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Optimization of Drying Conditions of White Grape Pomace from the *Fetească Albă V*ariety for Obtaining a Powder Rich in Phenolic Compounds and with High Antioxidant Activity

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ABSTRACT

In recent years, climate change has left a significant mark on food production, with the agri-food sector being strongly affected. Moreover, global population growth and the depletion of non-renewable resources have led to the development of action plans aimed at preventing food waste and losses, as well as promoting the valorization of by-products with economic and functional potential. White grape pomace is a by-product resulting from the winemaking process, which, due to its chemical composition, represents an important source of polyphenolic compounds with bioactive properties reported in the scientific literature. Beyond its traditional use as a fertilizer, which, when applied in excess, may negatively impact the soil microbiome, grape pomace can be transformed into a powder suitable for incorporation into various food matrices, such as bakery or pastry products, thereby enhancing their biological value.

The aim of the present study was to evaluate the effect of different drying temperatures (50–70 °C) applied through two distinct techniques: hot-air convection drying (CD) and infrared drying (IR). Principal component analysis (PCA) was employed to identify the components with eigenvalues >1, which accounted for the variations related to color parameters, physicochemical characteristics of the powders, polyphenolic compound stability, and antioxidant activity. The first three principal components explained 89.14% of the total variance and were used for 2D and 3D representations of the loading and score plots. According to the 2D representation for PC2, a positive correlation was observed between total polyphenol content and antioxidant activity, whereas the browning index showed a negative correlation. These results suggest that the application of higher drying temperatures reduces the activity of polyphenol oxidase, the enzyme responsible for polyphenol oxidation. The powder obtained through convection drying at 70 °C was characterized by a high polyphenol content and superior antioxidant activity.

INTRODUCTION

At the level of the European Union, numerous strategies have been launched to address current issues related to food waste, increasing consumer and food sector awareness regarding the efficient use of resources, and reducing the environmental impact of food production.

The valorization of by-products generated in the food industry, such as grape pomace, supports the transition of the food sector toward a sustainable, circular system that efficiently utilizes resources and significantly reduces waste generation. At the same time, it contributes to the development of innovative solutions for the enrichment of food products with bioactive compounds, generating economic benefits and supporting reuse principles [1].

AIM

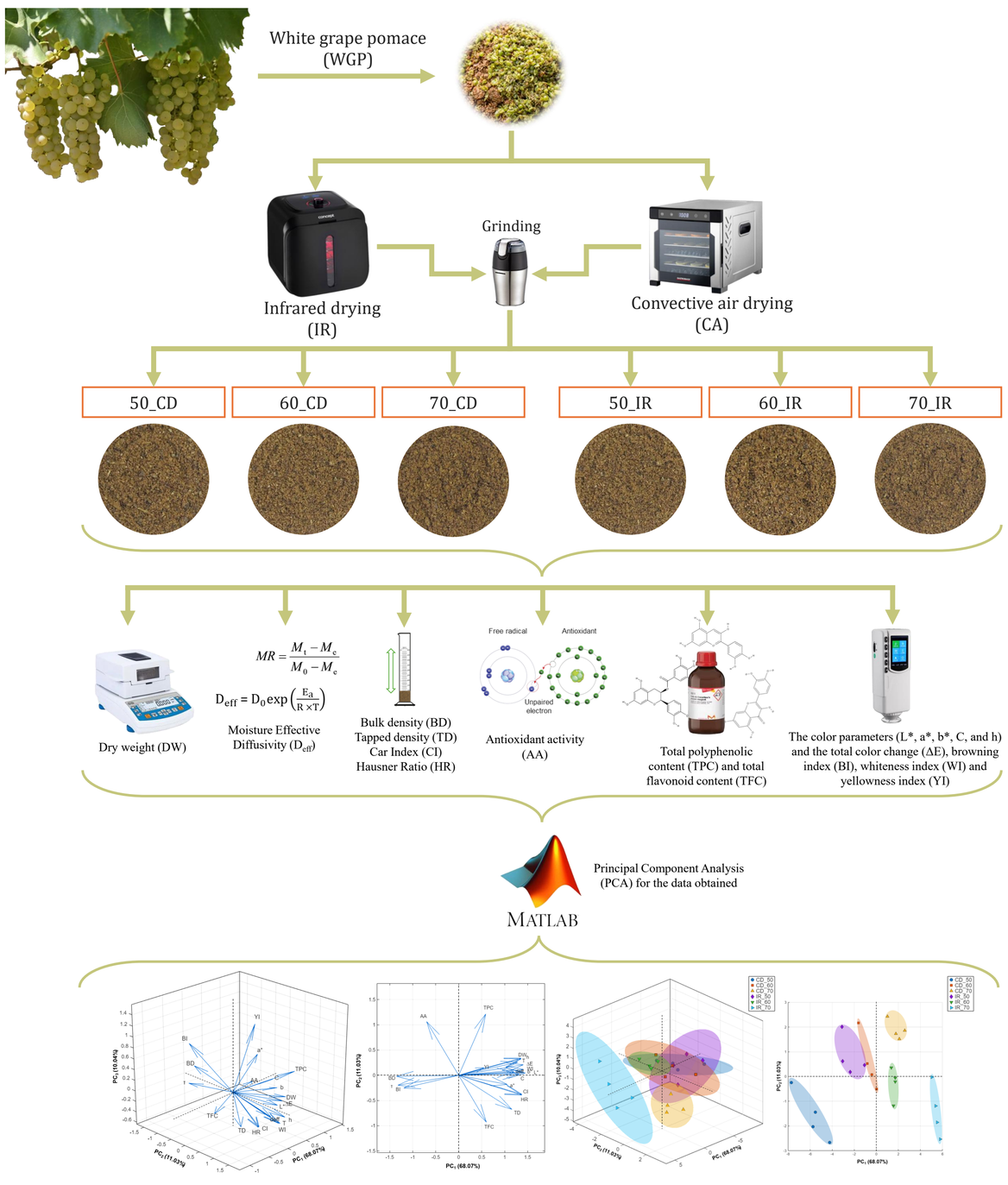
1. To apply two drying techniques, infrared (IR) and hot-air convection (CD), to white grape pomace (WGP).

2. To perform comparative analyses of color characteristics, powder flowability, and the effect of thermal treatments on bioactive compounds.

3. To employ Principal Component Analysis (PCA) for evaluating the impact of drying methods and temperatures by reducing dimensionality and identifying the most relevant principal components (PCs).

4. To determine optimal drying conditions for obtaining powders with enhanced sensory and phytochemical properties.

METODOLOGY



RESULTS AND DISCUSSION

In **Table 1**, it can be observed that the first principal component (PC_1) of the analyzed system explains 68.07% of the variation associated with color, powder flow properties, and the bioavailability of bioactive compounds.

In addition to PC_1, PC_2 and PC_3 were also considered, as their eigenvalues were greater than 1, indicating that these two components can explain a significant portion of the variability of at least one analyzed variable. Therefore, the first three selected principal components are able to account for 89.14% of the total variation of all dependent variables analyzed.

Tabel 1. *Eigenvalue analysis of the correlation matrix calculated for the dependent variables*

	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	PC_8	PC_9	PC_{10}	PC_{11}	PC_{12}	PC_{13}	PC_{14}
Eigenvalue	13.614	2.206	2.008	0.812	0.385	0.326	0.231	0.194	0.094	0.067	0.031	0.017	0.008	0.007
Proportion	68.07	11.03	10.04	4.06	1.92	1.63	1.16	0.97	0.47	0.34	0.16	0.09	0.04	0.03
Cumulative	68.07	79.10	89.14	93.20	95.12	96.75	97.91	98.88	99.35	99.69	99.93	99.97	99.99	100

Table 2 presents the values of the correlation coefficients established between the selected principal components (PCs) and all the analyzed dependent variables.

For PC_2, a negative correlation was observed with tapped density, Brown Index, and flavonoid content, while TPC and AA were positively correlated. According to the two-dimensional and three-dimensional plots, a distinct grouping of the analyzed powder samples was observed.

In the first region, defined by PC_2 and PC_3, the powder dried at 50°C by convection drying (CD) was classified, being associated, as shown in **Figure 1**, with the longest drying time. Conversely, in the region between PC_1 and PC_2, the powder dried at 70°C by CD was located, which, according to **Figure 2**, exhibited the highest TPC value.

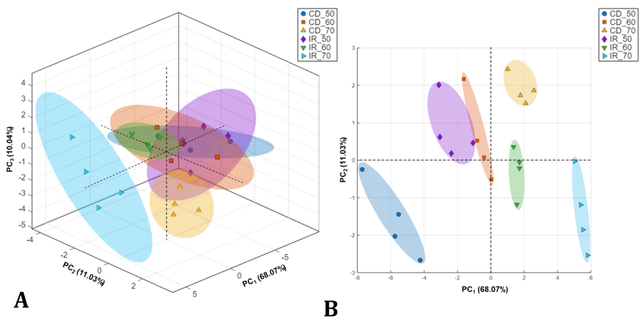


Figure 1. *PCA score plots showing the clustering of samples based on the first three PCs (A) and the first two PCs (B)*

Tabel 2. *Correlation coefficients between dependent variables and the first three principal component loadings*

	Symbol	PC_1	PC_2	PC_3
Temperature, °C	**T**	0.237	0.119	-0.185
Drying time, min	**τ**	-0.244	-0.090	-0.024
Dry weight, %	**DW**	0.251	0.156	0.054
Diffusion effective diffusivity	**D_{eff}**	0.222	0.033	-0.105
Bulk density, g/mL	**BD**	-0.250	-0.010	0.111
Tapped density, g/mL	**TD**	0.214	-0.311	-0.095
Car Index	**CI**	0.254	-0.173	-0.112
Hausner Ratio	**HR**	0.254	-0.181	-0.116
Lightness	**L***	0.268	0.021	0.028
Redness/blueness	**a***	0.195	-0.083	0.465
Yellowness/greenness	**b***	0.259	0.030	0.176
Total color change	**ΔE**	0.260	0.100	0.040
Chroma	**C**	0.244	0.004	0.250
Hue angle	**h**	0.251	0.149	-0.128
Browning index	**BI**	-0.221	-0.214	0.357
Yellowness index	**YI**	0.101	0.069	0.637
Whiteness index	**WI**	0.260	0.054	-0.149
Total polyphenolic content, mg GAE/g DW	**TPC**	0.109	0.558	0.093
Total flavonoid content, mg QE/g DW	**TFC**	0.111	-0.427	-0.002
Antioxidant activity, mMol Trolox/g DW	**AA**	-0.129	0.489	-0.109

The application of high drying temperatures leads to a reduction in polyphenol oxidase activity, an enzyme that catalyzes the oxidation of bioactive compounds, thereby decreasing the bioavailability of target compounds.

This effect is evident in **Figure 2** and **Table 2**, where the TPC and AA were associated with the group of powders dried by convection drying (CD) at 60°C and 70°C, as well as with the powder dried by infrared radiation (IR) at 50°C.

According to **Figure 2**, the highest values for Carr Index, Hausner Ratio, and tapped density were in the third quadrant of the two-dimensional (2D) representation, corresponding to the samples dried by IR at 60°C and 70°C, emphasizing that these powders exhibit very poor flow properties.

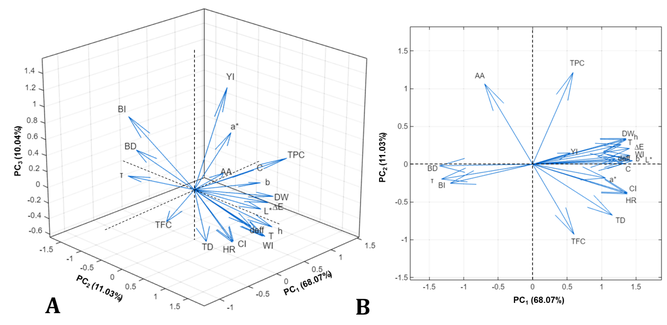


Figure 2. *Loading plots representing the relationship between dependent variables based on the first three (A) and the first two (B) principal components.*

CONCLUSION

Both the drying method and the applied temperature used for drying white grape pomace significantly influenced the color parameters, powder flow properties, and the retention of bioactive compounds.

An increase in drying temperature led to higher lightness values (L*) and a reduction in the browning index, indicating a partial inhibition of polyphenol oxidase activity. This enzymatic reduction resulted in higher total phenolic content (TPC) and antioxidant activity (AA) values for the powder dried by hot-air convection (CD).

In the case of infrared drying (IR), the powder dried at 50°C exhibited a high phenolic content and strong antioxidant activity, showing similar values to those obtained for the powder dried at 60°C by hot-air convection, as also confirmed by the Principal Component Analysis (PCA) results.

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