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Practical modeling and optimization of ultrasound-assisted bleaching of olive oil using hybrid artificial neural network-genetic algorithm technique

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ABSTRACT

Multi-objective modeling and optimization of ultrasound-assisted bleaching of olive oil were accomplished by a hybrid artificial neural network (ANN) and genetic algorithm (GA) method using an ultrasonic bath with a frequency of 25 kHz. The influence of process parameters including ultrasonic power, bleaching clay dosage, process temperature and time (inputs) on final Lovibond red (Lr) and peroxide value (PV) (outputs) was modeled by a multilayer feed-forward back propagation ANN. The accurate 2-hidden layer model with 20 neurons in each, high R^2 (up to 90%) and minimum mean square error (MSE) obtained by ANN was introduced to GA to find the best operation conditions to achieve minimum Lr and PV. The optimum treatment was found with ultrasonic power of 30%, bleaching clay of 1.2%, bleaching time of 13 min and temperature of 65 °C. Under optimal conditions, Lr and PV were 2.47 and 6.49 (meqO_2/kg), respectively, that were consistent with predicted values.

Optimally ultrasonic bleached olive oil and an industrially bleached olive oil were compared. In most cases, the results indicated no detrimental effects of ultrasound on oil structure. Thus, 40% reduction in bleaching clay dosage, 35% reduction in process temperature and 57% reduction in time over ultrasound-assisted bleaching which not only provided economic and environmental benefits, but also retained edible oil nutritional value in comparison to common bleaching procedure. The results of this study confirm the applicability of ultrasound-assisted bleaching by ultrasonic bath as an economic and feasible approach for bleaching of olive oil to reduce high bleaching costs.

1. Introduction

Commercial bleaching is primarily a multivariate adsorption procedure mediated by bleaching clays either in natural or acid activated form (Dijkstra and Segers, 2007). In practice, however, unfavorable side reactions are also likely to occur. To improve bleaching performance and counteract the drawbacks associated with the conventional method, several techniques such as membrane technology (Reddy et al., 2001), supercritical fluid (Ooi et al., 1996) and more recently, ultrasound-assisted methods have been developed. Ultrasound-assisted bleaching, as an alternative technique, offers numerous advantages over current bleaching procedure and it is gaining interest to be implemented in commercial oil refining. It is believed that ultrasonic irradiation can improve conventional adsorption by various mechano-chemical routes, although ameliorated edible oil bleaching after sonication by high intensity ultrawaves is assigned to physical effects rather than chemical alterations (Jahouach-Rabai et al., 2008). This effect is engaged in higher bleaching efficiencies in addition to decrease in operation time, diminish of the bleaching clay usage and in turn reduction in high bleaching costs. Subsided amounts of spent oil-laden bleaching clay can be promising for the management of environmental hazards as well (Abedi et al., 2015).

Olive oil is a popular cooking and salad oil that is widely consumed as virgin oil owing to its unique nutritional value (Matos et al., 2007). But, when the quality of extracted olive oil is low, a refining process is necessary to remove undesirable compounds

Abbreviations: ANN, artificial neural network; GA, genetic algorithm; VOO, virgin olive oil; UBOO, ultrasonic bleached olive oil; IBOO, industrially bleached olive oil; PV, peroxide value; Lr, Lovibond red; MLP, multilayer perceptron; LMBP, Levenberg-Marquardt back propagation; MSE, minimum mean square error; IOOC, International Olive Oil Council; BE_{410}, bleaching efficiency at wavelength 410; BE_{424}, bleaching efficiency at wavelength 424; FFA, free fatty acids; TBA, thiobarbituric acid value; IV, iodine value; HPLC, high-performance chromatography; ICP-OES, inductive coupled plasma-optical emission spectroscopy; GOF, goodness of fit; MUFA, monounsaturated fatty acids; Ly, Lovibond yellow.

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from oil (Morales et al., 2005). Bleaching is the critical step for the removal of chlorophyll pigments because these pigments are not susceptible to eliminate in deodorization unit (Ouyang et al., 1980). A large amount of acid activated bleaching clay is required to remove high chlorophyll content from olive oil. Supplying high amount of bleaching clay and oil loss (in the used clay) imposes high bleaching operation costs on oil industries. High bleaching clay usage (2–5%) along with high bleaching temperatures (80–120 °C) and long processing times (up to 30 min) (Zschau, 2001) permit prolonged catalytic activity of clay and deleterious reactions on fatty acids such as dimerization, polymerization, hydrolysis, isomerization (Chapman et al., 1994; Vasvazova et al., 1998) and finally drastic loss in quality of bleached olive oil. Degradation of natural antioxidants, namely tocopherols and sterols is plausible even at temperatures below 100 °C (Verleyen et al., 2002). It has been deduced that high intensity ultrasonic waves remarkably improve bleaching performance without considerable change in chemical composition of olive oil. Low linoleic acid content and relatively high stability of olive oil against oxidation proposed ultrasound-assisted bleaching as a suitable alternative technique for traditional bleaching (Jahouach-Rabai et al., 2008). However, there is the concern that ultrasonic cavitation and relating consequences may adversely influence edible oils. Lipid oxidation induced by ultrasound is reflected in diminishing organoleptic properties, slight decrease in essential oils while increasing dienic hydroperoxides (Chemat et al., 2004a). It is considered that by optimization of process parameters, one can achieve high bleaching efficiency with reduced bleaching clay consumption in significantly shorter processing time while nullifying disadvantages arising from acoustic cavitation.

Optimization of soybean oil bleaching by ultrasonic probe demonstrated two optimal conditions regarding ultrasonic power, bleaching clay dosage, process temperature and time (Abedi et al., 2015). Classic optimization methods usually deal with a lot of complex calculations and their performance would be restricted by discontinuities in the objective function (Lundstedt et al., 1998). Response surface methodology has shown advantage of modeling and optimization with a limited experimental work. However, the necessity of preliminary experimental design and fitting experimental data on a quadratic function limits its application for all modeling and optimization problems (Baş and Boyacı, 2007). High accuracy model predictions with satisfactory generalization characteristics have been achieved by artificial neural network (ANN). It fundamentally imitates the biological neural network in which a model is developed based on heuristic training (ZareNezhad and Aminian, 2011). ANN operation is a mathematical simulation of human contingency learning mechanism, i.e. by receiving preset dataset; it behaves as a black box perceiving a particular relationship between input and output data, known as pattern recognition. Thereafter, so-derived model can be used to predict further outputs from additional input values (Dasari et al., 2009). The superiority of ANN has been adopted from its peculiar features. The most notable capability of ANN is that it does not urge a preliminary pattern to be fitted with introduced inputs. In other words, it is trained based on non-designed or statistically-designed data, so there is no need for operator proficiency (Almeida, 2002). Flexibility is another advantage of ANN which qualifies it for the approximation of almost all linear and non-linear functions in industrial-scale processing (Zilouchian and Jafar, 2001). Genetic algorithm (GA) is a meta-heuristic methodology inspired by Darwinian Theory of natural evolutionary based on selection and "survival of the fittest" principles. Generally speaking, it stochastically searches through solution space to achieve the optimum. Integrating GA, as an optimization algorithm, into ANN makes it possible to fulfill a modeling and optimization outline (Nandi et al., 2002).

Hence, the objective of this study is to present a general practical model and optimization for ultrasound-assisted bleaching of olive oil using ANN-GA hybrid which to the best of our knowledge, no study has reported it to date. Additionally, we used ultrasonic bath for the current scenario since this device is economical and facile proposing a practical operation condition under modest ultrasonic exposure (Thompson and Doraiswamy, 1999) that have not yet been tested in prior research for this purpose. After finding optimum treatment according to color and oxidative parameters, virgin olive oil (VOO), optimally ultrasonic bleached olive oil (UBOO) and an industrially bleached olive oil (IBOO) were characterized and compared regarding their physicochemical properties.

2. Materials and methods

2.1. Materials

Virgin olive oil was obtained from a local refinery (Nab e Tavakoli) in Rudbar, Iran. All chemicals used in this study were of analytical grade and purchased from Merck (Darmstadt, Germany).

2.2. Ultrasound equipment

An ultrasonic cleaning bath (Pacisa SA, Spain) with a frequency of 25 kHz and working power of 400 W was used for ultrasound-assisted bleaching in this study. The ultrasonic processor is a rectangular chamber of size 30 cm × 15 cm × 15 cm equipped with temperature control unit.

The area with maximum cavitation intensity was qualitatively measured by simple aluminum foil test. Aluminum foil was cut into 6 cm × 4 cm pieces and submerged into different zones of the water bath. After 2 min insonation, the right zone was chosen based on maximum perforations tracked on the foil (Muqbila et al., 2005). Pretest data were collected in order to optimize water volume, and tube positions in ultrasonic bath, and ideal conditions were used for ultrasonic treatments.

2.3. Ultrasound-assisted bleaching

Acid activated bleaching clay (bentonite) was added to final concentration to 50 ml of virgin olive oil, and the mixture was thoroughly stirred. Experimental ultrasound-assisted bleaching was performed at a given power setting as the percentage of full power within a predetermined bleaching duration at desired temperature. After cooling, the slurry was centrifuged, and supernatant oil was filtered through Whatman No. 42 (Whatman International Co., Ltd., Kent, UK) filter paper. As soon as a clear filtrate was obtained, color (see 1.6.2 Color measurement) and peroxide value (PV) (see 1.6.1 Quality indices) were measured. The industrial sample was prepared without sonication using 2% activated bentonite at temperatures between 95 and 100 °C for 30 min under nitrogen gas. All experiments were carried out in triplicate.

2.4. Data set

Before optimization, some screening tests were carried out to decide appropriate levels for each variable. In this way, influence of different bleaching treatments with varying levels of ultrasonic power setting (0, 50, 100%), bleaching clay dosage (0, 0.5, 1 and 1.5%), process temperature (35, 45, 55 and 65 °C) and time (15, 20, 25, 30 min) were evaluated on Lovibond red (Lr) since it is the most common preliminary quality criterion (Mag, 1990).

Finally, in this study a full factorial design of experiments conducted using the various combinations of the following factor's levels: 0, 50, 100% for power setting; 0.5, 1, 1.5% for bleaching clay dosage; and 45, 55, 65 °C for process temperature and 15, 20, 25,