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MANAGEMENT AND VALORIZATION OF AGRICULTURAL WASTES FROM WINE PRODUCTION USING STATISTICAL ANALYSIS TO OBTAIN NOVEL FOOD

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Abstract

Proper management and valorization of waste from wine production is an important and difficult issue for winemakers. This type of waste contains valuable biologically active substances (dietary fiber, fats, polyphenols, etc.). With proper treatment, this waste can be used to produce new functional foods. The aim of the article is to determine the exact amount of grape pomace powder (GPP) in cakes using statistical data processing using the "Correspondence Analysis" method and using an initial model (second-order polynomial). Determination coefficient (R2), model coefficients, their standard error (SE), t-statistics (tStat), p-value, Fisher's criterion (F) are determined. An analysis of the residuals is made, which are determined by the difference between the values of the model and the actually measured ones. Stat Soft Statistica 12 (Stat Soft Inc.) software was used to create these models. The determined values are: coefficient of determination R^2=0.89-0.92; F (2.47)<$F_{critical}$; SE=0.01-0.09, models describing the indicated dependences were obtained. Using the applied linear programming algorithm, it is determined that the optimal amount of GPP=4.72%.

Key words: *management of agriculture, by-products, novel foods, statistical analysis*

INTRODUCTION

The concept of a circular economy was promoted due to a reassessment of the production methods used in the 1980s, and it was also necessary to pay attention to industrial ecology and environmental protection. Bio economy is a new concept that Europe began to pay active attention to in the early 2000s. It is defined as the production of various renewable biological resources and their transformation into novel foods, feed, biochemical and bioenergy products [9].
The food industry is playing a crucial role in the new era, especially during the COVID-19 pandemic crisis. It is essential to reduce food waste to low levels, taking into account its environmental and economic impact. This can be done by applying technologies such as dehydration, microwave-assisted extraction, ultrasound-assisted extraction, green extraction, etc. [3,4,6], which ensure food safety and recovery of biocaitus compounds from by-products after food processing, and their reuse in the food chain [12].
In recent years, food waste has been most often used to produce new functional foods enriched with bioactive substances. In addition to obtaining new products, there are technologies in which waste is added to improve existing foods. Wine production is of great importance in agriculture and the agro-industrial sector worldwide. Grapes are one of the most important fruit crops grown worldwide.
In 2018 grape production is estimated at about 77.8 milion tones [1]. During winemaking, a large amount of waste is created, which large producers have to deal with. Grape pomace (GP) is the main by-product of the wine industry, which is equal to 250 g/kg of pressed grapes and dry matter in stalks (~20 g/kg), seeds (~470 g/kg), skin and pulp (~510 g/kg) [9,2,17]. GP is a major source of

bioactive substances, especially polyphenols, lipids, proteins, dietary fiber and minerals [5,10,13,16]. GP can be a good alternative with huge potential for the production of many organic products (Fig. 1) [1].

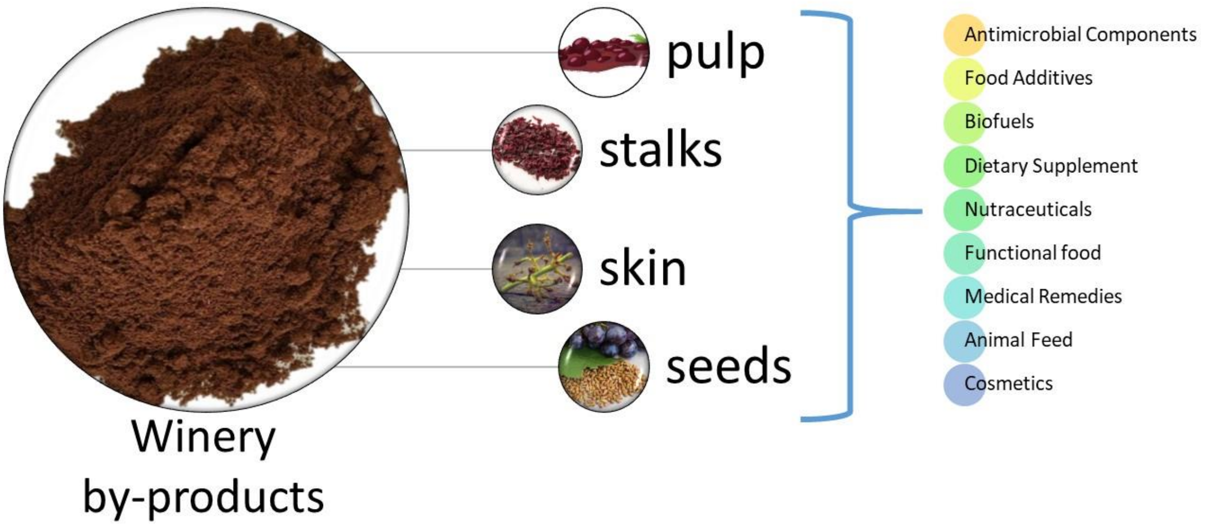

Fig. 1. Components of grape pomace and opportunities to produce many byproducts
Source: Own design.

From the available information in the scientific literature, we found that most often the amount of GP added to food products is based on sensory analysis of products.

As far as we know, there is no information in the scientific literature to determine the exact (optimal) amount of GP in cake products using statistical analysis.

Therefore, the aim of this article is, using an appropriate mathematical model and calculations, to determine the exact amount of GPP in cake products and thus to establish proper management and valorization of agricultural waste from wine production.

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MATERIALS AND METHODS

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The cakes are made with flour type T-550. The grape pomace powder (GPP) is derived from Muscat Hamburg grapes. The technological scheme described by Velioglu et al., 2017 [15] was used, with some modifications. Detailed data on the physicochemical and organoleptic characteristics of the studied products are presented in Nakov et al., 2020 [10].

Figure 2 shows a general view of a cake with the addition of GPP. As the grape seed supplement increases, the color of the product visibly changes to darker.

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a) Control b) 4% GPP c) 6% GPP d) 8% GPP e) 10% GPP

Fig. 2. Changes in the surface characteristics of a cake with GPP - general view
Source: Own design.

Table 1 shows the characteristics used, which vary depending on the amount of grape seed flour added to the cakes. The following were used: 5 color components from Lab and LCh color models, which were obtained after conversion from the RGB model; color difference ΔE; a total of 11 color indices, according to Pathare et al., 2013 [11]; 5 organoleptic indicators; 15 physico-chemical characteristics of the product.

Table 1. Cake's features used

Feature	Meaning	Feature	Meaning
F1	L	F21	Lipids, %
F2	a	F22	Proteins, %
F3	b	F23	Total Dietary Fibre, %
F4	C	F24	Peak Viscosity, Pa.s
F5	h	F25	Breakdown Viscosity, Pa.s
F6	ΔE	F26	Anthocyanins, mg/kg DM
F7	YI	F27	TPC, mg GAE/g DM
F8	WI	F28	DPPH, umol TE/g DM
F9	BI	F29	FRAP, umol TE/g DM
F10	SI	F30	Appearance
F11	CIRG	F31	Taste
F12	COL	F32	Aroma
F13	CI	F33	Odour
F14	ECB	F34	Texture
F15	FCI	F35	Overall Acceptance
F16	WL	F36	Hardness, N
F17	PACI	F37	Springiness
F18	pH	F38	Cohesiveness
F19	Moisture, %	F39	Chewiness, N
F20	Ash, %	-	-

Source: Own calculation.

The selection of informative features was made using the "Correspondence Analysis" method [8]. This is a method that determines the relationships between two data sets. It is applicable to matrices whose elements are the frequencies of simultaneously observed events of the respective classes of the two factors, represented by rows and columns of the table. The obtained results are entered in the vectors r_i and c_j. The values of the weights by rows and columns w_i and w_j are obtained from these vectors (equation 1):

$$w_i = \{r_i\} \qquad w_j = \{c_j\} \qquad (1)$$

Those traits that have weight coefficients with values above 0.9 are selected. A vector of signs is organized from them. The possibility of the Correspondence Analysis method is used to determine the dimensions of a data set. This feature was used to reduce the data volume of the resulting feature vector represented as FV=[D_1 D_2]. An initial model (second-order polynomial) was used, which is more often used in the analysis of products of biological origin [7], describing the relationship between selected characteristics of cake products of the type (equation 2):

$$z = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 \qquad (2)$$

where x and y are independent variables; z – dependent variable; b – model coefficients.

Coefficient of determination (R^2), model coefficients, their standard error (SE), t-statistics (tStat), p-value, Fisher's criterion (F) are determined. An analysis of the residuals is made, which are determined by the difference between the values of the model and the actually measured ones.

The coefficients of the model and their standard error are determined, and each of them is analyzed depending on the value of the p-level compared to the significance level α. Non-informative coefficients (those with p>α) were rejected by the model. The significance of the coefficients is determined by Student's criterion, and the adequacy - by Fisher's criterion. Stat Soft Statistica 12 (Stat Soft Inc.) software was used to create these models.

A linear programming algorithm was used to determine the appropriate amount of GPP. This algorithm is implemented through the linprog function in the Matlab software system (The Math Works Inc.). Linear programming is the solution of the problem of finding a vector "x" such that the linear function fTx, with linear constraints (equation 3 and 4):

$$\min_{x} f^T x \quad (3)$$

to be performed under one of the conditions:

$$Ax \leq b \qquad A_{eq}x = b_{eq} \qquad l \leq x \leq u \quad (4)$$

An "Interior-point-legacy" algorithm was used. This algorithm is applied when solving linear programming problems for which the simplex method is not suitable. The algorithm arrives at an appropriate solution by traversing the inner part of the data region [7]. Preliminary analyzes have shown that the other more commonly used algorithm "Dual-simplex", implemented using the linprog function, is not suitable for use in the solution of the problem. All data were processed at a level of significance α=0,05.

RESULTS AND DISCUSSIONS

A selection of features has been made using the Correspondence Analysis method. Figure 3 shows graphically the result of this analysis. The graph shows that all the individual color components are affected by the change in the amount of grape seed flour (GPP). CIRG, FCI, WL are excluded from the color indices. Only four of the organoleptic indicators were selected. Most of the physico-chemical parameters are removed in this selection.

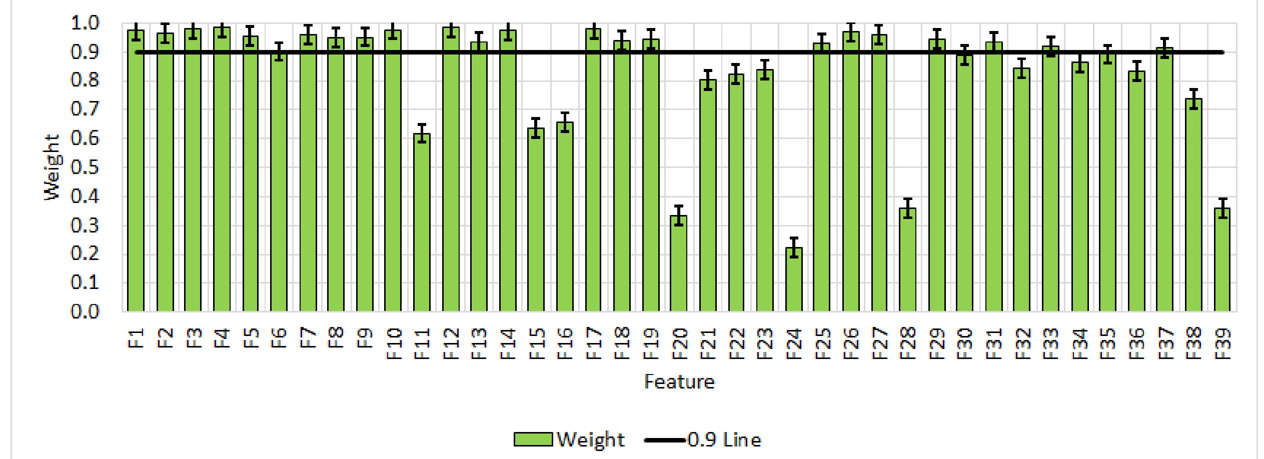


Fig. 3. Results from feature selection with "Correspondence analysis" method
Source: Own results.

From the selected characteristics of a cake with the addition of grape seed flour (GPP), a feature vector is composed, containing those that have a weight coefficient greater than 0.9. The vector contains a total of 25 features and has the following form (equation 5):

FV=[F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F12 F13 F14 F17 F18 F19 F25 F26 F27 F29 F39 F31 F32 F35 F37] (5)

The dimensions of the feature vector were calculated using the correspondence analysis method. Both dimensions describe the variance in the data by over 96%. A feature vector containing the two data dimensions FV=[D_1 D_2] was obtained. Models describing the functions D_1=f(D_2) and GPP=f(D_1, D_2) are defined.

After removing the insignificant coefficients with $p>\alpha$; coefficient of determination R_2=0.89-0.92; $F(2.47)<F_{critical}$; SE=0.01-0.09, models describing the indicated dependences were obtained.

The model describing the dependence PC_1=f(PC_2) has the form (equation 6):

$$D_1 = -44.75{D_2}^2 + 4.41D_2 + 0.02 \qquad (6)$$

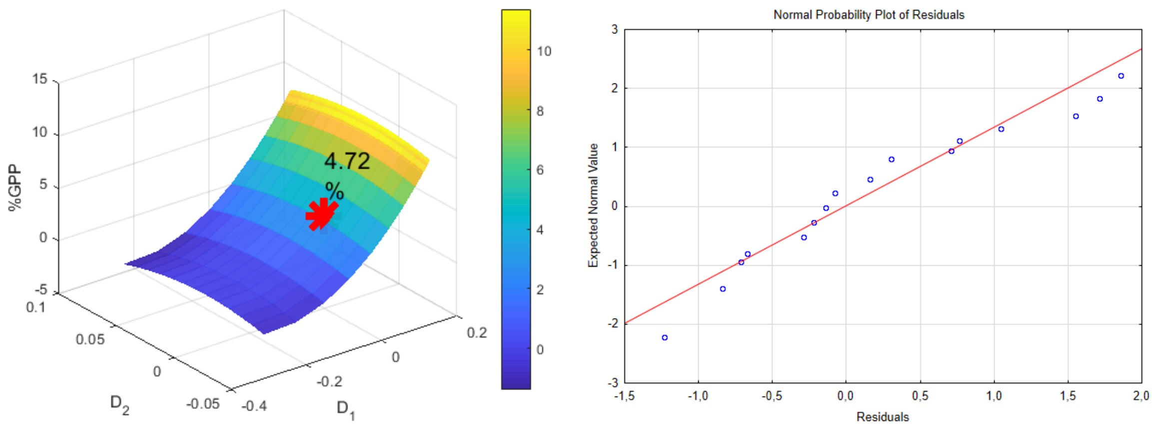
where PC_1 and PC_2 are denoted with D_1 and D_2, respectively.

The GPP quantification model has the form (equation 7):

$$GPP = 5.4 + 38.37D_1 + 67.33{D_1}^2 - 280.4{D_2}^2 \qquad (7)$$

Applying an algorithm for linear programming, an optimal amount of GPP = 4.72% was determined.

Figure 4 shows graphically the resulting model and the appropriate amount of GPP. A normal probability graph of the residuals of the obtained models is shown. Since the points are located close to the straight line, the residuals can be considered to have a distribution close to normal and it can be assumed that the prerequisites of the regression analysis are fulfilled. As can be seen from the distribution of the residuals, in the normal probability graph, they are close to the normal distribution and it can be considered that the prerequisites of the regression analysis are fulfilled.



a) Model b) Normal probability plot of residuals

Fig. 4. Determining the optimal amount of GPP
Source: Own results.

The obtained results complement those of the available literature. The required amount of GPP=4.72% obtained is in the range of 4-6%, as indicated by Nakov et al., 2020 [10]. Theagarajan et al. 2019 [14] prove that low amounts of GPP improve the nutritional and sensory characteristics of cakes. The method proposed in the present work with the combined use of data from physicochemical, color and organoleptic characteristics of cakes, which are reduced, improves the known ones, as the amount of GPP is refined so as not to violate these characteristics of the final product.

CONCLUSIONS

In the present work, by using a total of 25 characteristics obtained from physico-chemical, color and organoleptic analyzes of cakes, combined in a vector of features and reduced, through a mathematical model and appropriate calculations, the optimal amount of GPP in cakes is determined. Through the proposed mathematical models, an accuracy of up to 92% can be achieved in determining the allowable amount of GPP, which is 4.72% for cake products.

The “Interior-point-legacy” algorithm used in the present work is suitable within the framework of the problem to be solved and the data used. For example, the "dual-simplex" algorithm is not suitable for the analyzed data, which was found in preliminary analyzes.

As a result of the analyzes and calculations made, it can be considered that there is no universal statistical method for determining the amount of additives in cake products. The choice of method depends largely on the nature of the data obtained, their type and distribution.

As a recommendation for practice, as well as for further research, ways can be sought to generalize the mathematical apparatus to be used in determining the optimal amount of GPP additives in cakes. In this way, proper management and valorization of agricultural waste from wine production will be established.

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