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Classification modeling based on surface porosity for the grading of natural cork stoppers for quality wines

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ABSTRACT

The natural cork stoppers are commercially graded into quality classes according with the homogeneity of the external surface. The underlying criteria for this classification are subjective without quantified criteria and standards defined by cork industry or consumers. Image analysis was applied to premium, good and standard quality classes to characterize the surface of the cork stoppers and stepwise discriminant analysis (SDA) was used to build predictive classification models. The final goal is to analyze the contribution of each porosity feature and propose an algorithm for cork stoppers quality class classification. This study provides the knowledge based on a large sampling to an accurate grading of natural cork stoppers.

In average all the models presented accuracy in relation to the commercial classification over 68% with a higher mismatch in the mid-quality range. Color showed an important discriminating power, increasing the accuracy in 10%. The main discriminant features were porosity coefficient and color variables, calculated for the lateral surface. A quality classification algorithm was presented based on a simplified model with an accuracy of 75%. The classification based on color vision systems can ensure improved quality class uniformity and a higher transparency in trade.

Keywords: Natural cork stoppers; Quality classes; Image analysis; Porosity; Discriminant analysis; Classification algorithm

1. Introduction

Natural cork is an outstanding material for the closure of wine bottles combining physical performance and durability, and allowing a balanced development of wine during bottle aging through its oxygen transfer characteristics (Lopes et al., 2005). Cork is the closure material preferred by wine consumers, as shown by recent surveys (Barber et al., 2009). Natural cork stoppers have also a very favorable footprint and are associated to cork oak forests, a sustainable ecosystem with high biodiversity richness.

Cork is a cellular material with chemical inertia and a set of specific physical and mechanical properties that provide an unmatched closure for bottles and for high performance insulation, with natural cork stoppers as the premium product of the cork industry (Fortes et al., 2004; Pereira, 2007).

Natural cork stoppers are graded into quality classes in function of the apparent homogeneity of their external surface, as seen by human or machine vision (Fortes et al., 2004; Pereira, 2007). The heterogeneity of the cork surface is given primarily by the presence of lenticular channels, as well as by woody inclusions, small fractures or other defects, that can be visually outsingled from the cork surface and are named as the porosity of cork (Gonzalez-Adrados and Pereira, 1996; Pereira et al., 1996). This evaluation is made using automated image-based inspection systems with high throughput rates based on line-scan cameras and a computer embedded in an industrial sorting machine capable of acquiring and processing in real-time the surface image of the stoppers (Lima and Costa, 2006). The systems allow an identification of surface defects and quantification of porosity features, e.g. total area, number or concentration of pores (Chang et al., 1997; Jordanov

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and Georgieva, 2009; Pereira et al., 1994; Radeva et al., 2002).

However, it is known that the underlying criteria for the quality classification of cork stoppers are subjective to some extent and no standards were defined by the cork industry or the consumers to grade sorting (Pereira, 2007). The classification is usually based on reference samples showing the range of quality variation that can be found in the consignment for a given client (Lopes and Pereira, 2000).

Several studies have been published on identifying the contribution of each porosity feature for the grading of cork stoppers (Costa and Pereira, 2005, 2006, 2007, 2009), as well as of cork discs (Lopes and Pereira, 2000) and cork planks (Benkirane et al., 2001; Gonzalez-Adrados et al., 2000; Gonzalez-Adrados and Pereira, 1996; Pereira et al., 1996). All the studies have shown that there is overlap between classes and that the role of non-quantified features, i.e. related to operator or industry is significant. However, the sampling used in these studies was limited, e.g. in number of cork stoppers and in the surface area covered by image analysis, and doubts may remain regarding the selected features since the natural variability in cork is high. A recent study analyzed in detail the porosity of a large sample of natural cork stoppers, showing that variation of some of the pores characteristics throughout the lateral surface of the stopper is important (Oliveira et al., 2012).

Other studies have been published focusing on modeling the classification of cork stoppers and discs. Chang et al. (1997) proposed a cork stopper quality classification system based on features extraction and a fuzzy neural network, with 6.7% of rejection after reevaluation of the results by human experts. Vega-Rodríguez et al. (2001) presented a system for image processing using reconfigurable hardware and an algorithm for the cork stoppers classification that uses a simplified set of porosity features (defect area, size of the biggest defect and area occupied by defects of different sizes) for the two tops. Vitrià et al. (2007) presented a cork stopper classification model based on feature extraction and class-conditional independent component analysis, reaching an average error rate of 2%. Paniagua et al. (2011) developed for cork discs a neurosystem to model the human cork quality classification. Other techniques have been applied to cork classification such as X-ray Compton tomography (Brunetti et al., 2002) or terahertz/millimeter wave spectroscopy (Hor et al., 2008) in order to refine the visual classification with inclusion of possible voids, cracks, and defects inside the stopper. Recently, Gómez-Sánchez et al. (2013) used colorimetric image analysis techniques with application of segmentation algorithms to measure the porosity of cork samples. They obtained the best NIRS calibrations by measuring the porosity into three classes of color, matching the results obtained by image analysis.

This paper analyses in detail the porosity features of cork stoppers in the grades used today by the quality wine markets: three major quality grades, of premium, good and standard stoppers. The study was made on the total external surface (lateral surface and tops) of the stoppers, and was based on a large sample in order to encompass the cork natural variability and to allow better confidence in the results. The contribution of each porosity feature to quality classification is analyzed using adequate statistical validation, the significant indicators for the grading selected and a classification algorithm is proposed for cork stoppers quality classification using today's quality grades. The final goal is to define a simple and objective classification that could be used by the industry in order to ensure improved quality class uniformity and a higher transparency in trade, and additionally generate knowledge on the key features of the raw material that may be used in the research, development and enhancement of new products.

2. Materials and methods

2.1. Sampling

The natural cork stoppers (24 mm diameter × 45 mm length) used in this study were collected from one major Portuguese cork industrial unit. The stoppers were randomly sampled (before washing and surface treatment) after a first step grading by the automated vision system used routinely in the industrial production line. The criteria considered in such automated grading include total area and number of pores, area of the largest pores, pore concentration level, location of defects, vertical and horizontal projection of pores, and the presence of cracks. Subsequently they were inspected by skilled operators and graded into three references quality classes as required today by the wine market, coded as premium (including the traditional "flor" and extra commercial classes), good (superior and 1st commercial classes) and standard (2nd and 3rd commercial classes). After this manually validated classification, a sample of 200 cork stoppers of each quality class was randomly taken and used as the reference for the classification modeling.

2.2. Image acquisition

The natural cork stoppers were individually analyzed and their image surface (cylindrical lateral surface and circular bases) acquired with an image analysis system that included a digital 7 mega pixels in macro stand solution set on an acquisition Kaiser RS1 Board with a controlled illumination apparatus, connected to a computer using AnalySIS® image processing software (Analysis Soft Imaging System GmbH Münster, Germany, version 3.1).

The image acquisition covered 100% of the lateral area by using eight successive frames of the cylindrical lateral surface of the body. The first frame was acquired parallel to cork growth rings and the others subsequently taken by rotating the stopper 45° (Fig. 1). Two circular frames were acquired for the two tops corresponding to 96% of the total area. Due to the way stoppers are punched out from the cork strip, the tops correspond to transversal sections of cork while the lateral surface of the stopper includes tangential and radial sections of cork and all the in-between sections (Pereira, 2007; Pereira et al., 1987).

The object extraction was carried out inside two predefined regions of interest, one rectangular, 45.05 mm long and 9.41 mm wide (area 423.92 mm^2), for the lateral surface, and another circular for the tops with 23.51 mm diameter (area 433.92 mm^2). The image threshold was adjusted individually for each image and ranged in a RGB system from 65 to 135 for red, from 60 to 115 for green, and from 65 to 120 for blue.

2.3. Image data analysis

A set of variables was collected automatically for each pore: area (mm^2), calculated by the number of pixels of the particle times the calibration factors; mean diameter (mm), defined as the arithmetic mean of all diameters of a particle (range angles between 0° and 179°, with step width of 1°); maximum diameter (mm), is the maximum diameter of all maximum