



Classification of maize kernels using NIR hyperspectral imaging



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ABSTRACT

NIR hyperspectral imaging was evaluated to classify maize kernels of three hardness categories: hard, medium and soft. Two approaches, pixel-wise and object-wise, were investigated to group kernels according to hardness. The pixel-wise classification assigned a class to every pixel from individual kernels and did not give acceptable results because of high misclassification. However by using a predefined threshold and classifying entire kernels based on the number of correctly predicted pixels, improved results were achieved (sensitivity and specificity of 0.75 and 0.97). Object-wise classification was performed using two methods for feature extraction – score histograms and mean spectra. The model based on score histograms performed better for hard kernel classification (sensitivity and specificity of 0.93 and 0.97), while that of mean spectra gave better results for medium kernels (sensitivity and specificity of 0.95 and 0.93). Both feature extraction methods can be recommended for classification of maize kernels on production scale.

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1. Introduction

Maize hardness is a trait influenced by cultivar and environment, both contributing through effects on protein or starch (Fox & Manley, 2009). Maize protein plays a strong role in influencing the mechanical strength of endosperm, dependent presumably on its ability to pack between the starch granules, and to adhere to the granule surfaces (Fox & Manley, 2009). Unlike wheat, maize is comprised of both glassy (hard) endosperm and floury (soft) endosperm, and the ratio of these determines its hardness (Watson, 1987). Hard kernels consist predominantly of glassy endosperm while those comprised of a higher ratio of floury endosperm are soft. Kernels of medium hardness have approximately equal proportions of each endosperm type. The glassy endosperm is tightly compacted with few or no air spaces. The starch granules are held together by the protein matrix and protein bodies are found on the starch granules (Hoseney, 1994; Lee, Bean, Alavi, Herrman, & Waniska, 2006). The floury endosperm, on the other hand, comprises spherical starch granules covered with a protein matrix without zein (maize storage protein) bodies.

Kernel hardness is an important characteristic that influences the processing and end-use quality of maize (*Zea Mays* L.) products, and is of great importance to producers, processors and workers in the grain trade (Blandino et al., 2010; Pomeranz, Martin, Traylor, &

Lai, 1984; Watson, 1987). Hardness is a significant factor concerning losses during dry-milling (Tran, deMan, & Rasper, 1981), where softer kernels yield less quantities of large grits than harder kernels. On the other hand, extremely hard kernels require more energy input and are more prone to stress cracks and breakage. The dry-milling industry demands/would prefer kernels that fall in-between these extremes i.e. kernels that are hard enough for increased grit yield, yet soft enough to resist breakage.

Measuring and determining maize hardness has been the subject of research for many years with numerous methods tested and proposed, as reviewed by Fox and Manley (2009). A large proportion of these methods are destructive, time-consuming and labour intensive. Blandino et al. (2010) compared a number of laboratory tests to predict dry-milling performance and concluded that, among the hardness tests, the ratio of coarse-to-fine material was the best descriptor of milling ability, followed by the floating test. They also indicated that hectolitre mass (HLM) was a very good indicator of maize hardness and should be considered first. A few researchers have attempted to predict maize hardness by studying its pasting properties. Almeida-Domínguez, Suhendro, and Rooney (1997) reported that the Rapid Visco Analyser (RVA) profiles were highly correlated to maize hardness as determined by the floating test, density and the tangential abrasive dehulling device (TADD). They suggested that RVA has the potential to screen among groups of hard and soft maize. In a similar study, Guelpa et al. (2015) showed that RVA profiles can be used to determine maize hardness. The authors combined conventional hardness

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testing methods, such as HLM, hundred kernel mass (HKM), particle size index (PSI) and percentage chop with RVA curves using multivariate data analysis. Although these methods are promising and could replace conventional hardness techniques, they still involve destruction of the sample, are time consuming and require sample preparation.

A number of researchers recognized the potential of NIR spectroscopy and applied it to study maize kernel hardness and related properties. [Pomeranz et al. \(1984\)](#) used reflectance measurements at 1680 nm as an estimate of hardness. They found that it correlated well with primary hardness methods, such as density and average particle size (APS), and concluded that the three methods were equally sensitive. In another study, [Siska and Hurburgh \(1995\)](#) correlated near infrared transmission (NIT) spectra and maize density measurements with an R^2 of 0.76 and a standard error of prediction (SEP) of 0.0164 g/cm³. This was regarded as a crucial finding because maize density is indicative of product yield in dry-milling.

The ultimate goal of measuring maize hardness is to determine end-use quality and to estimate dry-milling yield. In a study by [Wehling, Jackson, and Hamaker \(1996\)](#) dry-milling quality was predicted by NIR spectroscopy. Dry-milling quality was first evaluated using TADD and a short-flow laboratory milling procedure first reported by [Kirleis and Stroshine \(1990\)](#). This procedure enabled the calculation of an index, the milling evaluation factor (MEF), reflecting the grit and total endosperm yield. These were then used to develop calibration models relating TADD index and

MEF to NIR measurements. It was concluded that dry-milling could be predicted with a reliability suitable for rough screening.

The benefits of using NIR/NIT spectroscopy for whole maize kernel characterisation are numerous and continues to be researched and implemented commercially. Although high in spectral resolution, traditional NIR is limited in the spatial dimension, offering no information regarding the location of the constituent or contaminant investigated. Measurements are made across a small area on the sample and averaged. In contrast, NIR hyperspectral imaging is a technique capable of incorporating localisation, thus measuring entire samples, rapidly and accurately ([Boldrini, Kessler, Rebner, & Kessler, 2012](#); [Geladi, Burger, & Lestander, 2004](#); [Gowen, O'Donnell, Cullen, Downey, & Frias, 2007](#)).

Primarily developed for remote sensing ([Goetz, Vane, Solomon, & Rock, 1985](#)), NIR hyperspectral imaging is now an established analytical laboratory technique for non-destructive analysis of biological material ([Manley, 2014](#)). The benefit of this technique, specifically to cereal science, is that it allows for single kernel characterisation ([Fox & Manley, 2014](#)). This is particularly useful when samples are limited, such as in breeding programmes. By doing this, plant breeders can identify appropriate material rapidly and non-destructively, with which to continue propagating for specific traits i.e. high protein content. This has been demonstrated by [Delwiche \(1998\)](#) using NIR spectroscopy. In addition, [Fox and Manley \(2014\)](#) reported on the importance of single kernel analyses using conventional and NIR hyperspectral imaging methods. Maize hardness has been investigated using NIR hyperspectral

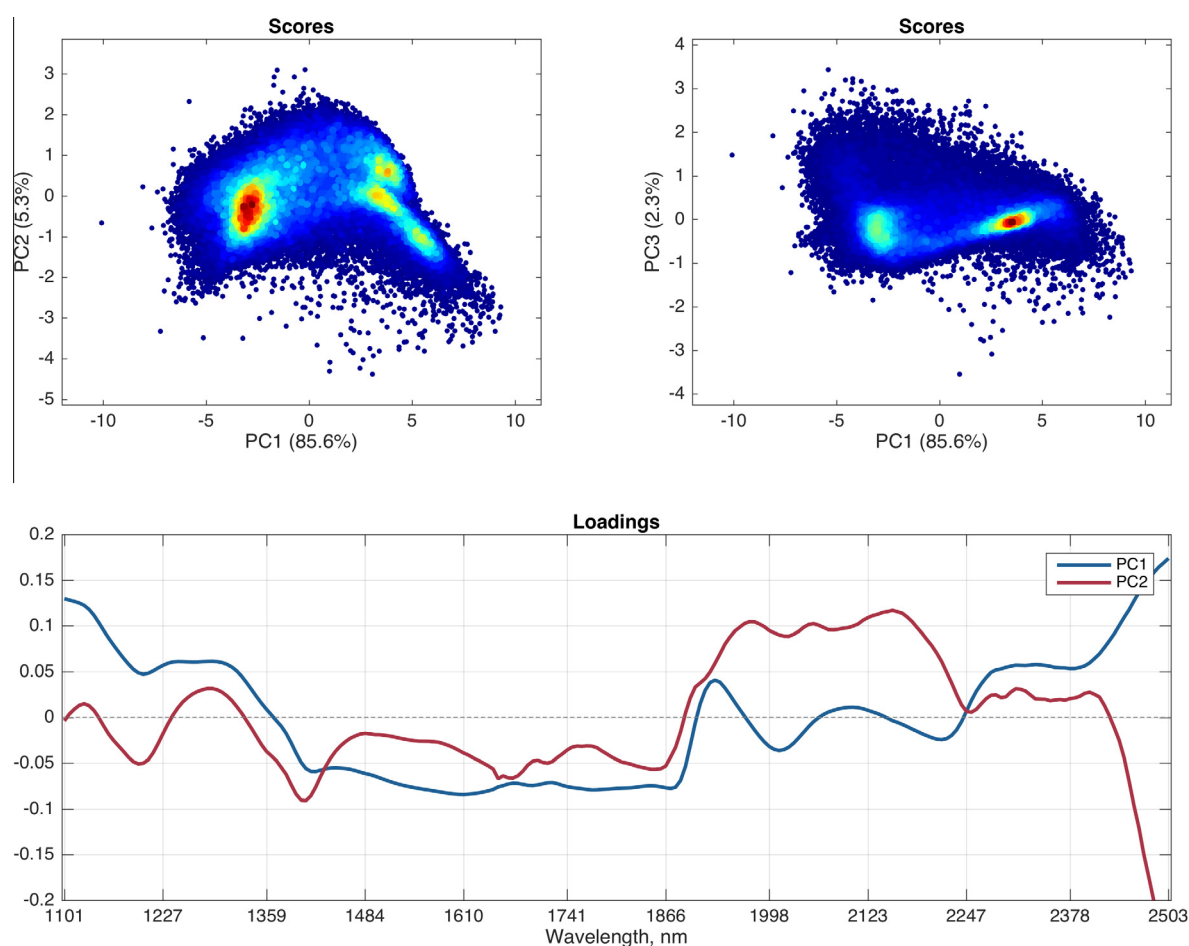


Fig. 1. Score density plots (top) and loading plot (bottom) for the SNV corrected PCA model.

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