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Original paper

The influence of climatic factors on the main phenological phases of grapevines from Stefanesti Viticultural Center, Romania

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Abstract

The growth and development of grapevine plants depend on climatic and orographic factors. The influence of these factors on plants creates a strong connection with environmental factors. The main purpose of this paper was to assess the climatic factors' level of influence on the grapevine phenophases from the Stefanesti area by using statistical methods less frequently used in the literature. The database we used is consistent and includes climatic factor from the period between 1989 and 2017. This MANOVA multi-factorial statistical analysis also included parameters that are less frequently encountered in the literature, such as the Huglin index or the number of days with precipitation levels higher than a reference level. The results showed that the blooming of the studied grapevine varieties depends primarily on the average annual temperature, the average of maximum temperatures, precipitation values, and the number of days with precipitation levels exceeding 10 mm.

Keywords Climate, management, flowering, veraison, ripening.

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Introduction

The grapevine and wine industries have been rapidly evolving in recent years. This is correlated with research and results in the literature that take into account geographical characteristics, including the topo-climate (MAHEIRO & al [1]; OLTEANU [2]; BUTIUC-KEUL & al [3]). In reality, *Vitis vinifera* L. represents one of the oldest perennial cultures (GHAFFARI & FERCHICHI [4]), whose vegetative cycle, morphologically described through phenological stages, is predominantly determined by air temperature (OLTEANU [2]; TSANTOUKA & al [5]). Precipitation levels, soil properties, and radiation are furthermore important, but to a lesser degree (OLTEANU [2]; PERKOULIDIS & al [6]).

In general, the process is easy to describe. After a winter period with low temperatures, the vegetation season begins with a spring warming. The specialty literature recognizes the essential character of the cumulative effect posed by temperatures over 10°C (basic temperature). This represents an essential thermic request that guarantees the apparition of the above-mentioned event (WINKLER & al [7]; COLA & al [8]). The principal subsequent stages are flowering, veraison, and maturity, followed by harvesting. During this final stage, the role played by warm temperatures and dry stable atmospheric conditions represents an essential aspect for increasing culture productiveness and wine quality (JONES & DAVIS [9]; SANTOS & al [10]).

Low temperatures and the total number of instances of precipitation in the latent period are essential for the subsequent growth season (SANTOS & al [10]; MURARIU & al [11]; KLIEWER [12]; RADULESCU & al [13]). Regardless of important regional differences, the strong inter-annual variability of climatic conditions can significantly influence grapevine phenology (MURARIU & al [11]; RADULESCU & al [13]). Furthermore, the calendar of each phenological phase differs based on each grapevine variety and is generally linked with local thermic conditions (PARKER & al [14]). Indeed, phenological models based on temperature accumulations higher than the reference temperature have been widely reported in studies (KLIEWER [12]; RADULESCU & al [13]; PARKER & al [14]). Complex models have also been developed by using different threshold values (PARKER & al [14]). A number of studies have shown that high temperatures are associated with the early phenological development of plants (COLA & al [8]; RADULESCU & al [13], FRAGA & al [15]).

Based on the phenological phase, the highest consumption of water is recorded during the maximum sprout and grapevine growth stages, while the lowest consumption recorded occurs between the beginning of weeping and flowering (OLTEANU [2]; RADULESCU & al [13]; OSLOBEANU & al [16]; ALEXANDRESCU & al [17]). The sufficient physiological temperature, in conditions of optimum temperature, activates the flowering.

The primary purpose of the present paper was to evaluate the influence of climatic factors on the main phenological phases of grapevines from the Stefanesti viticultural centre. The predominant method used for this study was ANOVA multi-factorial analysis, a procedure rarely used in the specialty literature. Furthermore, due to the consistent character of the database used, we were able to achieve a systematic analysis, introducing all the climatic factors frequently used in the literature.

Materials and Methods

The studies were realized in the period between 1997 and 2017 in the Stefanesti viticultural centre located in Romania, on the platforms and hill slopes from the southern part of Muntenia's Sub Carpathians. A multitude of soils can be found here, both in their natural placement and in anthropic profiles disturbed by management and hill-levelling works. Due to the wrestled relief, the soils are distributed in soil complexes: Regosols, Aluviosols, Eutricambisols, Preluviosols, Luvisols, Planosols, or Antrosols (DINCA & al [18]; SPANCHEZ & al [19]; CRISAN & al [20]).

During the vegetation stage, the grapevine situated in the fructification stage undergoes more phenological stages that influence the growth, development, and fructification processes. The present study followed the evolution of the principal phenological stages (flowering, blooming, ripening, and grape maturation) for eight species: Perlette, Muscat d'Adda, Feteasca alba, Muscat Ottonel, Pinot gris, Cabernet Sauvignon, Burgund, and Merlot.

The data were statistically analysed using Statsoft Statistica 13 software. The ANOVA method studies the variation in the dataset, while the work method used within this article (the multi-factorial ANOVA method) investigates the influence of each factor included by analysing and establishing the percentage and importance of each parameter based on the analysed dataset. As is already known, by evaluating the variation between the parameter groups, the multi-factorial method can identify the set of significant parameters and can appraise the percentage value for each parameter for a multidimensional linear model. The significance threshold was set at $p=0.05$.

Results and Discussions

1. Analysing the climatic parameters and their influence on the grapevines from Stefanesti

The predominant climatic conditions from the studied period were analysed. As such, based on the entire recording period offered by Goleasca meteorological station (44°51' N and 24°57' E) in Stefanesti Viticultural Areal, Argeş County, we were able to analyse the average monthly values of the air temperature for a period of 26 years, namely, between 1989 and 2017 (Fig. 1a). The following data were then represented as box-plot diagrams: average annual temperatures, the number of days

with precipitation levels higher than the reference threshold, Huglin index values, and the sum of temperatures from the vegetation period. Each diagram includes the ANOVA

analysis results, which clearly emphasize the time variation for each measurement, followed by a representation of tendencies established by the statistical analysis.

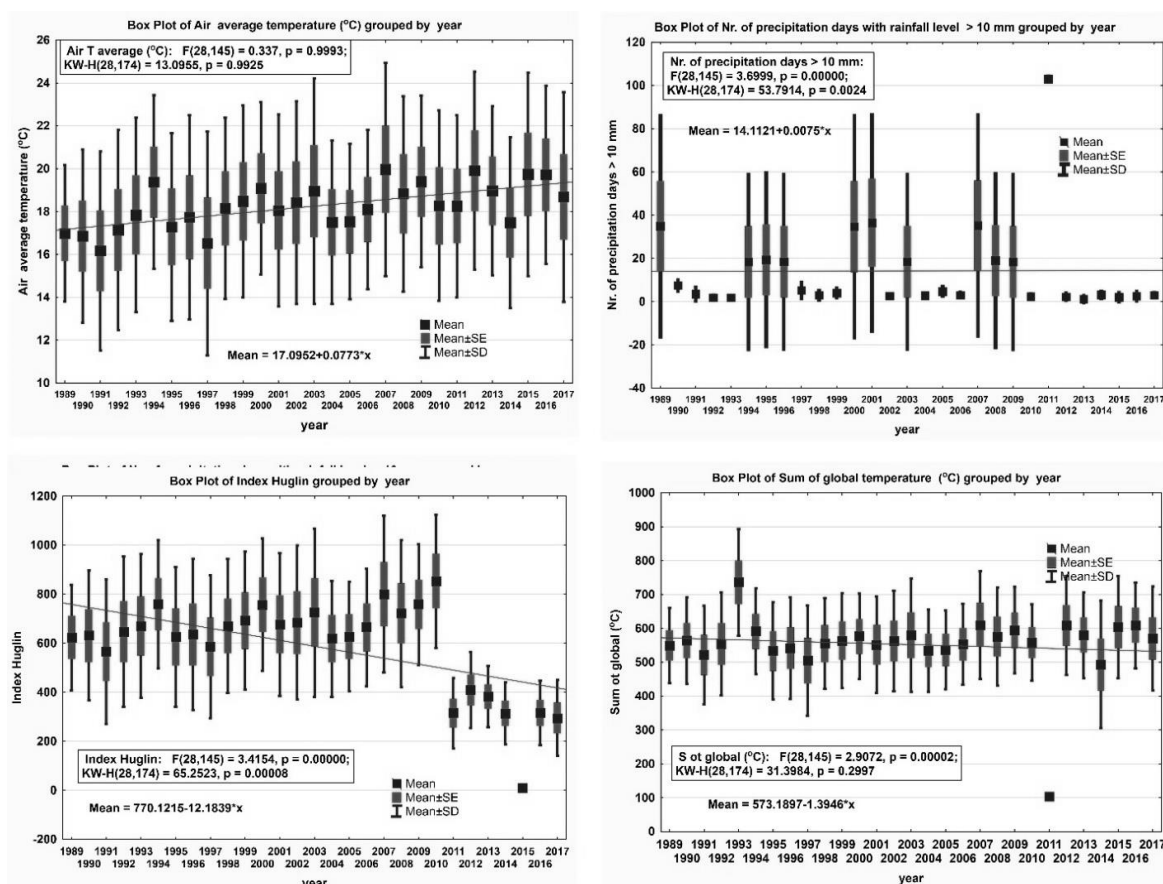


Figure 1. Box-plot representation for: (a) - average annual temperatures in the Stefanesti viticultural area, (b) - the number of days with precipitation levels exceeding 10 mm, (c) - average annual values of the Huglin index in the Stefanesti viticultural area, (d) - the sum of air temperatures from the Stefanesti viticultural area

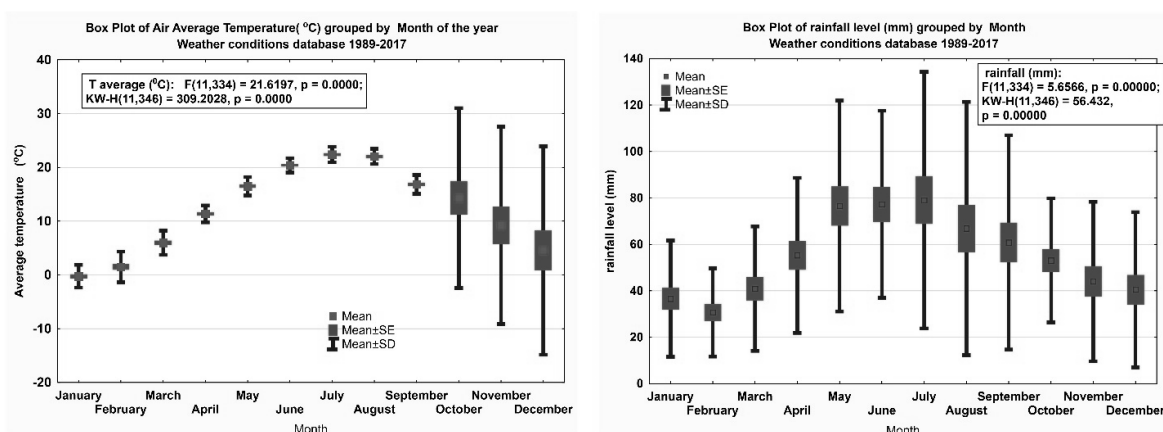


Figure 2. Box-plot representation for the average monthly air temperatures and precipitation values from the Stefanesti viticultural area

An increase in annual average temperatures can be observed in this area for the period between 1989 and 2017. This increase is situated within the general global-warming tendencies, however, and has an impact on the

advancement and decreasing of the phenological phases development period (KUHN & al [21]). On the other hand, the annual number of days with precipitation levels higher than 10 mm remained constant throughout the analysed

period. This fact suggests that the viticultural area studied ensures an optimum humidity for grapevine growth and fructification processes.

The Huglin index strongly decreases, mostly due to the values recorded more recently (between the years of 2011 and 2017). The monthly variation in the average temperatures and precipitation levels from the Stefanesti-Argeș area is of a Gaussian type: the maximum temperatures were recorded in July and August, and the minimum temperatures were recorded in January; meanwhile, high temperature variations were recorded between the months of October and December, followed by maximum precipitation levels in the months of May and June, minimum precipitation levels in the months of January

and February, and high variation in precipitation levels recorded in all months. As a result, grapevine culture is possible in this area, as the minimum temperatures occurring in winter do not negatively affect the viability of buds. Nevertheless, this fact imposes a need for continuous monitoring of climatic factors as well as measurements with regards to their influence on the grapevine phenological phases.

2. The influence of climate on the phenological phases of grapevines from Stefanesti

A multi-linear effect analysis example is rendered in Table 1.

Table 1. Multi-linear effect analysis - flowering phenological phase – during the month of April

April month		PE		MA		FA		MO	
Effect	Degr. of Freedom	Wald Stat.	p	Wald Stat.	p	Wald Stat.	p	Wald Stat.	p
Intercept	1	8.7260 91	0.0031 37	5.0518 74	0.0245 99	2.0612 40	0.1510 87	2.79786 8	0.0943 90
T average (°C)	1	4.6508 35	0.0310 38	1.5498 54	0.2131 57	0.2870 25	0.5921 33	0.35033 7	0.5539 23
T min. average (°C)	1	0.5570 59	0.4554 48	0.0647 93	0.7990 75	0.1386 70	0.7096 06	0.10229 5	0.7490 93
T max. average (°C)	1	3.6713 75	0.0553 55	3.8819 00	0.0488 09	2.8078 96	0.0938 01	3.56083 0	0.0591 58
April month		PG		CS		B		ME	
Effect	Degr. of Freedom	Wald Stat.	p	Wald Stat.	p	Wald Stat.	p	Wald Stat.	p
Annual rainfall (mm)	1	6.4136 94	0.0113 24	2.8112 29	0.0936 07	0.5124 61	0.4740 76	0.38288 5	0.5360 63
flowering period Rainfall (mm)	1	6.0465 90	0.0139 33	2.7559 97	0.0968 90	0.5442 40	0.4606 81	0.36421 5	0.5461 75
flowering period Index Huglin	1	3.4444 87	0.0634 63	2.8877 41	0.0892 56	2.6278 08	0.1050 07	3.30441 7	0.0690 94
flowering period - No of precipitation days > 10 mm	1	6.8895 71	0.0086 70	4.8272 59	0.0280 13	4.7371 40	0.0295 18	3.81096 2	0.0509 18
flowering period S ot global (oC)	1	0.2448 63	0.6207 16	0.0001 26	0.9910 50	1.1279 36	0.2882 16	1.29572 3	0.2549 96
flowering period S ot active (oC)	1	2.3187 10	0.1278 26	1.3358 91	0.2477 60	0.0233 69	0.8785 02	0.03580 4	0.8499 21
Intercept	1	0.5540 16	0.4566 81	1.1778 16	0.2778 01	0.8936 87	0.3444 80	1.42042 5	0.2333 33
T average (°C)	1	0.2584 53	0.6111 85	2.3031 83	0.1291 09	0.1325 02	0.7158 51	2.20171 5	0.1378 57
T min. average (°C)	1	0.1403 50	0.7079 33	0.5818 41	0.4455 92	0.0452 25	0.8315 90	0.75202 2	0.3858 37
T max. average (°C)	1	0.4092 97	0.5223 26	1.7493 82	0.1859 54	3.3648 35	0.0666 02	1.71486 8	0.1903 55
Annual rainfall (mm)	1	0.9031 72	0.3419 33	0.0794 63	0.7780 27	0.4687 68	0.4935 54	0.07764 4	0.7805 16
flowering period Rainfall (mm)	1	0.9772 14	0.3228 88	0.5497 53	0.4584 19	0.5105 83	0.4748 86	0.68873 9	0.4065 93
flowering period Index Huglin	1	1.0488 53	0.3057 71	4.2996 64	0.0381 20	3.3700 46	0.0663 92	4.45871 9	0.0347 24
flowering period - No of precipitation days > 10 mm	1	4.6971 12	0.0302 13	6.6143 91	0.0101 16	2.4244 02	0.1194 59	6.93465 6	0.0084 54
flowering period S ot global (oC)	1	1.4281 42	0.2320 68	0.7973 63	0.3718 83	1.3833 77	0.2395 27	0.69520 9	0.4043 98
flowering period S ot active (oC)	1	0.1537 92	0.6949 38	1.1898 75	0.2753 55	0.5682 01	0.4509 75	1.11398 9	0.2912 17

PE – Perlette, MA – Muscat d'Adda, FA – Feteasca alba, MO – Muscat Ottonel, PG – Pinot gris, CS – Cabernet Sauvignon, B – Burgund, ME – Merlot.

The blooming of the studied grapevine varieties was achieved differently, based on certain climatic parameters. As such, the Perlette variety's blooming was influenced by average temperatures, precipitation levels, and the number of days with precipitation levels higher than 10 mm; meanwhile, the Muscat d'Adda variety's blooming was influenced by the average of the maximum temperatures and the number of days with precipitation levels higher than 10 mm. The Feteasca alba and Pinot gris varieties' blooming was influenced primarily by the number of days with precipitation levels higher than 10 mm, while the Cabernet Sauvignon and Merlot varieties' blooming was influenced by the Huglin index as well as the number of days with precipitation levels higher than 10 mm. The blooming of the Muscat Ottonel and Burgund varieties, however, was not significantly influenced by climatic parameters (Table 1).

The time interval in which the phenological phases manifest can affect the dynamic of plant metabolites (KUHN & al [21]; MARTINEZ-LUSCHER & al [22]), while temperature and water deficits can advance the start of grapevine phenological phases. As a consequence, it is important to establish the effect of climatic factors on the phenological phases of plants in order to elaborate viticultural strategies (MARTINEZ-LUSCHER & al [22]).

For certain species, the start of the blooming phenological phase depends more on the average annual temperature, especially on the number of days with temperatures higher than 10°C ($p < 0.05$). For the veraison phenological phase, an essential parameter is the Huglin index ($p < 0.05$), while the maturation phase is represented by the sum of useful temperature degrees (useful thermic balance) accumulating up to that moment.

From a statistical point of view, an appropriate level of consistency can be observed in the method presented. If for the starting phenological phases, the sensitive parameters are the ones associated with air temperature and precipitation levels, for the final phenological phases, all the climatic parameters, including the auxiliary ones defined by the literature, have a more important influence. This phenomenon, which has been observed by a string of authors, emphasizes the perfectly functional character in the case of systematically applying the method presented.

Furthermore, the method is sensitive to the phenological stage studied, such that the sensitivity determined for the entrance measurements is certainly different to the sensitivity determined for the same set of parameters (Table 1). Due to the consistency and massive size of the database used, significant differences were determined between the different types of species studied. Moreover, the categories with a higher sensitivity towards the variability in meteorological factors can also be identified.

Conclusions

The multi-linear analysis method is a global method that facilitates establishing the sensitivity of different grapevine varieties to climatic parameters. Although this method has seldom been used in the specialty literature, it

proved highly efficient. Furthermore, the specific character of each variety can be observed relatively easily, as can the particular influence of environmental factors on each studied variety. The start of the blooming phenological phase for the studied grapevine varieties was primarily dependent on the average annual temperature, the average maximum temperatures, precipitation levels, and the number of days with precipitation levels higher than 10 mm.

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