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Application of pulsed electric fields and high voltage electrical discharges for oil extraction from sesame seeds

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ABSTRACT

Sesame is a widely cultivated oilseed and its oil presents high nutritional quality and economic value. The objective of this work was to evaluate two different electrical technologies: pulsed electric fields (PEF) and high voltage electrical discharges (HVED), as pre-treatments to oil extraction. These treatments were performed with the objective of damaging the seed cells prior to pressing for oil expression and were compared to a control sample and to grinding. Electrical treatments were carried out with different input energies varying between 40 and 240 kJ/kg. Evaluation of each treatment efficiency was performed through the analysis of the disintegration index of the seeds, oil yield, deformation curves and oil quality among others. The disintegration index increased with the energy input and it was higher for seeds treated by HVED. PEF treatment increased the oil yield by 4.9% and HVED, if accounted oil losses in water, resulted in the extraction of 22.4% more oil when samples are compared to control. The grinded sample presented higher oil yield than PEF and lower than HVED. The deformation curves were very similar for all samples, except for the grinded seed, which reached higher deformation values during pressing. Results of the HPLC analysis show that the oil lignan profile was the same for all analyzed treatments. Moreover, there were low protein and polyphenols losses during treatment and, therefore, a cake rich in these compounds is obtained as a by-product of the proposed process.

1. Introduction

Sesame (*Sesamum indicum* L.) cultivation presents great economic, agricultural and social potentials. These characteristics can be attributed to its tolerance to dry weather, easy handling and the obtention of seeds with high oil content with elevated stability (Araújo et al., 2006). The percentage of oil in this seed can range between 28% and 59% and the protein content is approximately of 20% (Shyu and Hwang, 2002). Sesame is an important crop around the world, being the ninth most cultivated oilseed. In 2011, the world production of sesame seeds was of 4.092 tons and, from this production, 70% is estimated to be designated for oil production (FAO, 2011; Namiki, 1995). Sesame oil presents high nutritional quality and economic value. The lipid profile of this oil is composed mainly of triglycerides, followed by diglycerides, free fatty acids, polar lipids and monoglycerides. Moreover, sesame oil presents high contents of phytosterols, tocopherols and lignans. The main lignans found in this product are sesamin and sesamolin (Reshma et al., 2010). These minor components should be taken into consideration, since they offer high oxidative stability to the oil and have several beneficial physiologic aspects (Hemalatha and Ghafoorunissa, 2007; Shahidi et al., 2006; Shahidi and Naczk, 2004). The ingestion of 10 mg of sesame oil daily has been shown to increase γ-tocopherol in the serum (Sharma et al., 2009) and decrease plasma cholesterol (Hirata et al., 1996).

Pressing and solvent extraction are the most common processes used for oil expression from seeds. Screw presses are usually used for industrial scale pressing; however the hydraulic presses can also be employed (Savoire et al., 2013). The hydraulic press is usually used at laboratory scale to investigate oil yield results, due to its simplicity (Gros et al., 2003; Lanoisellé et al., 1996). In general, the maximum yield when a press is used to obtain oil from seeds is of 80%. When solvents are used, they provide higher oil yields,

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however, the oil obtained using this methodology is of significant lower quality. For this reason, pressing is most commonly used for oils with high nutritional values as sesame (Willems et al., 2008). To improve pressing efficiency, thermal, mechanical, chemical and enzymatic pre-treatments can be performed. In this way, the press can be feed with raw or treated seeds (Savoire et al., 2013). These treatments need to be chosen carefully since they can affect the oxidative stability of the oils and of the lignans in the product (Fukuda et al., 1986; Hwang, 2005; Kamal-Eldin and Appelqvist, 1995).

Besides these pre-treatments, the application of pulsed electric fields (PEF) and high voltage electrical discharges (HVED) emerge as possibilities to provide a gentle, low-temperature and highly effective process to pre-treat the seeds. PEF results in the rupture of cell membranes when submitted to an external electric field, increasing the electrical conductivity and the permeability of intracellular material (Angersbach et al., 2000; Vorobiev and Lebovka, 2011; Zimmermann et al., 1974). HVED affects both the cell walls as well as membranes and can cause more extensive damage to the product. This technology is based on the phenomenon of electrical breakdown in water, which induces physical (e.g. shock waves) and chemical (e.g. formation of O_3) processes that affect the cell, enhancing the release of intracellular components (Boussetta and Vorobiev, 2014; Gros et al., 2003). Based on these effects, application of high-intensity electric fields could replace and upgrade conventional techniques in the recovery of plant oils (Jaeger et al., 2008).

PEF has been previously evaluated as a pre-treatment for oil extraction from maize, olives, soybeans and rapeseed (Guderjan et al., 2007, 2005). The authors showed that the pre-treatment with PEF improved the oil extraction yield significantly. Moreover, this electrical pre-treatment had a significant effect on the oil quality, increasing the content of bioactive compounds in the obtained oils. But there is still a lack of knowledge of the effects of different energy inputs in oil extraction. The previous studies using PEF were only focusing a small number of pre-treatments, whereas in this work a larger range of energies for PEF were evaluated and HVED was investigated as a possible technology to treat the seeds.

The objective of this work was to use PEF and HVED pre-treatments in sesame seeds to obtain higher oil extraction yields and preserve functional compounds. For this purpose, different input energies were applied to the seed prior to pressing. Results were compared to untreated, control and grinded samples to evaluate the effects of the electrical technologies.

2. Materials and methods

2.1. Materials and seed characterization

The sesame seeds (*S. indicum*) used in this work were bought in a local market and belonged to Indian cultivars. For the HPLC analysis, HPLC grade methanol from Vetec (Brazil) and Mili-Q water (Milipore, France) were used as solvents and sesamin (CAS 607-80-7) and sesamol (CAS 533-31-3) from Sigma Aldrich (United States) were used as standards. In the spectrophotometric analysis, the Folin–Ciocalteau and Bradford reagents and the standards for gallic acid (CAS 149-91-7), bovine serum albumin (BSA, CAS 9048-46-8), were purchased from Sigma Aldrich (France).

The seeds were characterized in its total oil content using a Soxhlet apparatus and petroleum ether as solvent. Oil extraction was carried out by placing the grinded seeds (2.5 g) in thimbles covered with glass wool, which were put in the Soxhlet equipment. Then, 200 mL of solvent were added extraction was performed for 360 min with boiling petroleum ether. The protein content was determined by the Kjedahl method. This methodology involves, initially, the digestion of the sample using sodium and ammonium sulfate and sulfuric acid, followed by distillation with boric acid. The moisture content in the seeds was also determined, according to the gravimetric method. All methodologies used were from the AOAC proceedings (AOAC, 1990).

2.2. Pre-treatments

For comparison, different treatments were applied in the seeds before pressing. The studied pre-treatments were: immersion in water followed by drying (ID); immersion in water, drying and grinding (IDG); and immersion, PEF or HVED treatment and subsequent drying. The ID sample was considered as a control since the immersion and drying steps were necessary to the process. The results were also compared to the untreated sesame (U) (without immersion and drying). For the immersion, sesame was covered in water and left to hydrate overnight. The seed moisture content was initially 3.6 ± 0.5% and, after this process, it increased to 39.05 ± 0.05%. Drying was performed after the treatments. The moisture content of the samples affects the pressing efficiency, for this reason this parameter was standardized through heating in an oven (Memmert, Germany) at 50 °C. Samples were dried until humidity reached a value between 5% and 8%. This parameter was chosen according to literature data (Guderjan et al., 2007; Willems et al., 2008). Fig. 1 shows a schematic diagram of the process performed with the sesame seeds. Electrically treated seeds are presented in Fig. 1(a), while the other treatments are described in Fig. 1(b).

The apparatus used for the application of the electrical treatments consists of a pulsed high voltage power supply (Tomsk Polytechnic University, Tomsk, Russia) and a treatment chamber with 1 L capacity. For PEF application the chamber was equipped with two parallel disc electrodes (11 cm of diameter), with an inter-electrode gap of 2 cm. For HVED, the chamber was set with one disc electrode in the bottom (3.5 cm of diameter) and one needle electrode in the top. The needle and the disk electrode were 5 mm distant. In the set-up used in these experiments, the pulse or discharge duration was of 10 μs and the frequency was 0.5 Hz. Each pulse or discharge applied provides a voltage of 40 kV. In our case, PEF treatments were performed using an electric field strength of 20 kV/cm and exponential decay pulses. A more detailed description of this equipment is in Boussetta et al. (2012).

For the pre-treatments, 100 g of seed and 300 g of distilled water were added to the chamber. Different treatment energies were applied to the seeds (40, 80, 160 and 240 kJ/kg): input energies were varied by changing the number of pulses in each treatment and were the same for PEF and HVED. Following the treatments, electrical conductivity was measured using a conductivity meter (Inolab, Level 1 model, Germany). The conductivity values were used to calculate the cell disintegration index (Z_C), as described in Eq. (1).

$$Z_C = (\sigma - \sigma_i)/(\sigma_d - \sigma_i) \tag{1}$$

In this equation, σ is the electrical conductivity after the treatment, σ_i is the initial electrical conductivity of the seeds only immersed in water (which was very close to zero), σ_d refers to the maximally disintegrated (grinded) seeds immersed in water. Grinding of the seeds was performed in a laboratory scale coffee grinder (*SEB*, France).

2.3. Analysis of the treatment water

The water placed in the chamber and used for the electrical treatments was analyzed for all different energies applied to evaluate if there were significant losses in this medium. The water was analyzed for turbidity, using a turbidimeter (Hach, model Ratio XR, United States), oil content, total phenolics and proteins. The oil