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EARLY ESTIMATE OF WINE PRODUCTION USING AIRBORNE POLLEN SAMPLES: APPLICATION TO NORTHERN PORTUGAL

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SUMMARY: A forecast model for estimating the annual variation in wine production has been developed for Northern Portugal regions – Vinhos Verdes and Bairrada. In these regions, annual wine production has been forecasted on basis of an hierarchical analysis (aeropalynoclimatological forecast models) including in a first step the determination of the potential production by measuring airborne pollen concentrations at flowering, followed by an evaluation of possible impact of the post-flowering conditions limited crop production. A comparison of declared productions and productions adjusted to aeropalynoclimatological forecast models showed an average spread deviation of 4% in RVV and 5% in Bairrada.
KEY WORDS: viticulture, wine forecast, pollen, climate, post-flowering, statistical model.

RESUMEN: Se ha desarrollado un modelo de estimación de la cosecha de vino para las regiones del norte de Portugal - Vinhos Verdes (RVV) y Bairrada. En dichas áreas, la producción anual de vino se ha previsto a partir de un análisis jerárquico (modelo aeropalinoclimático de previsión) que incluye, en un primer paso, la determinación de la producción potencial midiendo la concentración de polen aerotransportado durante la floración, seguido de una evaluación del posible impacto de las condiciones posflorales limitantes de la cosecha. Para ambas regiones, se tomaron 21 registros anuales de datos (RVV: 1992-2001; Bairrada: 1991-2001). De la comparación entre las estimaciones aeropalinoclimáticas y las producciones reales se desprende una elevada fiabilidad del método utilizado: en un 72% de los casos, la diferencia fue inferior al 5% y tan sólo en 4 observaciones la desviación fue superior al 10%, sin que la diferencia superar nunca el 17% (desviación media inferior a 4% en la RVV y 5% en Bairrada). Cuando estos modelos se aplicaron a 2000 y 2001 (datos externos) la previsión obtenida sólo se desvió de la producción real 1 y 10% en RVV y 1 y 9% en Bairrada. La fiabilidad y adelanto de esta información permite gestionar y desarrollar correctamente el mercado, gestionando stocks, estableciendo políticas de precios e interviniendo en la mejora de los mercados. En este sentido, permite incidir sobre la producción, moderando sus oscilaciones interanuales, especialmente importantes en nuestro país, y adaptando así mejor la oferta y la demanda.
PALABRAS CLAVE: Viña, estimación de cosechas, polen, clima, posfloral, modelos estadísticos.

INTRODUCTION

Wine production in the Northern Portugal is characterised by the presence, within a short time span, of abundant and meagre vintages, with adverse consequences for all operators related with the speculative wine business (CUNHA *et al.*, 2001). In this context, the regional wine forecasts can be performed to improve the efficiency of vineyard and winery operations. Growers can use wine forecasts to appraise crop size and develop marketing strategies, adjust crop loads to desire levels and to determine labour and equipment requirements for the harvest. Regional wine forecasts can also help vintners to evaluate grape supplies and organised delivery schedules, as well as to estimate cooperage and equipment demands for crush.

Wine production is a complex process, which takes place on farms fields level and varies over regions, farms, fields and years. Many different factors influence the crop production process, which can be studied in various disciplines. Depending on the scientific discipline, the cause of variation in crop production can be sought in several aspects like: i) abiotic factors (soil water, soil fertility, soil texture, soil taxonomy class, weather), ii) farm management factors (vine-growing systems, crop-growing techniques, crop protection against pests and diseases, harvest techniques, post harvest losses), iii) land development factors (field size, terracing, drainage, irrigation) and iv) socio-economic factors (distance to markets, population pressure, investments, costs of inputs, prices of outputs, education levels, skills, infrastructures and political situation).

Accurate and prompt wine forecast model over extended regions require repetitive high quality information of the factors refereed above on the crops development and on the occurrence, duration and impact of stress conditions. On other hand, when the influence of a factor or a group of factors is studied, it is implicitly assumed that the influence of all other non-studied factors is constant.

Wine production forecasting requires two types of basic information: the production area dimensions (obtained through the regional vine inventories) and the estimate of the production biological components. These estimates in plot vine samples, are time consuming, expensive and relatively subjective in its nature, especially when large regions are concerned. In this case, the development on structures and production areas are generally superior to the updating of the regional vines inventories. Therefore, the wine forecasts for a region, obtained with a reduced number of trial plots within a vineyard, not only lead to difficult sampling and high costs but also rise many forecast errors.

The integrated action of all these factors (evolution of production areas, biological components sampling and costs) led to the development of forecast models based on the use of Airborne Pollen Concentrations (APC), usually known as Aeropalynological Forecast Models (APFM).

The aim of this work is to demonstrate, in regions with different weather conditions, soils, vine-growing systems and vine varieties, the applicability of this forecast model for estimating the annual fluctuation in regional wine production on basis on APC, as well as meteorological and agro-technical conditions that occur between flowering and harvest: aeropalynoclimatological forecast models (APCFM). It is also one of ours expectations that this forecast model, because of its accuracy, feasibility and early-indication quality, can be useful in the decision-making process for vine-growers, wine-makers and wine-traders.

MATERIAL AND METHODS

VITICULTURE

Our work was carried in the regions of Vinhos Verdes (VVR: 41°16'N, 8°05'W) and Bairrada (40°26'N, 8°26'W), each differing in weather conditions, soils, vine-growing systems and crop-growing techniques. These regions represent about 25% of the total wine production of Portugal. In both regions, soil water content is high at bud-break, due to heavy winter rains. The available water reserve at the end of the ripening period for the 20[th] and 80[th] percentiles varies from 22 to 55% in VVR and from 20 to 35% in Bairrada (REIS & LAMELAS, 1988).

REGIONAL POLLEN INDEX

Pollen grains were sampled continuously since 1991 in Bairrada and since 1992 in VVR, using one Cour trap for each region (COUR, 1974). Pollen traps were placed approximately at 30 m above ground in Bairrada and 12 m in VVR (CUNHA *et al.*, 2001).

Pollen Emission Model (PEM: Fig. 1) was applied to define the beginning (x_i) and the end (x_s) of the main pollen period (MPP), the duration of *Vitis* pollen emission season and

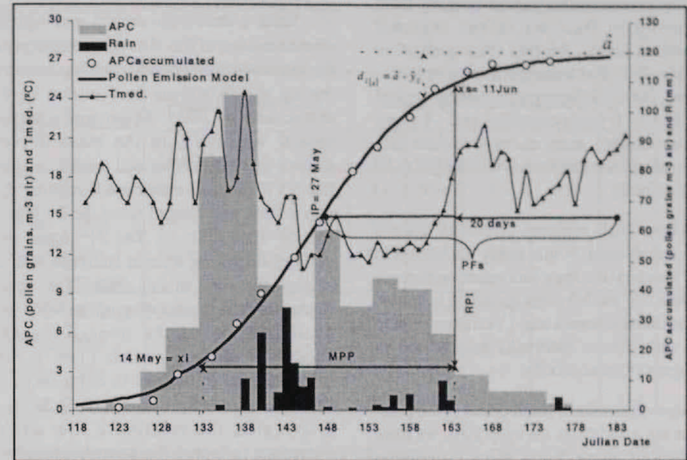

FIGURE 1. Observed APC and adjusted PEM: $y_t = \alpha[1+e^{-(\beta+\gamma x)}]^{-1} + e_t$, $t = 1, ..., n$, y_t is the amount of accumulated pollen up to day x_t, superior asymptote (a), inflection point of the model (IP), beginning (x_i) and end (x_s) of the MPP, definition of Regional Pollen Index (RPI) and the Flowering to Fruit Set Period (PFs). Evolution of means daily temperature (Tmed) and rainfall (R). Example of VVR in 1992; Fs = -1.

the Flowering to Fruit-Set period (PFs). In order to verify the thresholds where the daily difference between the PEM and their superior ($d_{\xi ri}=\hat{a}-\hat{y}_i$) and inferior asymptotes ($d_{\eta ri}=0-\hat{y}_i$) were significant, a one-sided t-test modality was used at the 5% level. The Regional Pollen Index (RPI), used in the forecast models, was calculated from the sum of the pollen obtained during the MPP (Fig. 1). The Inflection Point (IP) separates an interval at the rate of pollen increase with exponential type of an interval with decreasing increments of the pollen emission in the region. The abscissas IP_x and ($\hat{x}_i$ + 20 days), define the days which comprise the PFs (Fig. 1). In this work the IP_x is called the regional mean derived flowering date.

POST-FLOWERING CONDITIONS

To examine the role of meteorological conditions during the period ranging from flowering to fruit-set in the regional production levels, we rely on a qualitative variable (Fs), that assumes three categories (Cunha, 2001): 1 (favourable meteorological conditions), 0 (unfavourable) and –1 (very unfavourable) that correspond to the meteorological conditions in the PFs [IP, (+20 days)] (Fig. 1).

The overall regional effects of disease (ED) rating used in this study are scaled at three levels: 0 for the years when no disease problem occurs, 0.5 corresponding to severe but localised diseases and 1 as a catastrophic year with severe outbreaks generalised in the region (Cunha, 2001).

To evaluate the overall effect of the post-flowering conditions on crop size, we used the data of Wine Yield after Processing (WYP: L/1000kg), obtained by region, from production companies that are known to maintain consistent wine production techniques during the sampling period.

AEROPALYNOCLIMATOLOGICAL FORECAST MODELS (APFM)

Concerning both VVR and Bairrada regions (ri) a regression model was fitted by stepwise method: ($PRD_{ri} / WIP_{ri} = \beta_0 + \beta_1 RPI_{ri} + \beta_2 Fs_{ri} + \beta_3 ED_{ri} + e_i$). As independent variables in the forecast models, we tested declared regional wine production (PRD) and regional wine production corrected by WYP (PRD/WYP), whereby we can evaluate, for each region, the influence of the pre- and post-flowering periods upon the annual crop.

Parameters of each forecast model were fitted using 8 (VVR: 1992 to 1999) and 9 (Bairrada: 1991 to 1999) years. Models were tested (external validity) in order to predict in both regions the 2000 and 2001 vintage.

RESULTS AND DISCUSSION

Table 1 shows the annual and regional characteristics of the *Vitis* pollen season and the meteorological conditions that occurred during the flowering to fruit-set period determined by PEM. There was a marked annual variability in the mean derived flowering date among and within regions. For VVR, the mean derived flowering date was 1 June and ranged from the 1st May to the 15th June (Tab. 1). The 21st April 1997 derived flowering date in Bairrada was the earliest recorded in this study. The annual fluctuations in the duration of the MPP gave an indication of the overall weather conditions in those periods (Tab. 1). The lowest annual variations in duration of the MPP were recorded in Bairrada (7 days). In this region the relatively low annual variations reflected the great homogeneity of vine varieties that characterise its plantations, regularity in the mean annual temperature and the low precipitation values for this period.

The VVR was characterised by a MPP extended from 14 to 32 days, being the region with the highest precipitation values and lowest temperatures during the MPP. Short intervals in the MPP are associated with temperatures ranging form 17 to 25°C and the non-occurrence of lengthy periods of rain.

The APCFM adjusted for these regions describes about 96 to 99% of the regional wine production variations over years (Tab. 2). The regression diagnostics of the most influential observations carried out using alternative estimations Cook's distance, DfBeta's$_{j,i}$ and standardised influence of the observation *i*th on the predicted value (DfFits$_i$), have enabled us to check the absence of outliers and therefore the solidity of the model.

The ACP showed great annual and regional variation in the emission patterns. This way, the effective values of RPI able to be taken into account, but without calculating its recirculation due to wind. On other hand, the fertilisation process seemed to be sufficiently complete when the pollen count in the atmosphere begins to decline (Cunha, 2001 and Fornaciari *et al.*, 2002).

The analysis of WYP for both regions exhibited a variation coefficient always lower than 13.1%, indicating a strong annual stability when compared with regional production. The comparison of APFM established by corrected wine production and non-corrected wine production for the WYP, indicated that approximately 6% in Bairrada and 21% in VVR of annual fluctuations in wine production can be explained by WYP. According to our results, RPI is the variable with larger explanatory capacity for the annual fluctuations in regional wine production; appropriate statistical tests indicated that RPI,

Region	Statistics	Pollen Emission Model			Flowering – fruit set period (PFs.)					dummy variable
		Ipx (date)	MPP (days)	RPI	Tmed (°C)	R (mm)	nR (days)	nconR (days)	%nR (%)	Fs.
VVR n = 10	Average	150.7	23.6	223	17.6	55.0	7.0	4.2	24.8	-0.2
	Max.	165.0	32.0	520	20.0	163.3	14.0	9.0	47.9	1.0
	Min	120.0	14.0	117	14.0	8.2	1.0	0.0	3.6	-1.0
	C.v (%)	9.7	26.6	63	12.0	105.3	69.3	68.8	62.7	---
Bairrada n = 11	Average	140.8	14.0	95	18.6	18.9	7.1	3.4	31.8	0.0
	Max.	155.0	17.0	224	23.1	51.0	18.0	6.0	86.8	1.0
	Min	112.0	10.0	16	16.4	0.0	1.0	1.0	3.8	-1.0
	C.v (%)	9.4	20.8	63	10.3	104.4	87.7	54.1	93.4	---

TABLE 1. Descriptive statistics of regional characteristics of *Vitis* pollen season and meteorological data during the flowering to fruit-set period (PFs). Ipx: derived flowering date.MPP: duration of main pollen period, estimated by pollen emission model (PEM). RPI: regional pollen index; Fs: classification of the meteorological conditions during the flowering to fruit-set period; Daily average temperature (Tmed), precipitation (R), number of rainy days (nR and nconsR for the consecutive rainy days), and the percent of days with rain in the PFs period (nR%).

together with WYP, explain approximately 88 to 93% of the annual variability in wine production (Tab. 2).

Comparing the influence of pre- and post flowering factors, our work revealed a very low influence of this last on wine production. These results contradict VOSSEN & RIJKS (1995), BESSELAT *et al.* (1997) and other authors of the European pollen-traps network (CUNHA *et al.*, 2000). It has been suggested that the small adaptability of wine forecast models, based only in APC, in southern Europe vineyards, is related with a water supply problem that can modify the early crop potential acquired at flowering.

For both regions, 21 annual data records were taken. The comparison of declared productions and adjusted to APCFM productions showed that 72% of cases had differences of below 5% and that in only 4 situations were the differences higher than 10%, with no difference higher than 17% found (average spread deviation of 4% in RVV and 5% in Bairrada). This larger deviation is observed in Bairrada 1993 (Fig. 2) and it was caused by the occurrence of continuous periods of rain that continued abnormally during vintage, thereby precluding them (CEMAGREF and CNRS, 1993).

The R^2 prediction (R^2_{prd} = (1-(PRESS• Syy^{-1})); PRESS: Prediction Errors Sum of Squares) indicated that the models would be about 96 to 97% accurate in predicting wine volume production, which is strong evidence that the APCFM satisfactorily predicts the regional wine volume (Tab. 2). When these models were used in 2000 and 2001 (external data) the obtained forecast only deviated 1 to 10% in RVV and –1 to 9% in Bairrada from the actual reported production. (Fig. 2a and 2b).

In both regions, the observations used in the models were representative of the absolute maximum and minimum of the historical data of wine production, which allows the formulation of forecasts with a wide validation interval.

Región	Stepwise variables	Model summary				Models parameters				
		R^2	$R^2_{adj.}$	$R^2_{Prd.}$	SE_r	β	SE_p	*Sig.(P)*	*DfBeta*	*VIF*
VVR n=8	(Constant)					-1.780,8	528,75	0,028	0,96	
	Ln(RIP)	0,899**	0,882		234,3	690,4	93,70	0,002	0,85	2.710
	ED	0,971***	0.960		136,5	-539,8	98,80	0,005	0,98	2.630
	Fs.	0,991***	0,985	0,971	83,4	120,7	39,38	0,037	0,97	1.223
Bairrada n=9	(Constant)					-398,6	83,65	0,003	0,36	
	Ln(RIP)	0,935**	0,926		47,9	196,0	18,80	0,000	0,43	1.426
	Fs.	0,973***	0,963	0,959	33,7	40,7	14,22	0,029	0,68	1.426

TABLE 2. Aeropalynoclimatological Forecast Models (APFCM), selected variables by stepwise method, diagnostics, measures of model adequacy, estimates of coefficients for each region, their standard errors (SEp) and significant value of the t-statistic (Sig P). Statistics for detecting influential observations on regression coefficients (DfBeta'sj,i). R^2_{prd} = (1-(PRESS · Syy^{-1})), PRESS: Prediction Errors Sum of Squares; RPI – Regional Pollen Index; WYP – Wine Yield after Processing; Fs –meteorological conditions during the flowering – fruit set period; ED - Effects of Diseases in grapes; DfBeta's$_{ij}$ – annual maximum value of the standardised difference in coefficients values for each variable; VIF - Variance inflation factors.

CONCLUSION

The airborne pollen concentration, sampled by Cour traps, is a valuable instrument for vintage forecasts, because of it simultaneously integrates several factors that influence the crop production process. Some of these factors are the extent of pre-flowering conditions, the strength of the plants influenced by conditions in previous years, the easy sampling of the biological production components, the effects of diseases on

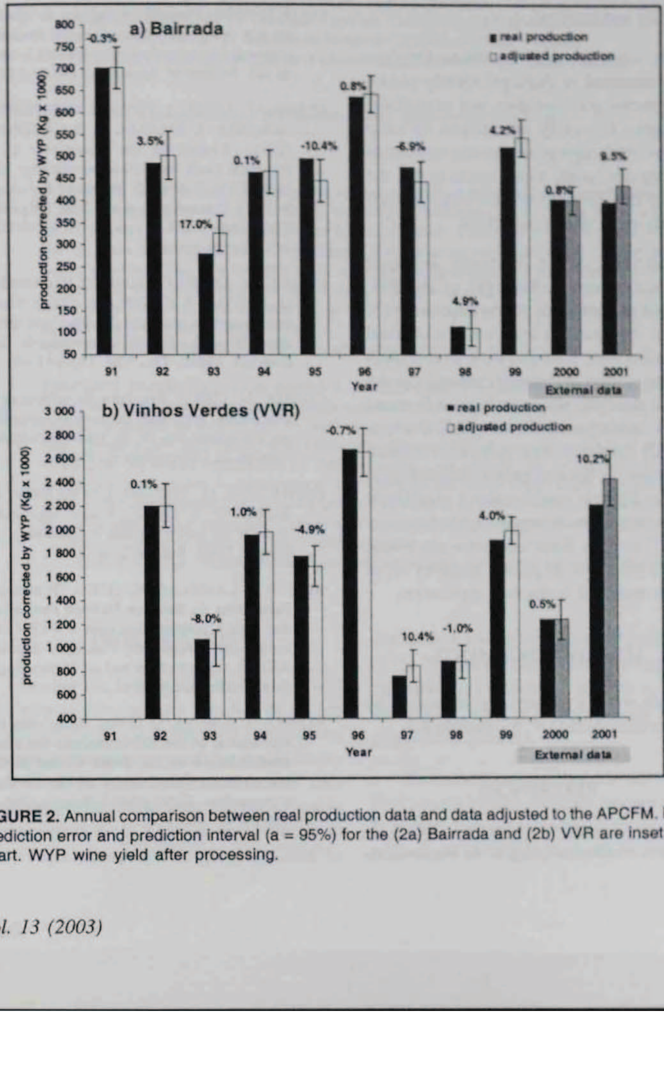

FIGURE 2. Annual comparison between real production data and data adjusted to the APCFM. Relative prediction error and prediction interval (a = 95%) for the (2a) Bairrada and (2b) VVR are inset in each chart. WYP wine yield after processing.

production levels previous to flowering and the development of the vineyard areas in production. However, the APC are not, by themselves, enough to establish a prediction of real production, thus, they must be integrated in a more inclusive system that takes into account the climatic and agro-technical conditions that occur between flowering and harvest.

The evaluation of the wine forecast results obtained in Portugal clearly shows the importance of the pre- and post-floral conditions for early estimation of crop volumes. Although summers are rainless in these regions, plant-water stress is not the greatest determinant of the large annual fluctuations in wine production.

Contrary to the tendency in other European countries, Portugal, after 1997, increased its number of pollen traps (now 11) to cover the southern wine regions. Agricultural authorities, vine-growers, winemakers and wine-traders in Portugal currently use the regional Aeropalynoclimatological Forecast Models, herein presented, as a predictive tool. The ready suitability of the method for defining the variables of the Aeropalynoclimatological Forecast Models could make a significant contribution towards improving the accuracy of the European Forecasts network, whose great investment in pollen samples is, at present, restricted in practical application.

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STATISTICAL EVALUATION OF THREE YEARS OF AIBORNE POLLEN SAMPLING IN BRAGA

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SUMMARY: Over the last three years the annual variation in airborne pollen concentration (CPA) of Braga region was studied during *Vitis vinifera* flowering season. During this period, the CPA average was about 3600 pollen grains.m^{-3} of air. Thirty-six taxa were observed and the main pollen types were *Olea*, Poaceae and Castaneae that represented 75% of the pollen spectrum. The CPA was positively correlated with temperature and wind direction (East, West and Northeast) and negatively with rainfall and number of rainy days. Appropriate statistical tests showed that 65% of the variation in CPA could be explained and predicted by these climatic variables.
KEY WORDS: Braga, aerobiology, meteorological parameters, pollen grains.

RESUMEN: Durante los tres años pasados la variación anual en la concentración aeropolinica (CPA) de la región de Braga fue estudiada durante la estación floreciente de *Vitis vinifera*. Durante el período de estudio, la CPA média era cerca de 3600 granos.m-3 in uperscipt del aire. Treinta y seis taxa fueron observados y las mayores CPA fueron *Olea*, Poaceae and Castaneae, los cuales representan el 75% del polen total contado. Se ha obtenido una correlacíon positiva con las temperaturas y la dirección del viento (Este, Oeste y Noroeste) y correlacíon negativa con la precipitación y el número de días lluviosos. A aplication de testes estadísticos apropiadas demuestran que el 65% de la variación en la CPA se podrían explicar y predecir por esas variables climáticas.
PALABRAS CLAVE: Braga, aerobiologia, parámetros meteorológicos, granos del pólen.

INTRODUCTION

During the last decade, in Europe, was observed an increasing number of pollen monitoring stations, for several applications namely in the alergological therapy. In Portugal, aerobiological studies are scarce and, until the present time, none was performed in Braga region. Since 1990, our researcher group develops aeropalynological studies in connection with a wine forecast programme. In the Botanical Department, during 1998, a palynological laboratory was set to perform analysis of airborne pollen, mostly for wine production forecast.

The study covers Braga's district (187 Km^2), in the Minho province, known as "Costa Verde", located at the Northwestern corner of Portugal (41°33'N; long. 8° 24' W), 50Km