Available online at www.sciencedirect.com

ScienceDirect

Sensors and Actuators B 129 (2008) 985–990

SENSORS AND ACTUATORS B CHEMICAL

www.elsevier.com/locate/snb

Review

A sensor-software based on artificial neural network for the optimization of olive oil elaboration process

A. Jiménez [*], G. Beltrán, M.P. Aguilera, M. Uceda

Venta del Llano, IFAPA-CICE (Junta de Andalucía), Ctra. Bailén-Motril, km 18.4, 23620 Mengibar, Jaén, Spain

Received 8 May 2007; received in revised form 12 September 2007; accepted 12 September 2007
Available online 16 September 2007

Abstract

An artificial neural network (ANN) was built for real-time prediction of the moisture and fat content in olive pomace using two-phase olive oil processing. Technological variables were used as input, including olive paste flow, olive paste temperature, coadyuvants addition, water dilution level, position of the exit of the oil in the ‘horizontal centrifuge decanter’, and the Wavelet pretreated near infrared spectra from the on-line scanned oils at the exit of the decanter. The results obtained indicate a very good predictive capacity of the three-layer ANN model with values of $r = 0.961$ and RMSEP = 0.32% for fat content and $r = 0.970$ and RMSEP = 1.01% for moisture.

Keywords: Olive oil; Elaboration process; Optimization; Neural network; On-line control; Sensor-software

Contents

1. Introduction

Virgin olive oil is obtained from the olive fruit (Olea europaea L.) by exclusive use of physical procedures [1]. This process begins with crushing the fruit to break the plant tissues in order to liberate the oil drops contained into mesocarp cells. Then the olive paste is kneaded in a thermo-malaxer to group the oil drops into a continuous oil phase. Solid–liquid phase separation, using centrifugal force, is carried out into a ‘decanter’ to separate olive oil from the water and solid matter [2]. The separation of oil from the rest of the components is not complete by using this physical procedure of centrifugation. The oil has moisture and fine solid matters (about 1–3%), whereas the olive pomace

---

[*] Corresponding author. Tel.: +34 953 366 380; fax: +34 953 374 017.
E-mail address: antonio.jimenez.ext@juntadeandalucia.es (A. Jiménez).

0925-4005/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.snb.2007.09.030

has high moisture and a fat level which depends on the grade of separation [3].

In this industry the process yield is habitually carried out with the knowledge of oil content in the olive pomace by the parameter 'fat on dried matter (FDM)'. The knowledge of this is very important to the process regulation. When the oil content is high the process has a loss of extractability, so that the plant operator will carry out an adjustment of the processing variables that will allow an improvement of this extractability such as the characteristics of the fruit in processing.

Habitually, these determinations are carried out in the laboratory, off-line, by spectroscopy techniques such as nuclear magnetic resonance [4] and near infrared (NIR) reflectance [5], or by Soxhlet chemical extraction [6], with a delay in the information for the possible regulation of the extraction process. Real-time analysis by NIR filters interference-based equipments [7] are beginning to be used, but a complex mechanism for automatic olive residue sampling is necessary with its increase of costs and also a continuous recalibration of the measuring equipment, according to the olive-residue type, is needed. A solution to this is to use sensor-software based on an artificial neural network (SS-ANN). These are computer programs that are able to predict properties of a product without the need to measure them directly by the use of other information more reasonable and related with those final properties. With this tool it is possible to make a prediction of what will take place. It will be in a visual format for the operator and/or applied to a system of automated control. The SS-ANN can be designed to give the opportune commands for system regulation [8,9].

The main objective of this work is to provide an automatic sensor-software based on artificial neural networks in order to predict, during the on-line elaboration process, the moisture and fat content of olive pomace from two-phase processing. These predictions are obtained by using the measurement of technological variables related to the extractive capacity of the process and instantaneous near infrared (NIR) spectral information of the oil output 'decanter'. This way, SS-ANN can provide a tool for the real-time control of the extraction processing in the olive mill (Fig. 1).

2. Experimental

2.1. Industrial 'olive mill'

For this work, a continuous 'two-phases' centrifugation system from 'Venta del Llano' IFAPA-center, was used [10]. This olive mill has a nominal processing of 45 tonnes/24 h and basically consists of a horizontal three-body malaxer (600 kg each one), a solid/liquid horizontal centrifugal decanter (two-phase) and a liquid/liquid vertical plate centrifuge.

2.2. Samples

Samples of olive pomace and oils have been analyzed in triplicate during the whole campaign (between November and January). Olive pomace and oils were gathered at the output of the solids and liquids from the horizontal centrifugal decanter (HCD) (Fig. 2). Different operational processing conditions were carried out for: temperature, flow and mass dilution; coadyuvant addition; oil off-carrier position in HCD.

2.3. Laboratory reference analysis

Moisture (MP) and fat content (FC) in olive pomace were analyzed by drying in an air forced oven at 105 °C and nuclear magnetic resonance (NMR), respectively. The oil moisture drying was carried out using the ISO 662 standard. All results were expressed in wt%. For olive pomace the 'fat content on dried matter (FDM)' was estimated by

$$\text{FDM}\,(\%) = \left(\frac{\text{FC}}{100 - \text{MP}}\right) \times 100 \qquad (1)$$

2.4. NIR instrumentation

An acousto-optic tunable filter (AOTF)-near infrared (NIR) (Brimrose Corp. EEUU) was used to obtain the oil spectrum from HCD (Fig. 3). This equipment allows the instantaneous scanning of the oil flowing through the sensor. For this work the equipment was programmed for the scanning of three spectra for each olive residue sample at a rate of 10 scan/s in the 1100–2250 nm range.

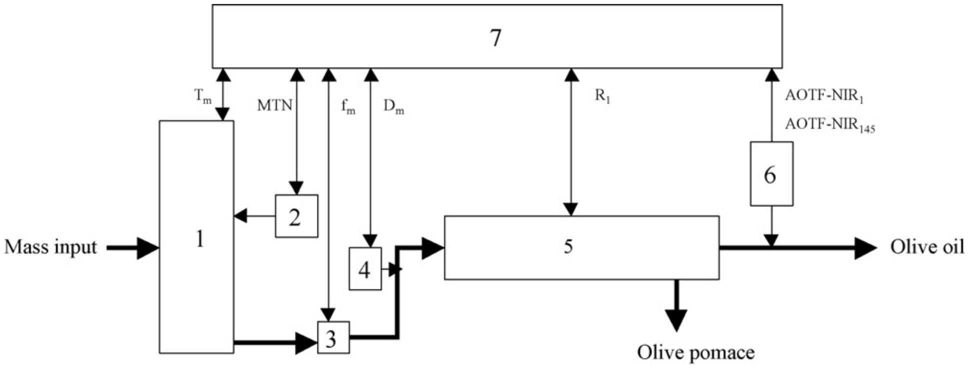

Fig. 1. Schematic block diagram of the olive oil process control by SCADA. 1 Thermo-malaxer. 2 Microtalc dossificator. 3 Mass pump. 4 Water dilution pump. 5 Solid bowl (decanter). 6 AOTF-NIR sensor. 7 SCADA. For variables names see Table 3.

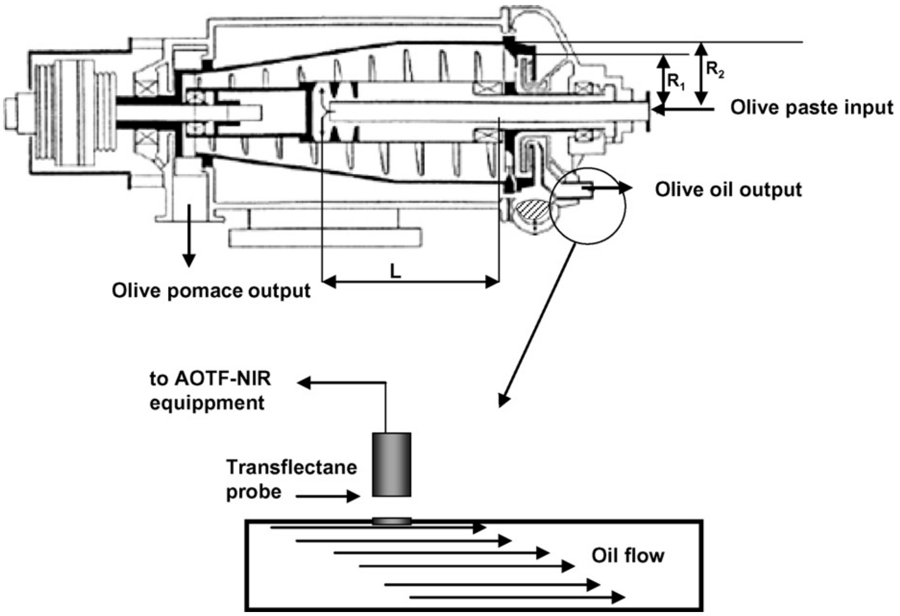

Fig. 2. Schematic decanter and localization for reflectance probe. R_2, decanter radius; R_1, level output oil; L, length of horizontal zone of decanter.

2.5. Spectral pretreatment

AOFT-NIR spectra were standardized to the baseline by the Unscrambler program (Unscrambler 7.5, Camo Inc.). A PCA analysis was carried out to detect anomalous spectra by means of the Holleling-T^2 function. Spectral noise is eliminated by application of Wavelet function 'Daubechies 4' at level three (Matlab 6.5, The Mathwork Inc.). A reduction of the number of initial spectral points (1150) to 145 was carried out.

2.6. Neural network (ANN)

Matlab software (The Mathwork, Inc.) [11] was used for the development of an artificial neural network based on the algorithm 'feed-forward back propagation'. This is a type of network of supervised learning that is based on an algorithm of descending gradients (LMS Algorithm Widrow–Hoff) in order to minimize the error. This ANN was designed for two exit-objectives, fat content and moisture of olive pomace, by using the 'Newff' function of this software. The number of ANN layers, neurons by layer, functions of transference between layers (tansig, logsig, purelin), algorithms in training of the network (trainrp, trianlm, traingda, traingdx) and the number of iterations in the training were analyzed. The training was carried out by varying the number of neurons by hidden layer (from 15 to 50 and step of 2 U) and the number of hidden layers (from 1 to 3 and step of 1 U), monitoring the mean square error (MSE) provided by Matlab after each training epoch.

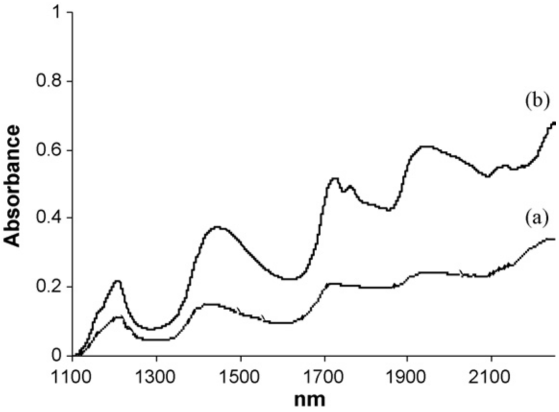

Fig. 3. AOTF-NIR spectra for oil output from decanter: (a) for oil from olive pomace with 5.25% fat on dried matter; (b) for oil from olive pomace with 14.95% fat on dried matter.

The experimental data were sorted by FDM and divided into three subsets: training, simulation and validation or testing, by generation of three 1-by-n matrices of sequential number accord Matlab operator [first:step:last] and values of step = 3, last = 204 and first = 1, 2 and 3 for 1st, 2nd and 3rd subset, respectively. First and third subsets were used for training and simulation, and the second subset for the ANN model validation. Error of prediction was estimated by root mean of squared error of prediction (RMSEP):

$$\mathrm{RMSEP} = \sqrt{\left\{\sum \frac{(y_{\text{SS-ANN}} - y)^2}{n-1}\right\}}$$

An F-test, at the 95% confidence level, was used to compare the results obtained of FDM by reference laboratory and SS-ANN prediction.

3. Results

3.1. Data for SS-ANN

From the point of view of olive oil two-phase process, the olive paste consists of two liquid phases (water and oil) and fine organic solid matters [12]. Using physical procedures, such as centrifugation, separation of the different components of olive paste cannot completely be carried out, thus the resulting oil has some moisture and some very fine solid matters, whilst the residue of solid matters outputs with a high moisture content and a small amount of oil (the olive pomace). The Stokes law of sedimentation velocity (V_s) takes place into the 'decanter' where the force of gravity is replaced by the centrifugal acceleration in a bowl with radius 'R_2' that turns at an angular velocity 'w' (Eq. (2)):

$$V_\mathrm{s} = \frac{D^2 w^2 R_2(\rho_\mathrm{s} - \rho)}{18\beta} \tag{2}$$

For a useful volume of 'decanter' (V_u), which is defined by (Eq. (3)), a solid particle located between R_1 and wall 'decanter' (r), needs a time of 't_s' for total sedimentation (Eq. (4)).

$$V_\mathrm{u} = \pi(R_2 - R_1)L \tag{3}$$

$$t_\mathrm{s} = \left[\frac{18\mu\ \ln(R_2/r)}{D^2((\rho_\mathrm{s} - \rho)k_\mathrm{e} w^2}\right] \tag{4}$$

These particles are subjected to an axial and radial movement, so that its optimal condition of separation from the liquid phases depends on the holding time of these in the bowl. This time 't_r' is defined by V_u and the olive paste flow to 'decanter' (Q) relation (Eq. (5)),

$$t_\mathrm{r} = \frac{[\pi(R_2 - R_1)L]}{Q} \tag{5}$$

so that the optimal separation conditions are defined by $t_\mathrm{s} = t_\mathrm{r}$. When $t_\mathrm{s} > t_\mathrm{r}$ sedimentation is high and the solid–liquids separation is not good, then the oil becomes very dirty and the olive residue output has a high oil content [13,14]. When $t_\mathrm{s} < t_\mathrm{r}$, most of particles settle before the liquid phases arise, the oil becomes very clean but there is a loss of productivity, and the olive residue can output with a higher oil content by the greater probability of dragging of the liquid phases with the solid matter.

As it can be seen, in a two-phase system, there is a relation between the olive residue characteristics (fat and moisture) and the characteristics of the oil on exit to the 'decanter'. These properties depend on technological variables such as: paste temperature, viscosity and density of liquid phases; paste flow to 'decanter', for t_r definition; talc coadyuvant addition, for solid phase density; level of paste dilution, that affects t_r, differences of liquids and solids densities, height of the oil–water interface; oil off-carrier position on HCD, that affects both t_r and t_s. All these technological variables are the most used for the regulation of the oil mill and they define the yield of the olive oil extraction process, and therefore they are selected as data input to SS-ANN.

In Table 1, the range for each parameter is specified. For 'Picual' cultivar, olive residues with FDM lower than 6.5% indicate a good extraction, but those higher than 7.5% indicate a loss of productivity.

Table 1
Ranges and mean values obtained for olive pomace by reference laboratory methods

Olive pomace	
Fat content (%) FC	3.20 ± 1.03 (1.80–7.66)
Moisture content (%) MO	61.90 ± 4.32 (48.87–69.93)
Fat content on dried matter (%) FDM	8.73 ± 2.31 (4.94–15.11)

$n = 204$; mean ± S.D.; (min–max).

3.2. Neural network modeling

A feed-forward ANN was designed using back propagation training algorithms. Three layers were optimized according to the number of input and output variables and complexity of the problem: input, hidden and output layers. The number of neurons of 25 and 39 for the two hidden layers were obtained. For the best results from the algorithms, the input data were normalized to the range $[-1+1]$ by the 'minmax' Matlab function before the training. Sigmoid 'tansig' for input-hidden, hidden-hidden layers and lineal 'purelin' for output layers were the applied transfer functions. The 'trainrp' was the best training function found; this function updates weight and bias values according the 'resilient back propagation algorithm'.

For constructing the ANN model the following variables were used as vector input: olive paste flow (f_m), olive paste temperature (T_m), coadyuvant addition (MTN), water dilution level (D_m), position of the exit of the oil in HCD (R_1) and oil NIR spectra pretreated (AOTF-NIR$_1$... AOTF-NIR$_\mathrm{i}$). Fat content and moisture of olive residue were used as output. Table 2 shows the ranges of these technological variables, and schematic details of the ANN obtained can be seen in Fig. 4.

3.3. ANN training and prediction

The best parameters for the network were chosen by the greater coefficient of linear correlation between that predicted by the ANN (with the simulation set) and the obtained values from the laboratory for both objective parameters by training and simulation of the ANN model with two sets of data using 68 and 68 samples, respectively. The number of iterations were optimized to 400, when MSE was relatively constant to 0.01. The validation of model was carried out by application of the trained network from the validation set (68 samples). Figs. 5 and 6 show the results of SS-ANN prediction from the validation set for fat content and moisture on fresh matter, respectively. As it can be seen, both show a highly linear correlation into the predicted and the real laboratory values, with values of $r = 0.9796$ and

Table 2
Ranges of technological variables

Technological variables	Minimum–maximum ranges
Olive paste flow (f_m)	700–1150 kg/h
Olive paste temperature (T_m)	13–48 °C
Coadyuvant addition (MTN)	0–0.2%
Water olive paste dilution level (D_m)	0–40%
Oil off-carrier position on HCD (R_1)	98–101 mm

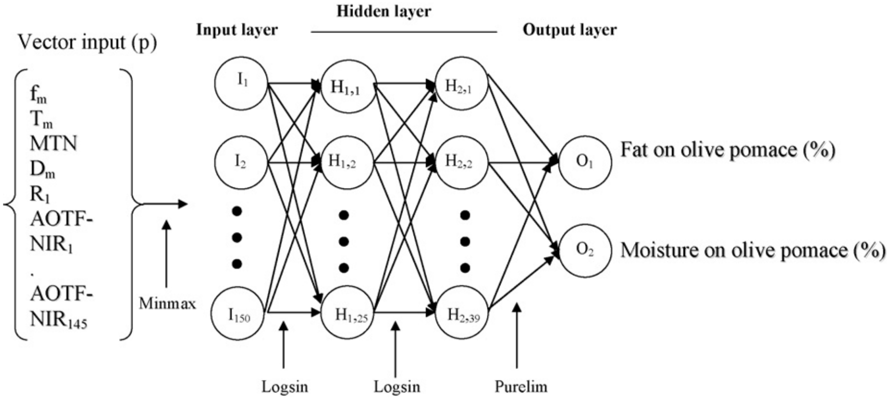

Fig. 4. Schematic diagram of the neural network build.

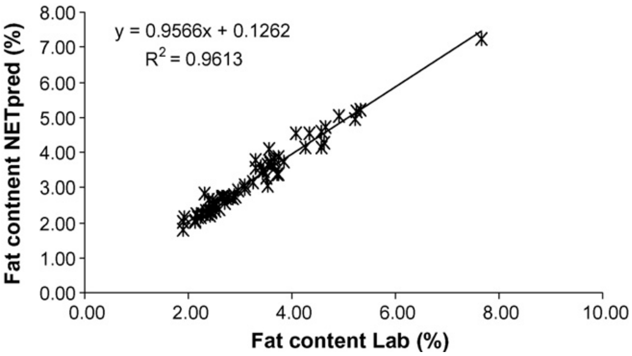

Fig. 5. Scatter plot of lineal correlation of the fat SS-ANN predicted vs. laboratory analysis on olive pomace.

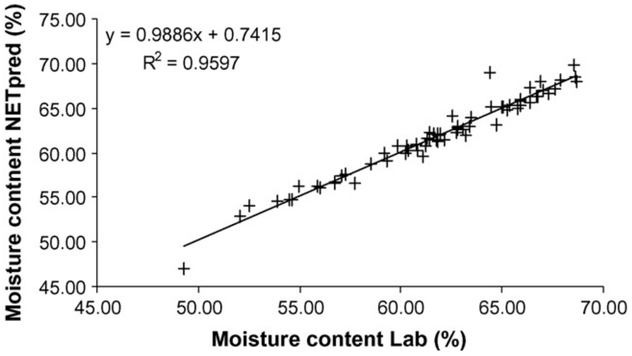

Fig. 6. Scatter plot of lineal correlation of the moisture SS-ANN predicted vs. laboratory analysis on olive pomace.

$r = 0.9804$ for moisture and fat content, respectively. The prediction errors, estimated by RMSEP, give values of 0.20% for fat content and 0.55% for moisture. These values are similar to those obtained by direct measurement by other analytical methods. Garcia et al. [5] found 0.24% and 1.19% for fat and moisture, respectively by laboratory NIR; García et al. [4] 0.11% for fat and 0.60% for moisture by NIR measurement; Jiménez et al. [6] 0.25% and 0.20% for fat by NMR and Soxhlet, and 0.45% for moisture by air forced oven, respectively.

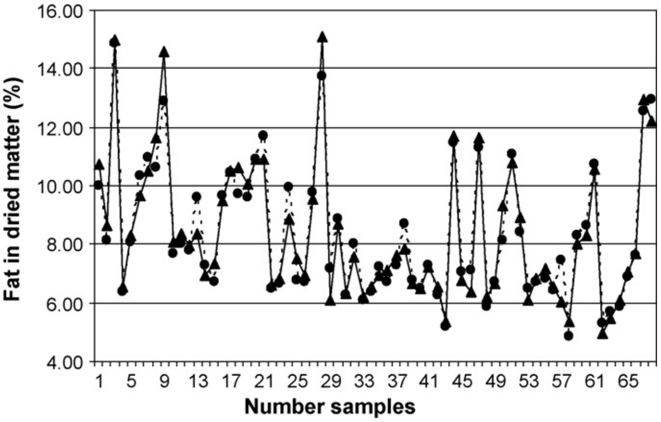

Fig. 7. A comparison between fat on dried matter from fat and moisture laboratory analysis (▲) vs. fat on dried matter from fat and moisture SS-ANN predicted (●).

For fat and moisture predicted by SS-ANN, FDM (Eq. (1)) was calculated and compared with those calculated with laboratory methods. Fig. 7 plots a flow-chart for monitorization of FDM prediction values against all validation samples and laboratory values (ordered by its sampling data). As it can be seen they produce similar curves, and the variation of FDM is clearly reflected. An *F*-test, for variance analysis of averages by both procedures, indicates that there are not significant differences between the SS-ANN prediction and the references values. The

Table 3
An example of the results of the validation test

AOTF-NIR	f_m (kg/h)	T_m (°C)	MTN (%)	D_m (%)	R_1 (mm)	Results for SS-ANN		Results from laboratory	
						Moisture (%)	Fat (%)	Moisture (%)	Fat(%)
(a)	900	13	0	0	98	65.15	5.39	64.82	5.26
(b)	800	25	0	37.5	100	64.77	2.12	64.97	2.07

AOTF-NIR spectra from Fig. 3.

calculated values of $F_{\text{cal}} = 1.10$ are less than the tabulated values for $F_{\text{theor}} = 1.499$, and for $P = 0.05$ and 67 degrees of freedom. In Table 3 an example of the results for the validation test is shown.

4. Conclusion

According to the obtained results, SS-ANN and AOTF-NIR could be a powerful tool in olive oil mills for on-line prediction of fat loss in olive pomace and to make possible a rapid regulation of the extraction process either manually or by an automatic control system. In particular it is possible to predict fat and moisture parameters by real-time measurement of a certain number of technological variables of the process and instantaneous NIR spectra of oils on HCD. The estimation can be performed quickly during the extraction process, allowing a rapid regulation of these technological variables for minimal fat loss.

Acknowledgements

This work is supported by FEDER-INIA RTA 04-128 ‘Research and application of new technologies in the on-line characteristics of virgin olive oil during its production in an oil mill’. Special thanks go to Tecnilab SL (Spain) for the Brimrose Luminar 5030, AOTF-NIR equipment supplied for this work.

References

[1] Regulation ECC/2568/91 on the characteristics of olive oil and olive pomace oils and on their analytical methods, Official Journal of the European Communities: Legislation, European Union, Brussels, 1991.

[2] M. Uceda, A. Jiménez, G. Beltrán, Olive oil extraction and quality, Grasas Aceites 57 (2006) 25–31.

[3] D. Boskou, Olive oil, Chemistry and Technology, AOCS Press, Champaing, USA, 1996.

[4] A. García, N. Ramos, E. Ballesteros, Comparative study of various analytical techniques (NIR and NMR spectroscopies, and Soxhlet extraction) for the determination of the fat and moisture content of olive and pomace obtained from Jaén (Spain), Grasas Aceites 56 (2005) 220–227.

[5] J.A. García, M. Hermoso, P. Cáceres, Determination of oil and moisture in two-phases olive-pomace by using near-infrared spectroscopy, Grasas Aceites 47 (1996) 317–322.

[6] A. Jiménez, G. Beltrán, L. Frias, M. Uceda, M. Hermoso, A comparative study of analytical methods for fat content of two-phases olive pomace, in: VII Symposium on Olive Oil, Expoliva’97, Jaén, Spain, 1997.

[7] M. Hermoso, M. Uceda, A. García, A. Jiménez, G. Beltrán, Preliminary results or NIR on-line for oil content and humidity in olive cake from the two-phases decanter, Acta Hortic. 474 (1997) 717–719.

[8] D.A. Rebién, S.M. Maze, J.P. Havener, The application of neural networks in the process industry, Instrum. Soc. Am. 31 (1992) 7–13.

[9] Y. Li, C.W. Brown, F. Sun, J.W. McCrady, R.W. Traxler, S. Lo, Non-invasive fermentation analysis using an artificial neural network algorithm for processing near infrared spectra, J. Near Infrared Spectrosc. 7 (1999) 101–108.

[10] A. Jiménez, M. Hermoso, M. Uceda, Extraction of virgin olive oil by two-phases continuous system. Influence of different variables of the process on certain parameters related to oil quality, Grasas Aceites 4–5 (1995) 299–303.

[11] H. Demuth, M. Beale, Neural Network Toolbox. For Use with MATLAB, User’s Guide, Version 4, 2001.

[12] J.M. Martinez, J.M. Moreno, Fundamentos fisico-químicos de la técnica oleicola, CSIC, Madrid, Spain, 1972.

[13] P. Amirante, P. Catalano, Theorethical and experimental analysis of olive oil extraction by centrifugation, Riv. Ital. delle Sostanze Grass. 70 (1993) 329–335.

[14] M. Hermoso, J. González, M. Uceda, A. García-Ortíz, J. Morales, L. Frías, A. Fernández, Virgin olive oil of quality, Elaboration by two-phases process 61/98, Consejería de Agricultura y Pesca, Junta de Andalucía, Sevilla, Spain, 1998.

Biographies

A. Jiménez is PhD in chemistry from the University of Jaén in 2003. Currently he is researcher of IFAPA-CICE (Andalusia, Spain) and he works in virgin olive oil extraction process and application of non-destructive techniques for real-time control of production and quality of oil. Main research interest: olive oil, process optimization, NIR-on line, GC-SPME.

G. Beltrán is researcher from IFAPA-CICE (Andalusia, Spain). He received his PhD from University of Jaén in 2000. He is head of the research group ‘Olive growing and olive oil quality-technology’ from IFAPA, and works in effect of agronomic and technological factors on virgin olive oil quality and its compounds with nutritional and sensory properties.

M.P. Aguilera is PhD in chemistry from the University of Jaén in 2006. Currently she is researcher of IFAPA-CICE (Andalusia, Spain). She works in the effect of agronomic and technological factors on quality and sensory properties of virgin olive oil and the compounds related.

M. Uceda is researcher from IFAPA-CICE (Andalusia, Spain). He is ‘Ingeniero Agronomo’ and he received his PhD from University of Jaén in 2005. He works in virgin olive oil, effect of agronomic on quality and sensory properties and extraction process.