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Control of the brewing process by using microwaves dielectric spectroscopy

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ABSTRACT

Dielectric spectroscopy in microwave and radiofrequency region is an emerging control technique used to obtain information about the transformation of biological systems. In microwave region, the main interaction is produced with different food constituents and water molecule. In this context, the dielectric properties were analyzed during beer production in order to improve beer quality. There were also analyzed the most important physical and chemical properties of beer through the process. Good correlations were found between loss tangent at 10 GHz and the ethanol and sugars concentration. Therefore, this technique can be used as a fast, accurate and non-destructive control method of beer production.

1. Introduction

Brewing is considered as an example of traditional biotechnology, because of its extremely ancient history. However, its industry applies new technical, genetic and microbiological advances in order to improve this process. Among others, it can be cited the high-gravity beer fermentation (Piddocke et al., 2009), immobilized yeast bioreactor (Tata et al., 1999) and genetic modifications of yeast strains to change some parameters of the final beer (Blieck et al., 2007; Nevoigt et al., 2002).

The composition of beer is complex and very variable depending of the kind of beer. According to Preedy et al. (2009), beer can be composed by more than 1000 compounds, the most important are: water, ethanol, carbohydrates and carbon dioxide. There exist numerous analytical methods for detecting these components. The High-Performance Liquid Chromatography (HPLC) makes possible the evaluation of carbohydrates and alcohol content (Panteloglou et al., 2010; Piddocke et al., 2009; Zengran et al., 2008). Other authors optimized and validated an HPLC method with an Evaporative Light Scattering Detector (ELSD) for the quantification of carbohydrates in the beer (Nogueira et al., 2005). On the other hand, the ethanol production during the fermentation process can be determined by NIR spectroscopy (Cavinato et al., 1990; Iñon et al., 2006; McLeod et al., 2009). The quantification of the escaped carbon dioxide can be measured by mass spectroscopy (Bideaux et al., 2006). The gas chromatography is used in order to determine total diacetyl, ethanol, and the flavor and aroma compounds (Castritius et al., 2010; McLeod et al., 2009; Zengran et al., 2008; Šmogrovičová and Dömén, 1999).

In recent years, other techniques had been used to improve different processes in order to obtain a better quality of the final product (Castro-Giráldez et al., 2010a). In this context, microwave dielectric spectroscopy is a non-destructive technique that has been recently used to on-line quality control of foods. Microwaves are part of the non-ionizing radiation and their frequency range spread from 100 MHz to 100 GHz (Kent et al., 2001). This technique has been also used in numerous investigation fields as medicine (Treo and Felice, 2009), pharmaceutical industry (Wojnarowska et al., 2011; Smith et al., 1995) and material sciences (Adous et al., 2006; Labidi et al., 2011). In food technology, this technique has been used for controlling the osmotic dehydration of apple (Castro-Giráldez et al., 2011a) and kiwifruit (Castro-Giráldez et al., 2011b), for determining the fruit ripening of apple (Castro-Giráldez et al., 2010b), for determining the salt content in butter (Shiinoki et al., 1998), characterization of alcoholic beverages and solutions of ethanol in water (Bohigas and Tejada, 2010), in the study of desalted cod (De los Reyes et al., 2009), to observe the behavior of beef meat during maturation (Damez et al., 2008), to monitor changes in the dielectric properties of whole meat across a temperature range (Brunton et al., 2006), to determine the dielectric properties of a whey protein gel, a liquid whey protein mixture (Wang et al., 2003) and also to detect the whey protein denaturation (Bircan et al., 2001).

Complex permittivity (ε_r) is the dielectric property that provides information about the interaction between electromagnetic

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Nomenclature

M	mass (kg)
G	generation (kg)
x	mass fraction (kg/kg)
N	cell population (cell/mL)
r	ratio (kg/min)
t	time (h)
F	fermentation
f	frequency (GHz)
$\tan\delta$	loss tangent (dimensionless)
ε'	dielectric constant (dimensionless)
ε''	loss factor (dimensionless)

Sub-indexes

E	ethanol
F	fructose
G	glucose
M	maltose
S	sucrose
CO_2	carbon dioxide
0	initial time

Super-indexes

0	initial time
F	fermentation
t	time (h)
H	hydrolysis

energy and the food (Datta and Anantheswaran, 2001; Metaxas and Meredith, 1993). It can be defined as:

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \quad (1)$$

where ε' is the real part or dielectric constant and describes the ability for a material to store energy when it is subjected to an electric field. ε'' is the imaginary part, or loss factor, and represents the ability of the material to dissipate the electromagnetic energy, which commonly results in heat generation.

The objective of this work was to measure the dielectric properties during the beer fermentation process, in order to control the quality of this beverage.

2. Materials and methods

2.1. Standard solutions

Standard solutions simulating the lager wort and lager beer composition were prepared. Their composition was based in bibliographic sources (Preedy, 2009). Moreover, sugar composition was obtained mixing 40% of maltose, 40% of sucrose, 10% of fructose, and 10% of glucose.

2.2. Beer experimental

Preliminary studies were done at the same working conditions, in order to select the measure times of fermentation process.

The beer was prepared using 115 g of commercial malt syrup with 0.35 g commercial *Saccharomyces cerevisiae* yeast (Brewmaker Original Lager Kit, Mr. Malt®, Italy), adding 60 g of pure sucrose and 1.5 L of distilled water.

Three different fermenters were used for beer production at 22 °C. At different times (12, 24, 36, 54, 60, 72, 75, 78, 84, 96 h), three aliquots were taken from each fermenter and tempered at 25 °C for measuring dielectric spectra, ethanol content, refractometry index, spectrophotometry and sugar chromatography. The carbon dioxide content was obtained by stoichiometry.

2.3. Dielectric properties measurement

The system used to measure dielectric properties consist of an Agilent 85070E open-ended coaxial probe connected to an Agilent E8362B vector network analyzer. The system was calibrated by using three different types of loads: air, short-circuit and 25 °C Milli®-Q water. Once the calibration was made, 25 °C Milli®-Q water was measured again to check calibration suitability. All determinations were made at 25 °C from 500 MHz to 20 GHz by introducing the coaxial probe at least 5 mm into the sample. Three measurements were done for every sample.

3. Physical–chemical analysis

An industrial densitometer was used at the beginning of the treatment for determining the ethanol content (OIV, 2004). Ethanol content was also estimated by using the transmittance measurement, previously calibrated by standard solutions of sucrose, ethanol and water mixtures (Labianca, 1996), in order to obtain a better control of ethanol quantity.

The transmittance of the sample was measured by using an UV/visible spectrophotometer at 600 nm (Helios Zeta v8.00 serie No. 164405).

The refractometry Index was determined by a refractometer (ABBE, ATAGO Model 3-T, Japan).

Sugars quantification was carried out by means of an ion chromatograph (Metrohm Ion Ltd., Switzerland) using a column (Metrosep carb 1: 250/4,6) and a precolumn (Metrosep carb 1 Guard). The mobile phase was a solution of NaOH 0.1 M. The samples were centrifuged (J.P. Selecta S.A., Medifriger-BL, Barcelona, Spain) at 4000 rpm during 20 min. 1 mL of supernatant was diluted with Milli®-Q water in a 100 mL Erlenmeyer flask. The dilution was filtered through a 0.45 μm Millipore filter and 15 mL was used to analyze the sugars content.

Analytical determinations described above were obtained by triplicate. Statistical analysis was carried out with the Statgraphic® Plus, version 5.1 (Statpoint Technologies, Inc., USA).

4. Results

Beer production is the result of some biochemical reactions coupled; these reactions produce fermentable monosaccharides, ethanol, carbon dioxide and some important compounds responsible of the beer flavors (Olmi et al., 2007); all these compounds produce the final quality characteristics of beer. The hydrolysis of maltose and sucrose occurs simultaneously with the fermentation reaction producing monosaccharides (see reaction in Fig. 1). Weight evolution was calculated applying an ethanol balance through the fermentation reaction with the hypothesis that all the carbon dioxide leaves the solution (obtained by stoichiometry relation with the ethanol).

The maltose concentration was calculated following the balances exposed in Fig. 1, using the glucose, fructose and sucrose concentration measured and the initial maltose concentration obtained from the overall sugars measured by refractometry in beer