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Use of optical oxygen sensors to monitor residual oxygen in pre- and post-pasteurised bottled beer and its effect on sensory attributes and product acceptability during simulated commercial storage

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ABSTRACT

Disposable optical oxygen sensors were used to non-destructively assess the levels of residual oxygen in the headspace of commercially produced Lager beer in 330 ml clear glass bottles. Monitored before and after pasteurisation, oxygen concentration was observed to drop as oxygen diffused into the beer. Oxygen levels between 0% and 5% were present in the bottle headspace pre-pasteurisation. Oxygen diffusion into the beer was monitored over time under refrigeration (~4 °C) and a sensory panel was used to determine the effect of residual oxygen on the sensory quality of the beer. The headspace in the bottles was also monitored over time where oxygen increased to a level of ~0.5% on average over the course of the shelf life. Interestingly, results showed that beer samples possessing higher levels of oxygen present prior to pasteurisation also possessed the most negative sensory attributes associated with the beer, particularly those consistent with beer staling. The developed optical sensor was shown to act as a predictor of sensory quality and may have on-line applications in the beer packaging sector.

1. Introduction

Alcohol-based beverages contribute €6.6 billion (euro) to the Irish national economy and provide over 100,000 jobs, which makes this industry a vital part of Irish social and economic life. Beer constitutes the biggest alcohol-based product category, accounting for about 50% of the market, and an average of 40% of all beer brewed in Ireland is exported (Irish Business and Employers Confederation, 2010). Pale lager is the most widely consumed and commercially available style of beer in the world. The flavour of these products is usually mild and the producers often recommend that the beers be served refrigerated. In general, lagers display less fruitiness and spiciness than ales, simply because the lower fermentation temperatures associated with lager brewing causes the yeast to produce fewer of the esters and phenols associated with those flavours. The typical brewing process is finalised by filling, packaging and pasteurisation steps. Depending on the packaging selected, pasteurisation can take place prior to, or post filling. The only successful way to prevent beer spoilage by microorganisms is to thermally destroy organisms via pasteurisation (Wainwright, 1999a). In most popular cases, tunnel pasteurisation is carried out when bottling. Tunnel pasteurisers allow for the destruction of microorganisms and residual yeasts at 65–68 °C over a period of 20 min. The tunnels are usually divided into a number of heating zones where atomized water sprays heat the filled containers as they pass on a conveyor giving incremental rises in temperature until pasteurisation is achieved (Fellows, 2000).

The packaging of beer using glass bottles is still a preferred packaging approach. Despite negative features such as packaging fragility and final package weight, glass bottles used for beer packaging still possesses features that still make it the most suitable form of packaging for use on high speed filling lines, namely, it is inert and so does not chemically interact with the beer itself, provided that the correct closure system is used, glass is completely hermetic and consequently prolongs product shelf-life, it offers greatest container rigidity and consequently, it is easily, filled, stored and transported and is available in a variety of sizes, shapes and colours. Products look better, taste purer and are secure when packaged in glass (Yam, 2009). When used as a beer package, the premium image and end-use market make glass very acceptable to the consumer, especially traditional consumers who perceive bottled beer as being of a superior quality (Giles, 1999). The final processing of larger-style beer generally results in the production of a clear beer which should possess a commercial shelf-life, as a minimum, of six months.

However, beer products, if inappropriately processed or packaged can oxidise, may spoil due to microbial growth or develop hazing

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(which can produce turbid-like appearances in the beer) during storage. Flavour stability in beer depends to a great extent on the lack of oxidation of the beer. If there is a relatively large volume of air in the final container, oxidation inevitably occurs (Wainwright, 1999b). At the end of the fermentation stage, beer is completely free of oxygen. At this point, beer is highly susceptible to oxidation, which has the following affects on the end product; undesirable taste, cloudy/hazy beer, increased beer astringency and darkened beer colour.

During the filling process, beer bottles are lifted to an individual filling point with a tube which projects into the bottle. The bottles are filled based on height, weight or volume. At the end of the filling process, there should be less than 2 ml of gas space in the bottle and the oxygen content in the beer should be below 0.1 mg/L (Giles, 1999). Prior to capping, the bottles are usually at full fill point with foam. This level of carbonation resulting in foaming helps expel oxygen from the bottle and usually keeps oxygen from entering the bottle. Production of flavour-active compounds like carbonyls are associated with extended storage. Oxygen plays a key role in bottled beer, where, beer of high oxygen contains significantly higher levels of carbonyls after storage. Although a degree of protection is obtained by minimizing the oxygen content of beer after packaging, a high level of oxidation during earlier stages of brewing also results in flavour instability in the final beer (Varnam & Sutherland, 1994). Almost all beers taste best immediately after they have been produced and usually start to deteriorate/age/stale over time; this is where best before dates are set. The primary quality issue associated with bottled beer is the change of its chemical composition during storage, which subsequently alters its sensory properties (Vanderhaegen, Delvaux, Daenen, Verachtert, & Delvaux, 2007; Vanderhaegen, Neven, Verachtert, & Derdelinckx, 2006).

Optical oxygen sensors have been used as a non-destructive method of oxygen detection in recent years (O'Riordan, Voraberger, Kerry, & Papkovsky, 2005; Papkovsky, 1995, 2004). Optical oxygen sensors use a phosphorescent dye embedded in a polymeric film which is quenched by oxygen and can be used within food packaging to assess the levels of oxygen present. Oxygen-sensitive platinum octaethylporphyrin-ketone (Pt-OEPK) in polystyrene is used as a typical optical sensing probe. The use of such sensors have been well documented and used in food packaging applications, such as modified atmosphere packaging and vacuum packaging systems, where foods such as beef (Smiddy, Fitzgerald et al., 2002) processed meats (Smiddy, Papkovsky, & Kerry, 2002) chicken patties (Smiddy, Papkovskaia, Papkovsky & Kerry, 2002), sous vide products (O'Mahoney et al., 2004) and cheese (O'Mahoney, O'Riordan, Papkovskaia, Kerry, & Papkovsky, 2006), have all been assessed. The reversibility of the sensor response allows for continuous, non-destructive measurement of oxygen while contained within a food package up to the expiration date and beyond. The use of optical oxygen sensors provides the perfect tool to measure the level of oxygen present in bottled beer during processing, transport, storage and sale. The principle objective of this experiment was to determine the effectiveness of incorporating an oxygen sensor into lager beer bottles and predicting the sensory quality of the beer with respect to oxidation and staling. The level of oxygen in bottled beer pre- and post-pasteurisation was measured and its affect on sensory attributes was assessed during shelf life stability testing conducted over a storage period of seven months.

2. Materials and methods

2.1. Sensor preparation

Optical Oxygen Sensors were prepared using (Platinum octaethyl porphyrin-ketone) (Pt-OEPK) (Luxcel Biosciences, Cork, Ireland) spotted on Durapore (Millipore Inc, Bedford, USA) paper using Gilson P100 pipette (Gilson, WI, USA) and allowed to dry and cut to a size of 5 mm diameter. The sensors were batch-calibrated using a phase detector (Luxcel Biosciences, Cork, Ireland) and a customised load cell, where one sensor was flushed with oxygen of varying concentrations (0, 0.5, 1, 2, 5, 8, 21%, respectively) and their phase determined. A calibration curve was constructed representing phase versus oxygen, to convert phase readings to percent oxygen. These were then attached to 3 cm stickers for adhesion to the interior neck of the bottles. In order to withstand the bottling process (pre-wash, wash, drying, filling and capping) initial trials were carried out within the bottling plant to establish the adequate adhesion required for stickers to remain attached to the bottles throughout the various steps involved in the filling process. Three forms of stickers were used; pricing stickers (Avery price marking), labelling stickers (Avery 35 mm laser labels) (Avery Dennison, California, USA) and masking tape (3M Scotch tape, 3M, Minnesota, USA). Using all three types of adhesive-coated stickers available, six bottles were pre-fitted with each type of potential sensor supporting adhesive-coated matrix in the bottle neck area and passed through the commercial bottling process. All three forms of stickers were assessed for their ability to; adhere to the applied internal surface of the bottle, resist peeling, resist flaking and resist curling. These were assessed over a 30-day period to determine which sticker was optimally suited for a larger and more long-term beer storage study. Once adhesive label selection was made, sensor materials were spotted to a 5 mm diameter in the centre of the stickers. These constituted the sensors for further application and have a shelf life of over one year. Sensors were incorporated to beer bottles and exposed to the complete packaging process including pasteurisation. Immediate post packaging sensor checks and recalibration were carried out to insure sensors withstood the temperature shock inflicted by the pasteurisation process. Results yield no change in performance to sensors and re-confirm initial calibration checks.

2.2. Sample preparation

A local brewery (Beamish and Crawford Ltd., Cork, Ireland) provided access to their production facilities and provided all of the samples necessary for this study. Empty clear coloured glass 330 ml bottles were collected and fitted with sensors in the upper neck of the bottle. Once prepared these bottles were transported to the bottling facility and added on to the filling line. Once washing, drying, filling and capping were complete, the bottles were taken off-line where sensors were visually assessed and instrumentally read for the first time. Following this procedure, the bottles were again returned to the bottling line so that the bottles could go through the pasteurisation process. Pasteurisation was carried out in a tunnel pasteuriser for 25 min where samples were subjected to 68 °C heat and then cooled back to refrigeration temperature (4 °C). A batch of 48 samples were produced and regularly monitored for oxygen over time (bottles were read in triplicate, where standard deviation was $<0.1\%$ O_2). Samples were categorised according to their pre-pasteurisation oxygen content and were grouped into levels that represent 0, 0.5, 1.0, 2.0 and 5.0 ml of O_2 per 100 ml of air and these were designated as 0.0%, 0.5%, 1.0%, 2.0% and 5.0%, respectively. These groups were subsequently used for sensory analysis. The level of oxygen present prior to pasteurisation was assessed in an attempt to ascertain if this oxygen level would have an impact on shelf life and product sensory attributes. All samples were continuously measured on a monthly basis, for seven months, while maintained at 4 °C. Equipment was blanked each test day before readings were taken, using sensors maintained at 0% and 21% oxygen.

2.3. Sensory analysis

A 26 member sensory panel was recruited in University College Cork, Ireland. Age range of panellists was 21–40 years old and