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A MACHINE VISION SYSTEM TO DETECT HARD VITREOUS KERNELS IN DURUM WHEAT

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Abstract

*The percentage of hard vitreous kernels (HVK) in a sample is internationally recognized specification determining the value of durum wheat (*Triticum durum*). Amber durum wheat is milled to make semolina, the main ingredient of pasta. The higher the percentage of HVK in a sample, the higher the milling yield of semolina. HVK is related to protein content that affects the cooking quality of pasta. Thus, measuring the amount of HVK in a sample is an important part of the inspection and grading process. The current method of visual inspection to determine HVK is subjective and tedious. A machine vision system was developed to determine percentage of HVK in a sample using a flatbed scanner. Bayesian classifier classified durum wheat kernels into 3 classes namely vitreous, starchy and piebald with accuracy approaching 86% on a test set (91% on the training set). Classification based on levels of piebald (low, medium and high piebald) was up to 80%. The effect of bleaching on the HVK classification was investigated.*

Introduction

Hard vitreous kernel (HVK) content is an internationally accepted grading factor in durum wheat that is associated with kernel hardness, milling properties, and cooking quality. Vitreousness is the natural translucent coloring that gives the wheat kernels a hard, glossy appearance, and is usually related to protein content. Wheat lots with a high HVK percentage show the best milling performance in terms of semolina yield. According to guidelines set by the Canadian Grain Commission (CGC), HVK content is an important measurement in determining the grade classifications for durum wheat. However, measuring the HVK content of a durum sample involves a manual visual separation that is subjective and tedious which leads to bottlenecks at high throughput grain elevators when the primary grade determinant is HVK. As a result, the development of a rapid, objective and consistent procedure for HVK determination as part of grading is a high priority of the CGC.

Wang et al. (2002) used near infrared spectroscopy (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 grain NIRS classified obviously vitreous and non-vitreous durum wheat kernels in perfect agreement with grain inspectors. However, the accuracy of classification dropped to only 75% when more difficult-to-classify kernels were present. Dexter et al. (1988) found that the hardness range for commercially grown Canadian western amber durum (CWAD) lots of variable HVK was too narrow to allow meaningful segregation by NIRS particle size index.

The single-kernel characterization system (SKCS), which determines wheat moisture content, kernel weight, kernel diameter and hardness on individual kernels, was developed in the United States to aid in classifying hard and soft common wheat (Martin et al. 1993). The extreme hardness of durum wheat compared to most common wheat classes makes SKCS potentially useful for determining adulteration of durum wheat by common wheat (Williams 2000), and for determining HVK in durum wheat (Sissons et al. 2000). Calibration equations have been developed with the SKCS to predict common wheat milling yield (Satumbaga et al. 1995). 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. Recent work in our laboratory (Symons et al. 2003) using individual rail car shipments of CWAD indicates that SKCS hardness index is of limited value in predicting HVK. There is a wide hardness range within rail carlots of comparable HVK, and there is overlap of hardness index values between samples differing widely in HVK. Fully starchy kernels are significantly softer than vitreous durum wheat kernels, but partially vitreous (piebald) kernels, which are considered non-vitreous, are almost as hard as fully vitreous kernels (Dexter et al. 1989). Piebald kernels commonly make up a large proportion of non-vitreous kernels, explaining why NIRS particle size index was unable to predict CWAD HVK or semolina milling yield (Dexter et al 1988).

Image analysis, or machine vision, has promise as a rapid aid to wheat grading and classification. Image analysis classifies kernels on the basis of size, shape, colour and texture. Sapirstein and Kohler (1995 and 1999) concluded that the ability of machine vision to detect differences in kernel features among grades of Canadian wheat demonstrated potential to objectively classify wheat according to grade. Machine vision has enormous potential for assessing wheat physical condition related to the estimation of HVK (Sapirstein and Bushuk 1989; Shatadal et al. 1998; Symons et al. 2003) – an application of particular interest to durum wheat millers. The methods are based on the relative translucency of vitreous and non-vitreous durum wheat kernels. The procedure of Symons et al. (2003) classifies individual kernels according to degree of vitreousness, which allows a percentage HVK to be computed. Results on bulked carlot samples and export cargoes agree reasonably well with Canadian Grain Commission visual HVK values, particularly when visual HVK values exceed 70%. In a recent study, Xie et al. (2004) were able to detect HVK in amber durum with high degree of accuracy (~93%) by using reflectance and transmittance images. Relatively lower accuracy was acchieved for bleached (87%), cracked (85%) and mottled (71%) kernels.

The aim of this study was to develop a low cost, quick and reliable image analysis based classification system to determine the percentage of HVK in durum wheat from a small sample. To accomplish this, the potential of a scanner-based imaging method to predict durum wheat HVK was assessed. Specific objectives were to develop classifiers to

a) Classify durum wheat kernels into vitreous, starchy and piebald classes,

b) Sub-classify piebald kernels into low, medium and high piebald levels, and

c) Detect bleached kernels in a sample.

Materials and Methods

Cargo and railcar samples of CWAD were received from the CGC Industry Services centers at Vancouver and Thunder Bay. Individual kernels were carefully segregated into various classes by CGC inspectors as vitreous, starchy, weathered or bleached, and piebald. Piebald kernels were further classified based on the size of the starch spot in proportion to the kernel area as low piebald (<10%), medium piebald (10-75%) and high piebald (>75%). Kernel classifications were verified on the light table.

Images of non-touching seeds were gathered using a scanner (ScanMaker 9800XL, MikroTek, USA) both in reflected and transmitted modes at a resolution setting of 300 pixels per inch (ppi). Kernels were hand placed on the scanner glass for imaging. From these images, the colour and density histograms as well as density moment and textural features were measured with KS400 image analysis software (Carl Zeiss, Germany). Salient features were ranked and selected using stepwise discriminant analysis (SAS Institute Inc., Cary, USA) based on their significance.

Three Bayesian classifiers were developed and tested to achieve 3 levels of classification of durum kernels using respective selected features: Vitreous-starchy-piebald classifier; Piebald level classifier; Bleached-non-bleached classifier. For the vitreous-starchy-piebald classification, 3997 kernels were used to develop and test a Bayesian classifier. Data from 3015 kernels (888 vitreous, 1107 starchy and 1020 piebald) was used to develop the model and data from 982 kernels (396 vitreous, 262 starchy and 324 piebald), not used in model development, was used to test the model. For the piebald-level classification, 1727 kernels were used to develop and test a Bayesian classifier. 1333 kernels (204 low, 602 medium and 527 high piebald) were used to develop the model and 394 kernels (42 low, 154 medium and 198 high piebald), not used in model development, were used to test the model. For the bleached-non-bleached classification, 1512 kernels (756 bleached and 756 non-bleached) were used to develop and test the classifier. Data from 1138 kernels in the training set (569 bleached and 569 non-bleached) were used to develop the model and 374 kernels (187 bleached and 187 non-bleached), not used in model development, were used to test the model.

Results and Discussion

The vitreous-starchy-piebald classifier achieved an overall accuracy of 85.6% on an independent test set (91% cross-validation on the training set). Class-wise classification results are shown in Table 1. Classification of starchy (non-vitreous) kernels was highly accurate (~96) on both training and testing sets followed by the piebald kernels (86-88%). Classification of vitreous kernels on the test set was lower (76%) than on the training set (90%). None of the vitreous kernels were misclassified as starchy and vice versa. Most of the vitreous kernels that were misclassified as piebald were bleached or weather-damaged highlighting the need for identifying bleached kernels prior to vitreous-starchy-piebald classification.

The piebald level classifier achieved an overall accuracy of approximately 80% on the test set and 81% on the training set (Table 2). Reasonably accurate classifications were achieved the medium (80%) and high piebald levels (84%). Accuracy for the low piebald level was low (77%) on the training set, which further dropped to 55% on the test set. Errors in the visual assessment of piebald levels could be one of the reasons behind misclassification of low piebald kernels. However, this clearly indicates the need for a larger image set to model piebald level variations more effectively.

Classification results based on bleaching of kernels are shown in Table 3. Overall 80% accuracy was achieved on the training set while accuracy on the test set was 72%. Obviously, more work needs to be done in order to improve the performance of this classifier. Larger image set may improve the model, however, more image features to effectively capture sample variations need to be explored.

Conclusions

a) Scanner-based imaging system can effectively classify durum wheat kernels into vitreous, starchy and piebald classes,

b) Sub-classification of piebald kernels into low, medium and high piebald levels can be done reasonably accurately, and

c) Detection of bleached kernels in a sample needs improvements.

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Table 1: Vitreous-starchy-piebald classification results for training and testing data sets.

HVK Class	Training set			Testing set		
	Vitreous	Starchy	Piebald	Vitreous	Starchy	Piebald
Vitreous	90.5	0.0	9.5	76.0	0.0	24.0
Starchy	0.0	95.8	4.2	0.0	96.9	3.1
Piebald	4.3	3.8	85.7	4.3	7.4	88.3

Table 2: Piebald level classification results for training and testing data sets.

Piebald Level	Training set			Testing set		
	Low	Medium	High	Low	Medium	High
Low	77.0	22.0	1.0	54.8	45.2	0.0
Medium	8.8	80.6	10.6	4.6	80.5	14.9
High	0.0	16.5	83.5	0.0	15.7	84.3

Table 2: Bleached-non-bleached classification results for training and testing data sets.

Bleaching	Training set		Testing set	
	Bleached	Non-Bleached	Bleached	Non-Bleached
Bleached	80.1	19.9	67.4	32.6
Non-Bleached	20.2	79.8	24.9	76.1