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Optical measurements and pattern-recognition techniques for identifying the characteristics of beer and distinguishing Belgian beers

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ABSTRACT

A miscellaneous assortment of 86 beers was characterized using non-destructive, rapid and reagent-free optical measurements. Diffuse-light absorption spectroscopy performed in the visible and near-infrared bands with the use of optical fiber spectrometers was tested innovatively to gather turbidity-free spectroscopic information. Furthermore, conventional turbidity and refractive index measurements were added in order to complete the optical characterization. The scattering-free near-infrared spectra provided a novel and straightforward turbidity-free assessment of the alcoholic strength. The entire optical data set was then processed by means of multivariate analysis in a search for a beer grouping in accordance with the characteristics and identity of each type. The results indicated that optical technologies could be successfully used for beer differentiating between several classes of beers. Moreover, since half the beers were typical Belgian beers, multivariate processing of the optical data was also applied in order to achieve a differentiation of the Belgian beers as compared with all the others, thus demonstrating a potential method for authenticating the country of production.

1. Introduction

Beer originates from prehistoric times [1]. Nowadays, with an average consumption of about 80 l per person in 2009 [2,3], beer is the third most often consumed drink worldwide, after water and tea, and the first most widely consumed alcoholic beverage. Indeed, since it consists of 93% water, beer is a refreshing, enjoyable, thirst-quenching long drink with a relatively low alcoholic strength and glycemic load which brings pleasure to and instigates social interaction among many people. In addition to water, beer is made from wholesome raw materials: malted barley, other cereals, hops, and yeast. As in any natural food, many healthy ingredients can be identified in beer [4], including antioxidants [5] – mainly polyphenols [6], essential vitamins – particularly B vitamins [7,8], and minerals. While underage and heavy drinking have harmful effects and leads to chronic diseases, recent studies have reported that a responsible light-to-moderate consumption of beer by healthy adults has many beneficial effects, including a reduction in the risks of cardiovascular diseases, osteoporosis and diabetes [9]. Moreover, beer is the only significant dietary source of hops, which are not only responsible for the bitter taste and provide preservative agents, but are also a unique source of isohumolones, which can reduce hyperglycemia in subjects with prediabetes [10].

Indeed, beer is an undistilled fermented beverage, in which a source of starch consisting of malted barley and wheat is converted by means of hot water into a sugary liquid which undergoes a fermentation process triggered by the addition of yeast. Many types of beers are brewed depending on the type of producer, which range from multinational companies to small producers, or else brewpubs or regional micro-breweries that produce with a limited amount of artisan-made beers [11,12].

Beers are differentiated mainly according to their visual appearance and their fermentation process. The visual appearance of beer depends on both its color and its turbidity. This is not only because scattering reduces the transparency of beer, but also because the suspended particles themselves can contribute to light absorption. Both these factors are heavily influenced by the brewing method. Thermal treatment can be applied to different extents in order to accelerate the drying of the malt, and this results in darker, more reddish, beers [13]. Suspended sediments due to yeast residuals can be found in top-fermented beers, which are often unfiltered or bottle-conditioned. The use of malted or unmalted wheat also influences the beer's color. At times, other colorants, such as caramel, are added in order to "adjust" the color to the desired shade.

Depending on the yeast used and the fermentation temperature, three main beer categories can be identified: top-fermented,

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bottom-fermented, and naturally-fermented. Top-fermented beers, which are also called "Ale", are produced by adding *saccharomyces cerevisiae* yeast in the 15–20 °C temperature range, and offer a fruity-flavored aroma. Bottom-fermented beers, which are also called "Lager", are produced by adding *saccharomyces uvarum* (or pastorianus) at cooler temperatures, namely between 7 and 12 °C: the lower temperature inhibits the production of esters and other by-products, thus producing a cleaner-tasting beer. Naturally-fermented beers, which are produced mainly in Belgium, where are commonly called "Lambic", make use of wild rather than cultivated yeasts. The entirely natural process guarantees an unusual aroma and sourness.

Every recipe and production method, provides the beer in question with a distinctive quality and taste. Indeed, the quality differentiation of beers, as of many other foodstuffs, is a marketing requisite that exists in order to satisfy consumers who have become more critical, more demanding and more fragmented in their food choices, especially in developed countries. It has been demonstrated that competing on the basis of price alone is no longer the most effective business strategy. A holistic approach that satisfies a sense of good mood and positive emotions is a more modern, attractive, and consumer-oriented tactic, which equates quality with all the desirable properties that a product is perceived to have [14]. In front of a crowded shelf in a supermarket, or inside a small niche-shop, the consumers' cognitive mechanisms are driven by attractive indicators, especially by three main extrinsic cues: brand, country of origin, and quality label [15,16]. With particular reference to the beer market, it has been demonstrated that brand identity [17,18], the country of production [19–21], and a label with information about the manufacturing process [22], provided differentiating and added-value concepts linked to sensory properties.

Optical methods, especially optical spectroscopy, provide a modern and effective means for non-destructive food analyses. In fact, in addition to non-destructive testings, they represented a "*green*" approach to sustainable analytics, since they are considered to be user-friendly, general, and moderate-cost technologies [23]. Optical methods measure the sample "*as it is*", without using reagents, functionalization, or chemical treatments. Since no chemical reagents are involved there are no discharges to recycle. Moreover, avoiding treatments leads to a safer handling of samples which is helpful also in the case of non-trained operators. The potential lack of selectivity and sensitivity can be compensated for by using mathematical algorithms – the so-called system intelligence. Typically, chemometrics has been considered to be a robust and popular approach for processing optical data; in particular, for more than 40 years, it has demonstrated effectiveness in all kinds of spectroscopic applications [24,25].

Many spectroscopic studies have been dedicated to beer-quality applications, always combined with a chemometric treatment of optical data. Fluorescence measurements have been used for monitoring beer quality during storage [26], for analyzing vitamins [27], as well as for assessing the content of nutraceutic factors such as riboflavin and aromatic amino acids [28], in addition to the renowned "resveratrol" antioxidant compound [29]. Near-infrared spectroscopy alone, and the combination of mid- and near-infrared spectroscopy have been extensively employed for quantifying important quality parameters of beers, such as alcoholic content, and original and real extracts [30–34]. The most recent works on optical methods for beer-quality assessment have shown how to confirm the brand identity of a famous Belgian beer by using near-infrared transflectance spectroscopy [35], and how to discriminate beers of the same brand, even if brewed in different factories, using spectroscopic data which have been fused with other sensory data from e-tongues [36].

In order to meet the requirements of product differentiation and authentication, this paper presents an experiment which makes use of non-destructive, rapid and reagent-free optical measurements for the purpose of recognizing beer varieties. A wide collection of beers was considered; these were produced in different countries using all fermentation methods. Unusual and more conventional setups for optical measurements were used to analyse the entire collection. Diffuse-light absorption spectroscopy, performed by means of an integrating sphere in the visible and near-infrared bands and using optical fiber spectrometers, proved to be capable of providing scattering-free absorption measurements – that is, without having to take into consideration of the natural turbidity of the beer, which could impair traditional absorption spectroscopy measurements. In addition to these unusual absorption spectroscopy measurements, other physical parameters such as turbidity and the refractive index were measured using conventional optical instruments, in order to complete the optical characterization of the beer collection. Intuitively speaking, while diffuse-light absorption spectroscopy provided information on color (the visible band) and alcoholic strength (the near-infrared band), the turbidimetry and refractometry were related to the intrinsic sample turbidity and to Brix, respectively. Indeed, Brix provides the sugar content of an aqueous solution. It is usually measured by means of refractometry, so as to keep track of the degree of fermentation [37].

A straightforward prediction of the alcoholic strength was obtained by means of the scattering-free near-infrared spectra, thus demonstrating a novel approach which can be used online during beer production. The scattering-free visible and near infrared spectra, together with the turbidity and refractive index values were then combined for the first time to create a data matrix, which was processed by means of multivariate analysis. This novel method was capable of grouping the beer collection according to the individual fermentation method (Lager, Ale, Lambic), and color (Golden, Dark). These groups reflect the individual identities of the various beers, thus indicating that optical technologies can be successfully used for beer differentiation among several classes. Moreover, since half of the beers were typical Belgian beers, multivariate processing of the optical data was also applied in order to achieve a classification of the Belgian beers with respect to all the others, thus demonstrating a method for authenticating the country of production.

2. Experimental

2.1. The beer collection

The beer collection used in this experiment consisted of 86 beer samples, each of a different brand. 50 beers were produced in Belgium, while the others came from other countries, such as Italy, Germany, Denmark, England, The Netherlands, Japan, The Czech Republic, Cuba, and Mexico, as listed in Table 1. These were top-fermented (Golden Ale, Dark Ale, Weiss), bottom-fermented (Lager, Doppelbock, Mexican), and spontaneously-fermented (Golden and Cherry Lambic) beers, with different colors, and alcoholic strengths in the 0.5–11% vol range.

Only one bottle for each beer type was available. In order to mitigate experimental uncertainties, each measurement was performed three times, and the average was then taken. All experimental data reported refer to the average values.

2.2. Diffuse-light absorption spectroscopy in the visible and near-infrared bands

Diffuse-light absorption spectroscopy makes use of an integrating sphere that contains the sample being tested [38–40]. The