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Research Note

Quality assessment of durum wheat storage centres in Sicily: Evaluation of vitreous, starchy and shrunken kernels using an image analysis system

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ABSTRACT

The proportion of vitreous kernels in a sample is an internationally recognized specification for determining the value of durum wheat (*Triticum durum* Desf.). Vitreous kernels are mostly related to quality, which affects the pasta performance during cooking. Vitreousness and the amount of shrunken kernels are visually assessed during the grading process. This assessment is subjective and tedious.

A machine vision system was developed to determine the percentage of vitreous, starchy, piebald and shrunken kernels in approximately 100 grain samples, using a trans-illuminated image of one layer of non-singulated kernels (in bulk) acquired by a digital camera. Classification models were developed with stepwise Linear Discriminant Analysis, as well as an on-line Bayesian classifier integrated with an image analysis system. The overall correct classification in *Starchy classifier* was high 98.58% in the Training set, made up of 6679 grains, following the Linear Discriminant Analysis classification, of 30 Italian cultivars harvested in 2005 in three localities. An independent Test set was constituted by samples collected in 30 Sicilian Storage Centres in the 2007 harvest season. The overall classification was 96.03%. For the *Shrunken classifier* 95.27% of the Training set and 99.58% of the Test set were correctly classified. The image analysis system was more reliable than the human inspectors who validated the system, both for the same samples measured many times and at different times.

1. Introduction

Durum wheat (*Triticum durum* Desf.) accounts for approximately 8% of the total world wheat production (Abaye et al., 1997).

Durum wheat is mainly used to make semolina for macaroni, spaghetti, and other pasta products. The best durum wheat for pasta products is hard, glassy, and translucent, and it should have an amber colour, and a good protein content (around 12%) that contributes to good cooking quality of pasta. Vitreousness describes the nature of an object that resembles glass in transparency. Glass differs from opaque objects in its ability to reflect or transmit light. Non-vitreous (starchy) kernels are opaque or contain opaque regions of varying size (piebald), due to air spaces between starch granules (Dexter et al., 1989) and are softer, resulting in a decreased yield of coarse semolina. A shrunken kernel develops due to imperfect maturation caused by heat, drought or biotic stress during the filling phase of seed development in the field. Consequently, when milled, starchy and/or shrunken kernels reduce to fines, decreasing semolina extraction (Dexter and Matsuo, 1981).

The estimation of vitreous kernel content in durum wheat is an important international grading factor and it is performed using visual inspection by trained personnel (ICC Standard Methods, 1980). This method is both subjective and tedious. It also produces great variations in results between different individual inspectors. The decision-making capabilities of a grain inspector can at times be affected by his/her condition, such as fatigue and eyesight, mental state caused by biases and work pressure, and adverse working conditions such as improper lighting, climate, etc.

Targeting the disadvantages of human inspection, considerable research has been conducted to develop objective, rapid, and automated grain-grading systems, to determine vitreous kernels in durum wheat. Such a grading method should greatly reduce the work and subjectivity of grain inspectors, and consequently benefit wheat producers, processors, and handlers. Various methods have been proposed to detect vitreousness of durum wheat kernels.

Quick methods have been applied in the investigation of vitreousness. The Single Kernel Characterization System (SKCS) measures hardness (related to vitreousness) by crushing single kernels between the crescent and a toothed rotor (Osborne and

Abbreviations: ANOVA, Analysis of Variance; LDA, Linear Discriminant Analysis; NIRS, Near infrared spectroscopy; SKCS, Single Kernel Characterization System.

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Andersen, 2003). Sissons et al. (2000) were not able to develop sufficiently strong relationships between SKCS data and durum wheat semolina yield to be useful for prediction purposes.

In recent years, optical, mechanical, and electronic techniques have been applied to rapid grain grading and classification. Near infrared spectroscopy (NIRS) is one of the most used systems for many purposes. Wang et al. (2002) used NIRS to determine the content of dark hard vitreous kernels in hard red spring wheat. Bleached kernels were the most difficult to classify because of their high lightness values. More than 75% of misclassified kernels were bleached. Dowell (2000) found that whole grains classified by NIRS, in which the durum wheat kernel studied were of two categories, obviously vitreous and non-vitreous. The evaluation was in perfect agreement with grain inspectors. However, the accuracy of classification dropped to only 75% when more difficult-to-classify kernels were present.

As a rapidly developing technology, 'machine vision' has shown great potential to assess physical properties of grain (Sapirstein and Bushuk, 1989; Shatadal et al., 1998). Many researchers have combined image acquisition, processing, and analysis techniques with advanced classification algorithms, to detect grain kernel characteristics, such as colour, texture, and various types of damage (Bacci et al., 2002; Luo et al., 1999; Ruan et al., 2001; Zayas et al., 1994).

Symons et al. (2003) developed a machine vision based system to classify durum wheat kernels according to the degree of vitreousness. Their results were highly consistent with those of human inspection. Xie et al. (2004) were able to detect vitreous kernels in amber durum with a high degree of accuracy (~93%) by using reflectance and transmittance images. Relatively lower accuracy was achieved for bleached (87%), cracked (85%) and mottled (71%) kernels. Wang et al. (2005) using transmitted images reached an overall correct classification of 94.83% for vitreous, non-vitreous and mottled (piebald) kernels. Shahin et al. (2005), using images acquired by a flatbed scanner (reflected and transmitted images), obtained a 90.66% correct classification of vitreous kernels in the Training set and 87.07% in the Test set. Neethirajan et al. (2006), using transmitted images, obtained an 89.5% correct classification of vitreous kernels. *Acurum* (www.acurum.dupont.com) and *Cervitec* (www.foss.it) are image analysis based systems available in the market, that claim to be able to measure vitreousness on durum wheat samples. They are very similar regarding the acquiring system and the reliability of results (Andrén, 2008; Boyer et al., 2008). Both use reflected light images acquired by a colour camera with mechanically singulated grains.

The most promising image types with the highest vitreous correct classification are the transmitted images acquired by a colour camera (Wang et al., 2005). The present research team has made some attempts (data not shown) using images acquired by a flatbed scanner in transmitted mode, but results were not convincing. Similar poor results (about 87% of overall correct classification) were achieved by Shahin et al. (2005) using images acquired by a flatbed scanner. In fact, because of the insufficient power of transmitted scanner light, kernels, with small starchy spots were not clearly detected in our acquiring condition. For this reason we decided to acquire trans-illuminated images using a colour digital camera (Fig. 1a and b).

The aim of the present work was to obtain high degrees of correct classification for vitreous, non-vitreous, piebald (mottled) and shrunken kernels in durum wheat samples, and to validate the classification model using samples collected in 30 Sicilian Storage Centres (Elevators) in the 2007 harvest season. In order to train the Bayesian classifier integrated in the analysis system, grains classified by inspectors (that use visual and subjective evaluation) were not used. Instead, only grains correctly classified by LDA (Linear

Fig 1. (a) Reflected light (scanner) from left to right: starchy–normal, piebald–normal, vitreous–normal and vitreous–shrunken. (b) Transmitted light (trans-illuminator) from left to right: starchy–normal, piebald–normal, vitreous–normal and vitreous–shrunken.

Discriminant Analysis), were used, this classification is therefore objective and it is based on the best discriminant variables chosen by the model itself.

2. Experimental

2.1. Grain samples

Thirty durum wheat cultivars from the Italian National Adaptability Trials (Desiderio et al., 2005) were used to train the image analysis system. These included the most common Italian cultivars, harvested in three different locations, Santo Pietro (lat. 37°07′ long. 14°31′ province of Catania), Gela (lat. 37°06′ long. 14°17′ province of Caltanissetta), and Castel di Iudica (lat. 37°29′ long. 14°38′ province of Catania). In addition 192 samples of 30 Sicilian Storage Centres (Elevator) collected in the 2007 harvest season, were used to validate the system. Thirty durum wheat cultivars (Italian National Trials) were visually evaluated, by four different inspectors (Rossella, Rosaria, Peppe and Marisol), according to ICC method 129 (1980). The evaluation was repeated three times over a period of three successive weeks on the same samples. In addition to the ICC considered categories (vitreous and non-vitreous), piebald (starchy kernels having a starchiness ranging between 10 and 80%) and shrunken (stunted kernels) versus normal (well shaped), categories were also taken into account. The category shrunken/normal was visually inspected only by Rossella for two locations.

For the 30 durum wheat cultivars, six sub-samples for each cultivar of about 100 grains, two images for each sub-sample (approximately 36,000 grains) were used to realize the Training set. The Test set was constituted by the 192 samples collected in 30 different Storage Centres in Sicily (approximately 20,000 grains).

The cultivars showed high degree of variation for all kernel categories (Table 1), as highlighted by the standard deviation; that is, one of several indices of variability to characterize the dispersion among the measures in a given population.

2.2. Instrumentation

Zeiss KS-400 V3.0 (Carl Zeiss Vision GmbH, Hallbergmoos, Germany, 2001) image analysis software was used. This software can be customized, by users to develop specific applications by editing appropriate image analysis algorithms in "Macros", able to automate the analysis.