Furthermore, temperature changes can influence host-pathogen interactions, altering disease dynamics, and transmission rates **(Kirk et al., 2023)**. Some pathogens have been observed to be more aggressive and virulent at higher temperatures, leading to increased disease outbreaks **(Singh et al., 2023)**. Therefore, understanding the relationship between temperature and plant diseases is crucial to predict and managing disease risks in temperate regions **(Sbeiti et al., 2023)**. The forecast model can be used to predict the infestation of powdery mildew in grapes. In this context, this type of study also has environmental and quality implications, since it allows the application of a phytosanitary treatment if a real infection is detected **(Arafat, 2015).** Additionally, the measurement of chlorophyll in date palm leaves can serve as an indicator of leaf spot disease **(Arafat et al., 2021)**. Similarly, salinity can be used as a variable to indicate root rot disease in alfalfa **(Arafat et al., 2023).** These studies highlight the potential of using specific variables to predict and monitor different diseases in various crops, providing valuable information for disease management and improving environmental and quality implications in agriculture **(Kishi et al., 2023).** The impact of temperature stress on the severity of date palm root rot disease is a topic of interest in the field of agriculture. According to a study by **(EL-Morsi et al., 2012),** temperature stress can have a significant impact on the incidence and severity of date palm root rot disease. The study found that high temperatures can increase the incidence of the disease, while low temperatures can reduce it. Another study by **(EL-Morsi et al., 2015)** found that temperature stress can also affect the growth and development of date palm trees, which in turn affect their susceptibility to root rot disease. The impact of temperature stress on the severity of date palm root rot disease can be predicted by considering various factors. Studies have shown that increased temperature and low relative humidity can induce date bunch fading disorder (DBFD), which is associated with fruit wilting and damage to date palm products **(Preeti et al., 2023)**. Furthermore, fungal infections have been identified as probable factors contributing to DBFD **(Izadi & Shahsavar, 2015)**. Furthermore, the temperature and humidity conditions favor the development of a leaf spot caused by *Graphiola phaenicis*, which can lead to a reduction in the leaf area covered by the fungus **(Sattar et al., 2013)**. These findings suggest that temperature stress can exacerbate the severity of date palm disease caused by fungal pathogens **(Tilgam et al., 2024)**. However, more comprehensive research is needed to fully understand the molecular mechanisms underlying the response of date palms to pathogens during high temperature stress **(Cohen & Leach, 2020)**.

To predict the impact of temperature stress on the severity of date palm root rot disease, various methods can be used, such as statistical modeling, machine learning, or simulation. For example, data on the incidence of the disease under different temperature conditions can be collected and used to train a machine learning model. This model can then be used to predict the impact of temperature stress on the severity of the disease **(Baraka et al., 2011)**. By combining these approaches, researchers can gain insight into the relationship between temperature stress and the severity of date palm root rot disease, leading to improved prediction and potential treatment strategies. Therefore, a warning system based on environmental factors that affect pathogenic fungi could be a useful tool to assist farmers in controlling decisions. The purpose of this study was to determine which month the severity of palm disease will be higher and lower using equations in a simulation model with metrological data to determine the influence of temperature on disease severity in Egyptian conditions in Kharga Oasis is being investigated.

MATERIALS AND METHODS

Meteorological data and analysis: Meteorological data were collected from Kharga Oasis, in the New Valley governorate, Egypt, to examine the effect of global warning, the annual average temperature changes during the 32 years from 1988 to 2019 were analyzed using data download from the National Center for Environmental Information **(NCEI, 2019)** to calculate the correlation between the average air temperature (TAVG) and the severity of pathogenic fungi (DS%) that cause root rot disease in date palm trees.

Equation applied

The effect of average temperature on the percent of disease severity (DS%) of pathogenic fungi i.e., *F. oxysporum*, *F. moniliforme*, *F. solani*, *B. theobromae*, *T. paradoxa* and *R. solani* were estimated from (Baraka et al., 2011) using the equations in (Table 1).

Table (1): Equation of predication DS% for each pathogenic fungi caused root rot disease

Pathogenic fungi	Equation
F. oxysporum	DS% = -8.12889 + 1.20767*temp-0.0203333*temp^2
F. moniliforme	DS% = -12.7397 + 1.45698*temp-0.0239683*temp^2
F. solani	DS% = -4.53254 + 0.88246*temp-0.0143651*temp^2
B. theobromae	DS% = -11.0198 + 1.70683*temp-0.0314286*temp^2
T. paradoxa	DS% = -3.64048 + 1.17341*temp-0.0218254*temp^2
R. solani	DS% = -7.48492 + 1.03897*temp-0.017381*temp^2

Statistical analysis

Significant main effects and interactions were determined by the *F* test and multiple range tests. STATGRAPHICS software (Centurion XV Version 19.6. 2023 Stat Point, Inc.) was used for all statistical analyzes (Mead, 2017).

RESULTS

The present predicted results are statistically analyzed to illustrate the relationship between TAVG and date palm root rot DS%.

Yearly average temperature changes from 1988 to 2019

A review of meteorological parameters for 32 years (Fig. 1 and Table 2) shows that the mean TAVG is 25.670 °C, the minimum is 6.720, the first quartile (Q1) is 18.48, the median is 26.880, the third quartile (Q3) is 32.48 and the maximum 41.440 °C of annual average changes occurred in Kharga Oasis during 1988–2019.

Monthly Average Temperature Changes from 1988-2019

The maximum TAVG in August, July, June, and September of 32 years above 30 °C was recorded as 34.86, 33.42, 32.46 and 32.45 °C, respectively. While values below 30 °C were reached in October, May, November, and April the medium TAVG was 30.45, 29.07, 24.22 and 23.68 °C, respectively. Furthermore, the minimum TAVG that was below 20 °C in March December, January and February was recorded as 19.67, 18.41, 15.73 and 15.49 °C, respectively (Fig. 2).

Expected average temperature model in the Kharga Oasis, Egypt

The calculated correlation between monthly and average monthly temperature was carried out in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative monthly temperature correlations. The output shows the results of fitting a double reciprocal model to describe the relationship between TAVG (°C) and month.

The data in (Fig. 3) show that the double reciprocal model: Y = 1/ (a + b/X) has the highest percentage of predictions of the expected TAVG with month (r^2 = 42.48%) and (r^2 adjusted for d.f.= 42.33%). The regression equation of the double reciprocal model is TAVG (°C) = 1/ (0.0329348 + 0.0380587 / month). Since the p-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between TAVG (°C) and month at the 95.0% confidence level. The R-squared statistic indicates that the model as fitted explains 42.4822% of the variability in TAVG (°C). The correlation coefficient is 0.651784, indicating a moderately strong relationship between the variables. The standard error of the estimate shows that the standard deviation of the residuals is 0.0111921. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu. The mean absolute error (MAE) of 0.00871515 is the average value of the residuals.

Table (2): A statistical analysis of TAVG and DS% of root rot pathogenic fungi

Variable	Mean	Minimum	Q1	Median	Q3	Maximum	Variance	Lower Bound	Upper Bound
TAVG (°C)	25.670	6.720	18.480	26.880	32.480	41.440	.000	25.5324	25.8081
DS% F.o. vs (TAVG)	8.3146	-0.9316	7.2448	9.1693	9.6456	9.8031	.000	8.2815	8.3476
DS% F.m. vs (TAVG)	7.5011	-4.0312	5.9999	8.7554	9.2341	9.4014	.000	7.4582	7.5440
DS% F.s. vs (TAVG)	7.8357	0.7489	6.8695	8.6428	8.9424	9.0199	.000	7.8088	7.8625
DS% B.t. vs (TAVG)	10.2935	-0.969	9.467	10.853	11.736	12.152	.000	10.2588	10.3282
DS% T.p. vs (TAVG)	10.8553	3.259	10.154	11.303	11.796	12.131	.000	10.8321	10.8784
DS% R.s. vs (TAVG)	6.7417	-1.2879	5.7795	7.5362	7.9247	8.0407	.000	6.7127	6.7707

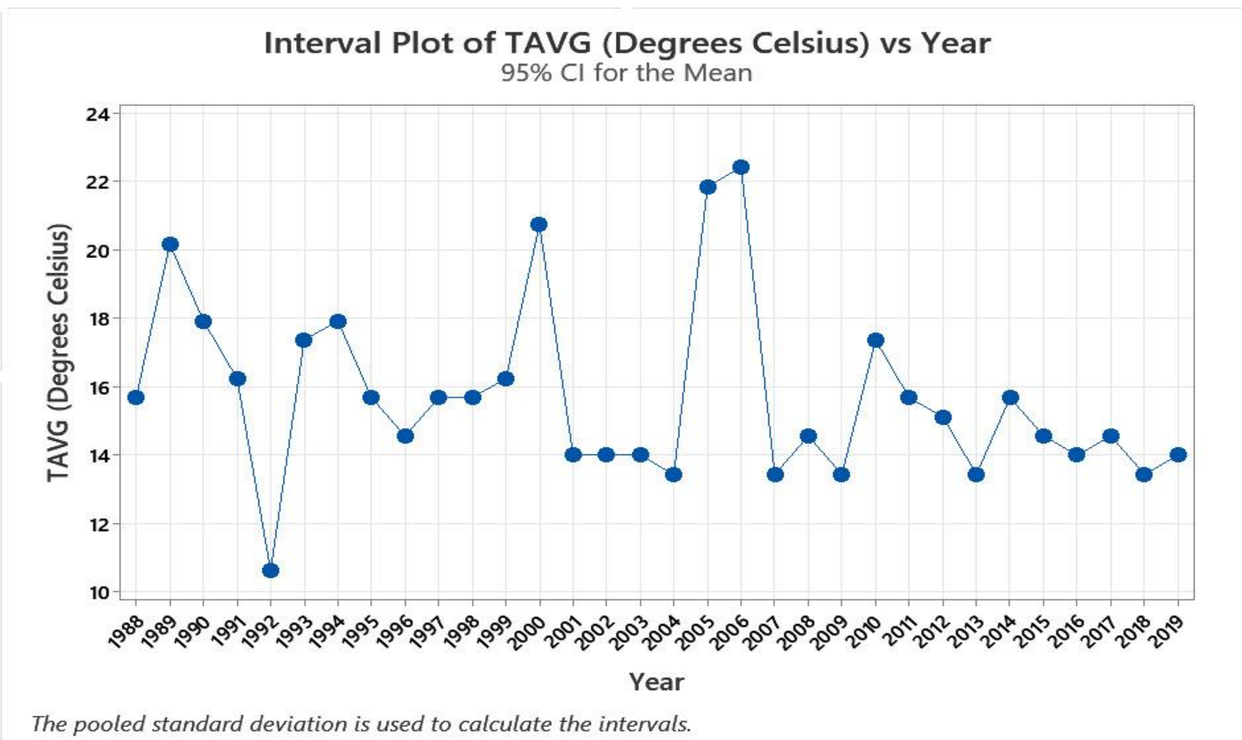

Figure (1): Average annual temperature changes in Kharga Oasis, Egypt, from 1988–2019

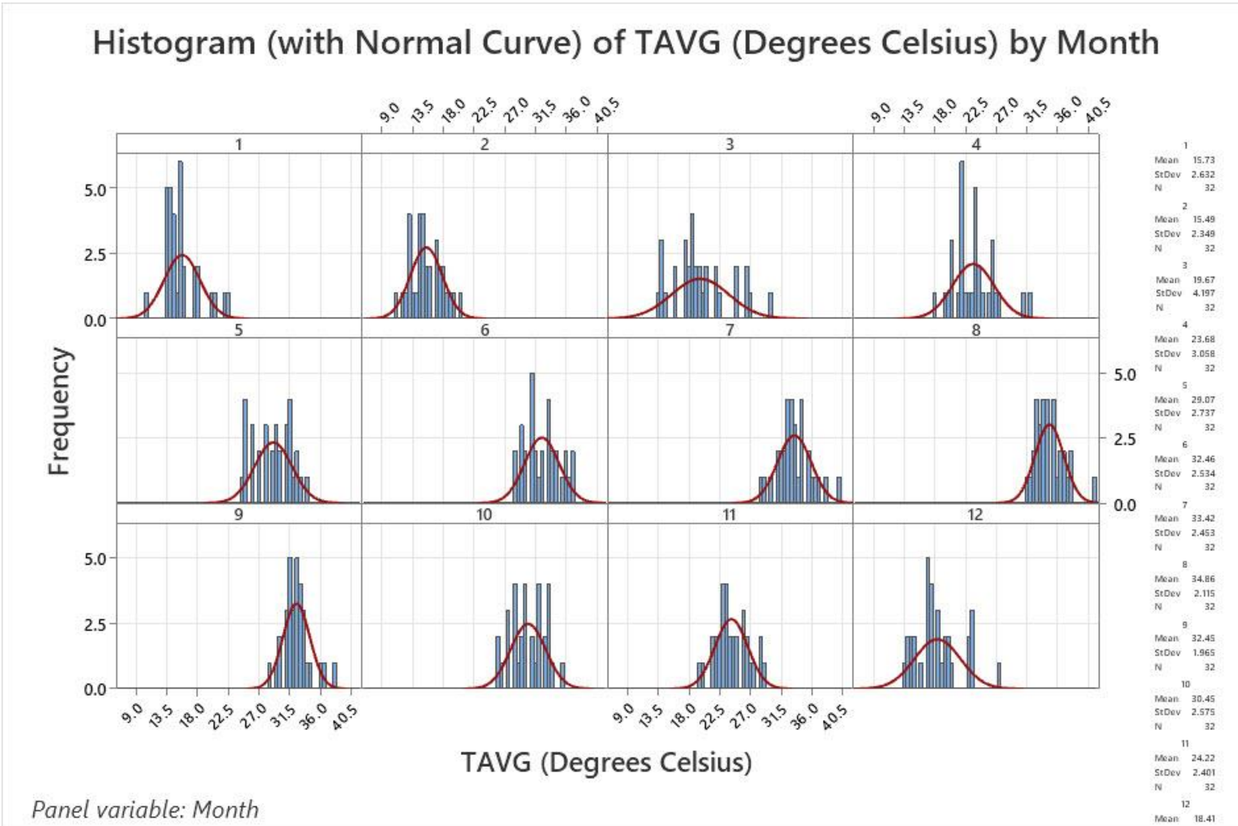

Figure (2): Monthly Average Temperature Changes in Kharga Oasis, Egypt from 1988–2019

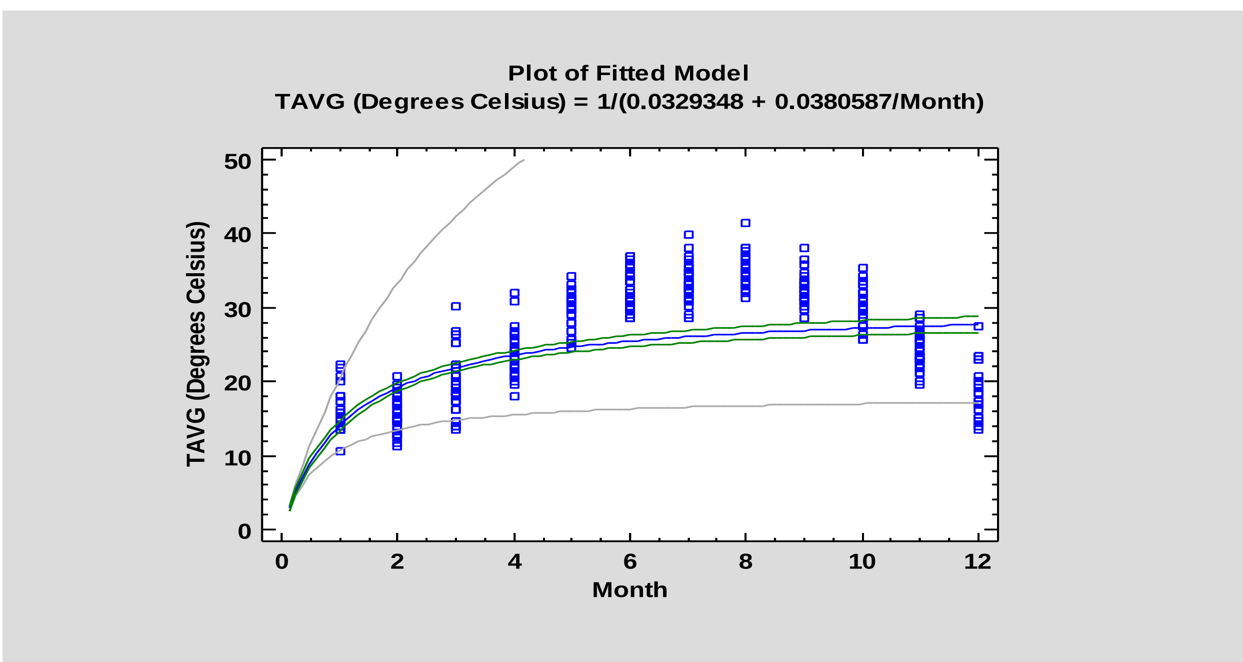

Figure (3): Expected average temperature model in the Kharga Oasis, Egypt
Prediction of DS% vs. TAVG models for date palm root rot diseases

The severity of root rot disease is influenced by the activity and growth rate of the causal pathogen. Different root rot pathogens have specific temperature ranges in which they thrive. Some pathogens can be more active and cause more severe disease symptoms under certain temperature conditions. The interaction between the date palm and the root rot pathogen is crucial to determine DS%. Temperature stress can weaken the defense mechanisms, making it more vulnerable to pathogen attack and subsequent disease development.

Relationship between DS% and TAVG of *F. oxysporum*

Relationship between mean DS% of *F. oxysporum* vs. yearly change of TAVG from 1988–2019

The effect of TAVG on the DS% of *F. oxysporum* was estimated for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 8.31%, the minimum was -0.93%, Q1 was 7.24%, the median was 9.17%, Q3 was 9.64% and the maximum was 9.80% of the annual average changes in Kharga Oasis, Egypt (Fig. 4 and Table 2).

Relationship between mean DS% of *F. oxysporum* vs. monthly change of TAVG from 1988 to 2019

The correlation between the mean DS% of *F. oxysporum* and the months 1988 to 2019 was shown in (Fig. 5). The months of October and May (9.66 and 9.65 DS%, respectively) had the highest mean DS%, followed by September, June and July (9.57, 9.52 and 9.40 DS%, respectively). On the contrary, the months of August, November, April, March and December had the moderate mean DS% (9.17, 9.08, 8.88, 7.41, and 6.99 DS%, respectively). Furthermore, January and February had the latest DS% (5.70 and 5.59 DS%, respectively).

Predictive model mean DS% of *F. oxysporum* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The output shows the results of the fitting of a reciprocal X model to describe the relationship between DS% *F. oxysporum* and TAVG (°C). The data in (Fig. 6) shows that the regression equation of the fitted model is DS% *F. oxysporum* VS (TAVG) = 13.0925–110.241/TAVG (°C). Since the p-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between DS% vs. TAVG °C at the 95.0% confidence level. The R-squared statistic shows that the fitted model explains 90.7716% of the variability in DS% vs. (TAVG). The correlation coefficient is–0.952741, indicating a relatively strong relationship between the variables. The standard error of the estimate shows that the standard deviation of the residuals is 0.549793. This value can be used to create prediction boundaries for new observations by selecting predictions from the text menu. The MAE of 0.435999 is the average value of the residuals. Since the p-value is less than 0.05, there is an indication of a possible serial correlation at the 95.0% confidence level.

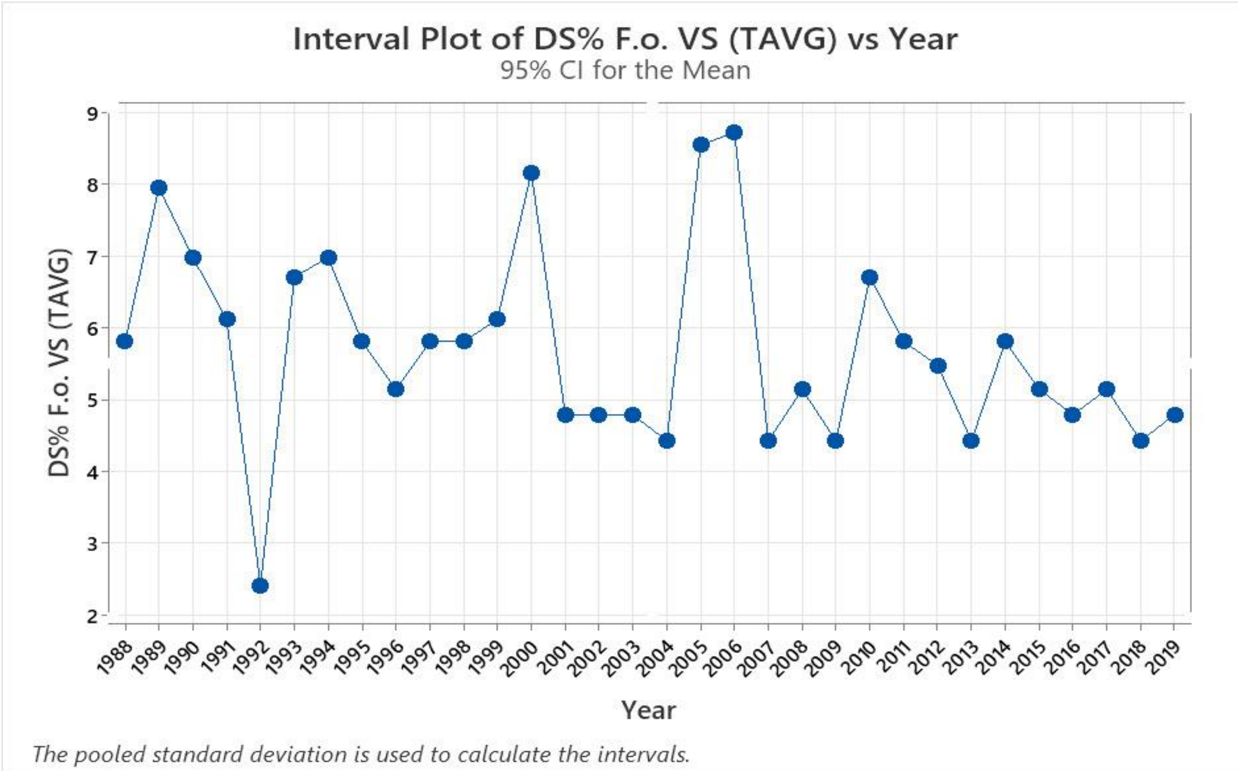

Figure (4): Changes in yearly mean DS% of F. oxysporum vs TAVG in Kharga Oasis, Egypt, from 1988–2019

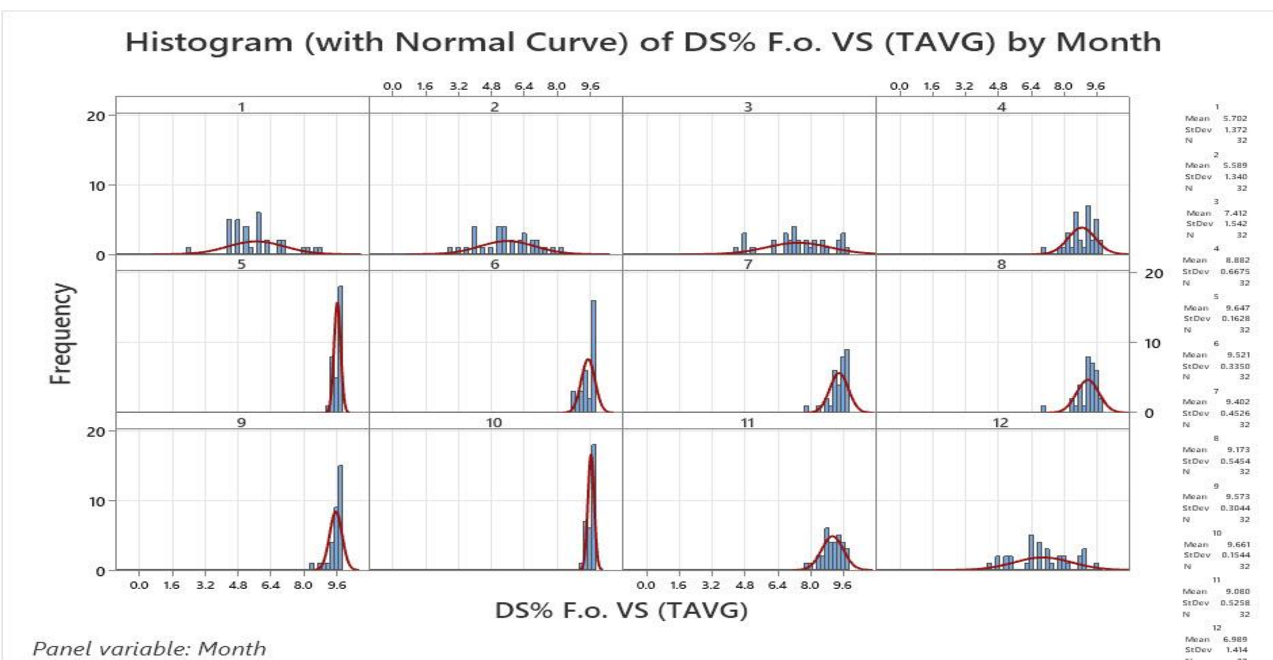

Figure (5): Monthly mean changes in DS% of *F. oxysporum* vs TAVG in Kharga Oasis, Egypt from 1988 to 2019

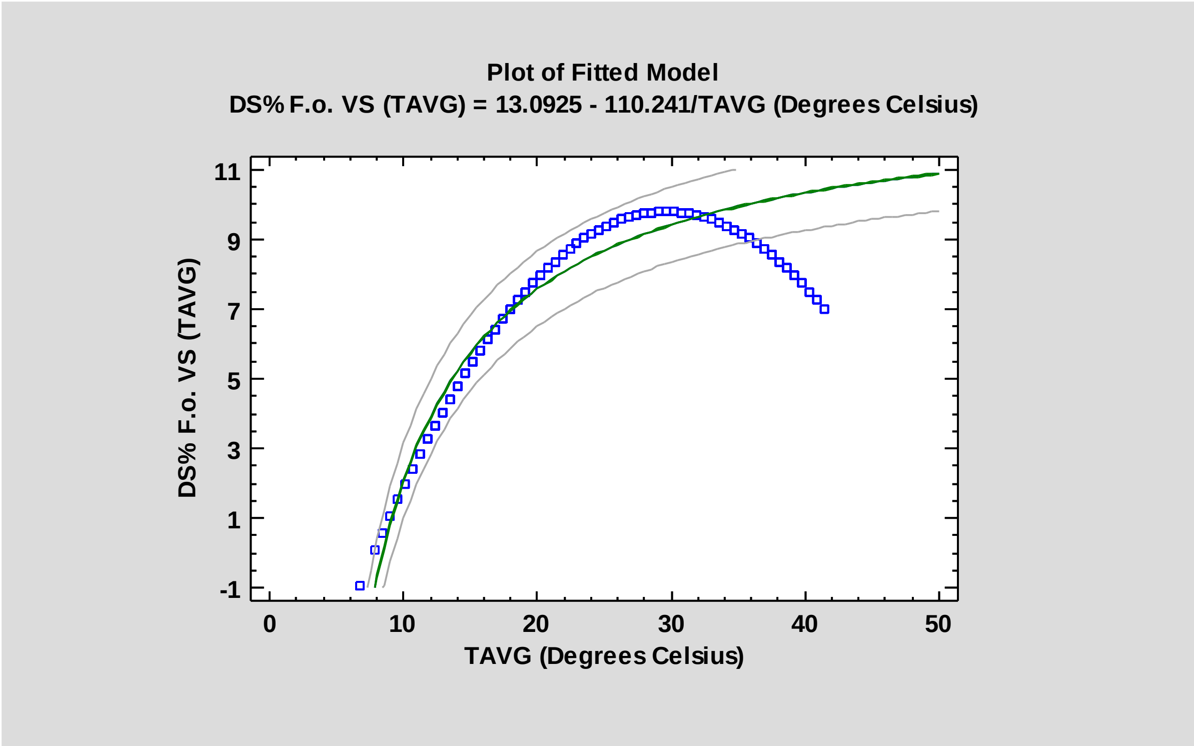

Figure (6): Predictive model mean of DS% of F. oxysporum in Kharga Oasis, Egypt

Relationship between DS% and TAVG of *F. moniliforme*

Relationship between mean DS% of *F. moniliforme* vs. yearly change of TAVG from 1988 to 2019

The effect of TAVG on the DS% of *F. moniliforme* was estimated for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 7.50%, the minimum was –4.03%, Q1 was 6.00%, the median was 8.75%, Q3 was 9.40% and the maximum was 9.40% of the annual average changes in Kharga Oasis, Egypt (Fig. 7 and Table 2).

Relationship between mean DS% of *F. moniliforme* vs. monthly change of TAVG from 1988–2019

The relationship between the mean DS% of *F. moniliforme* and the months 1988 to 2019 was shown in (Fig. 8). The highest mean DS% was recorded in the months of October, September, May, June and July (9.25, 9.21, 9.19, 9.15 and 9.04%, respectively), followed by August, November, April, and March (8.82, 8.35, 8.10 and 6.24%, respectively). The last mean DS% was in the months of December, January and February (5.70, 4.09 and 3.95%, respectively).

Predictive model mean DS% of *F. moniliforme* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The reciprocal X model fitting the relationship between DS% *F. moniliforme* and TAVG °C. yields a regression equation of DS% *F. moniliforme* VS (TAVG) = 13.7997–145.326/TAVG (°C) (Figure 9). The ANOVA table's P value being < 0.05 indicates a significant relationship between DS% *F. moniliforme* and TAVG °C at a 95.0% confidence level. The R-squared statistic of 93.6101% suggests that the model explains a substantial portion of the variability in DS% attributed to *F.*

moniliforme vs. TAVG. A high correlation coefficient of 0.967523 signifies a strong relationship between the variables. The standard error of the estimate, indicating a residual standard deviation of 0.593878, highlights the model's accuracy in predicting DS% *F. moniliforme* based on TAVG. This value can be used to create forecast boundaries for new observations by selecting Forecasts from the text menu. The MAE of 0.466561 is the average value of the residuals. Since the p-value is less than 0.05, there is an indication of a possible serial correlation at the 95.0% confidence level.

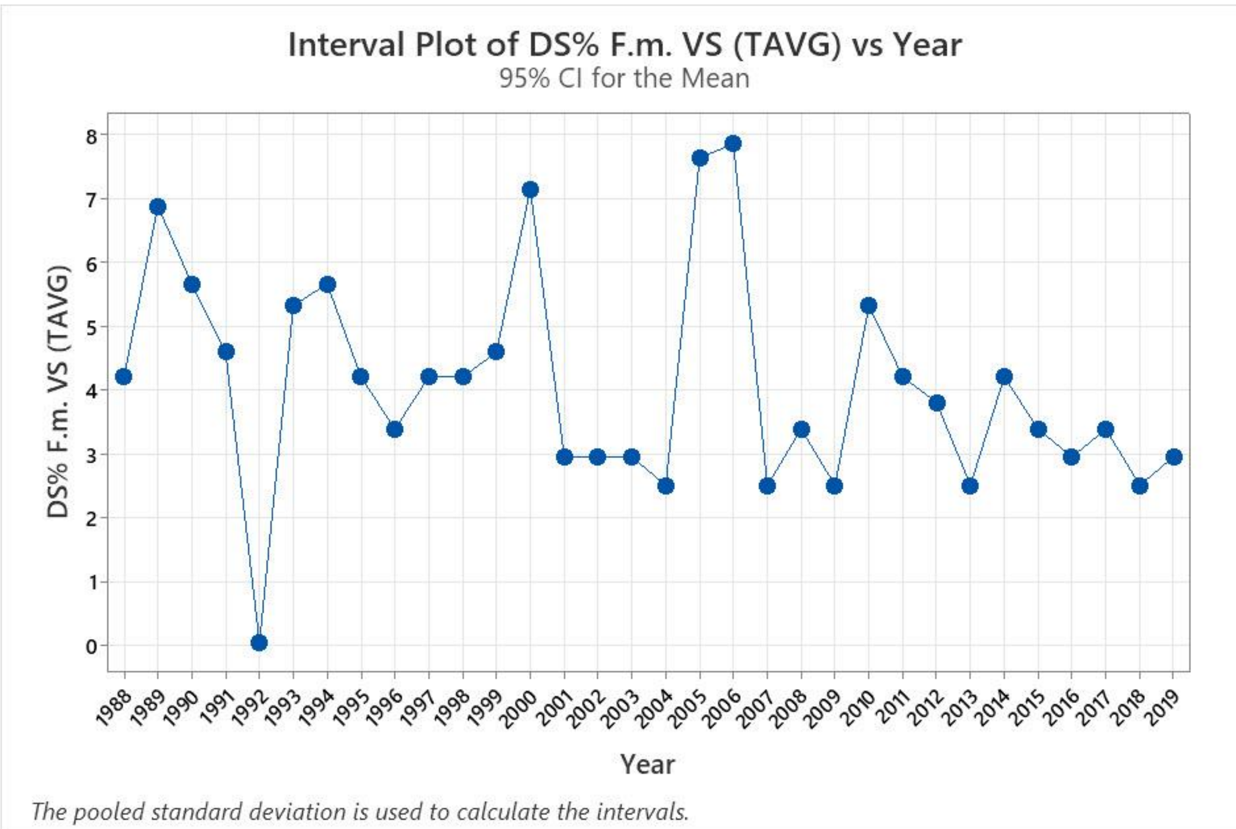

Figure (7): Changes in yearly mean DS% of F. moniliforme vs TAVG in Kharga Oasis, Egypt, 1988-2019

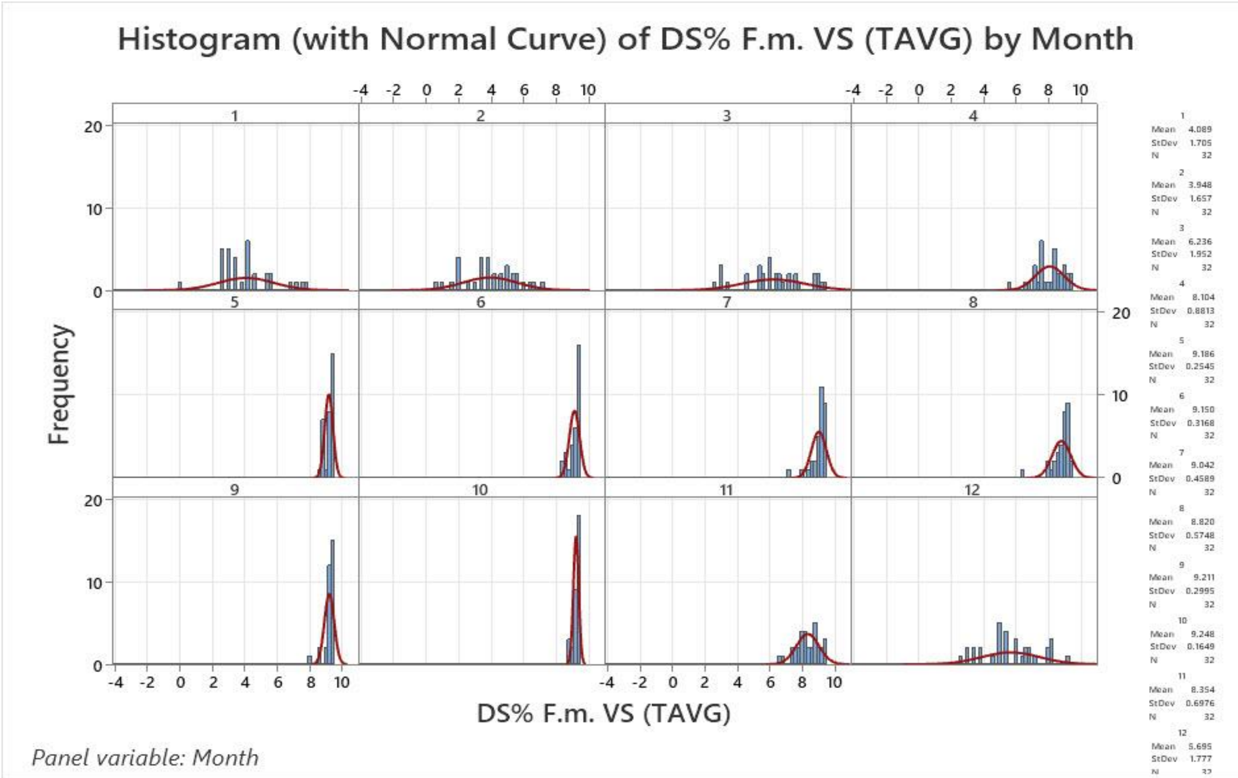

Figure (8): Monthly mean changes in DS% of *F. moniliforme* vs TAVG in Kharga Oasis, Egypt, from 1988–2019

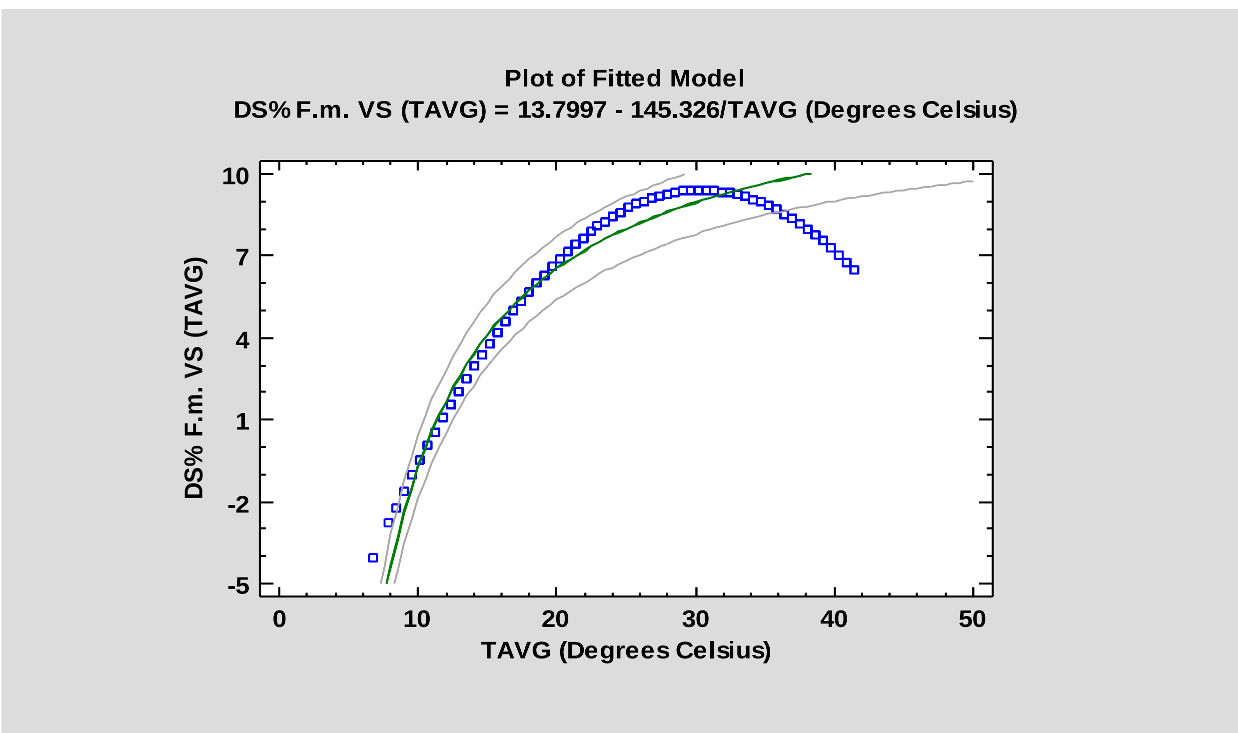

Figure (9): Predictive model mean of DS% of *F. moniliforme* in Kharga Oasis, Egypt

Relationship between DS% and TAVG of *F. solani*

Relationship between mean DS% of *F. solani* vs yearly change of TAVG from 1988 to 2019

The effect of TAVG on the DS% of *F. solani* was estimated for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 7.83%, the minimum was 0.75%, Q1 was 6.87%, the median was 8.64%, Q3 was 9.02% and the maximum was 9.02% of the annual average changes in Kharga Oasis (Fig. 10 and Table 2).

Relationship between mean DS% of *F. solani* vs. monthly change of TAVG from 1988 to 2019

The relationship between the mean DS% of *F. solani* and the months 1988 to 2019 was shown in (Fig. 11). The highest mean DS% was recorded in the months of October, September, June, May, July, August, November, and April (8.93, 8.92, 8.88, 8.88, 8.83, 8.71, 8.33 and 8.18%, respectively), followed by March and December (7.02 and 6.69%, respectively). The last mean DS% was in the months of January and February (5.70 and 5.61%, respectively).

Predictive model mean DS% of *F. solani* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The reciprocal X model is fitted to describe the relationship between DS% *F. solani* and TAVG °C. It shows a statistically significant relationship with a p-value less than 0.05. The model explains 94.5824% of the variability in DS% *F. solani* with a strong correlation coefficient of 0.977535. The standard error of the estimate of 0.34196 can be used to create prediction limits for new observations. The MAE of 0.267348 represents the average value of the residuals. Furthermore, the evidence of possible serial correlation at the 95.0% confidence level suggests an association between successive observations in the data.

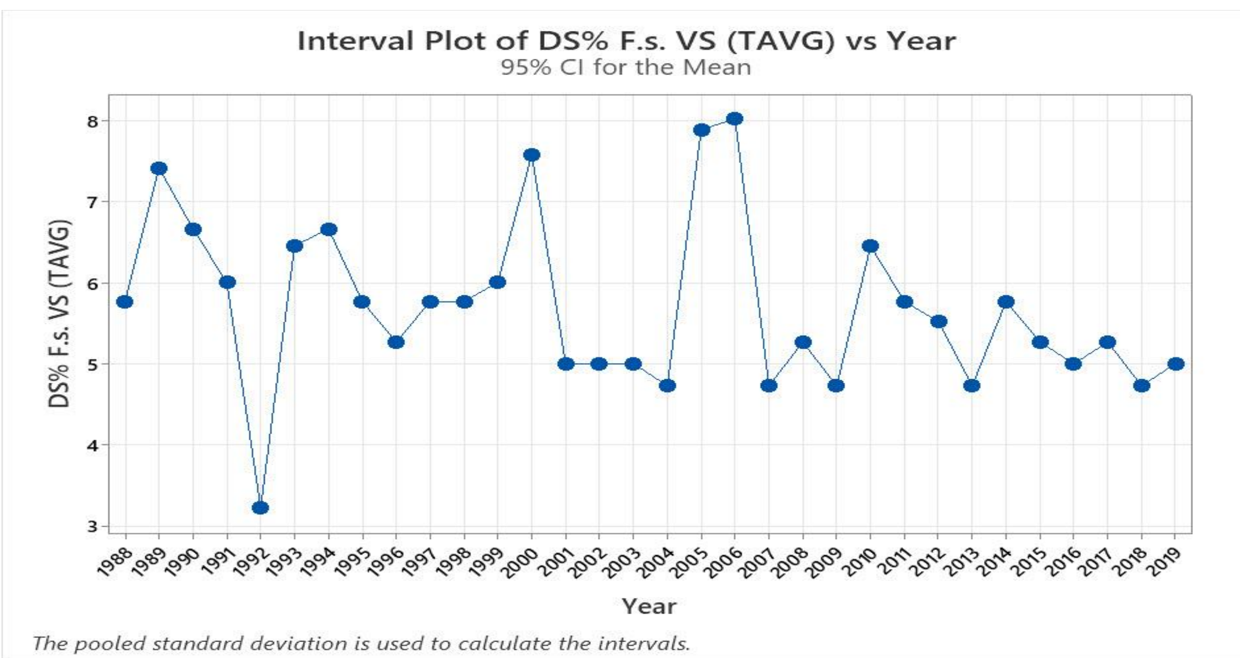

Figure (10): Changes in yearly mean DS% of F. solani vs TAVG in Kharga Oasis, Egypt, from 1988–2019

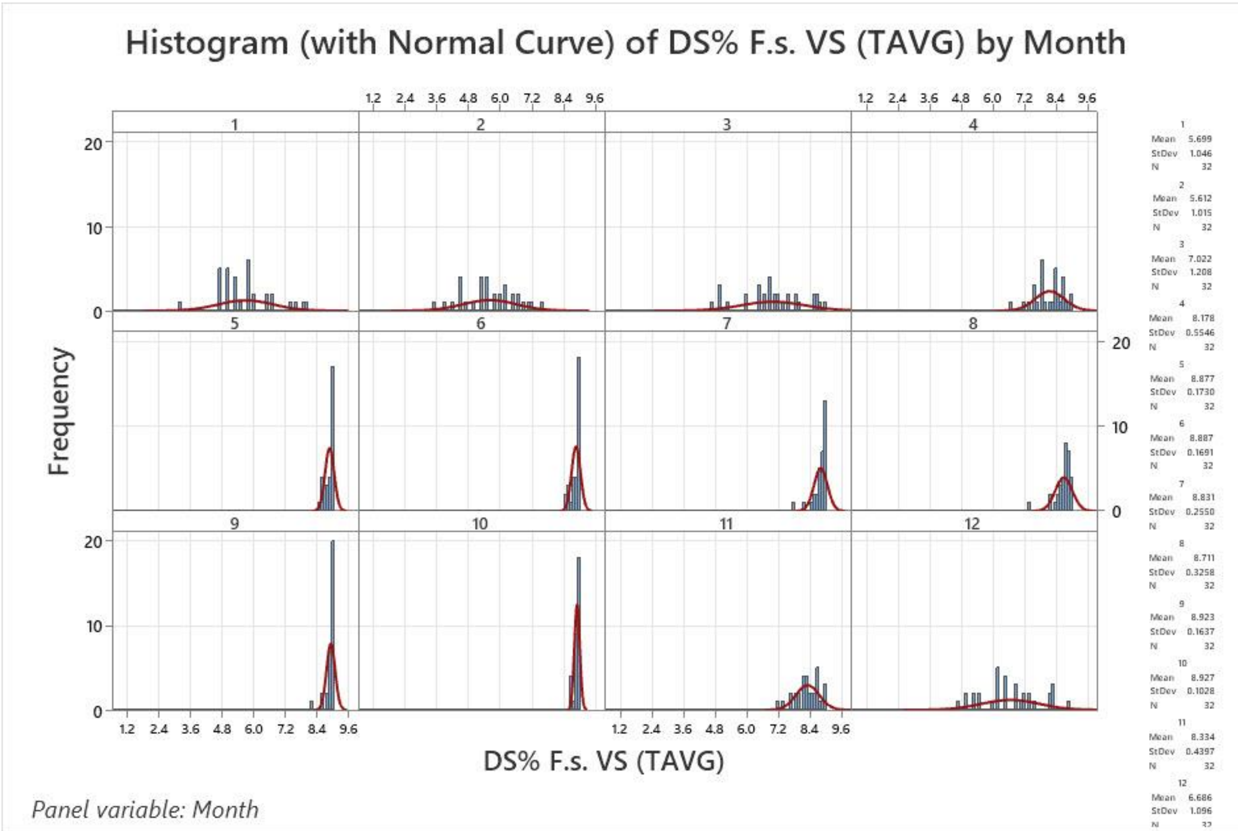

Figure (11): Monthly mean changes in DS% of F. solani vs TAVG in Kharga Oasis, Egypt, from 1988–2019

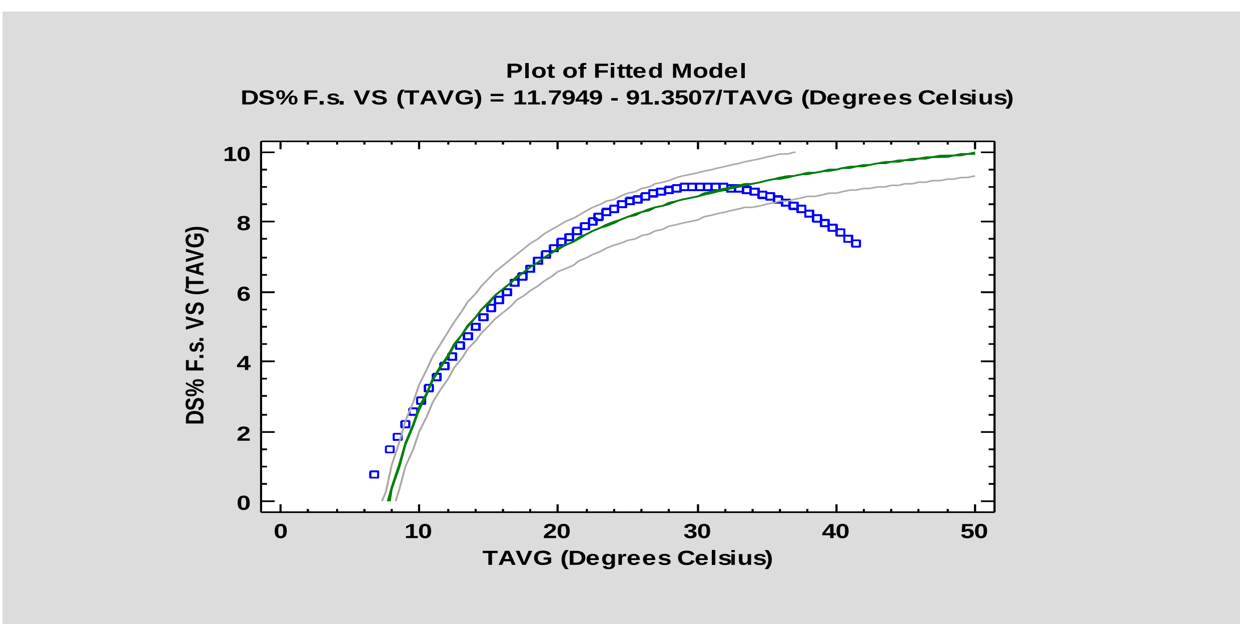

Figure (12): Predictive model mean of DS% of F. solani in Kharga Oasis, Egypt

Relationship between DS% and TAVG of *B. theobromae*

Relationship between mean DS% of *B. theobromae* vs. yearly change of TAVG from 1988–2019

The effect of TAVG on the DS% of *B. theobromae* for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 10.29%, the minimum was –0.97%, Q1 was 9.47%, the median was 10.85%, Q3 was 11.74% and the maximum was 12.15% of the annual average changes in Kharga Oasis (Fig. 13 and Table 2).

Relationship between mean DS% of *B. theobromae* vs. monthly change of TAVG from 1988 to 2019

The relationship between the mean DS% of *B. theobromae* and the months 1988 to 2019 was shown in (Fig. 14). The highest mean DS% was recorded in the months of May, November, October, April, September, and June (11.81, 11.71, 11.61, 11.49, 11.16 and 11.07, respectively). followed by July, August, March, and December (10.73 10.15, 9.86 and 9.40%, respectively). The last mean DS% was in the months of January and February (7.84 and 7.71%, respectively).

Predictive model mean DS% of *B. theobromae* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The output shows the results of fitting a reciprocal X model to describe the relationship between DS % ***B.*** *theobromae* vs. TAVG °C. The data in (Fig.15) shows that the regression equation of the fitted model is DS% ***B.*** *theobromae* vs. (TAVG) = 14.4906–96.8386/TAVG (°C). Since the P-value in the ANOVA Table is less than 0.05, there is a statistically significant relationship between DS% ***B.*** *theobromae* vs. TAVG °C at the 95.0% confidence level. The R-squared statistic indicates that the model as fitted explains 63.5972% of the variability in DS% ***B.*** *theobromae* vs. (TAVG). The correlation coefficient of 0.9797478 suggests a moderately strong relationship between the variables. The standard error of the estimate, which gives a remaining standard deviation of 1.14595, can be used to set forecast boundaries for new observations by selecting Forecasts from the text menu. Furthermore, the mean absolute error (MAE) of 0.926336 represents the average value of the residuals. Since the p-value is less than 0.05, there is an indication of a possible serial correlation at the 95.0% confidence level.

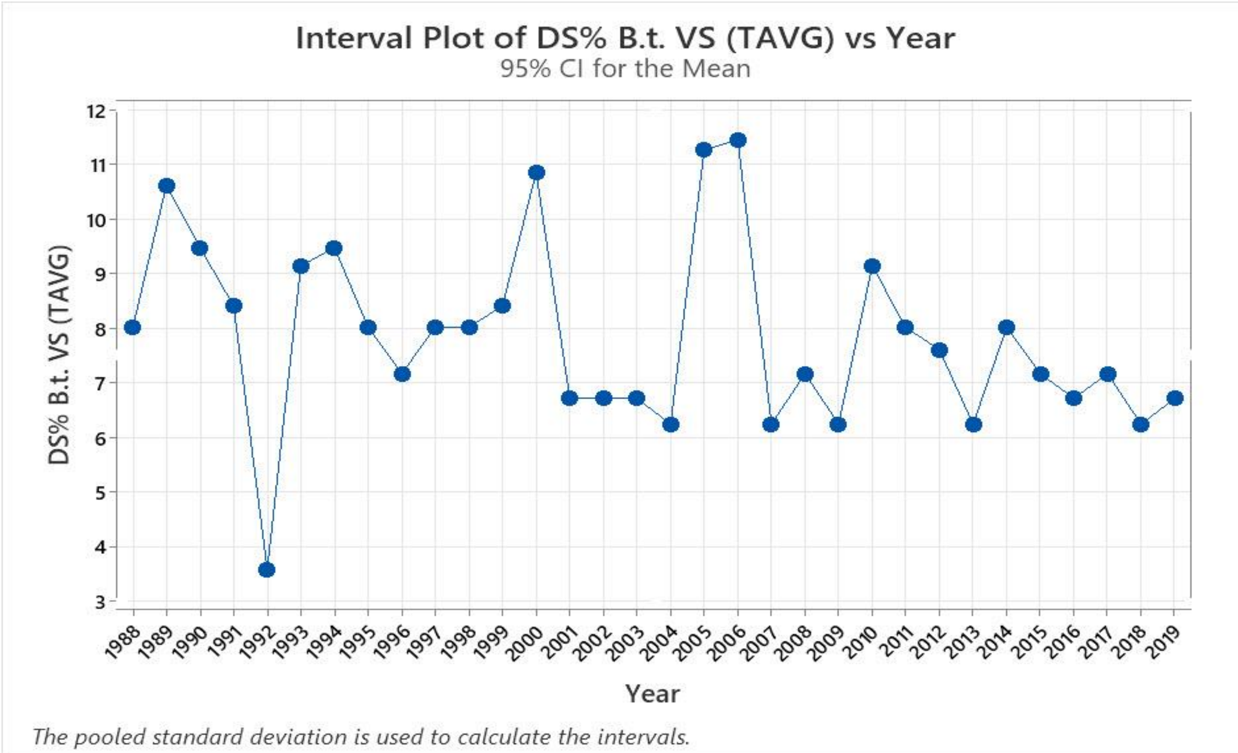

Figure (13): Changes in yearly mean DS% of B. theobromae vs TAVG in Kharga Oasis, Egypt, from 1988–2019

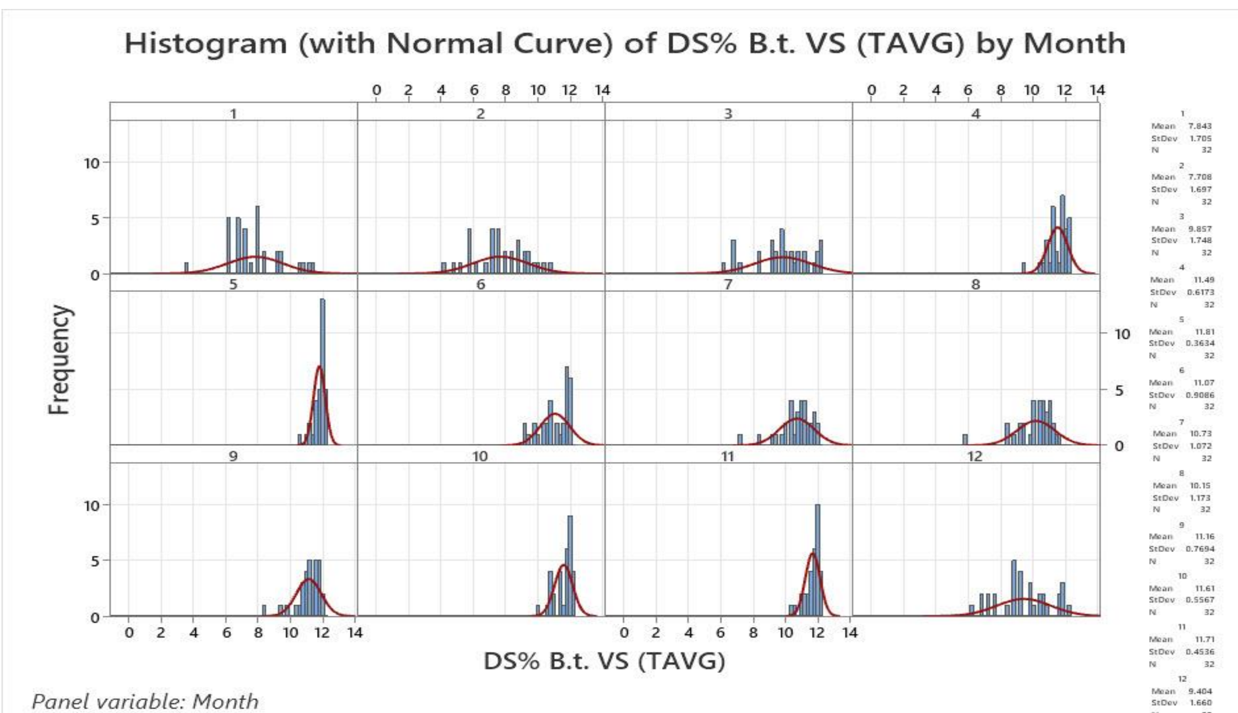

Figure (14): Monthly mean changes in DS% of B. theobromae vs TAVG in Kharga Oasis, Egypt, from 1988–2019

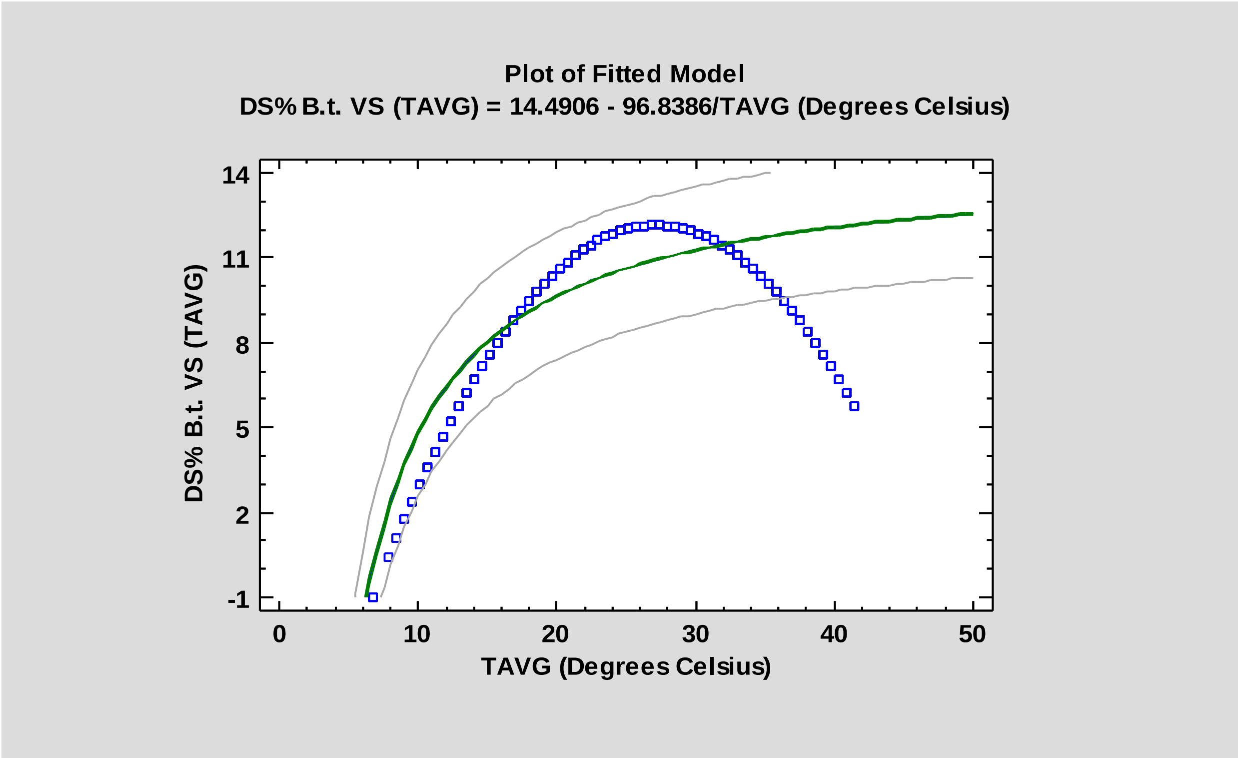

Figure (15): Predictive model mean of DS% of B. theobromae in Kharga Oasis, Egypt

Relationship between DS% and TAVG of *T. paradoxa*

Relationship between mean DS% of *T. paradoxa* vs yearly change of TAVG from 1988–2019

The effect of TAVG on the DS% of *T. paradoxa* was estimated for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 10.85%, the minimum was 3.26%, Q1 was 10.15%, the median was 11.30%, Q3 was 11.80% and the maximum was 12.13% of the annual average changes in Kharga Oasis (Fig. 16 and Table 2).

Relationship between mean DS% of *T. paradoxa* vs. monthly change of TAVG from 1988 to 2019

The relationship between the mean DS% of *T. paradoxa* and the months 1988 to 2019 was shown in (Fig. 17). The highest mean DS% was recorded in the months of May, November, October, April, September, June, and July (11.87, 11.85, 11.71,11.71, 11.37, 11.32 and 11.07%, respectively). followed by August, March, and December (10.65, 10.62 and 10.32%, respectively). The last mean DS% was in the months of January and February (9.27 and 9.18%, respectively).

Predictive model mean DS% of *T. paradoxa* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The output shows the results of fitting a reciprocal X model to describe the relationship between DS % *T. paradoxa* vs. TAVG °C. The data in (Fig. 18) showed that the regression equation of the fitted model is DS% *T. paradoxa* VS (TAVG) = 1/ (0.0633716 + 0.700049/TAVG (°C). Since the p-value in the ANOVA Table is less than 0.05, there is a statistically significant relationship between *T. paradoxa* vs. TAVG (°C) at the 95.0% confidence level. The R-squared statistic indicates that the model as fitted explains 60.4569% of the variability in DS% *T. paradoxa* vs. (TAVG). The correlation coefficient is 0.77754, indicating a moderately strong relationship between the variables. The standard error of the estimate shows that the standard deviation of the residuals is 0.0088554. This value can be used to construct prediction limits for new observations by selecting the forecasts option from the text menu. The MAE of 0.00669773 is the average value of the residuals. Since the p-value is less than 0.05, there is an indication of a possible serial correlation at the 95.0% confidence level.

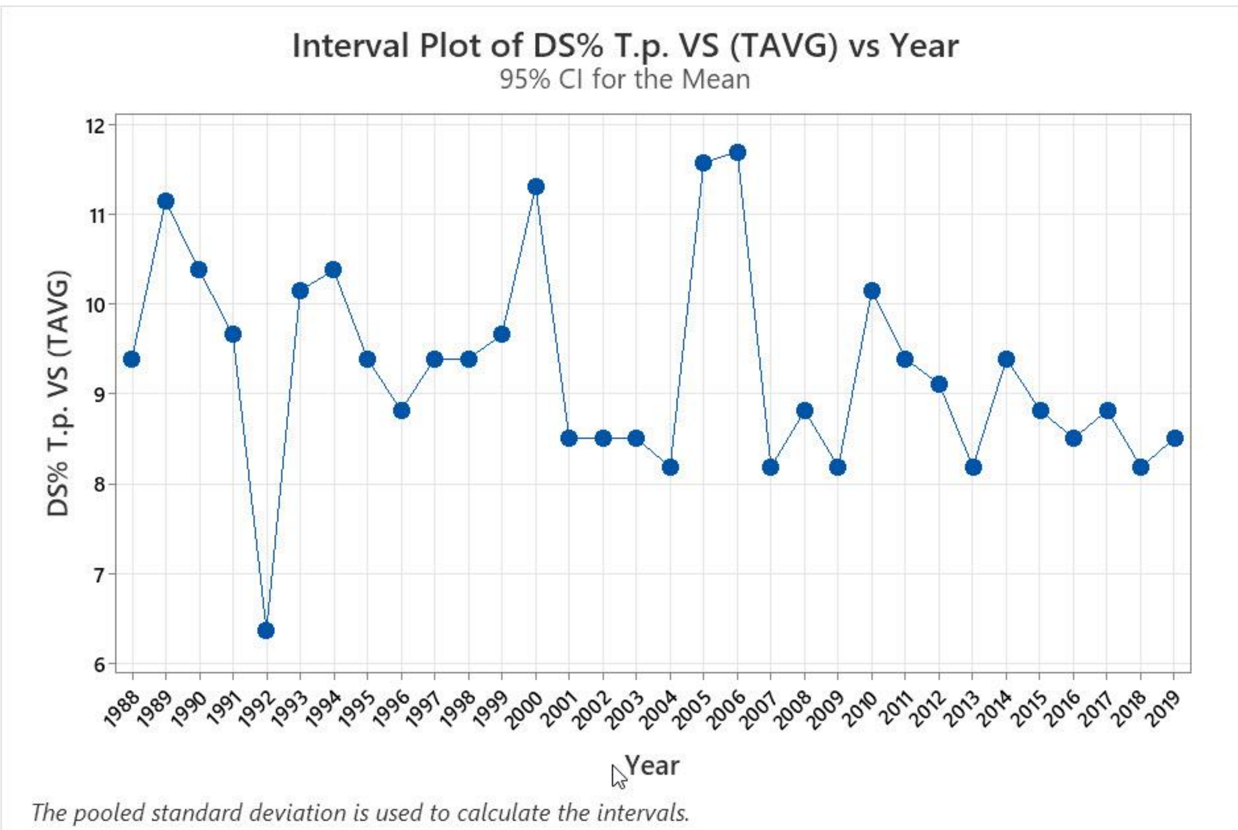

Figure (16): Changes in yearly mean DS% of T. paradoxa vs TAVG in Kharga Oasis, Egypt, from 1988–2019

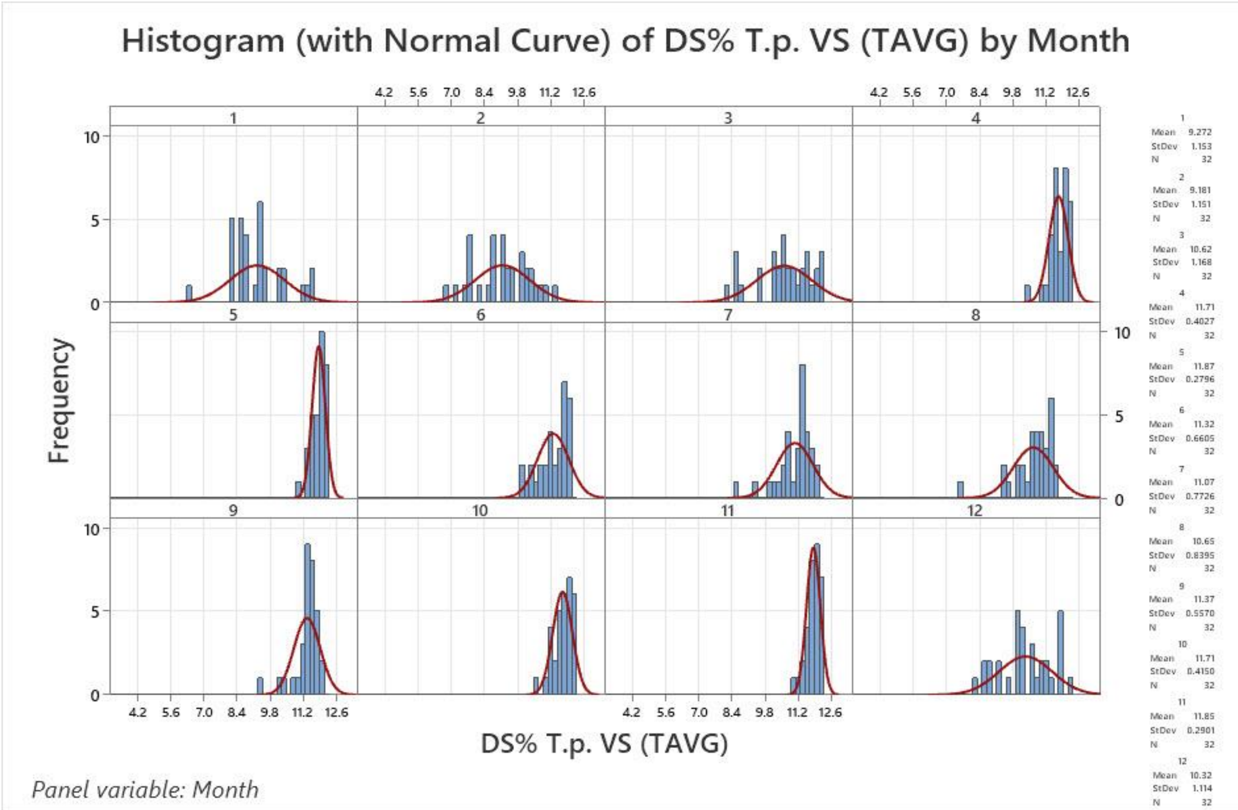

Figure (17): Monthly mean changes in DS% of T. paradoxa vs TAVG in Kharga Oasis, Egypt, from 1988–2019

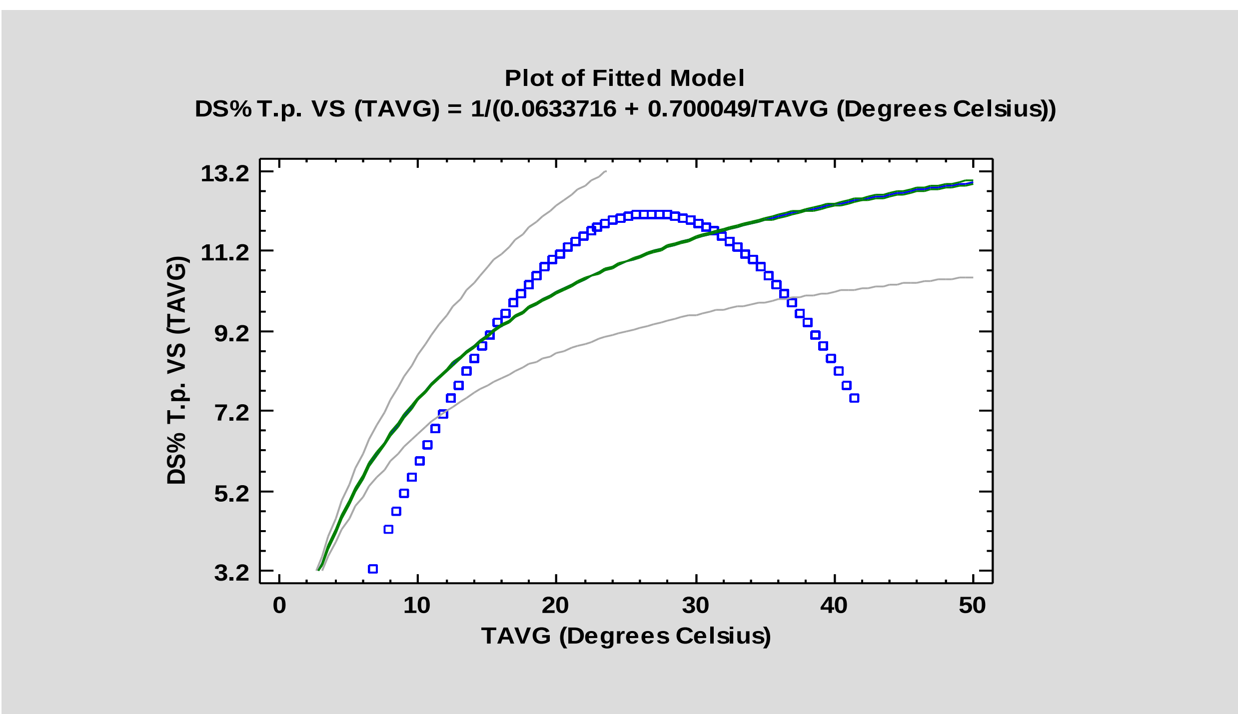

Figure (18): Predictive model mean of DS% of *T. paradoxa* in Kharga Oasis, Egypt

Relationship between DS% and TAVG of *R. solani*

Relationship between mean DS% of *R. solani* vs yearly change of TAVG from 1988 to 2019

The effect of TAVG on the DS% of *R. solani* was estimated for Kharga Oasis. Annual changes in mean DS% versus TAVG were analyzed from 1988 to 2019. The mean DS% was 6.74%, the minimum was –1.29%, Q1 was 5.78%, the median was 7.54%, Q3 was 7.92% and the maximum was 8.04% of the annual average changes in Kharga Oasis (Fig. 19 and Table 2).

Relationship between mean DS% of *R. solani* vs. monthly change of TAVG from 1988 to 2019

The relationship between the mean DS% of *R. solani* and the months 1988 to 2019 was shown in (Fig. 20). The highest mean DS% was recorded in the months of October, May, September, June, July, August, November, and April (7.92, 7.90, 7.86, 7.82, 7.72, 7.547.39 and 7.21%, respectively). followed by March and December (5.93 and 5.56%, respectively). The last mean DS% was in the months of January and February (4.44 and 4.34%, respectively).

Predictive model mean DS% of *R. solani* in Kharga Oasis, Egypt

The calculated correlation between mean DS% and TAVG was conducted in Kharga Oasis from 1988 to 2019 and identified regions with positive and negative mean correlations of DS% and TAVG. The output shows the results of fitting a reciprocal X model to describe the relationship between DS % *R. solani* vs. TAVG (°C). Data in (Fig. 21) showed that the regression equation of the fitted model is DS% *R. solani* vs. (TAVG) = 10.9585–97.2938/TAVG (°C). Since the P value in the ANOVA Table is less than 0.05, there is a statistically significant relationship between DS% *R. solani* vs. TAVG (°C) at the 95.0% confidence level. The R-squared statistic indicates that the model as fitted explains 91.666% of the variability in DS% *R. solani* vs. (TAVG). The correlation coefficient of -0.957423 suggests a strong negative relationship between the variables. The standard error of the estimate, indicating a residual standard deviation of 0.458856, can be utilized to establish forecast boundaries for new observations by selecting the Forecasts option from the text menu. Furthermore, the Mean Absolute Error (MAE) of 0.363055 represents the average value of the residuals. Since the p-value is less than 0.05, there is an indication of a possible serial correlation at the 95.0% confidence level.

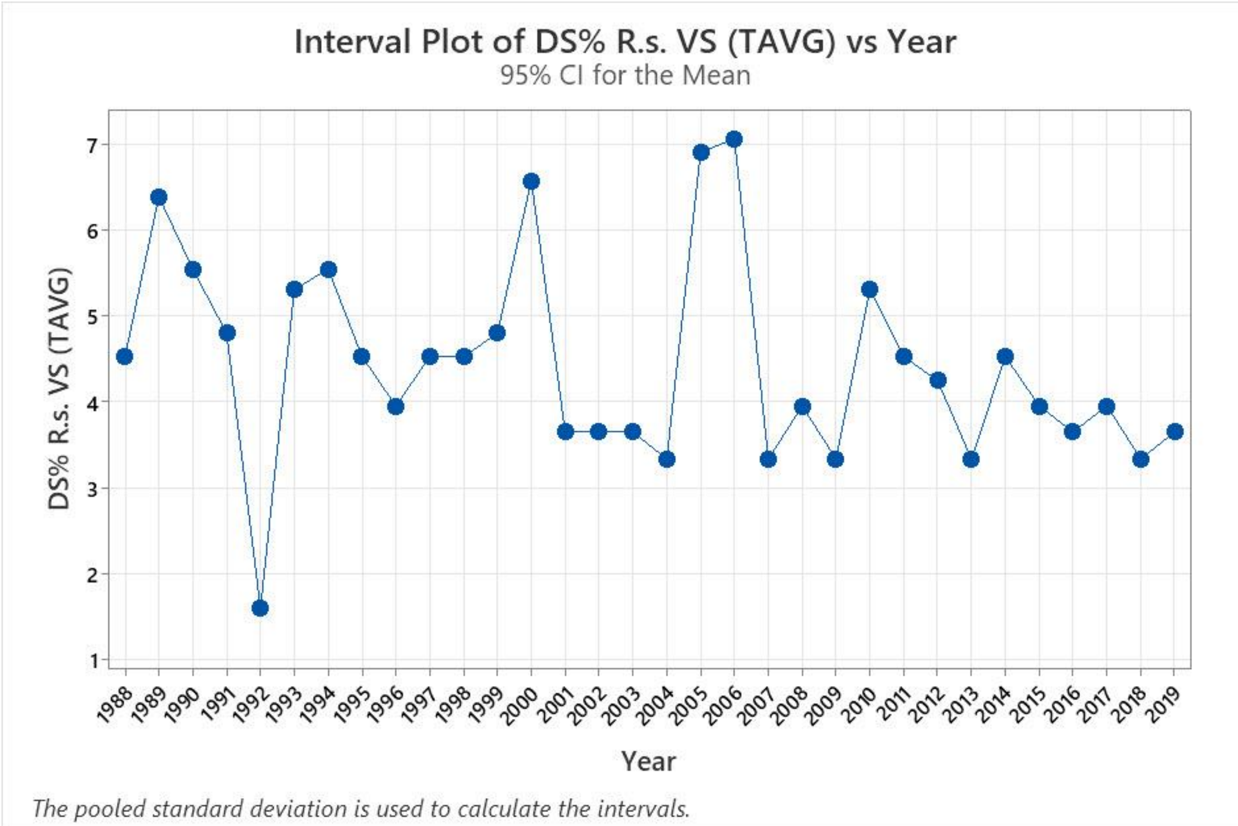

Figure (19): Changes in yearly mean DS% of *R. solani* **vs** TAVG in Kharga Oasis, Egypt, from 1988–2019

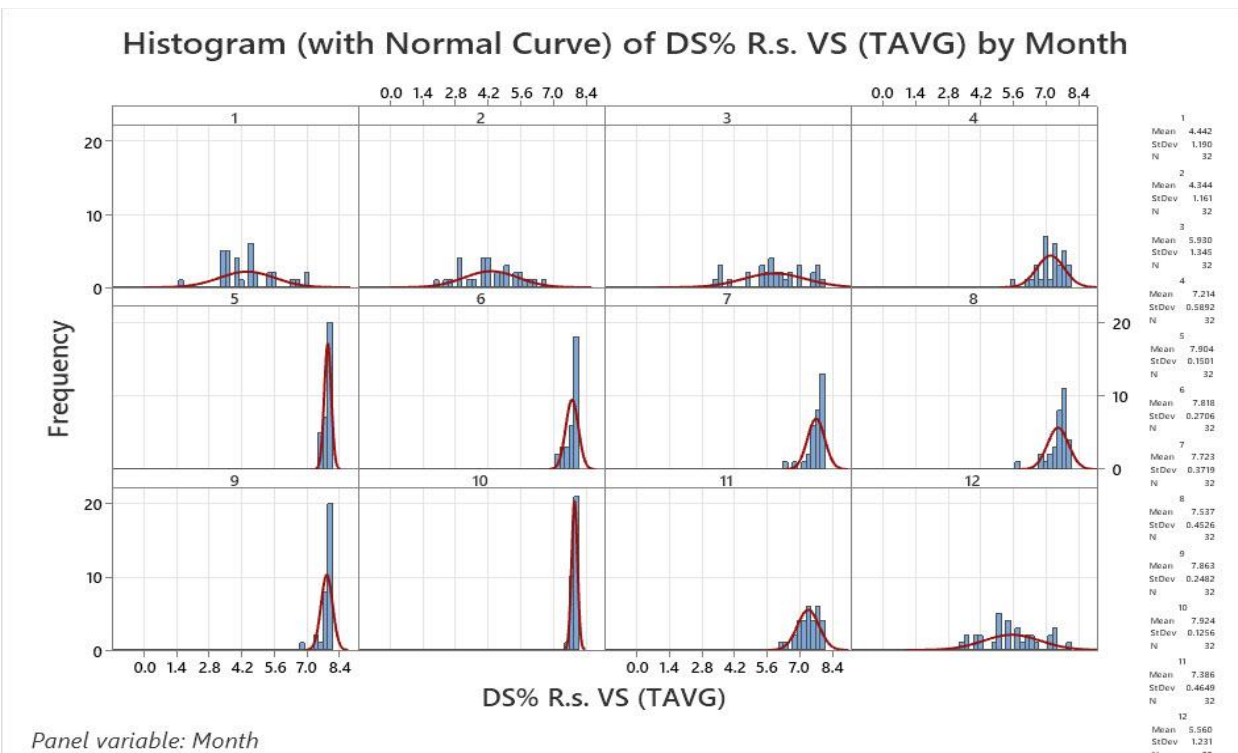

Figure (20): Monthly mean changes in DS% of R. solani vs TAVG in Kharga Oasis, Egypt, from 1988–2019

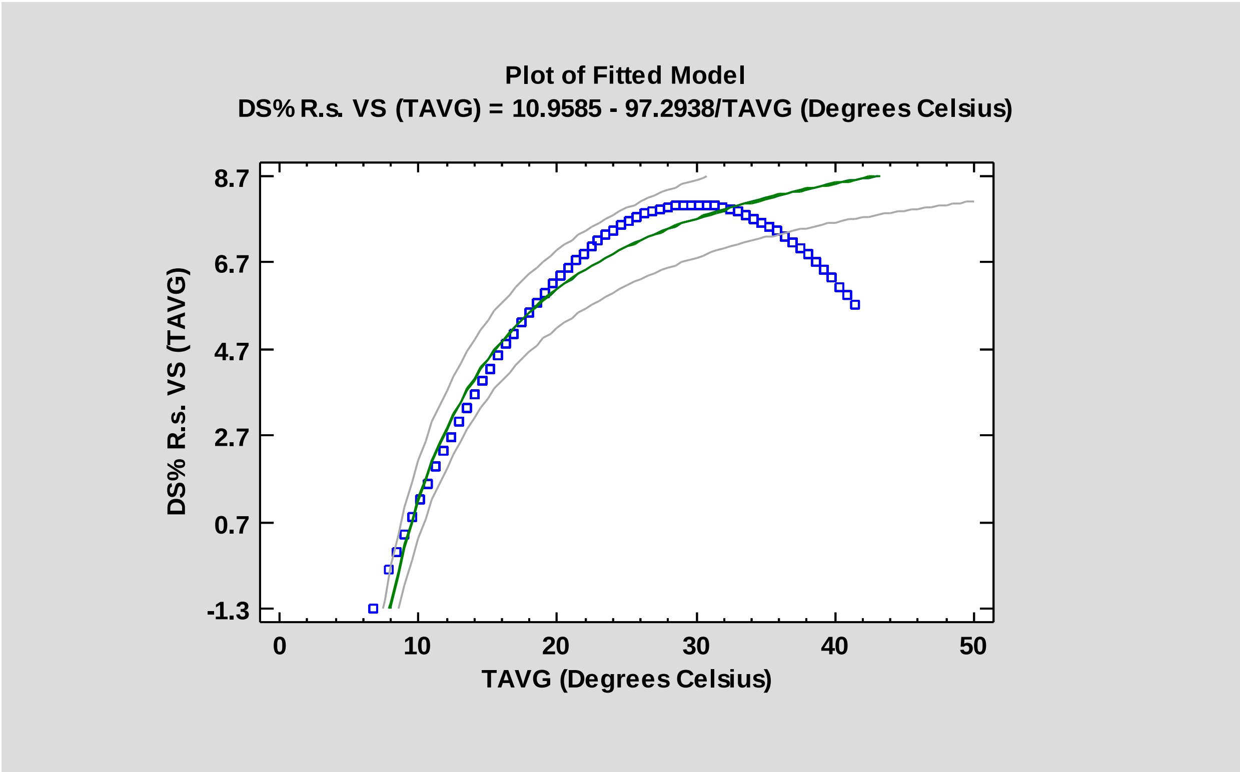

Figure (21): Predictive model mean of DS% of R. solani in Kharga Oasis, Egypt

DISCUSSION

In many arid and semi-arid regions, date palms are an important crop that provides food, income, and cultural significance. However, several diseases, such as root rot caused by fungi like *Fusarium* species, *Botryodiplodia theobromae*, *Thielaviopsis paradoxa*, and *Rhizoctonia solani*, pose a threat to their cultivation.

According to an analysis of annual temperature changes from 1988 to 2019, there were several reasons that contributed to the increase in temperature in Kharga Oasis, Egypt, between 1988 and 2019. The mean annual temperature of 25,670 °C indicates a warm, dry climate typical of desert regions. The wide range between the minimum (6,720 °C) and the maximum (41,440 °C) suggests significant temperature fluctuations during cold and extremely hot periods. The first quartile (18.48 °C) means that in 25% of the years the average temperatures were below this value. The third quartile (32.48 °C) means that in 75% of the years the average temperatures were below this point. The median tells us that half of the years were colder than 26,880 °C and the other half were warmer. It would be interesting to analyze these data in the context of longer-term climate trends to see if there are signs of warming over time. Breaking down the data by month or season could reveal more detailed patterns of temperature fluctuations. The data clearly show that August, July, June and September are consistently the hottest months of the year. During these months, maximum temperatures regularly exceed 30 °C, suggesting that heat waves or prolonged periods of heat are likely to be commonplace. October and May serve as transition months between warmer and cooler periods. Their average temperatures are just below 30 °C, suggesting a greater mix of warmer and cooler days. Cooler months: There are significantly cooler temperatures from November to April. Their average temperatures drop below 30 °C, and even their minimum temperatures fall below 20 °C in the coldest months (December, January and February). The fitted model accurately captured the seasonal pattern of the average temperature. Seasonal temperature fluctuations have an amplitude of around 14 °C. This suggested that the summer temperatures in the Kharga Oasis are typically 14 °C higher than the winter temperatures. According to the model, the average temperature in April will be around 22 °C. This was consistent with the observed data, suggesting that the average temperature begins to rise in April. It is important to remember that this model simplifies reality. A variety of other variables can also affect the average temperature in Kharga Oasis, including cloud cover, wind speed, and precipitation. However, it provides a practical way to summarize the relationship between average temperature and the month of the year. Overall, the data suggest that the average temperature of the Kharga Oasis follows a clear seasonal pattern that faithfully reflects the fitted model. The model can be used to make predictions about the average temperature in different months of the year. The model prediction type was double reciprocal. The model explains 42.48% of the variability in TAVG with a correlation coefficient of 0.651784. This means a moderately strong relationship between temperature and month of the year. The model confirms that the temperature in the Kharga Oasis fluctuates throughout the year. This pattern is consistent with the expectations of seasonal temperature changes. Although the model captures a significant portion of the temperature fluctuations, it is important to remember that approximately 58% of the fluctuations remain unexplained. In addition to the month of the year, other factors also influence the temperatures in the region. This model can be used to predict the expected (TAVG) for a specific month. The p-value is less than 0.05, which confirms a statistically significant relationship between TAVG and month. The correlation coefficient of 0.651784 indicates a moderately strong positive relationship between TAVG and month (i.e., temperatures tend to increase over the months). However, it is important to note the standard error of the estimate (0.0111921), which indicates some degree of uncertainty in individual predictions. These results aligned with the findings of (Afify et al., 2023; Bank, 2021; Kimura et al., 2020), who stated that Egypt's annual mean temperature is predicted to rise from 1 °C to 5 °C by the 2080s based on analysis of 32 Global Climate Models (GCM) by the German Climate Service Center (GERICS). By the 2080s, maximum temperatures are predicted to rise by 2 °C to 5 °C, while minimum temperatures are predicted to rise by 1 °C to 4 °C during that time. Cold spells will decrease while heat waves will increase significantly in severity, frequency, and duration. Heat waves are predicted to last an extra 9 to 77 days. Temperature increases are predicted to range from 2 °C to 3 °C by the middle of the century, with the highest increases occurring in the summer months of July through September and the fastest increases occurring in the interior regions of the nation.

The results of the relationship between the mean DS% of *F. oxysporum* and the annual change in TAVG from 1988 to 2019 show that the average DS% of *F. oxysporum* in Kharga Oasis, Egypt, has increased over time. The 95% confidence intervals for the mean also show that the DS% *F. oxysporum* varies widely. Values from year to year. The average DS% value of *F. oxysporum* has increased from about 3.5 in 1988 to about 7.5

in 2019. The 95% confidence intervals for the mean are widest in the early years of the graph and narrow in later years. This suggests that the DS% values of *F. oxysporum* fluctuated more in the early years of the study than in the later years. There are some years in which the 95% confidence intervals for the mean do not overlap. This means that the average value of DS% *F. oxysporum* in these years was statistically different from the average DS% *F. oxysporum* value in other years. The relationship between the mean DS% of *F. oxysporum* and the monthly change in TAVG from 1988 to 2019 shows a slight upward trend in the DS% values of *F. oxysporum* over time. This means that the average DS% *F. oxysporum* value for each month was higher in the later years than in the earlier years. There appears to be a seasonal pattern in the data, with *F. oxysporum* levels peaking in the summer months (June to August) and being lower in the winter months (December to February). The data vary greatly, both between months and between years. This means that the DS% *F. oxysporum* value for a given month can vary significantly from year to year. The model demonstrates a statistically significant negative relationship between mean DS% of *F. oxysporum* and TAVG in Kharga Oasis. This means that as average temperatures increase, the disease severity of *F. oxysporum* tends to decrease. The data fit well to a reciprocal X model. This type of model is used when the relationship between variables is not linear, but rather one variable changes at a decreasing rate in response to the increase in the other variable. A p-value of less than 0.05 indicates that the relationship between DS% and TAVG is statistically significant. The R-squared value of 90.7716% means that the model can explain 90.7716% of changes in DS% based on changes in TAVG. This is a very good agreement, suggesting that the model is reliable. Equation: DS% *F. oxysporum* VS (TAVG) = 13.0925–110.241/TAVG (°C). The correlation coefficient: -0.952741 confirms a strong negative correlation. Standard error of estimate: 0.549793 indicates how much the data points are likely to deviate from the model's predictions. MAE: 0.435999 tells us the average size of errors made by the model.

The relationship between the mean DS% of *F. moniliforme* and the annual change in TAVG from 1988 to 2019 shows that the DS% of *F. moniliforme* has increased over time. The mean DS% *F. moniliforme* increased from approximately 1% in 1988 to approximately 7% in 2019. The 95% confidence interval also shows that the DS% *F. moniliforme* has increased over time. The confidence interval is larger in some years than in others, meaning that there is greater uncertainty about what average DS% *F. moniliforme* consists of in those years. The data also show that there is an association between DS% *F. moniliforme* and the TAVG. The TAVG is the average temperature for each year. The data show that the DS% *F. moniliforme* is higher in years with higher TAVG. This suggests that there may be a causal relationship between TAVG and the DS% that makes up *F. moniliforme*. However, the data suggested that there may be a relationship between temperature and the percentage of *F. moniliforme* in the Kharga Oasis in Egypt. In general, the data show that the DS% *F. moniliforme* in Kharga Oasis, Egypt, increased from 1988 to 2019. The data also suggested that there may be a relationship between DS% *F. moniliforme* and the TAVG.

The relationship between the mean DS% of *F. moniliforme* and the monthly change in TAVG from 1988 to 2019 shows that the DS% of *F. moniliforme* has increased over time. The mean DS% of *F. moniliforme* increased from approximately 2% in May to approximately 8% in November. The 95% confidence interval also shows that the DS%

of *F. moniliforme* increased over time. The confidence interval is larger in some months than in others, meaning that there is greater uncertainty about the mean DS% of *F. moniliforme* in these months. The data also showed that there is an association between DS% *F. moniliforme* and the TAVG. The TAVG is the average temperature for each month. Data show that DS% *F. moniliforme* is higher in months with higher TAVG. This suggested that there may be a causal relationship between TAVG and the DS% *F. moniliforme*. However, the graph suggests that there may be a relationship between temperature and the percentage of *F. moniliforme* in the Kharga Oasis in Egypt.

Predictive model mean DS% of *F. moniliforme* in Kharga Oasis, Egypt. The equation for the fitted model is DS% *F moniliforme* vs. (TAVG) = 13.7997–145.326/TAVG (°C). This means that the model predicts the percentage of *F. moniliforme*. The R-squared value for the model is 0.936101, which means that the model explains 93.61% of the variability in the data. The p-value for the ANOVA table is less than 0.05, which means that there is a statistically significant relationship between the percentage of *F. moniliforme* and the average temperature. The standard error of the estimate for the model is 0.593878. This means that the average difference between the model's predicted values and the actual value in the data is 0.593878 percentage points. The MAE of the model is 0.466561. This means that the average absolute difference between the model's predicted values and the actual value in the data is 0.466561 percentage points. The p-value for the serial correlation test is less than 0.05, indicating that there may be serial correlation in the data. Serial correlation means that the errors in the model are not independent of each other, which can make it difficult to accurately assess the reliability of the model. Overall, the results of the linear regression model show that there is a strong negative relationship between the percentage of *F. moniliforme* and the average temperature in Kharga Oasis, Egypt, between 1988 and 2019. The model fits the data well.

The relationship between the mean DS% of *F. solani* vs. the yearly change of TAVG from 1988 to 2019 shows that the results show that the average annual changes of *F. solani* from 1988 to 2019 were positive. The average annual change was highest in 1992 at about 0.08. The average annual change was lowest in 2002, at about 0.02 %. The 95% confidence interval shows that the average annual changes from 1990 to 2003 and from 2008 to 2019 were statistically significant. The results also show that there was a positive correlation between the average annual changes in *F. solani* and TAVG. This means that the average annual changes in *F. solani* were higher in years with higher TAVG. The correlation coefficient was 0.53, which is statistically significant. The results of this study suggested that the average annual changes of *F. solani* in Kharga Oasis, Egypt, were positive from 1988 to 2019. The average annual changes were highest in 1992 and lowest in 2002. There was a positive correlation between the average annual changes of *F. solani* and TAVG.

The relationship between the mean DS% of *F. solani* and the monthly change in TAVG from 1988 to 2019 shows that the highest mean DS% was recorded in the months of October, September, June, May, July, August, November and April. The lowest mean DS% was recorded in the months of January and February. The results showed that there is a seasonal pattern in the DS% of *F. solani* in Kharga Oasis. The DS% is highest in the summer months (June to August) and lowest in the winter months (December to February). This pattern is likely due to the fact that the temperature and humidity are higher in the summer months, which favors the growth of *F. solani*. The results also showed that the DS percentage of *F. solani* increased over time. This increase is likely due to a number of factors, including climate change, changes in agricultural practices, and the use of fungicides.

The prediction model uses a reciprocal X model to establish a relationship between the disease severity percentage (DS%) of *F. solani* and the TAVG °C. DS% *F. solani* vs. (TAVG) = 11.7949–91.3507/TAVG (°C). The model strongly suggested a negative correlation between TAVG and DS%. This means that as average temperatures increase, the disease severity of F. solani tends to decrease. The p-value of the ANOVA table of less than 0.05 means a statistically significant correlation between DS% of *F. solani* and average temperature (TAVG) with a confidence level of 95%. This means that changes in average temperature have a significant impact on the predicted DS%. The correlation coefficient of 0.977535 shows a strong negative relationship. As the average temperature (TAVG) increases, the DS% of *F. solani* is expected to decrease. The high R-squared value of the model (94.5824%) shows that it accounts for a significant part of the variability in DS% of *F. solani*. This implied that the model can effectively predict the DS% based on the average temperature. The standard error of the estimate (0.34196) provides information on the typical deviation of predicted values from actual observations. The MAE of 0.267348 indicates that, on average, the predictions deviate from the true values by approximately 0.267348 DS% units. The p-value indicates the possibility of a serial correlation.

The relationship between the mean DS% of *B. theobromae* vs. the yearly change of TAVG from 1988 to 2019 shows that the mean DS% of *B. theobromae* increased with time. The 95% confidence intervals for the mean also show that the DS% *B. theobromae* varies greatly from year to year. The mean DS% of *B. theobromae* was lowest in 1988 and highest in 2019. The 95% confidence intervals for the mean are widest in the early years of the data set and narrower in the later years. This suggests that there is greater uncertainty about the mean DS% of *B. theobromae* in the early years of the data set. There is a positive correlation between DS% *B. theobromae* and TAVG. This means that years with higher TAVG also tend to have higher DS% of *B. theobromae*.

The relationship between the mean DS% of *B. theobromae* vs. the monthly change of TAVG from 1988 to 2019 shows that the months with the highest mean DS% are May, November, October, April, September, and June. The months with the lowest mean DS% are January and February. The data also showed that the monthly change in TAVG for each month from 1988 to 2019. There is a positive correlation between the mean DS% of *B. theobromae* and the monthly change in TAVG. This means that the months with the highest mean DS% also have the highest monthly change in TAVG. In general, the result suggested that there is a positive relationship between the mean DS% of *B. theobromae* and the monthly change in TAVG in Kharga Oasis, Egypt, from 1988 to 2019.

The prediction model shows that the mean DS% of *B. theobromae* in Kharga Oasis, Egypt, has a p-value of less than 0.05 in the ANOVA table and a statistically significant relationship between the mean DS% of *B. theobromae* and TAVG. DS% ***B.*** *theobromae* vs. (TAVG) = 14.4906–96.8386/TAVG (°C). This means that the relationship between the two variables is unlikely to be due to chance. The R-squared value of 63.5972% means that the model explains a good portion of the variability in the mean DS% of *B. theobromae*. In other words, about 63% of the changes in mean DS% can be attributed to temperature changes. The correlation coefficient of -

0.797478 indicates a moderately strong negative relationship. This means that as TAVG increases, the mean DS% of *B. theobromae* tends to decrease. This model could be used to predict the mean DS% of *B. theobromae* based on temperature values in the Kharga Oasis. Understanding these patterns could have implications for agricultural practices or disease management strategies associated with *B. theobromae*. Temperature sensitivity: The results highlight the sensitivity of *B. theobromae* to temperature changes. This could be important for monitoring and managing organism populations, particularly in the context of fluctuating temperatures. The results provide a solid basis for understanding the relationship between temperature and mean DS% of *B. theobromae* in the Kharga Oasis. This model could be a valuable tool in agriculture and disease management. However, it is important to consider the possible limitations and the role of other factors that could influence the mean DS% of *B. theobromae*.

The relationship between the mean DS% of *T. paradoxa* and the annual change in TAVG from 1988 to 2019 shows that the mean DS% was 10.85% and the mean TAVG was 95%. The DS% values fluctuate from year to year without any discernible trend. The lowest DS% value was measured in 1989, with the highest DS% value in 2019. The TAVG values also fluctuate from year to year, but there is a slight upward trend over time.

The relationship between the mean DS% of *T. paradoxa* and the monthly change of TAVG from 1988 to 2019 shows that the highest mean DS% of *T. paradoxa* was found in the months of May, November, October, April, September, June and July, according to the figure. The lowest mean DS% was found in the months of January and February. It is important to note that this graph only shows the average DS% for each month. The actual DS% of *T. paradoxa* may vary from month to month. The DS% values are highest in the summer months (June, July, and August) and lowest in the winter months (December, January, and February). There is a small peak in DS% in the spring month of April. There is a small decrease in DS% in the autumn month of November.

The predictive model of the mean DS% of *T. paradoxa* in Kharga Oasis, Egypt, shows that the most appropriate model describing the relationship between the mean DS% of *T. paradoxa* and TAVG (°C) is: DS % *T. paradoxa* VS (TAVG) = 1/ (0.0633716 + 0.700049/TAVG). There is a statistically significant relationship between the mean of DS% and TAVG (with 95% confidence). This means that the relationship is unlikely to be based on coincidence. The model explains 60.4569% of the changes in mean DS%. This suggests a good fit, but there is still room for other factors that affect the mean DS%. The correlation coefficient of 0.77754 indicates a moderately strong positive relationship. As TAVG increases, the mean DS% of *T. paradoxa* also increases. The developed model establishes a significant relationship between the mean DS% of *T. paradoxa* and the average temperature (TAVG) in the Kharga Oasis. This may clarify how temperature fluctuations might affect the population of *T. paradoxa*.

The relationship between the mean DS% of *R. solani* and the annual change in TAVG from 1988 to 2019 shows that the data points show a slight increasing trend in DS% over the years. There is also a weak positive correlation between DS% and the annual change in TAVG, meaning that as the average temperature increases, the DS% also increases. The graph also shows 95% confidence intervals for the mean DS% for each year. The confidence intervals are wider in years with fewer data points, suggesting that the estimate of the mean DS% is less precise in these years. Overall, the graph suggests that there may be a weak positive association between DS% of *R. solani* and the annual change in TAVG in Kharga Oasis, Egypt.

The relationship between the mean DS% of *R. solani* vs. the monthly change in TAVG from 1988–2019 shows that *R. solani* is a soil-borne fungal pathogen that causes a variety of diseases in many plants. The data suggest a positive correlation between TAVG and the mean DS% of *R. solani.* This means warmer months, higher disease severity: The months with the highest mean DS% (October, May, September, etc.) correspond to warmer periods of the year. Cooler months, lower disease severity: The months with the lowest mean DS% (January and February) are typically cooler. Discussion This observed association is consistent with knowledge of *R. solani*. This fungus thrives in warm and moist conditions. Higher temperatures often create a more favorable environment for the fungus to grow and infect plants, leading to an increase in DS%.

The mean value of DS% of the prediction model of *R. solani* in Kharga Oasis, Egypt shows that the reciprocal X model was used because a non-linear relationship between temperature and DS% is likely. DS% *R. solani* vs. (TAVG) = 10.9585–97.2938/TAVG. p-value < 0.05 indicates a significant relationship between temperature and DS. The model explains 91.666% of the variation in DS%, indicating a good fit. A strong negative correlation (-0.957) suggests that DS tends to decrease with increasing temperature. The p-value indicates a possible serial correlation in the data. This means that the severity of the disease in one year could be related to the severity of the disease in previous years.

Date palm root rot DS% can be influenced by temperature stress. In a study by Rees **(Rees et al., 2007)**, it was found that *Ganoderma boninense*, the pathogen that causes the disease, showed optimal growth at temperatures of 25-30 °C and did not recover from temperatures of 45 °C (Preeti et al., 2023). This suggests that the pathogen is inhibited in exposed soils where temperatures frequently exceed 40 °C. Symptoms of the disease often appear in mature plantations when canopy formation creates shade, resulting in lower soil temperatures. Therefore, temperature stress can affect the severity of date palm root rot disease, with higher temperatures inhibiting the pathogen's growth and lower temperatures potentially reducing disease symptoms.

Climate change is making temperature stress more and more problematic as it can worsen the severity of root rot through interaction with fungi. Predicting these impacts is important for creating effective management plans **(Anli et al., 2023).** Date palm root rot can be caused by fungi and temperature stress in the following ways: 1) High temperatures can weaken the date palm's defenses, making it more susceptible to fungal infections. In addition to causing disruption, heat stress can also affect the ability of the root microbiome to defend the plant against infection **(Alotaibi et al., 2023; Chouhan et al., 2023; Wesener et al., 2023)**. 2) Fusarium species are examples of fungal pathogens. thrive in warm and humid environments. They produce enzymes that break down root tissue, preventing the plant from absorbing water and nutrients, and ultimately leading to death **(Khan et al., 2023)**. 3) Interaction: Fungal pathogens and temperature stress can interact to dramatically worsen root rot. Under heat stress, fungal pathogens can more easily penetrate roots and cause devastating damage **(Anthony et al., 2021; Rineau et al., 2023).**

Impact prediction: The effects of temperature stress on date palm root rot disease are being predicted through modeling techniques. To do this, mathematical models are being developed that simulate the intricate relationships between temperature, fungal pathogens, and date palm health. With these models, disease outbreaks can be predicted under various climate scenarios. Predictive mathematical models are used by researchers to accomplish several tasks. Firstly, they can create early warning systems to anticipate the occurrence of root rot outbreaks. Secondly, these models help in the implementation of targeted measures to prevent and control such outbreaks. Additionally, researchers can selectively breed date palm varieties that show greater resistance to both heat stress and fungal diseases. Ultimately, the ability to predict the effects of temperature stress on date palm root rot disease becomes crucial to maintaining the sustainability of date palm cultivation amid a changing climate **(Hameed et al., 2022)**.

Conclusion

In conclusion, the study provides valuable insights into the influence of temperature stress on the severity of date palm root rot. By predicting the impact of temperature stress, farmers can take proactive measures to protect their date palm plantations and maintain their productivity. Furthermore, our research highlights the importance of climate-adaptive strategies in the agricultural sector to address the challenges posed by changing environmental conditions.

List of Abbreviations

DBFD	Date bunch fading disorder
DS	Disease severity
GCM	Global Climate Models
MAE	Mean absolute error
TAVG	Temperature average
ANOVA	Analysis of variance
GERICS	The Climate Service Center German

Reference

Afify, N. M., El-Shirbeny, M. A., El-Wesemy, A. F. & Nabil, M. (2023). Analyzing satellite data time-series for agricultural expansion and its water consumption in arid region: a case study of the Frafra oasis in Egypt's Western Desert. *Euro-Mediterranean Journal for Environmental Integration*, *8* (1): 129-142. https://doi.org/10.1007/s41207-022-00340-4

Alemayehu, M. (2023). Growth Requirements and Propagation of Date Palm. In *Date Palm* pp. 141-178. GB: CABI. https://doi.org/10.1079/9781800620209.0005

Alotaibi, K. D., Alharbi, H. A., Yaish, M. W., Ahmed, I., Alharbi, S. A., Alotaibi, F., & Kuzyakov, Y. (2023). Date palm cultivation: A review of soil and environmental conditions and future challenges. *Land Degradation & Development.* ***34***(9): 2431-2444. https://doi.org/10.1002/ldr.4619

Anli, M., Ait-El-Mokhtar, M., Akensous, F.-Z., Boutasknit, A., Ben-Laouane, R., Fakhech, A., Ouhaddou, R., Raho, O., & Meddich, A. (2023). Biofertilizers in Date Palm Cultivation, in *Date Palm*. CABI GB. 266-296. https://doi.org/10.1079/9781800620209.0009

Anthony, M. A., Knorr, M., Moore, J. A., Simpson, M. and Frey, S. D. (2021). Fungal community and functional responses to soil warming are greater than for soil nitrogen enrichment. *Elem Sci Anth*, *9* (1), 000059. https://doi.org/10.1525/elementa.2021.000059

Arafat, K. (2015). Application of statistical model for forecasting powdery mildew of grapes under Egyptian conditions based on meteorological data. *Int. J. Plant Pathol. 6*: p. 48-57. DOI: 10.3923/ijpp.2015.48.57

Arafat, K. H., Hassan, M., & Hussein, E. A. (2021). Detection, disease severity and chlorophyll prediction of date palm leaf spot fungal diseases. *New Valley Journal of Agricultural Science*, *1*(2), 98-110. DOI: 10.21608/nvjas.2022.110022.1027

Arafat, K. H., Hassan, M. H., & Mahmoud, O. H. (2023). Predicting the Severity of Alfalfa Root rot Disease Under Salinity Conditions. *Assiut Journal of Agricultural Sciences*, *54*(4), 154-167. DOI: 10.21608/AJAS.2023.223841.1280

Bank, W. (2021). Egypt: Climate risk country profile [Report]. [Report]. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-04/15723-WB_Egypt%20Country%20Profile-WEB-2_0.pdf

Baraka, M. A., Radwan, F. M. and Arafat, K. H. (2011). Survey and identification of major fungi causing root rot on date palm and their relative importance in Egypt. *J. Biol. Chem. Environ. Sci*, *6*(2): 319-337. CrossRef

Chakrabarti, D. K. and P. Mittal (2023). Predicting Variables, in *Plant Disease Forecasting Systems: Procedure, Application and Prospect*. Springer. p. 11-15. https://doi.org/10.1007/978-981-99-1210-0

Chouhan, D., Mathur, P., & Choudhuri, C. (2023). Plant-Microbe Interaction and Their Role in Mitigation of Heat Stress. In *Microbial Symbionts and Plant Health: Trends and Applications for Changing Climate* (pp. 127-147). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-0030-5_6

Cohen, S. P. and Leach, J. E. (2020). High temperature-induced plant disease susceptibility: more than the sum of its parts. *Current opinion in plant biology*. ***56***: p. 235-241. https://doi.org/10.1016/j.pbi.2020.02.008

De, A., Nandi, A., Mallick, A., Middya, A. I., & Roy, S. (2023). Forecasting chaotic weather variables with echo state networks and a novel swing training approach. *Knowledge-Based Systems. 269*: p. 110506. https://doi.org/10.1016/j.knosys.2023.110506

EL-Morsi, M., Abdel-Monaim, M. & Ahmad, E. (2015). Management of root rot and wilt diseases of date palm offshoots using certain biological control agents and its effect on growth parameters in the New Valley Governorate, Egypt. *Journal of Phytopathology and Pest Management*, 2(1): 1-11. https://core.ac.uk/download/pdf/267929634.pdf

EL-Morsi, M. E., Rehab, A., Mohsen, E., & EL-Morsy, S. A. (2012). Survey and control trials of root rot/wilt of date palm offshoots in New Valley Governorate. Egyptian Journal of Agricultural Research, 90(4), 1403-1414. DOI: 10.21608/EJAR.2012.163415

Hameed, A., Atiq, M., Ahmed, Z., Rajput, N. A., Younas, M., Rehman, A., ... & Ansari, M. J. (2022). Predicting the impact of environmental factors on citrus canker through multiple regression. *Plos one*, *17*(4), e0260746. https://doi.org/10.1371/journal.pone.0260746

Izadi, M. & Shahsavar, A. R. (2015). Influence of Meteorological Factors on

Date Bunch Fading Disorder. International Journal of Horticultural Science and Technology, 2 (2): 213-18. https://doi.org/10.22059/ijhst.2015.56438

Khalil, M.H. & Gira, A.A. (2012). The Bio-Climatic Analysis and Thermal Performance of Residential Building in Upper Egypt A Case Study,"East El-Owauinat Region". In *The International Conference on Civil and Architecture Engineering* (Vol. 9, No. 9th International Conference on Civil and Architecture Engineering, pp. 1-20). Military Technical College. https://doi.org/10.21608/iccae.2012.44239

Khan, R. R., Haq, I. U. & Naqvi, S. A. (2023). Pest and Disease Management in Date Palm, in *Date Palm*. CABI GB. p. 297-338. https://doi.org/10.1007/978-3-031-37077-9_13

Kimura, R., Iwasaki, E. & Matsuoka, N. (2020). Analysis of the recent agricultural situation of Dakhla Oasis, Egypt, using meteorological and satellite data. *Remote Sensing. 12*(8): 1264. https://doi.org/10.3390/rs12081264

Kishi, S., Sun, J., Kawaguchi, A., Ochi, S., Yoshida, M., & Yamanaka, T. (2023). Characteristic features of statistical models and machine learning methods derived from pest and disease monitoring datasets. *Royal Society Open Science*, *10*(6), 230079. https://doi.org/10.1098/rsos.230079

Laine, A.-L. (2023). Plant disease risk is modified by multiple global change drivers. *Current Biology. 33*(11): R574-R583. https://doi.org/10.1016/j.cub.2023.03.075

Mead, R. (2017). Statistical methods in agriculture and experimental biology. Chapman and Hall/CRC. https://doi.org/10.1201/9780203738559

Preeti, Panwar, D., Saini, P., & Vats, J. K. (2023). Effect of Temperature and Defense Response on the Severity of Dry Root Rot Disease in Chickpea Caused by *Macrophomina phaseolina*. In *Microbial Symbionts and Plant Health: Trends and Applications for Changing Climate* (pp. 367-395). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-0030-5_14

Qu, Y., & Shi, X. (2023). Can a machine learning–enabled numerical model help extend effective forecast range through consistently trained subgrid-scale models? *Artificial Intelligence for the Earth Systems*, *2*(1).https://doi.org/10.1175/AIES-D-22-0050.1

Rees, R. W., Flood, J., Hasan, Y., & Cooper, R. M. (2007). Effects of inoculum potential, shading and soil temperature on root infection of oil palm seedlings by the basal stem rot pathogen *Ganoderma boninense*. *Plant Pathology*, *56*(5), 862-870. https://doi.org/10.1111/j.1365-3059.2007.01621.x

Rineau, F., Reyns, W., Carpentier, C., Van Der Plas, F., Bardgett, R., Beenaerts, N., & De Laender, F. (2023). Fungal pairwise interactions shift from positive to negative under warming stress. In *EGU General Assembly Conference Abstracts* (pp. EGU-1282). https://doi.org/10.5194/egusphere-egu23-1282

Sattar, M. A., Aulaqi, W. A., & Ibrahim, A. R. Y. (2013). Occurrence of False Smut on Date Palm (Phaenix dacyilifera L.) in the Southern Coastal Plain of

Yemen. *Journal of Agricultural Science*, *5*(4), 22. https://pdfs.semanticscholar.org/d53d/9d3a46b39fc2f94f41b002c99ec68ee34b0f.pdf

Sbeiti, A. A. L., Mazurier, M., Ben, C., Rickauer, M., & Gentzbittel, L. (2023). Temperature increase modifies susceptibility to Verticillium wilt in Medicago spp. and may contribute to the emergence of more aggressive pathogenic strains. *Frontiers in Plant Science*, *14*, 1109154. https://doi.org/10.3389/fpls.2023.1109154

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., & Trivedi, P. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nature Reviews Microbiology*, *21*(10), 640-656. https://doi.org/10.1038/s41579-023-00900-7

Soomro, A. H., Marri, A., & Shaikh, N. (2023). Date Palm (*Phoenix Dactylifera*): A Review of Economic Potential, Industrial Valorization, Nutritional and Health Significance. *Neglected Plant Foods Of South Asia: Exploring and valorizing nature to feed hunger*, 319-350.https://doi.org/10.1007/978-3-031-37077-9_13

Wesener, F., Rillig, M. C., & Tietjen, B. (2023). Heat stress can change the competitive outcome between fungi: insights from a modelling approach. *Oikos*, *2023*(6), e09377. https://doi.org/10.1111/oik.09377

Tilgam, J., Bhavyasree, R.K., Saakre, M. and Ashajyothi, M. (2024). Impact of Climate Change on Disease Incidence of Crop Plants. In *Climate-Resilient Agriculture* (pp. 81-105). Apple Academic Press. https://doi.org/10.1201/9781003455271

Zakaria, L. (2023). Fusarium Species Associated with Diseases of Major Tropical Fruit Crops. Horticulturae. **9**(3): p. 322. https://doi.org/10.3390/horticulturae9030322