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THE MULTIVARIATE RELATION BETWEEN THE
QUANTITY AND QUALITY OF WINE AND THE MAJOR
METEOROLOGICAL CHARACTERISTICS OF VINTAGE
IN THE TOKAJ-HEGYALJA REGION

Ph.D. DISSERTATION THESES

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1. INTRODUCTION

The Tokaj-Hegyalja wine-growing region is the first closed wine region in the world and was declared part of the World Heritage by the UNESCO World Heritage Committee in 2002.

The wine of Tokaj is unique. Its bouquet, flavour and aroma are irreproducible. Its production area is easily confinable and has remained unchanged since centuries as its loam, climate and the ecological conditions of viticulture are unified here. It has a special history. Its physiological impact is far-famed. It is only Tokay that has a legend. Tokay is probably the most famous special wine in the world whose bouquet, flavour and aroma are not producible elsewhere. It is the flagship wine of Hungary, the noblest wine in the world that is also referred to in the Hungarian national anthem. No other wine has played and probably will ever play such a significant role in the universal cultural history. Tokay is a concept.

The natural background of the special quality of wine of the Tokaj-Hegyalja region is ensured by its soil of volcanic origin and also by the specific macro- and microclimate of the area. The warm and dry summers are followed by precipitation in September that brings about such favourable conditions for a mould fungus called *Botrytis cinerea* to settle on grape buds. Therefore good quality wine can be mellowed from the grape that has high sugar level and is rich in microelements and fruit acids as the microclimate of the cellars of the Tokaj-Hegyalja region ensure the permanent temperature of 10-12 C° and the high- 90-100%- vapour content. The latter is ensured by evaporation of barrels full of wine.

The Tokaj-Hegyalja wine-growing region has matchless conditions. These are (1) the special production area, (2) the varieties of grape that have been indigenous for centuries; (3) the cellars carved into clay- and loess and into volcanic tuff, (4) strict regulations (applied to the grape-by-grape picking of the shrivelled grape, to the encirclement of the production area of Tokaj-Hegyalja region and to the classing of the field), and (5) the knowledge of the people dealing with grape-and wine culture through generations.

On the basis of the aspects mentioned above, we would like to investigate the impact of meteorological elements on the quantity and quality of wine in the total area of the historical Tokaj-Hegyalja wine-growing region.

2. OBJECTIVES

Within the Ph.D. programme of the Institute of Geography at the University of Pécs, the complex research of an area or smaller region plays an important role. This dissertation is also strongly related to this idea as its objective is to investigate the impact of the meteorological elements on the quantity and quality of wine in the total area of the historical Tokaj-Hegyalja wine-growing region.

On the basis of the points mentioned above, we introduce the results of our research done in the following main fields:

- (a) We analyse the trends of time series of the quantity and quality of wine;
- (b) We investigate whether there are any significant breaks in the time series of the quantity and quality of wine;
- (c) We produce the contingency tables applying to the examined meteorological parameters of quantity and quality of wine, and we analyse that out of these which shows significant relation with the quantity and quality of wine;
- (d) With the formulation of the Lorenz diagrams of the variables showing significant relation with the quantity and quality of wine, we determine the characteristics of these significant relations;
- (e) Factor analysis, with the application of special transformation we settle the order of rank of the meteorological variables having impact on the quantity and quality of wine- on the target quantities;
- (f) With the application of Pearson's chi-square test we determine whether the quantity and quality of wine depend on the types of vintage;
- (g) Pearson's chi-square test, on the basis of the methods of special transformation and generalised correlation we determine the common parameters significantly determining the quantity and the quality of wine;
- (h) We analyse that out of Pearson's chi-square test and the special transformation which describes better the relation between explanatory variables and result variables;
- (i) We determine the characteristics of the extreme quantity and quality of wine according to the meteorological types;

- (j) We examine the role of objective vintage types played in the classification of the quantity and quality of wine;
- (k1) We analyse the relation between the objective vintage types that we created on the basis of the homogeneous groups of the monthly values of the examined meteorological parameters, and the quantity and quality of wine;
- (k2) We produce the statistics and characteristics of the objective vintage types related to the quantity and quality of wine and we analyse them.

3. DATABASE

3.1. Meteorological data

The meteorological data are derived from the meteorological station of the Research Institute for Viticulture and Enology of Kecskemét of the Ministry of Agriculture and Rural Development operating in Tarcál settlement.

We had been analysing the monthly data provided by the three meteorological parameters of the station during a period of 104 testing years, between the years 1901 and 2004 on a half-year, 6-6 month basis, between April and September months. These meteorological parameters are: monthly mean temperature (T_{mean} , °C), monthly precipitation sum (P, mm) and the number of monthly sunshine hours (S, hour).

3.2. The quantity and quality of wine parameters

Due to the Research Institute for Viticulture and Enology of Kecskemét such a database stands at our disposal that gives the extension of the cultivated vineyard (ha), the annual vintage (thousand hl) of the total Tokaj-Hegyalja region during the 104 years, between 1901 and 2004, and it also characterises the quality of wine. Originally, the quality of wine was indicated on a five-level scale with Roman and Arabic numerals, which was upgraded to be nine-levelled (old code) with the combinations of the levels of the scale. The coding of the scale was simplified to the use of Arabic numerals only (new code) and the later analyses were done on the basis of it.

The investigated variables relate to Tarcál but the wine parameters are characteristic to the whole of Tokaj-Hegyalja because no such information is at our disposal from Tarcál.

3. THE METHODS OF INVESTIGATION

The applied methods of investigation in the dissertation are the followings.

(1) Linear trend analysis

for the controlling of the significance of the linear trend of any arbitrary part period of the data line of any given length;

(2) The Makra-test (a new interpretation of the classical two-sample test)

to investigate whether a significant deviation can be shown between the average of an arbitrary subsample of any data line and the total sample average;

(3) Generalized correlation

which in case of a normal distribution of two variables is in a simple functional relationship with r correlation;

(4) Pearson's chi-square test, test of independence

to decide whether the investigated samples can be regarded independent;

(5) Factor analysis and special transformation

Factor analysis: for the reduction of the dimension of the starting data set, and thus for the explanation of the relations between the investigated variables;

Special transformation: for defining that to what extent the considered variables have impact on the target quantity and to give the order of rank of their influence;

(6) Cluster analysis

for the grouping of the individual variables into so-called 'clusters' in such a way that the homogeneity of the objects is the highest in the cluster and at the same time the their heterogeneity is the highest among the clusters;

(7) One-way analysis of variance (ANOVA)

to decide whether the variance measuring the deviations among the groups is significantly higher to the samples grouped according to any respect than the variance showing fluctuation within the groups;

(8) Tukey's test

to determine that after the application of ANOVA which groups differ significantly from each other on the basis of the average of the groups involved in the investigation;

(9) The Lorenz diagram and the Gini coefficient

Lorenz diagram: to determine the nature of the relation of the investigated variable pairs by graphical representation;

Gini coefficient: to determine to what extent the distribution of the result variable as a function of the explanatory variable is deformed compared to the uniform distribution;

3.1. APPLIED COMPUTERIZED AIDS

- EXCEL software
- SPSS software
- GNUPLOT software

4. THE EXTENSION OF TOKAJ – HEGYALJA

According to time, the extension of the closed wine growing region (890 km²) was various. The nobles and the members of bourgeois held a meeting in the district of the county of Zemplén and Abaúj even in 1603 to regulate the wine growing and wine making. Probably, seven cities participated in that meeting from the Tokaj region.

The following settlements consulted in Mád in 1641: the representatives of Tokaj, Tarcál, Mád, Tállya, Szántó, Zombor, Szerencs, Ond, Rátka, Bénye, Tolcsva, Liszka és Keresztúr. As a result of this meeting, a regulation of 48 headings was established.

Thanks to the proposal of the Zemplén County in 1773, approved by the king and the 4th article of the royal legislative decree enumerated the settlements where grapes suitable for “Tokaj Wine” could be grown. It is stated that that the wines which grow in the mountains of Tállya, Golop, Rátka, Mád, Zombor, Ond, Tarcál, Keresztúr, Kisfalud, Szeg, Bénye, Vámosújfalva, Tolcsva, Liskai, Zsadány, Olasz, Patak, Újhely, Kistoronya, Erdőhorvát and Szánta “*must be cherished as Tokaj Wine...that is why it should be treated in the same way and should be sold in the cask equipped with identical seal*” (Trans.). Thus, the first closed wine growing region came into existence.

In case of new plantation only furmint, wine of the linden-leaf grape, muscat can be taken into consideration. The following twenty eight settlements belong to the region: Abaújszántó, Bekecs, Bodrogkeresztúr, Bodrogolaszi, Bodrogszegi, Erdőbénye, Erdőhorváti, Golop, Hercegkút, Károlyfalva, Legyesbénye, Mád, Mezőzombor, Monok, Olaszliszka, Ond, Rátka, Sározsádány, Sárospatak, Szegilong, Szerencs, Tarcál, Tállya, Tokaj, Tolcsva, Vámosújfalva, Végárdó és Sátorajjáújhely. The number of the community has decreased by four because 2 settlements were appointed to Slovakia (Kistoronya és Szőlőske), and into cases two settlements (Kisfalud és Bodroghalász) were merged.

5. OUTGROWTH OF RESEARCH

(1) For the total data line of 104 years we perceived a significant trend at 95% probability level. In addition, in the data line of the quantity of wine altogether 3-4 –element significant

trend can be traced whose distribution is sporadic. On the other hand, no significant trends can be detected at all in the time series of the quality of wine.

(2) With the help of the Makra-test in the data line of the quantity of wine between the years of 1916 and 1946, a positive part period of a time span of 31 years, and between 1947-1971 a negative part period of a time span of 25 years were diagnosed. However, in the data line of the quality of wine only one break could be discovered that was a significant negative part period of 45 years, between 1938-1982. The significant part periods of the data line of the quantity and quality of wine are of different length and they are only partly congruent in a segment of 11 years (between 1972-1982). Because of this, we cannot interpret the common segment of these 11 years of the significant breaks in a way that the significantly higher quantity of wine directly goes with the notable reduction of the quantity of wine. The higher wine quantity can have a dependency relation with the low wine quality but between these two variables there is no definite correlation. This is indicated by the value of the correlation coefficient (0.1444) between the data line of wine quantity freed from the trend and the data line of wine quality, which is not significant neither at 95% probability level nor at 99% probability level. These two wine parameters can not only be influenced by environmental but by social factors as well.

(3) By applying Pearson's chi-square test to the contingency tables related to the 18 meteorological parameters of the wine quantity and wine quality we discovered that five meteorological variables (the mean temperature of September and the sunshine duration of April, May, June, July) show statistically significant relation with the wine quantity moreover, one variable (the mean temperature of May) indicates important correlation with the wine quality. Beyond that (at lower significance level) it is the precipitation sum in April that has the most influence on the wine quantity and the sunshine duration in May on the wine quality.

(4) According to the Lorenz diagram and the significant connection between the quality and the quantity of the wine we can claim that the quantity of the wine decreases if the mean temperature in September and the sunshine duration in April, May, June and July have a mean value. (The least rainfall in April). At the same time the quantity of the wine increases if these parameters have high value. (Expect for the rainfall in April). The

quantity of the wine shows significant connection only with the mean temperature in May and the duration of the sun in May (with latter one only 90% probability).

According to the Lorenz diagram the quality of the wine is low if the duration of the sun in May is around the average. Moreover, the quantity of the wine decreases on the greatest extent if not only the mean temperature in May is high but the duration of the sun in May as well.

- (5) With the application of special transformation the quantity and the quality of the wine were determined and we identified the order of the meteorological variants as an objective quantity that should be reached.

According to this five variant show significant connection with the quantity of wine (order of importance): duration of the sun in May (+), sunshine duration in August (+), the total rainfall in June (-), sunshine duration in June (+), and the rainfall in September (+). There are seven factors, variant that show remarkable connection with the quality of the wine (order of importance): duration of the sun in May (+), the total rainfall in June (-), the mean temperature in May (+), the total rainfall in September (+), the total rainfall in May (-), sunshine duration in August (-), and the total amount of rainfall in July (-).

- (6) We used the Pearson's chi-square test to decide whether the quantity and the quality of the wine depend on the vintage. We got the result that the quality of the wine is independent from the vintage, but at the same time the dependence of the vintage and the quantity of the wine is only granted on 90 percent.

- (7) We used the test of independence (Pearson's chi-square test), and the special transformation on observed factors and in some cases the different climate variants showed significant relation to the quantity and the quality of the wine. On the other hand, we have to remark that if we observe statistic problems with more methods then the difference in the result is absolutely natural.

- (8) With the help of Pearson's chi-square test, and the special transformation and the correlation we observed that what influences significantly the quantity and the quality of wine are the certain climate variants. We accepted the effect of those variants which show

significant relation with the parameters of the wine on the bases at least two methods. According to this what influences the quantity of the wine are the sunshine duration in May, June, July, in August and the total amount of rainfall in September. Moreover what have a considerable impact on the quality of the wine are the mean temperature, the sunshine duration and the rainfall in May, and the rainfall in July and the sunshine duration in August.

- (9) We determined that the linear relationship between the significant climate variants and the outcome variants are better interpreted by the factor analysis than the major climate variants from the chi-square test. At the same time, neglecting the independence (chi-square test) –whatever of character - does not refer only to linear relationship.
- (10) The greatest quantity of wine occurs in the 5th vintage type. This is the most distinctive vintage determining the wine quantity because it has a characteristic of seven meteorological parameters from which three has significant role in the formation of the wine quantity.
- (11) The smallest wine quantity is related to the 1st vintage type. This type is not a full bodied wine because it has a characteristic of four meteorological parameters from which only one has significant role in the formation of the wine quantity.
- (12) The best quality wine is related to the 3rd vintage type. The odd thing about this type is that it gives the best quality wine and having three characteristic parameters, none of them have significant role in the formation of the wine quality, though.
- (13) The weakest quality wine related to the 2ⁿ vintage type. It has a characteristic of six meteorological parameters from which only two has significant role in the formation of the wine quality.
- (14) Only the 1st and the 5th vintage types play a major role in the average separation of wine quantity related to the examined 104 year period. There is no significant difference among the particular vintage types in connection with the wine quality.

- (15) The homogenous classification of vintage types – as climate variants – were more effective in separation of wine quantity according to separation of groups on the basis of average value than the similar classification of the wine quality. The given vintage types are the homogeneous groups of meteorological variants. On the contrary, the approach of one variant factor where we analyzed the connection between the explanatory variant (only one) and the outcome variant and examined the combined effects of the explanatory variants on the outcome variant in the vintage types. In addition, we got a more complex result in the connection with the scheme of environmental outcome variant.
- (16) The classification and the analysis of wine quality and wine quantity (outcome variants) based on vintage types is original in this field, and as a new method it can be suggested in evaluating the environmental connection scheme of the cause and effect interaction in the given territory. The results can be used to create quantity and quality estimation strategies as well.

6. UTILIZATION OF THE OUTGROWTH OF THE RESEARCH

In the dissertation we analyzed the effect of meteorological parameter in connection with its impact on the quantity and the quality of wine in the historic wine growing region of Tokaj.

The out coming results can provide useful information related to the effects of meteorological parameters for the grape and wine growing sector.

We brought the vintage types from 1901 into connection with the parameters of the annual asset of the quality and the quantity of the wine.

From the observed wine parameters only the quantity of wine can be related to vintage. As a result, the expected wine quantity can be predicted only and if only the reliable climate forecast is available. The value of this information is decreased because the mean value of the wine quantity has the probability of 85.93%, namely they show less significant difference among the weather types than expected in the statistical practice. At the same time we have to emphasize that the vintage types are not the only factors in monitoring of the wine quantity (or even in quality of the wine). The given vintage types only influence the quality and the quantity of the wine on which other natural factors have an influence. (For example:

solum type, angle of slope and the latitude, the functions of the latter are the meteorological variant observed in the dissertation). In addition the observed meteorological parameters the quality and the quantity of the wine have significant human factors as well. Such factors can be the method of wine growing (trellis, grove, vineyard, and parcel), the method of cultivation, cultivation of vine stock and the method of pruning, amelioration, protection against pest, applications of the different growing method and equipment (technique and technology), the method of supporting of the vine stock (staking, cordon cultivation, application of low and high cordon), thinning of bunches, selection of the time of the grape harvest, financial incentives etc. Thus, the dissertation observes the effect of the natural active components -but only if its slice (meteorological parameters) - on the formation of the quantity and the quality of the wine. The above mentioned sociological active components are completely disregarded. Because of all this for a good wine quality and quantity what we need is not only the climate forecast but the overall knowledge and database of the missing natural active component and the entire social component as well.

7. SOME POSSIBLE DIRECTIONS OF THE CONTINUATION OF THE RESEARCH

- (1) Moreover, the data of the mean monthly temperature, the monthly total rainfall, monthly sunshine duration, which were used in the dissertation, the wine quality and the wine quantity of Tarcia region can be observed as well (if there are local data related to wine).
- (2) Taking into consideration not only the meteorological parameters but other natural factors and the entire available social parameters as well we can achieve a possible extensive analysis related to region of Tokaj-hegyalja.
- (3) The above mentioned task should be accomplished to the entire historical wine regions of Hungary – if it is possible. The particular data from the certain regions should be compared, analyzed, and evaluated.
- (4) Analysis of chemical combination of the full-bodied wine, from the region of Tokaj-hegyalja, based on sufficient length data line

- (4a) the particular year depending on the natural and social parameters
- (4b) choice of the material (for example: wood, metal etc.) of the storage unit (for instance: barrel) and its age depending on the parameters of the recently stored wine
- (5). Comparative analysis of the chemical combination of the oxidative and non-oxidative wine in the region of Tokaj-hegyalja etc

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