GRASAS Y ACEITES 65 (4)
October–December 2014, e046
ISSN-L: 0017-3495
doi: http://dx.doi.org/10.3989/gya.0226141

Analysis of the influence of multiple parameters on the commercial categories of Extremadura virgin olive oils

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Submitted: 14 February 2014; Accepted: 16 June 2014

SUMMARY: Although Extremadura is an important producing region of Spanish virgin olive oils, it has not been always known for the high quality of its oils. However, implementation of continuous extraction systems in most of its olive mills has shown a general improvement in the quality of most virgin olive oils, but not in all of them. The aim of the present study was to examine how different variables, such as fruit quality discrimination or payment system, affected the overall quality of virgin olive oils from Extremadura. To do so, a screening experimental design and the corresponding statistical analysis of the collected data were performed. Sixty Extremadura oil mills were evaluated (50.4% of the total) by taking bottled virgin olive oil samples from each of them. Statistical relationships between physicochemical parameters and production process variables were evaluated, showing that only three of them (separation of ground- and tree-harvested fruits, differential payment according to acidity, and extraction process) were significantly correlated with the quality index and acidity of virgin olive oils.

KEYWORDS: *Acidity; Ground-harvested olives; Olive payment; Quality parameters; Virgin olive oil*

RESUMEN: ***Análisis de la influencia de diferentes parámetros en la categoría comercial de los aceites de oliva vírgenes de Extremadura***. Extremadura es una importante región productora de aceites de oliva vírgenes de España, aunque no siempre ha sido conocida por la producción de aceites de oliva de alta calidad. Sin embargo, desde la implantación de los sistemas continuos de extracción de aceite en la mayoría de sus almazaras, ha tenido lugar un aumento de la calidad en muchas de éstas. El objetivo de este trabajo ha sido estudiar cómo algunas variables, como la clasificación de las aceitunas por la calidad, o su sistema de remuneración, influye en la calidad global de los aceites de oliva vírgenes extremeños. Para ello, se ha hecho uso de un diseño experimental de barrido y el análisis estadístico del mismo. Sesenta almazaras fueron evaluadas en Extremadura (50,4% del total) y se tomó una muestra de aceite de oliva virgen envasado de cada una de las almazaras. Los resultados de los análisis físico-químicos fueron analizados estadísticamente junto con algunas variables del proceso de elaboración. Solo tres variables (separación suelo-vuelo, pagos diferenciados en base a la calidad y el proceso de extracción) resultaron significativos y, por lo tanto relacionados con un índice global de calidad adaptado y la acidez de los aceites de oliva vírgenes.

PALABRAS CLAVES: *Aceite de oliva virgen; Aceituna de suelo; Acidez; Pago de aceitunas; Parámetros de calidad*

Citation/Cómo citar este artículo: Montaño A, Sáiz-Abajo MJ, Espinosa F, Garrido I, Llerena JL. 2014. Analysis of the influence of multiple parameters on the commercial categories of Extremadura virgin olive oils. *Grasas Aceites* **65** (4): e046. doi: http://dx.doi.org/10.3989/gya.0226141.

1. INTRODUCTION

The Spanish Autonomous Community of Extremadura is an important olive oil producing region of Spain, with an annual output of over 50,000 tons of virgin olive oil (VOO). The area devoted to olive groves, 262,700 ha, is greater than that devoted to any other crop, reflecting the perfect adaptation of olives to the regional setting. This area represents 10.56% of Spain's total olive grove extension, and 2.60% worldwide (Llerena *et al*., 2009).

Extremadura is thus a significant olive oil producer for national and international packaging firms. In the 1990s, as with many other Spanish producing regions, there was significant improvement in its production systems with most of its industries introducing continuous milling systems. This, together with the incorporation of new, more modern olive groves into production, led to an increase in the manufacture of the top oil category – extra virgin olive oil (EVOO) – and a concomitant reduction in the production of lampante olive oil (LOO) (IEEX, 2010). Since the beginning of the century, extra virgin olive oils of the highest quality have been produced in this region. Similar developments took place in the rest of the Spanish producing regions at the end of the twentieth century (Uceda *et al*., 2001), as well as in other areas of the world such as Turkey (Artukoglu and Olgum, 2008) and Slovenia (Valencic *et al*., 2007). Nevertheless, most of the oils from Extremadura are still being marketed under the category of virgin olive oil.

In general, the quality of olive oil starts from the fruit and ends with the bottle, each stage rigorously controlled since any factor can negatively affect its final quality. In particular, different quality grades have to be constantly separated for the end result to be a product of quality (Salvador *et al*., 2003; Beltran *et al*., 2011). Variables affecting the quality of olive oil fall into two categories – agronomic and industrial. The former can in turn be separated into intrinsic variables, which are difficult to counteract (e.g., olive variety or agrological environment), and extrinsic, which can be controlled with relative ease (e.g., cultivation techniques, harvesting method, fruit sorting according to quality, transport type or delay in fruit processing) (Uceda *et al*., 2001; Valencic *et al*., 2007; Artukoglu *et al*., 2008).

Another extrinsic variable with a major influence on quality is the extraction system. Currently, extraction is performed by centrifugation rather than pressing. This greatly reduces the loss in quality during oil extraction (Uceda *et al*., 2001). Many studies have examined how the different steps of the extraction process affect the final quality of the oil, regarding not only the milling system, mill type (stone or hammer mills) (Veillet *et al*., 2009), or new mill improvements (Beltran *et al*., 2011), but also the flow rate (Bianchi and Catalan, 1996), decisively influencing the concentration of substances of nutritional interest such as phenolic compounds. The processes of preparing the paste, temperature conditions, malaxation time (Di Giovacchino *et al*., 2002; Artajo *et al*., 2007; Inarejos *et al*., 2009), and partial or total de-stoning of fruit (Montaño *et al*., 2011) condition the concentration of minority compounds due to the balance between oxidation and degradation processes and changes in solubility with temperature. The methodology used to separate the solid and liquid phases (by presses, two- or three-phase centrifuges, or the so-called third generation decanters), will also affect the final quality of the oil, with different contents of substances of not only nutritional, but also sensorial interest (Vaz-Freire *et al*., 2008; Amirante *et al*., 2010). The cleansing of the resulting oily phase, whether by natural decanting or vertical centrifuging, is another step of the extraction process which has a decisive effect on oil quality: the final concentration of minor compounds (phenols and aromatic compounds) will be reduced by contact with water, the loss being greater the higher the temperature, the greater the temperature difference between the two liquid phases, and the greater the volume of water used (Masella *et al*., 2011; Jimenez *et al*., 2011).

Although the extraction system has been the object of many studies, Di Giovachino (1991) rejected it as the most important variable for determining oil quality, and estimated its influence to be around 30% of its final value with the ripeness stage of the fruit accounting for another 30%, the variety 20%, and other variables (harvesting method, transport, and storage) for the remaining 20%.

Accordingly, the aim of the present study is to determine the most important variables which affect the quality of virgin olive oils from Extremadura, while taking into account the specific regional socio-economic factors involved in the production chain.

2. MATERIAL AND METHODS

2.1. Study population

A set of olive mills were identified across Extremadura and subjected to the two-phase cluster sampling technique, where a target population is grouped into clusters simultaneously selected at random to represent the regional oil-producing zones (Llerena *et al*., 2009). From these clusters, a random sample of mills was selected. This representative selection comprised 60 (50.4%) of the total 119 olive mills located in Extremadura during the 2005/2006 campaign. Surveys conducted in mills collected organizational and oil processing information as well as samples from already bottled oils to be analyzed in our laboratory. Surveys were performed following a random itinerary system that divided the region into homogeneous olive oil transformation areas.

2.2. Samples and variables

The data matrix comprised 60 representative virgin olive oil mills of Extremadura. The surveyed 30 variables were related to processing method, olive harvesting method, olive variety, product quality control, differential payment based on oil quality, yield, or other parameters related to olive production and quality. Most of these variables were dichotomous, and coded in the data matrix for subsequent statistical analysis as −1 if negative, and + 1 if positive. Others were continuous variables, such as milling capacity, percentage of packaging, duration of the season or olive oil quantity produced. In these cases, four value ranges (categories) were established for each of these variables, and real values were classified into these categories, so that their corresponding entries in the data matrix were of an ordinal type.

2.3. Physicochemical parameters

At each mill, a single oil sample was taken from the tank being bottled at that moment for physicochemical and organoleptic analysis as a representative sample of the olive oil commercialized by this industry. Each sample was stored at −30 °C until analysis. The procedure followed for the analysis corresponds to the EC Regulation N° 2568/91, and measures free acidity (%), peroxide index ($meqO_2 \cdot kg^{-1}$), the ultraviolet extinction coefficient at 270 and 232 nm (K_{270} and K_{232}), sitosterol (%), erythrodiol and uvaol (%), waxes ($mg \cdot kg^{-1}$), as well as an organoleptic assessment.

The compiled data was used to calculate a modified "Overall Quality Index" (OQI) as proposed by Gutiérrez (1989). The index modification was imposed by current legislation which mandates that a sensory evaluation cannot be assigned a numerical value (as with the original OQI), but instead the median of the oils' fruitiness and negative attributes. Since it is currently impossible to include the sensorial analysis results in OQI calculations, the present work's results are solely based on physicochemical parameters. Thus, we calculated a Physicochemical Overall Quality Index (PCOQI) adapted from Gutierrez (1989) and defined by the following formula:

$$PCOQI = 11.781 - (1.615 \cdot \%A + 18.180\ K_{270} + 0.05 \cdot PI)$$

Where %A corresponds to acidity, K_{270} to absorbance at 270 nm, and PI to peroxide index ($meqO_2 \cdot kg^{-1}$).

2.4. Data analysis

The data were analyzed using two specific chemometrics and experimental design software packages: Parvus to perform a principal components analysis, and Nemrod-W (Nemrod-W Software, 2008) to design the experiments and statistically analyze results. Significant differences ($p<0.05$) between data sets were evaluated by one-way ANOVAs followed by Duncan's multiple range test when necessary, carried out using software package SPSS version 17.0 for Windows.

Principal component analysis (PCA) is a statistical method of reducing the dimensionality of data by means of a covariance analysis among variables. It is especially well suited for data sets which involve many variables. When these variables have been measured for a set of samples and are plotted spatially, the result is a cloud of values in a multidimensional space. PCA can be used to automatically identify the trends exhibited by these samples and the measured variables, extracting directions in the space along which the cloud is densest.

A statistical analysis was performed using the experimental design software package, Nemrod-W. Each response can be described by the following first-order model:

$$\eta = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \beta_3.X_3 + \beta_4.X_4 + \beta_5.X_5 + \beta_6.X_6 + \beta_7.X_7 + \beta_8.X_8 + \beta_9.X_9 + \beta_{10}.X_{10} + \beta_{11}.X_{11} \quad (1)$$

where η is the theoretical response function, X_j are the coded variables of the system, and β_0 and β_j are the true model coefficients.

The observed response y_i for the i-th experiment is:

$$y_i = \eta_i + e_i \quad (2)$$

where e_i is the error.

The model coefficients β_0 and β_j are estimated by least squares fitting the model to the experimental results obtained at the design points. The notation b_0 and b_j were used for the estimates of these coefficients. The computed values of the responses were then given by $\hat{y}$:

$$\hat{y} = b_0 + b_1.x_1 + b_2.x_2 + b_3.x_3 + b_4.x_4 + b_5.x_5 + b_6.x_6 + b_7.x_7 + b_8.x_8 + b_9.x_9 + b_{10}.x_{10} + b_{11}.x_{11} \quad (3)$$

The model's goodness of fit was tested by comparing the variance due to the lack of fit with the pure error variance using the F-statistic. The model is considered adequate if the variance, due to the lack of fit, is not significantly different from the pure error variance.

3. RESULTS AND DISCUSSION

3.1. Physicochemical parameters

Table 1 lists the physicochemical results from each olive oil sample collected at every surveyed mill. Mean olive oil acidity was 0.6%. Values greatly varied, with only 50% of samples registering values between 0.3% and 0.8%. Over 76% of samples showed acidities below the maximum allowed for EVOO. One of the samples (1.7% total) presented an above 2% acidity value.

With respect to peroxide index values, all samples presented values below the maximum allowed by European Regulations for qualities fit for bottling. It was noteworthy that 75% of the samples showed values below 10 $meqO_2 \cdot kg^{-1}$.

The average for the K_{232} absorbance values was 1.95, with almost 97% of samples showing below the legislated maximum for EVOO: only two samples (3.4% of total) presented a value above 2.50. With respect to K_{270} values, over 86% of the samples registered values below the legislated maximum for EVOO. Only two samples presented values above 0.25. With regards to Delta K values, all samples were within the legislated limits.

All sitosterol values satisfied the legislated minimum of 93.0%, with the average being 94.7%, and only one sample showing the minimum value allowed by law.

Triterpene alcohols, erythrodiol and uvaol registered a mean value of 2.6%, but showed above 4% values in 10% of the oils. Only one sample recorded a value above the legislated maximum. This same sample had a wax content of 125 $mg \cdot kg^{-1}$. It is likely that these values corresponded to the character of the predominant oil varieties in its area of origin and/or poor processing practices rather than potential fraudulent admixtures.

With regards to the sensorial analysis, only 35% of samples registered fruitiness intensities above zero and lack of defects, thus corresponding to the EVOO category. While 58.3% of the samples were designated as VOO according to the sensorial analysis, only 56.6% also satisfied the required physicochemical criteria for this category. In addition, 10% of the oils corresponded to the LOO category which is unfit for bottling, although only 6.7% of them fell into this category solely due to their sensorial characteristics. Nevertheless, it should be noted that, at the time the samples were analyzed, Regulation 2568/94 classified oils as LOO when the median defect was 2.5 of intensity, and this value was later increased to 3.5 when the EC Regulation N° 640/2008 of 4 July 2008 came into effect.

TABLE 1. Descriptive statistics of physicochemical parameters of olive oil samples.

	Reg. EC 1991/2568	Mean	S.D.	Maximum	Median	Minimum	Percentile 25	Percentile 75	EVOO %	VOO %	LOO %
Acidity (%)	EVOO≤0.8; 0.8>VOO≤2.0; LOO>2.0	0.6	0.4	2.5	0.5	0.1	0.3	0.8	76.7	21.6	1.7
Peroxide index ($mEqO_2.kg^{-1}$)	EVOO & VOO≤20	9	2	16	9	5	8	10	100.0		–
K_{232}	EVOO≤2.50; VOO≤2.60	1.95	0.24	2.65	1.93	1.34	1.78	2.08	96.6	1.7	1.7
K_{270}	EVOO≤0.22; VOO≤0.25	0.15	0.03	0.24	0.15	0.10	0.13	0.17	86.7	10.0	3.3
Delta K	EVOO & VOO≤0.01	0.00	0.00	0.01	–	–	–	0.01	100		–
PCQGI		7.7	1.0	9.0	7.8	3.3	7.1	8.3			
Sitosterol	EVOO & VOO≥93.0	94.7	0.8	96.8	94.8	93.0	94.4	95.2	100.0		–
Erythrodiol and Uvaol (%)	EVOO & VOO≤4.5	2.6	0.9	5.3	2.4	1.2	2.0	3.3	98.3		1.7
Waxes (mg/kg)	EVOO & VOO≤250; LOO≤300	73	27	138	70	30	50	96	100.0		–
Sensorial analysis	EVOO Md<0, Mf>0; VOO Md <2.5, Mf>0; LOO Md>2.5	VOO		EVOO	VOO	LOO	VOO	EVOO	35.0	58.3	6.7
Categories	Reg. EC 1991/2568							35.0	56.6	10.0	

S.D.: standard deviation; Md: median of defect; Mf: median of fruitiness

Table 2 shows the average values of the analyzed parameters with oils grouped under the correctly assigned commercial category. The mean free acidity of the EVOO category (35% of samples) was 0.3%, with 50% of values between 0.2 and 0.4, while the VOO category showed a mean value of 0.7. The corresponding values of the LOO category were widely spread, indicating that the parameter primarily responsible for their lower rating corresponded to the intensity of their negative attributes in the sensorial analysis.

The oil peroxide index values were significantly different ($p<0.01$) among the three categories, with the lowest values corresponding to the top category. There were no significant differences, however, among the values of K_{232} or erythrodiol and uvaol. For K_{270}, sitosterol, and waxes, the LOO rated oils showed significantly higher values than the other two categories.

The calculated values of PCOQI were significantly different ($p<0.05$) among groups, although the formula used to define this index would not correctly classify oils since two LOO category samples registered values above 8.2, emphasizing the relevance of the sensorial analysis in rating the quality of olive oils.

The above results indicate that the main reason for olive oils not qualifying for the top category is their performance in the sensorial analysis. In particular, although their physicochemical parameters might satisfy the thresholds set in the legislation, they may present negative attributes in the tasting panels at intensities which do not allow them to be classified as highest quality. The causes of this sensorial impairment may be varied, and require an analysis of the processing at each mill to identify the main cause responsible for the loss in virgin olive oil quality.

3.2. Principal component analysis

In the present study, PCA was used as an exploratory analysis to search for clustering within the set of variables and samples, hence reducing the number of variables needed to explain their relationships. Data sets were subject to different pre-treatments, and the procedure applied implemented the NIPALS (Nonlinear Iterative Partial Least Squares) algorithm. Figure 1 shows the plotting of loadings and scores on the first two principal components' space. In this figure, column auto scaling has been applied to the data (to equalize the variances), and oil samples and variables are represented by producer identification number and name code, respectively.

The results revealed no clustering trend in either variables or samples. The oil samples were fairly evenly distributed over the experimental space, and only producers 89, 94, and 103 were notably distant from the origin of the PCA plot.

TABLE 2. Descriptive statistics of physicochemical parameters of samples corresponding to the three commercial categories of olive oil

	EVOO				VOO				LOO			
	Mean ± S.D.	Median	Percentile 25	Percentile 75	Mean ± S.D.	Median	Percentile 25	Percentile 75	Mean ± S.D.	Median	Percentile 25	Percentile 75
Acidity (%)	0.3 ± 0.2a	0.2	0.2	0.4	0.7 ± 0.5b	0.6	0.4	0.9	1.0 ± 0.9b	0.9	0.3	1.0
Peroxide index ($meqO_2 \cdot kg^{-1}$)	7 ± 1a	7	7	9	10 ± 2b	9	9	11	13 ± 2c	13	12	14
K_{232}	1.98 ± 0.17a	1.99	1.86	2.06	1.94 ± 0.28a	1.88	1.77	2.10	2.04 ± 0.36a	1.98	1.82	2.02
K_{270}	0.15 ± 0.02a	0.15	0.14	0.16	0.15 ± 0.03a	0.15	0.13	0.17	0.18 ± 0.05b	0.18	0.13	0.21
Delta K	0.00 ± 0.00a	0.00	0.00	0.00	0.00 ± 0.00a	0.00	0.00	0.00	0.01 ± 0.00b	0.01	0.01	0.01
Sitosterol	94.8 ± 0.7a	94.9	94.5	95.3	94.6 ± 0.7a	94.7	94.2	95.0	95.5 ± 0.6b	95.8	95.4	96.2
Erythrodiol and Uvaol (%)	2.6 ± 0.7a	2.5	2.1	2.9	2.7 ± 1.0a	2.4	2.0	3.4	2.3 ± 1.1a	2.1	1.9	2.2
Waxes ($mg \cdot kg^{-1}$)	63 ± 24a	55	50	80	77 ± 27ab	75	55	100	94 ± 33b	93	80	110
PCOQI	8.3 ± 0.5c	8.3	8.6	7.5	7.5 ± 0.8b	7.4	7.0	8.1	6.3 ± 2.1a	6.3	5.4	8.3

Different letters in the same row indicate significant differences ($p<0.05$). S.D.: standard deviation.

3.3. Screening study of variables with the greatest leverages

The variables with greatest leverage values (distance from the origin of the first two principal component axes) were selected as the most descriptive of the sample set. The greater the leverage value and its corresponding projection onto each principal component axis, the greater the amount of information it carries about the system for each of the two principal components represented. Figure 1 shows that variables such as differential payment for clean fruit and for variety, and type of weighing carry no relevant information for the purposes of the study since they are positioned close to the origin. In contrast, 11 variables were pointed out by the screening study as explaining most of the relevant physicochemical information in the system. These variables, the scores corresponding to the dichotomous responses, and the number of positive responses for each variable are listed in Table 3.

Surveys were carried out at 60 olive oil mills, collecting information on 30 parameters related to the processing method. Virgin olive oil samples were analyzed by measuring the parameters as described in the Data Analysis. The resulting models from each response were only found to be significant for PCOQI and acidity, but unexpectedly not for the organoleptic assessment. These two indicators were influenced by ground/top separation of fruits, differential payment based on acidity, and type of process (continuous/press).

Other variables did not affect the final product quality, one of them being ownership type. It could be expected that links between cooperative olive mills and their suppliers would be more internalized than in privately owned mills since suppliers themselves are partners and have the guarantee that each annual crop has a buyer (Moyano and Núñez-Nickel, 2007). The fact that this does not seem to be the case may reflect a lack of involvement from growers in the marketing of the end product, and in particular, a certain lack of concern about its final quality, since they see the milling industry as a mere transformer of their olives (Montegut-Salla *et al.*, 2007).

Differentiated payment based on fruit characteristics (such as fruit cleanliness, oil yield, variety, acidity, etc.) had no statistically significant influence on the final quality of the oil; Neither did specific steps during the transformation process such as the use of decanting wells prior to shipment to the warehouse, the establishment of quality control procedures, or even the sensorial analysis which, although vital for marketing, were not found to influence the final quality of the oil. This may be because the initial separation of ground- from tree-harvested fruit outweighs other variables in oil production. In particular, since this separation would

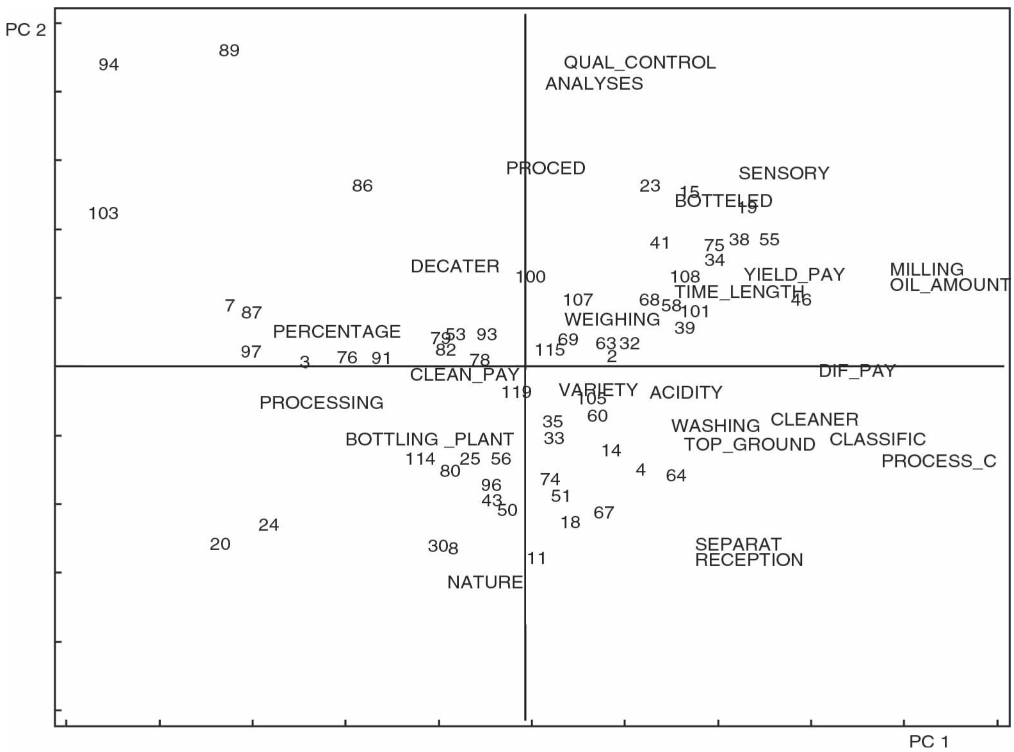

FIGURE 1. Principal Components Analysis 2-dimensional graph.

TABLE 3. Responses to the 11 dichotomous variables included in the screening study

Variables		Response	Percentage of surveyed oil producers
U1	Ownership	Private	42
		Cooperative	58
U2	Fruit separation (ground/top)	No	20
		Yes	80
U3	Differential payment on fruit quality	No	75
		Yes	25
U4	Differential payment on ground/top fruit	No	70
		Yes	30
U5	Differential payment on yield	No	57
		Yes	43
U6	Differential payment on acidity	No	70
		Yes	30
U7	Fruit classification on receipt	No	20
		Yes	80
U8	Decanter	No	53
		Yes	47
U9	Quality control	No	35
		Yes	65
U10	Taste assessment by official panel	No	73
		Yes	27
U11	Production method	Continuous	85 (of which 86% two-stage and 14% three-stage)
		Press	15

be the first step in the production chain, it may already establish whether or not the final olive oil will be of high quality, so that the following steps in the process have no further statistical significance (Jimenez *et al*., 1998).

Other variables studied showed no statistically significant influence on the analytical parameters: content in erythrodiol and uvaol, sitosterol, and waxes, the spectrophotometric measurements (K_{232} and K_{270}), and the peroxide index.

Influence of variables on PCOQI. Only one variable (ground/top separation of fruits) significantly influenced the PCOQI indicator. Table 4 lists the estimated values of coefficients (weights associated with each variable considered in the model) and results of the t-test significance analysis. These results are graphically presented by two histograms on Figure 2. Plotting on the left shows the weight of each of the 11 variables taking the highest level as reference, and on the right, displays the estimates of the coefficients corresponding to these variables in the model explaining the quality indicator (PCOQI). As shown in Fig. 2, only coefficient b2 reaches significance.

These results confirm other findings in the literature (Jiménez *et al*., 2003) which state that the separation of ground- from tree-harvested fruits is crucial in order to obtain the highest quality olive oils, since the fall from the tree and contact with the soil promotes a marked increase in free fatty acid content, the variable which has the greatest weight in the PCOQI formula.

Of all surveyed mills, 20% continue to harvest fruit without classification (Table 3), which leads to final lower quality oils which have to be marketed as VOO. Several of these mills attributed the lack of separation to logistic reasons (absence of facilities to carry it out) and to growers refusal to perform this separation since they are usually not paid extra for this quality improvement. This latter aspect was clearly reflected on mills which paid differentially for ground-harvested and tree-harvested olives producing virgin olive oils with lower free acidity content.

It can then be concluded that olive oil producers who separate ground from top fruit during harvesting score higher on PCOQI. This seems to be related to the general oil quality increase trend registered in Extremadura and other producing regions during the last 15 years. For instance, Extremadura has gone

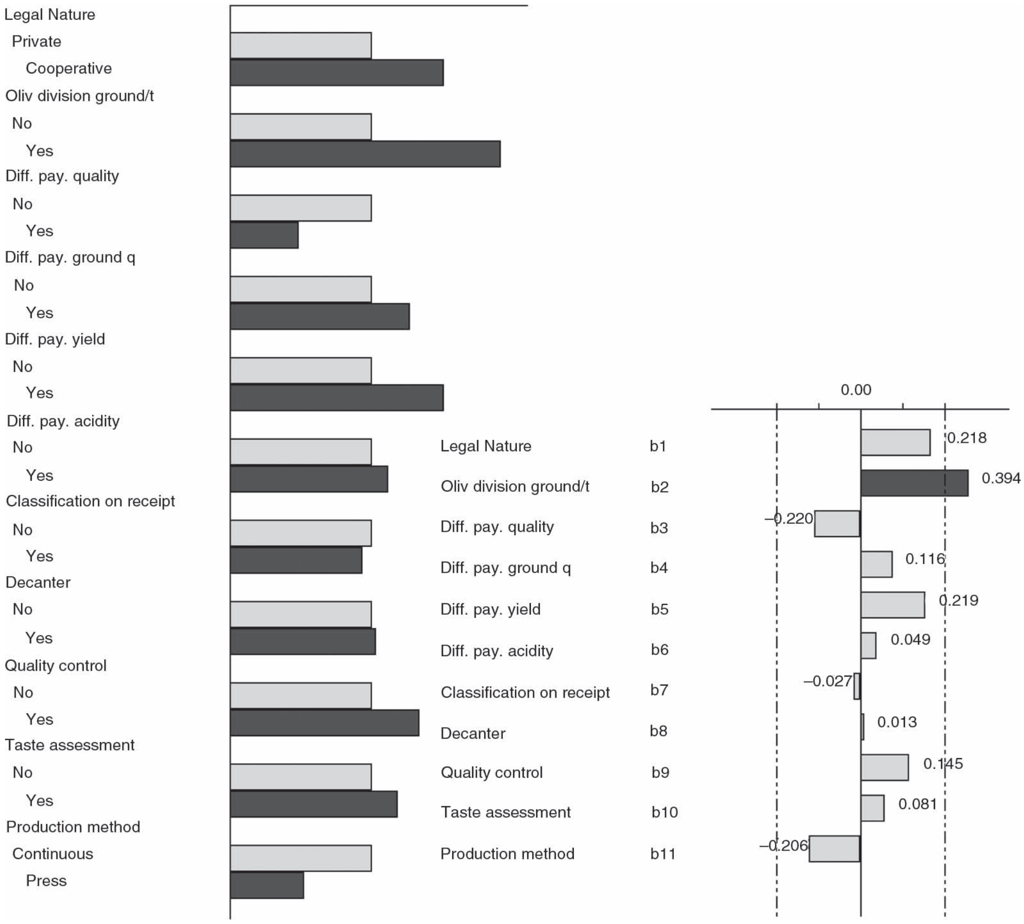

FIGURE 2. Graphical representation of the effects of variables on the quality indicator, PCOQI (Quality Index). Left: Histogram of total effects (scaled relatively to the maximum value). Right: Influence of variables (weights in the model) on the response (Quality Index), and their significance.

from applying ground-top separation at only 19% of its mills (Uceda *et al.*, 2001) to 63% in 2006 (Llerena *et al.*, 2009). A similar increase has been described for Andalusia, from only 11% of its mills in the period from 1993-1999 (Uceda *et al.*, 2001) to 58% in the period from 2001-2002 (De Toro-Jordano, 2002).

This quality increase derives from a greater awareness of its importance in marketing the final bottled EVOO product. Progress is still slow because many mills are not oriented towards the final consumer market. Their focus is on competing to capture the producer end of the chain since they think the VOO they produce will sell on the bulk market at a price only slightly cheaper than a good EVOO (Moyano and Núñez-Nickel, 2006). It is also possible that, rather than a lack of awareness from growers and mill owners, the quality differentiated production of oils may be economically unviable due to limited production of raw material in the local area served by the mill and the consequent limited processing capacity of the mill itself.

Influence of variables on acidity. Acidity is related to the proportion of free fatty acids in the oil, and related to the physical integrity of the fruit before being processed (Panzanaro *et al.*, 2010). The data screening revealed three variables significantly affecting acidity: ground/top fruit separation, differential payment based on acidity, and production method. Table 4 lists the estimated values of coefficients (weights associated with each variable considered in the model), and Figure 3 graphically presents the results in two histograms. Plotting on the left shows the weight of each of the 11 variables taking the highest level as reference, and on the right displays the estimated values of coefficients corresponding to the weight of these variables in the model explaining the quality indicator (acidity). It can be observed that oils with the highest acidity values correspond to those where the process used is batch production by pressing and which lack olive separation and differential payment based on acidity.

Table 4. Estimated coefficients of the 11 parameters included in models explaining the two olive oil quality indicators: PCOQI and Acidity

	Quality index (PCOQI)				Acidity			
Estimated coefficient	**Value**	**S.D.**	**t. exp.**	**Signif.**	**Value**	**S.D.**	**t. exp.**	**Signif.**
b0	7.53	0.26	28.57	<0.01***	0.61	0.10	6.28	<0.01***
b1	0.22	0.13	1.69	9.7	−0.07	0.058	−1.40	16.9
b2	0.39	0.15	2.60	1.25 *	−0.21	0.06	−3.75	0.048***
b3	−0.22	0.20	−1.09	28.1	0.07	0.07	0.96	34.0
b4	0.12	0.15	0.80	43.0	−0.03	0.05	−0.63	52.9
b5	0.22	0.14	1.56	12.5	−0.06	0.05	−1.20	23.4
b6	0.05	0.13	0.38	70.7	−0.10	0.05	−2.08	4.26*
b7	−0.03	0.16	−0.18	86.0	0.08	0.06	1.36	18.2
b8	0.01	0.12	0.11	91.0	0.03	0.04	0.58	56.8
b9	0.14	0.13	1.16	25.4	0.01	0.05	0.27	78.8
b10	0.08	0.14	0.58	56.2	−0.05	0.05	−0.95	34.7
b11	−0.21	0.17	−1.25	21.9	0.14	0.06	2.36	2.22*

*α<0.05, ** α<0.01, *** α<0.001.
S.D.: standard deviation. t.exp.: experimental t value.

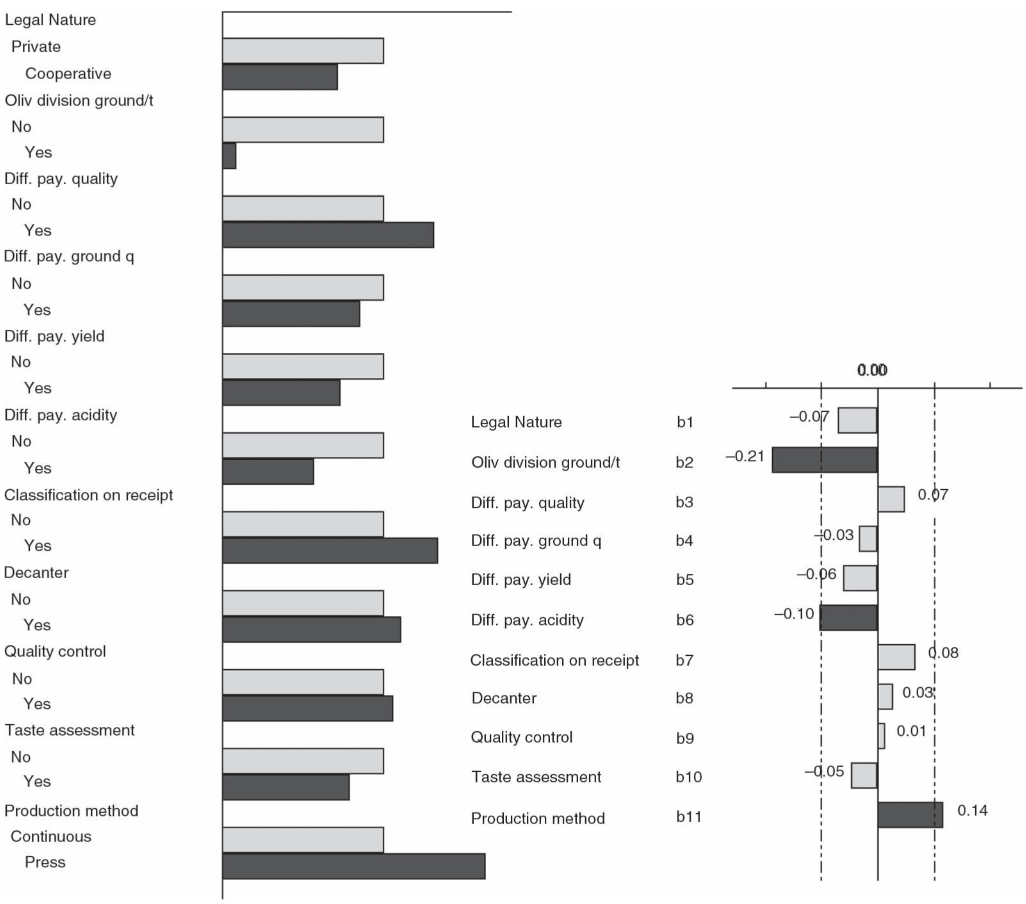

FIGURE 3. Graphical representation of the effects of variables on the quality indicator, Acidity. Left: Histogram of total effects (scaled relatively to the maximum value). Right: Influence of variables (weights in the model) on the response (Acidity), and their significance.

Acidity is related to what has been examined in the previous subsection, since this parameter has the greatest influence on the value of PCOQI. Not only do other analytical parameters, such as peroxide index or K272, have less influence in the formula, but their values are similar in VOO and EVOO oils.

García *et al*. (2006) estimated that a 20% proportion of ground-harvested fruit is enough to cause the free acidity of the resulting oil to exceed the ceiling of the EVOO category (established at 1.0%), although with the current lowering of the maximum acidity to 0.8%, this proportion is reduced to 2.5% to 10.0%, depending on the quality of ground-harvested olives (Montaño, 2010).

A second variable that affected the quality of the final product was differential payment for ground/top harvested fruit. This clearly represents an incentive for growers to separate the two qualities of olives. With this payment difference, the mill shows that it is willing to obtain different oil qualities (extra virgin and virgin), and is therefore willing to pay somewhat more to growers who bring fruit separated by harvesting method.

The third relevant variable in the production of low acidity virgin olive oils was the production system, which was second in terms of weight after ground/top separation of fruit. This finding is consistent with those previously reported in the literature (Di Giovacchino *et al*., 1994; Uceda *et al*., 2001) stating that the continuous systems facilitate the production of higher quality oils than batch press systems. Although theoretically any system which protects fruit quality is potentially capable of producing extra virgin olive oils, in practice this is not so. The reason is that the intrinsic characteristics of olive harvesting campaigns, where variables such as cleanliness, work load, olive pulp and oil areas of contact (batch filters versus stainless steel containers), etc., lead to the batch press system significantly undermining the theoretical quality of the final olive oil versus the better maintenance of quality in continuous extraction systems.

4. CONCLUSIONS

The quality of the olive oil produced in Extremadura has been studied and steps of the virgin olive oil production chain at which there is a quality loss have been detected. This loss of quality is reflected by the fact that only 35% of the virgin olive oils bottled in Extremadura were categorized as EVOO, and most of them are classified as VOO. Specifically, although over 76% of the samples met the physicochemical requirements to be classified under EVOO category, only 35% showed the sensorial analysis attributes that allowed them to be marketed as such.

The variable which is mainly responsible for this quality loss was found to be whether the fruit was separated or not according to harvesting method (from ground, or from tree). The second variable in relevance was whether the grower was offered differential payment according to the mentioned harvesting methods. This variable is clearly related to the need of growers to gain awareness of the relevance that separating their fruit has on oil quality. The third major variable showed that mills which continue to use batch pressing systems to extract the oil obtain a final product of lesser quality. Finally, the organoleptic quality of bottled virgin olive oils was not found to be directly related to any of the 30 variables studied.

In order to improve the prospects of the olive oil sector in Extremadura, while it is vital to provide it with better tools, it must first counteract the weaknesses that still exist and were detected in the present study.

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