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Foliar symptoms of Esca as a sign of vine mortality: A binary logistic regression approach

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Abstract

Foliar symptoms of Esca as a signal of vine mortality: a binary logistic regression approach—the study aims to evaluate how temporal dynamics influence vine mortality in plants that have previously shown symptoms of Esca. Esca is a complex of trunk diseases caused by various wood-infecting fungi, including *Phaeomoniella chlamydospore, Phaeoacremonium aleophilum,* and *Fomitiporia mediterranea*. The situation with Esca disease in our country, every year is variable and depends from variety, climate changes and conditions, and measurement for grapevine protection. For this research, Vranec black grapevine variety was observed, at an experimental field in Smilica, Kavadarci, Republic of North Macedonia. Our initial assumption was to monitor the progress of the Esca disease in vines that displayed interveinal necrosis on their leaves. Due to the inconsistency and fluctuation of foliar symptoms at vines over several years, it is necessary to use a binary logistic regression analysis using IBM SPSS software to analyze and predict the percentage of vine deaths. A binary logistic regression model was chosen because the dependent variable distinguishes between chronic and acute forms of Esca disease, with values coded as 0 and 1. Esca disease is associated with the development of internal wood necroses, which are chronic and acute and discussed in the context of these findings.

Keywords: Esca Disease; Vranec; Disease Incidence; Logistic Regression; Foliar Symptoms; Dead Vines; Wood Necroses

1. Introduction

The presence of Esca disease in vineyards has been documented since ancient times and has a direct association with decreased longevity and economic profitability of vineyards. It has a complex a etiology, involving various biotic factors (pathogenic fungi), and possibly abiotic factors associated [1]. The disease's complexity arises from the fungal diversity in vine's woody parts.In the etiological sense, vines infected with Esca disease exhibit two forms of the disease: chronic and acute. The symptoms of chronic esca are characterized by interveinal necrosis on leaves, so-called tiger stripe symptoms. According to [2] the presence of the vascular pathogens *Phaeomoniella chlamydospora* and *Phaeoacremonium aleophilum* is likely the cause of the typical foliar tiger stripe symptoms. This suggests that toxic metabolites are produced by these fungi within the host tissue and may have a role in the expression of esca symptoms [3]. In our case, the coloration of leaf necrotic tissue is red-brown, attributed to the black grape variety Vranec, while the shoots remain green (Figure 1). During summer, the external symptoms of esca are easily noticeable, yet a notable feature of the disease is its unpredictable variation in foliar symptom presentation from one year to another. It is assumed that the aforementioned vascular pathogens (*Phaeomoniella chlamydospora*; *Phaeoacremonium aleophilum*) may make vines more susceptible to wood white rot, which develops slowly and gradually and is caused by *Fomitiporia mediterranea*. Cross-inoculation experiments were designed to study the interaction among the three fungi, *Phaeoacremonium chlamydosporum*, *P. aleophilum* and *Fomitiporia punctata* most commonly associated with esca of grapevine [3].

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Figure 1 Overview of the chronic form of esca. Photo of the author, Smilica locality 2023

As the disease progresses, it develops into a severe form of Esca, characterized by the presence of all three causal fungi. The initial two fungi cause tracheomycosis (*Phaeomoniella chlamydospora*; *Phaeoacremonium aleophilum*), while the third triggers white rot. Grapevine infection by both tracheiphilous species, with their hyphae readily growing within the xylem vessels and the consequent wood gummosis and discoloration, had all the features of a real tracheomycosis, while infection by the lignicolous basidiomycete *F. punctata* caused relatively slow but progressive degradation and rot of the woody tissue [3]. This ultimately leads to the complete death of the vines, which is noted as the acute form. Apoplexy, the sudden wilt of vines that occurs in summer, is generally considered as the severe (or acute) form of esca and terminates in partial or total vine death [4]. The acute form of plant disease is represented by sudden wilting of entire vines in mid-summer (Figure 2).

Figure 2 Overview of the acute form of esca. Photo of the author, Smilica locality 2020

In this paper, the term chronic esca, referring to tiger stripe symptoms on leaves or typical esca, is employed without verifying the presence of white rot in all symptomatic vines. The term acute esca (apoplexy form) refers to the complete wilting of vines observed during the summer. One of the essential questions that remains unanswered in these studies is the survival duration of infected vines. The main obstacles arise from the slow development of internal necrosis in the wood tissues and the unpredictable foliar expression of the diseases. Therefore, the main focus of this paper is on the probability of vine mortality percentage in plants with leaf tiger stripe symptoms.

2. Material and Methods

2.1. Vineyard survey

Our study aims to investigate the relationship between chronic and acute forms of esca disease to understand the dynamics of vine decline in survey vineyard plot. To determine which vines were at risk of dying off, we compared the data for chronic and acute forms of the esca disease after certain years of the survey. The research was completed in a vineyard located at Smilica, near Kavadarci Republic of North Macedonia (41°42`71.4" N, 22°0`10.75"E) on the black grape variety Vranec. The vineyard has a total area of 9 hectares, but we will only present data from the plot with an area of 0,93 ha due to the extent of the information. A double Guyot pruning system was applied in the vineyard. Two variables were identified under field conditions: chronic and acute esca, which are represented by disease incidence coefficients. The annual disease incidence of the chronic form of esca (CDI) is determined by the number of vines showing symptoms of chronic esca in a given year, divided by the total number of living vines, multiplied by 100 (Equation 1). The annual incidence of an acute form of esca (ADI) also was calculated in the same way (Equation 2).

$$CDI = \frac{Number\ of\ vines\ with\ \ a\ chronic\ form\ of\ esca\ disease}{Total\ number\ of\ vines\ in\ vineyard\ plot} \times 100 \quad \ldots\ldots \text{Equation (1)}$$

$$ADI = \frac{Number\ of\ vines\ with\ \ an\ acute\ form\ of\ esca\ disease}{Total\ number\ of\ vines\ in\ vineyard\ plot} \times 100 \ldots\ldots \text{ Equation (2)}$$

2.2. Variable description

The essence of this research lies in determining the probability index of vine mortality for vines exhibiting symptoms, aiming to gain insight into the dynamics of vineyard decline. Therefore, the study explores and examines the relationship between the response variable (acute form of Esca) and the explanatory variable (chronic form of Esca) individually for each respective year (Table.1). The research spanned over a period of six years. During the first three years (2018-2020), data was collected on the chronic forms of the disease, whereas the remaining three years (2021-2023) focused on data collection of the acute forms of the disease that resulted in the death of the vines. The results of this study could contribute to a better understanding of the rate at which vineyards decline.

Table 1 Overview of Key Variables in Binary Logistic Regression Model

Variable name	Variable description	Nature of the variable	Response / Variable value
Incidence of Esca Disease	Response Variable (ADI) Explanatory Variable (CDI)	Dichotomous variable Continuous variable	Y=1 (chronic form of Esca disease) Y=0 (acute form of Esca disease)

Binary logistic regression was used in the study to determine if esca foliar symptoms were significantly associated with vines at risk of dying off. The ultimate goal of the binary logistic regression model is to compare the chronic and acute forms of the disease to obtain the probability of vine dieback, expressed as the Index of Vine Mortality. The results from logistic regressions of Grapevine Trunk Diseases, as suggested by [5] can be interpreted in a probabilistic manner and used to create tools for predicting the likelihood of the disease. Most often this type of regression is used when the dependent variable Y is binary or dichotomous (0 and 1). In our survey, the acute and chronic forms were represented by 1 and 0, respectively, where n=1 indicates the presence of the chronic form, while 0 represents the acute form. Primarily, we employed the logistic sigmoid equation (Equation 4), to model a binary response variable, denoting the presence of the acute form of Esca (ADI), where the chronic form of Esca (CDI) served as the explanatory variable.

$$\hat{p} = \frac{e^{\beta o+\beta 1(x)}}{1+e^{\beta o+\beta 1(x)}} \ldots\ldots\ldots \text{ Equation (4)}$$

The logistic sigmoid equation facilitates the prediction of response variable values based on given values of the explanatory variables. In this equation: $\hat{p}$ – Represents the predicted probability of an event occurring; The expression $e^{\beta o+\beta 1(x)}$ – represents the exponentiation of a linear combination of parameters (β0 and β1) along with the input variable *x* where *e* is Euler's number (approximately 2.71828). In this context, the intercept coefficient β0 signifies the onset of vine dieback without preceding symptoms, while β1 represents the coefficient estimated from the regression model, indicating either the acute or chronic stage of the disease, which is expressed through the disease incidence coefficient; $1 + e^{\beta o+\beta 1(x)}$ – is the denominator, ensuring that the predicted probability $\hat{p}$ always falls between 0 and 1.

The Probability Index of Vine Mortality (PIVM) served as a measure to quantify the relationship between the response variable and the explanatory variable, indicating the likelihood of an event occurring (Equation 5). Here, *Pacut* represents the *P*-value of the acute form of Esca, and *Pchron* represents the *P*-value of the chronic form. In this context, the 'event' refers to the category of vines currently at risk of mortality. The equation defining PIVM is as follows:

$$PIVM = \frac{Pacut.}{(Pchron.+Pacut.)} \text{……… Equation (5)}$$

3. Results and discussion

3.1. Descriptive statistics

Most commonly, every year in late July and early August, both the chronic and acute forms of esca disease manifested and were duly recorded. The incidence of the disease generally ranged from 5.82 to 16.29 (Figure 3). In general, the values of the acute form were lower than the chronic form. Compared to the chronic form, the acute form exhibits more constant values without significant fluctuations. The peak of foliar symptoms of Esca disease in 2019 corresponded to the peak of vine mortality in 2022. As a result of this insight, a comparison was made between two groups: (i) the incidence of the disease in chronic forms only for the period 2018-2020; (ii)the incidence of the disease in acute forms only for the period 2021-2023 (Table 2). Statistical confirmation of the relationship between the incidence of chronic form (tiger stripe symptoms on leaves) and acute form (dead vines) has been achieved using Pearson correlation test. In the table 3, the Pearson correlation test indicated a significant correlation ($P<0,028$). The table 3 illustrates a strong positive correlation between the two variables, with a Pearson correlation coefficient of 0.999. The study by [6] found a strong correlation between the incidence of esca in year n and the percentage of dead vines in the following year (n+1), which aligns with the results of logistic regression. This indicates that as the chronic form variable increases, the acute form variable also increases proportionally.

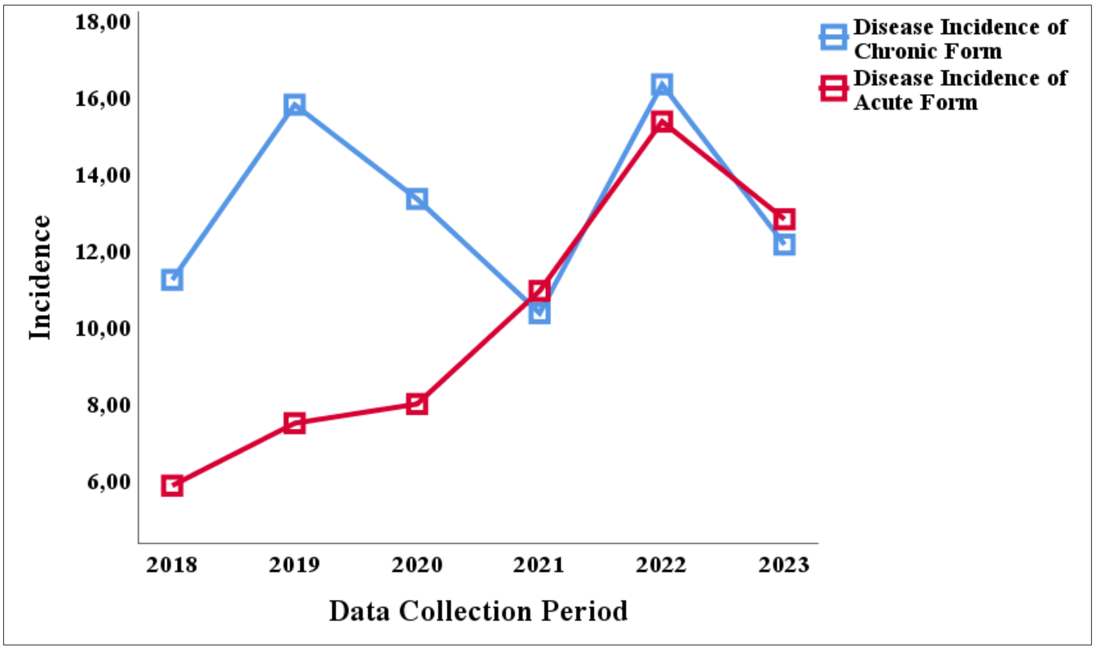

Figure 3 Overview of annual incidence of acute and chronic form of Esc

Table 2 Comparative Overview of Disease Incidence Coefficients: Chronic Form (Tiger Stripe Symptoms) vs. Acute Form (Dead Vines)

Chronic disease collection period	Disease incidence of chronic form	Disease incidence of acute form	Acute disease collection period
2018	11.19	10.90	2021
2019	15.76	15.32	2022
2020	13.30	12.77	2023

Table 3 Pearson Correlation Test Results of the Correlation and Significance between the Values Taken from the Chronic and Acute Incidence of Esca Disease

Correlations			
		Acute form of disease (dead vines)	**Chronic form of disease (tiger stripe symptoms on leaves)**
Acute form of disease (Dead vines)	Pearson Correlation	1	0.999*
	Sig. (2-tailed)		0.028
	N	3	3
Chronic form of disease (tiger stripe symptoms on leaves)	Pearson Correlation	0.999*	1
	Sig. (2-tailed)	0.028	
	N	3	3
*. Correlation is significant at the 0.05 level (2-tailed).			

3.2. Data analysis

Table 4 Overview of Binary Logistic Regression Analysis

Variables in the Equation									
		B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I.for EXP(B)**	
								Lower	**Upper**
Step 1a	Incidence of Esca Disease	1.895	0.590	10.326	1	0.001	6.652	2.094	21.129
	Constant	-5.533	1.782	9.638	1	0.002	0.004		
a. Variable(s) entered on step 1: Incidence of Esca Disease.									

In Table 4, the explanatory variable (incidence of Esca disease) and specific outcomes are displayed, where the odds ratio is greater than six and statistically significant. Over the period of research spanning from 2018 to 2023, the odds ratio for vine mortality was found to be 6.652 times higher in vines exhibiting symptoms compared to those without any signs of Esca disease. The 95% confidence interval for this odds ratio ranges from 2.094 to 21.129, further supporting the significance of this relationship.The variable Incidence of Esca Disease has a coefficient of 1.895, indicating that for every unit increase in the incidence of Esca disease, the log odds of the outcome variable increase by approximately 1.895, holding other variables constant. This coefficient is statistically significant ($P < 0.001$), suggesting a strong association between the incidence of Esca disease and the outcome. Additionally, the constant term in the model is -5.533, indicating the expected log odds of the outcome variable when all other predictor variables are zero. This constant term is also statistically significant ($P < 0.002$).

3.3. Model fitting information

Table 5 Model fitting information

	Chi-square	**df**	**Sig.**
Omnibus Tests of Model Coefficients	17.155	1	0.000034
Hosmer and Lemeshow Test	5.112	7	0.646
Model Summary: Goodness-of-Fit Measures (Variance Explained by Cox & Snell R Square and Nagelkerke R Square)			
Cox & Snell R Square	0.379		
Nagelkerke R Square	0.508		

The Omnibus test yielded a chi-square statistic of χ^2=17.155 with 1 degree of freedom and a sample size of N=36, resulting in a highly statistically significant p-value of less than 0.000034. Consequently, we reject the null hypothesis, indicating differences in the probability of the outcome variable based on the explanatory variable. This suggests that the model as a whole is well-suited for predicting the outcome variable effectively (Table 5).The Hosmer-Lemeshow test, as presented in Table 5, returned an insignificant result with a p-value of 0.646. This outcome is generally desirable, indicating that the logistic regression model adequately fits the data. Furthermore, Cox & Snell R Square and Nagelkerke R Square both assess the goodness-of-fit of the logistic regression model, aiming to estimate the variance explained by the model. Cox & Snell's R-square indicates that the model explains 37.9% of the variance, whereas Nagelkerke's R-square provides a higher estimate of 50.8% (Table 5).

3.4. Model building

Table 6 Comparison of Binary Regression Analysis Results for Data Sets across Multiple Years

Comparison by Years	**Disease incidence**	**Squared Disease Incidence**	**Constant**	**Regression Coefficients (B)**	**Logistic Sigmoid Equation** $\hat{p} = \frac{e^{\beta o+\beta 1(x)}}{1+e^{\beta o+\beta 1(x)}}$	**Probability Index of Vine Mortality** $PIVM = \frac{Pacut.}{(Pchron.+Pacut.)}$
First Set of Data						
2018	chronic form	3.35	-5.533	1.895	0.693227118	0.49249237
2021	acute form	3.30	-5.533	1.895	0.672717111	
Second Set of Data						
2019	chronic form	3.97	-5.533	1.895	0.879759006	0.496406283
2022	acute form	3.91	-5.533	1.895	0.867202834	
Third Set of Data						
2020	chronic form	3.65	-5.533	1.895	0.799592591	0.491930949
2023	acute form	3.57	-5.533	1.895	0.774194653	

Table 6 shows the variables for the chronic and acute forms of the disease, appropriately grouped by time intervals across different years: the first set of data from 2018 to 2021, the second set from 2019 to 2022, and the third set from 2020 to 2023. All coefficients obtained from the sigmoidal function ($\hat{p}$) for each dataset indicate that they surpass the threshold of 0.5, thereby increasing the probability of the outcome occurring. The result obtained from PIVM is consistently around 0.49 for all datasets across different years.

4. Conclusion

The temporal disparity in data collection between chronic and acute forms is attributed to the inconsistency and fluctuation of foliar symptoms in vines over several years. It was necessary to allow sufficient time for the disease to fully develop as the infected vines undergo a slow dying process that takes several years. It is not certain that the symptoms of esca will appear every year at the same vines, which adds a layer of complexity. For esca, vineyard surveys over several years have shown that the symptoms fluctuate from one year to another, and that plants that express foliar symptoms one year do not necessarily express those symptoms the following year [7]. The transition from a symptomatic chronic state to the acute form, characterized by vine mortality, is a gradual process that spans several years and requires prolonged observation to understand the complete pathogenesis of the disease. However, the results of the PIVM indicate a consistent vine mortality rate of 0.49, which corresponds to 49% of vines in all data sets that exhibited visible symptoms of esca in previous years (Table 6).

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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