Use of Factor Analysis for the Characterization and Modelling of Maturation of Palomino Fino Grapes in the Jerez Region

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Factor analysis was made of data derived from monitoring maturation of Palomino fino (*Vitis vinifera L.*) over eight years during the decade 1983-1992 in the wine producing area of Jerez, Spain. Factor analysis was necessary to interpret the many data coming from the grape maturation study (8 vintages, 14 plots, 6 berry samples per plot and vintage, and 10 berry composition variables for each sample). Three factors were identified as a result of the analysis of the factor loading pattern that were designated as maturation, concentration, and mineral factors, according to their meaning. These factors accounted for 59% of the variance within the data, enabled the modelling of the maturation process, and showed the influence of climatological and location factors.

KEY WORDS: factor analysis, maturation, *Vitis vinifera L.*, Palomino fino, Jerez, characterization

Grape harvest marks the end of vine growing season and the start of wine production. The degree of berry maturation is the most important factor to fix the date of the harvest. Once this phenological period [*i.e.*, commercial maturity (6)] has been achieved, the grapes have reached the ideal physicochemical characteristics for further use in winemaking. Geographical, climatological and agricultural factors play a crucial role during this period and, to a large extent, determine the quality of the harvested fruit (13).

In the Jerez area, the date of the harvest has been traditionally established upon the compositional simple ratios of maturation, like °Baume/titratable acidity. The information supplied by this ratio is insufficient to determine an appropriate harvest time since does not consider other important berry composition variables.

Previous research focused on defining grape maturity has produced large set of data, but its interpretation became increasingly difficult. Consequently, it is necessary to consider multivariate statistics to study grape maturation (1,2,5,14). The present study examines the applicability of the principal component analysis to evaluate the influence of the climate and the site of culture on the maturation of *Palomino fino* grapes over eight grape seasons in the Jerez region (Spain). It was our objective that the results obtained would provide a deeper knowledge of the maturation of *Palomino fino* grapes, and emphasize the influence of the climatology and the differences between the many microzones in the region in the grape maturation pattern.

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Materials and Methods

Vineyards included in this study: From 1982 until 1992, the Department of Chemical Engineering of the University of Cádiz conducted a research project under an agreement with the Regulating Authority of the Jerez Denomination of Origin. A total of 14 plots from the various districts of the Jerez production area, spread across the municipal districts of Chiclana, Jerez, Trebujena, and Sanlucar de Barrameda were used in the present study (Fig. 1) (10). Each plot contained 900 vines. The years included in the study were 1983, 1984, 1985, 1989, 1990, 1991, and 1992.

Meteorological data: Mean monthly temperature and precipitation data for 1982-1992 period were compiled, together with the average for the last 99 years, from the Experimental Vine-culture Station of "Rancho de la Merced" (I.N.I.A.), located in the municipal district of Jerez de la Frontera, close to most of the studied vineyards (Fig. 1).

Grape sampling: The samples were taken weekly for six weeks from the last week of July (veraison) to the first week of September (start of harvest) (10). Samples of approximately 2.5 kg per plot were taken, in clusters of 10 berries each. Vines were randomly selected from different parts of the plot to be as representative as possible of the overall condition of the grapes.

Monitoring commercial grape maturity (1982-1992): The following berry composition variables were analyzed: mean berry fresh weight; dry residue at 110°C (dry berry weight); dry residue at 550°C (ash); soluble solids (°Baumé); pH; titratable acidity (TA); tartaric acid; alkalinity of ash; and concentration of potassium (K), ammonia (NH_4) and phosphates (P). Determination of mean berry weight, dry weight, ash, °Baume, pH, and TA were measured by conventional methods (9), while tartaric acid, alkalinity of ash, and K, NH_4, and P were done according to previously published methods (4).

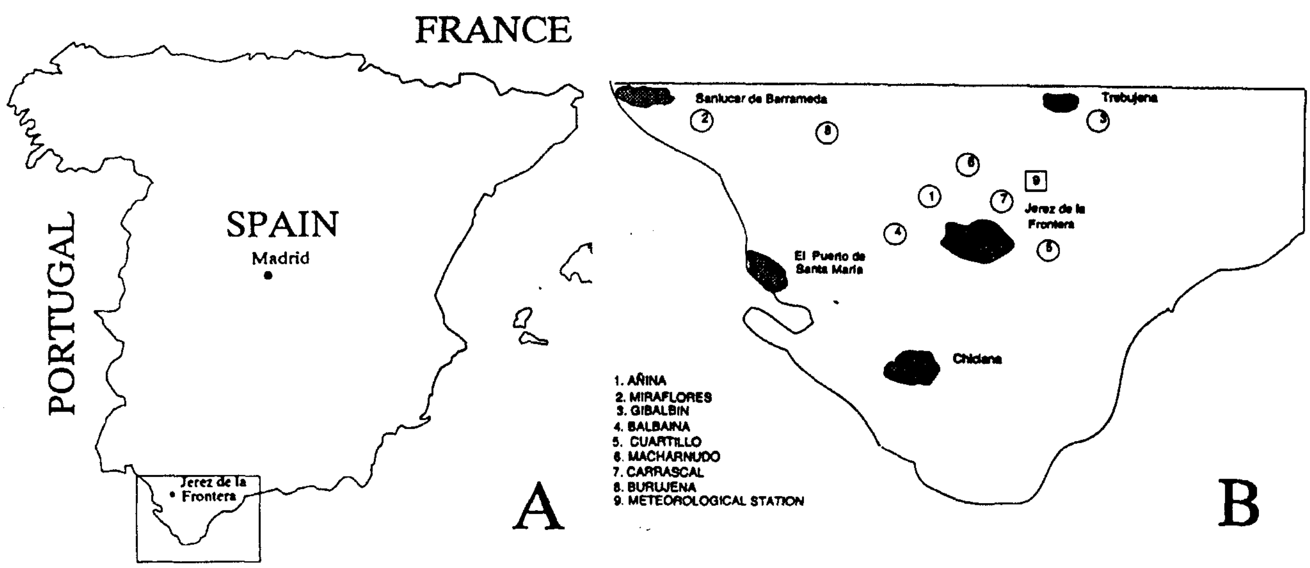

Fig. 1. Estates of the Jerez Production Area. (**A**) Location of the Jerez region in Spain; (**B**) specific sub-zones of grape production in the Jerez region.

Multivariant statistical analysis: The berry compositional data from the eight vintages were used in a factor analysis using a BMDP statistical package (3). The 4M subroutine was applied using principal component analysis (PCA) with orthogonal rotation ("varimax") as the factor extraction method (3,8).

Results and Discussion

Factor analysis: PCA was applied to 10 berry composition variables (°Baume, pH, NH_4, TA, dry weight, alkalinity of ash, tartaric acid, P, K , berry weight), which were measured during maturation of *Palomino fino* grapes in eight seasons. Three factors were extracted, which accounted for 58.4% of the total variance within the data (Table 1). Subsequent factors were neglected because each one accounted for a variance less than 10%. The percentage of variance explained is relatively small. This is believed to be due in part to the long period of data collections and to the regional diversity of the plots (14 plots).

Table 1. Results of factor analysis of 10 Palomino fino berry composition variables.

Loading factors	Factor 1	Factor 2	Factor 3
Soluble solids	0.891	0.000	0.000
pH	0.756	-0.278	0.000
NH_4	-0.751	0.000	0.254
Titratable acidity	0.745	0.276	0.000
Dry weight	0.642	0.342	0.000
Alkalinity of ash	0.000	0.707	0.332
Tartaric acid	0.000	0.643	0.000
P	0.000	0.000	0.799
K	0.000	0.000	0.656
Berry weight	0.000	-0.447	0.262
Variance (data)	33.76	12.43	12.26
Variance (factors)	57.75	21.28	20.07

Factor 1 (33.8% of the total variance) was highly correlated with variables associated with fruit maturity (°Baume, pH, NH_4, TA, and dry weight); was negative correlation with NH_4 and positive with all others. Hereinafter, Factor 1 is designated as the maturity factor (Table 1). A progressive and constant increase of the maturity factor was observed during the maturation process, culminating in the sixth and final week of the study at its maximum value except for 1992 (Fig. 2). Figure 2 represents the values of Factor 1, for every year studied, during the maturation period. The values correspond to the average of the plots studied. The value of this factor indicates the state of grape maturity before the harvest and, therefore, is useful to characterize the different vintages, as well as to permit a comparison of the degree of ripening reached by the individual plots.

Factor 2 (12.4% of the total variability) was positively correlated with tartaric acid and alkalinity of ash and negatively with berry weight (Table 1); hereinafter it is referred as the concentration factor. These variables were not heavily loaded on Factor 1 and were strongly influenced by climatic conditions, especially rainfall. The degree of dehydration of the grape berry during maturation can, therefore, be determined from the value of this factor. A high, positive value of the concentration factor is indicative of a high concentration in the grape berry as result of the low rainfall. A high negative value indicates dilution as a result of high rainfall, particularly if it takes place during the summer.

Factor 3 (12.3% of the variance) was positively correlated with two mineral elements (P and K) (Table 1); hereinafter it is referred as the mineral factor. Therefore, it can be considered in the evaluation of the mineral content of the grapes and, indirectly, of the soil in which the vines were grown. The mineral factor served to determine or confirm the differences existing be-

Table 2. Annual precipitation (AP), mean temperature (summer) (T), factor of maturity (F1), factor of concentration (F2), titratable acidity (TA), and soluble solids (SS) for eight vintages in the Jerez de la Frontera area of Spain.

Campaigns	AP (L/m²)	T (°C)	F1	F2	TA (g tartaric acid/L)	SS (°Be)
1983	266.9	21.8	0.86	1.66	5.1	10.0
1984	446.3	23.2	0.24	0.34	3.7	10.3
1985	616.8	23.8	1.32	-0.53	3.3	11.0
1986	416.7	23.0	1.35	-0.33	3.4	11.2
1989	352.8	24.9	1.46	0.39	3.7	11.2
1990	637.2	24.3	0.87	-0.18	3.0	10.4
1991	484.8	25.0	1.06	-0.47	3.0	11.0
1992	367.2	22.9	0.26	0.11	3.4	9.6

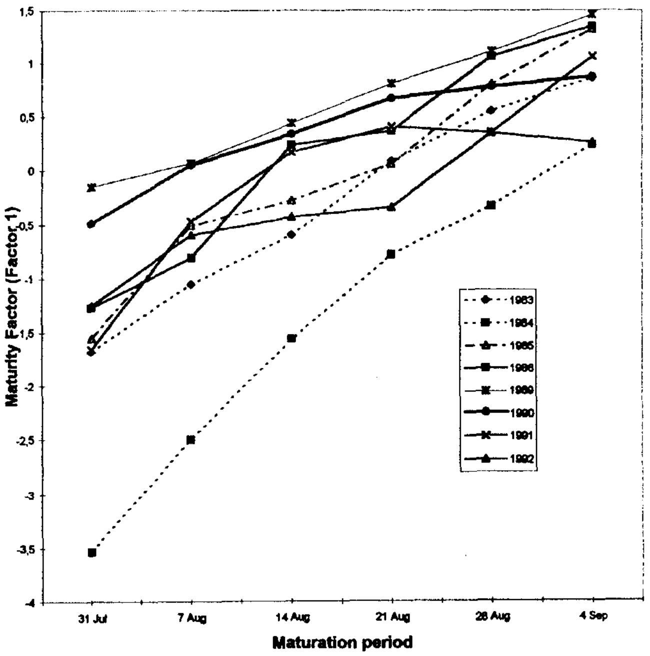

Fig. 2. Changes in the maturity factor over the course of the maturation period of Palomino fino grapes in the Jerez region.

tween the production sub-zones or micro-zones within the overall area. It is also an element to analyze the potential fertility of the soil, the incidence of the fertilizers used, and the enrichment or impoverishment of the soil in mineral nutrients.

Characterization of the vintages: The vintages can be classified into three groups depending on the final value of the maturity factor. The first group comprised the 1985,1986, and 1989 vintages that show values between 1.2 and 1.6. The second group (1983, 1990 and 1991) displayed values between 0.6 and 1.2. The third group, (1984 and 1992) displayed final maturity factor's values of approximately 0.2 (Table 2; Fig. 2).

Although temperature is never a limiting factor for normal vine growth in a "warm climate" zone (7), rainfall certainly is important. The 1982-92 period was especially dry (472 L/m² per year) in comparison with the average annual rainfall over the past 99 years (636 L/m² per year). Therefore, one of the main factors limiting the grape maturity has been the low rainfall value.

The vintage with highest maturity factor (1989) was that with the lowest rainfall and the highest average temperatures during the summer (Table 2). Such conditions contributed to high water evaporation from the grape berry, typical of over-ripening, and produced musts rich in sugars, with TA slightly higher than average (Table 2). Although a high sugar concentration in berries may be beneficial in sherry wine production, since there is less need for fortification and hence some cost-saving, this could nonetheless have certain negative implications. For instance, if berry dehydration leads to a high concentration of malic acid, as it degrades, it could encourage bacterial infections that might greatly affect the aging of the wines (11,12).

Concentration factor and rainfall were inversely related in all seasons ($r^2 = 0.6$) (Table 2; Fig. 3). How-

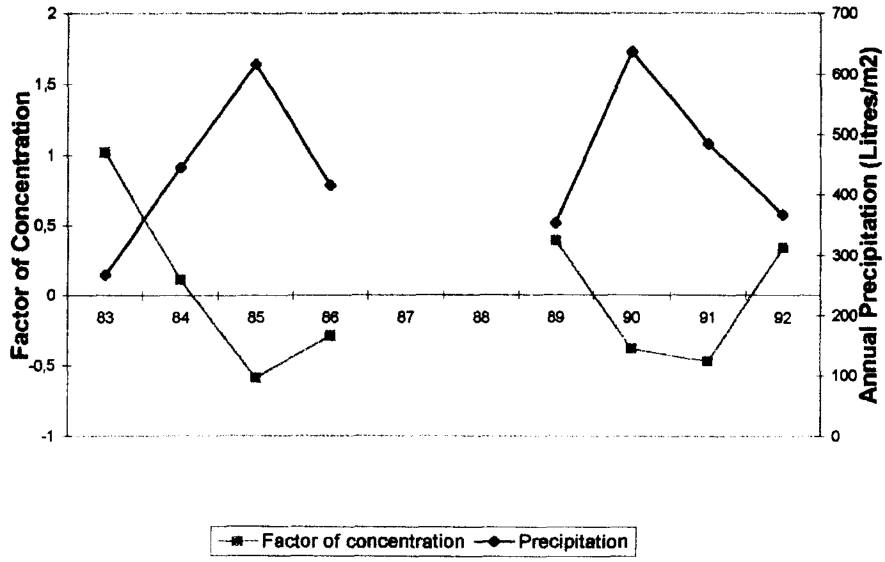

Fig. 3. Relationship between the concentration factor and annual precipitation for eight vintages in the Jerez region.

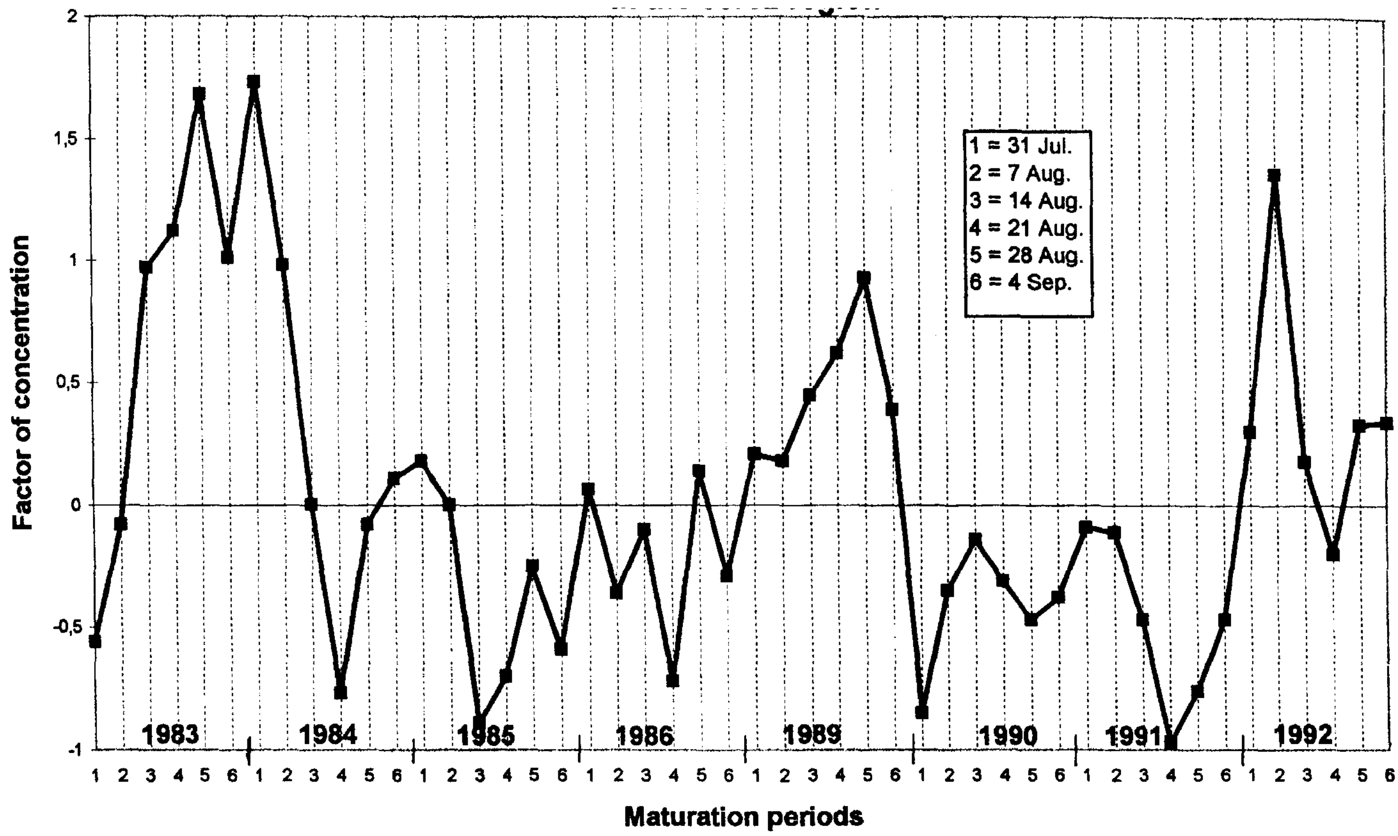

Fig. 4. Maturation and seasonal changes of the concentration factor for eight vintages in the Jerez region.

ever, this relationship was not linear because the concentration factor also included influences of rainfall of the previous year, particularly if that year was unusually dry or wet. This apparent interdependence between successive years suggests that, for many vintages, the rainfall of the year has not a direct effect in the composition of the must.

In relatively dry years or those following a extended period of drought, the values of the concentration factor are positive (1983, 1984, 1989, and 1992) (Table 2; Fig. 3). This implied substantial water evaporation of the berry and, consequently high metabolite concentration. In practical terms, it is known that serious deficiencies in must composition exist if there is a high value for the maturity factor.

The years of relatively high rainfall were most favorable for maturation of the fruit, whereas the years 1985, 1986, 1990, and 1991, with severe drought, showed negative final values for the concentration factor (Table 2; Fig. 3). In these vintages, the vines were not water stressed, hence transpiration, metabolite translocation, and organic acid metabolism occurred under favorable conditions. These processes play a crucial role in both the fruit maturation process and must composition.

The concentration factor at harvest appears to affect its value at the beginning of following season (Fig. 4). This trend suggests that this factor (indicative of the water content of the grape berry) can be correlated with the recent history of the plant: a very dry year determines not only high value of the concentration factor but also a relatively high initial value for the next year.

The concentration factor at harvest can also be used as a gross estimate of the soil water content and, therefore, may be a guide to define the optimum soil water content for the maturation of the fruit. Thus in cases where this optimum is not met, corrective viticultural practices such as controlled irrigation can be implemented.

The degree of fruit maturation within individual vintages could be characterized by using final values of the maturity and dilution factors (Table 2). Best vintages, during the years studied (according to the grape requirements for Jerez wine production), with a high maturity factor and a negative concentration factor were: 1985, 1986, 1990, and 1991 (Table 2).

Characterization of the plots: PCA offered a criterion to establish clear differences among the various production sub-zones. As example, the results were analyzed for four plots in the Jerez area: Burujena, Añina, Cuartillo, and Gibalbin (Fig. 1). Burujena presented a particular behavior with respect to the others plots, with minimum values for Factor 1 and 3 and maximum for Factor 2 (Table 3). The relatively low value for the maturity factor and the high value of the concentration factor of this plot suggest certain deficiencies in the grape which could eventually impair the fruit maturity. Furthermore, Burujena also showed

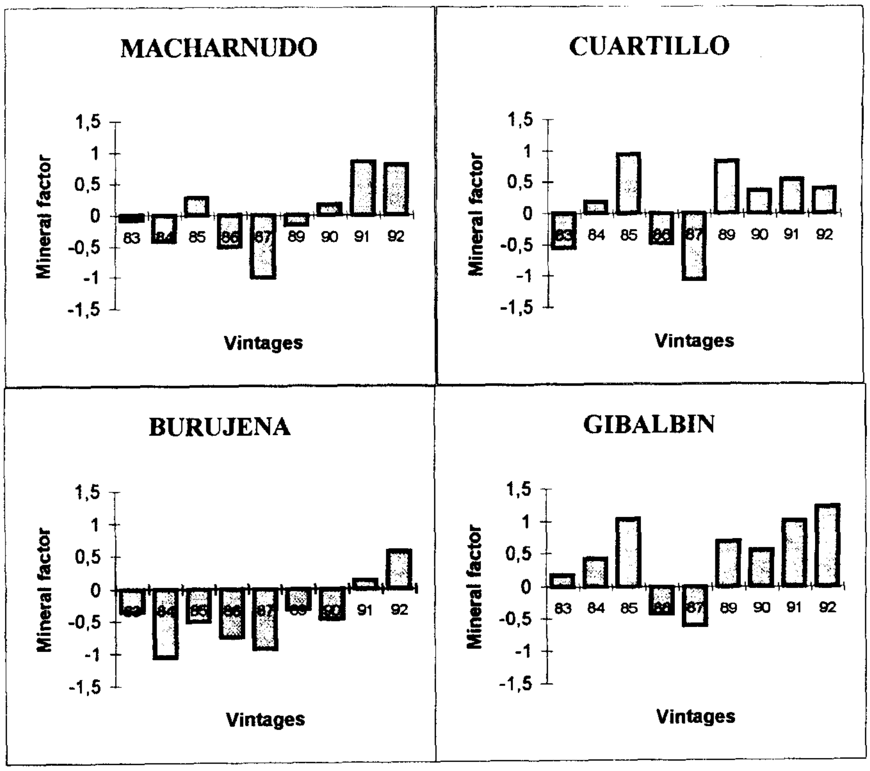

Fig. 5. Mineral factor for four plots in the Jerez region.

Table 3. Mean values of the Factors 1, 2, and 3 for four plots in the Jerez de la Frontera region of Spain.

	Factor 1	Factor 2	Factor 3
Macharnudo	0.84	0.28	0.11
Burujena	0.51	0.55	-0.35
Cuartillo	0.85	0.11	0.42
Gibalbin	0.80	0.35	0.58

negative values for the mineral factor in most of the vintages (Table 3; Fig. 5), irrespective of the annual climatic variations, suggesting that mineral deficiencies may be a cause of poor fruit maturity. Finally, the analysis of the fruit composition and the berry weight from Burujena plot showed a significant low value of K and P (111.7 and 1387.8 mg/L, respectively) related with the plots overall values (1387.8 and 1555 mg/L), confirming the information supplied by the mineral factor.

Conclusions

Multivariate analysis is a useful tool to interpret the chemical aspects of grape maturation. The influence exerted by the meteorological conditions and the site of plant cultivation on the maturation process can also be evaluated.

Using PCA analysis three factors were identified as contributing to the maturation process: maturity, concentration, and mineral. The three factors enable the modelling of the maturation process, collecting the most significant information provided by the 10 physicochemical variables analyzed. Vintages were grouped according to maturity and concentration factors. The best vintages displayed high and positive values for the maturity factor and negative values for the dilution factor.

The differences in mesoclimate and cultivation, as well as those typical of the land, included in the factors of maturity, dilution and mineral content, significantly effected the maturation process and served as a criterion to characterize the different production sub-zones. The comparison of the results of four plots showed that, although there exists a high degree of homogeneity within the boundaries of the plot, certain differences in maturation could be noted in the Burujena plot. In this is probably due to an impoverishment of the land in mineral nutrients (P and K).

In spite of the abundant information already processed in this study, it is necessary to continue the systematic compilation and processing of data relative to the maturation of grapes in the Jerez area, to obtain a more complete characterization and optimal modelling of this important phenomenon, since climatic cycles may span longer than the 10 years studied here.

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