
Classification of bulk cereals using visible and NIR reflectance characteristics

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¹Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba R3T 5V6, Canada; and ²Agriculture and Agri-Food Canada, Cereal Research Centre, Winnipeg, Manitoba R3T 2M9, Canada. *Email: Digvir_Jayas@Umanitoba.ca

Mohan, L.A., Karunakaran, C., Jayas, D.S. and White, N.D.G. 2005. **Classification of bulk cereals using visible and NIR reflectance characteristics.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 47: 7.7-7.14. Image analysis in common machine vision systems could be greatly improved by using special filters to enhance specific features. In this study, diffuse reflectance characteristics of cereal grains were determined and specific wavelength bands were identified. Bulk samples of seven cereal grains were tested for their reflectance characteristics using spectral wavelengths in the visible and the near-infrared (NIR) spectrum. The effect of moisture content, foreign material content, and growing regions on the reflectance characteristics of Canada Western Red Spring wheat was determined. Features such as ratio and slope were derived from percent reflectance of samples. Linear parametric classifier and back propagation neural network (BPNN) were used for identification and classification of the grains. A comparative study on visible and NIR reflectance regions indicated that better classification accuracy was achieved using reflectance in the NIR region. In the NIR spectrum, classifications obtained using the slope features were better than the direct reflectance and ratio features. A classification accuracy of 99.5% was achieved by the linear parametric and BPNN classifiers using the top five slope features selected by STEPDISC and BPNN in the NIR spectrum. The effects of moisture content, foreign material content, and growing locations were not significant in affecting the reflectance characteristics of cereal grains when treated as individual classes as against pooling each variable as a single class. **Keywords:** spectroscopy, visible, near-infrared, diffuse reflectance, cereal grains, moisture content, foreign materials, growing regions, linear parametric classifier, back propagation neural network.

L'analyse d'image dans les systèmes conventionnels de vision artificielle pourrait être grandement améliorée par l'utilisation de filtres spéciaux permettant d'amplifier certaines caractéristiques. Dans cette étude, les caractéristiques de réflectivité diffuse de grains de céréales ont été déterminées et des spectres de longueur d'ondes spécifique ont été identifiés. Des échantillons en vrac de grains de sept céréales ont été testés pour leur caractéristiques de réflectivité en utilisant des spectres de longueurs d'ondes dans le visible et l'infrarouge rapproché (IRR). Les effets de la teneur en eau, du taux d'impuretés et de la provenance des échantillons sur les caractéristiques de réflectivité du blé Canada Western Red Spring ont été déterminés. Des caractéristiques spécifiques comme le ratio et la pente ont été dérivées des pourcentages de réflectivité des échantillons. Un classificateur paramétrique linéaire et un réseau neuronal à propagation arrière (RNPA) ont été utilisés pour l'identification et la classification des grains. Une étude comparative sur les bandes de réflectivité dans le visible et le IRR a indiqué qu'une classification plus précise pouvait être obtenue en utilisant la réflectivité dans la région du IRR. Dans le spectre du IRR, les classifications obtenues en utilisant les caractéristiques de la pente étaient meilleures que celles provenant des caractéristiques de réflectivité directe et de ratio. Une précision de classification de 99,5% a été obtenue avec les

classificateurs paramétrique et RNPA utilisant les caractéristiques des cinq premières pentes sélectionnées par STEPDISC et RNPA dans le spectre IRR. Les effets de la teneur en eau, du taux d'impuretés et de la provenance des échantillons de grains n'ont pas affecté significativement les caractéristiques de réflectivité des grains de céréales lorsque traités comme classes individuelles comparativement à la situation consistant à considérer chaque variable comme une classe individuelle. **Mots clés:** spectroscopie, visible, infra-rouge rapproché, réflectivité diffuse, grains de céréales, teneur en eau, impuretés, régions de production, classificateur paramétrique linéaire, réseau neuronal à propagation arrière.

INTRODUCTION

Canada is among the top exporters of grain in an increasingly sophisticated and competitive international market. On average, Canada produces about 59 Mt (million tonnes) of grains and oilseeds annually (Canada Grains Council 2002). About 60 – 70% of the produced crop is exported (CIGI 1993). Canada has a stringent grain inspection and grading process and hence is known for its superior quality grain in the global market. At present, grain inspection and grading are carried out manually, which is laborious and time consuming. Human involvement induces problems like inconsistency, high labor cost, and fatigue. This can lead to economic losses due to poor grade determinations (Bevilacqua 1987). As a result of the increased number of cultivars and amount of grain handled in recent times, it makes it difficult to train grain inspectors every year to grade all incoming grain objectively (Delwiche and Norris 1993). These problems can be eliminated by the use of an automated system based on the principles of machine vision.

Machine vision systems (MVS) and pattern recognition are used to determine external features and internal characteristics of products giving objective results rapidly. The feasibility of using MVS for identification and classification of seeds has been reported widely. Machine vision systems use optical properties such as reflectance to determine color, shape, size, and textural features of seeds (Barker et al. 1992; Majumdar et al. 2000a, 2000b, 2000c, 2000d; Sapirstein and Bushuk 1989; Symons and Fulcher 1988; Zayas et al. 1986). A common MVS consists of a camera and a computer to acquire, record, and analyze images. Most studies using MVS have been carried out using manually singulated grain kernels of clean samples and very little work has been done on bulk images. But real time applications requiring rapid classification, as in the case of making a decision in unloading a railcar based on the contents, requires bulk image analysis. All cereal grains have been correctly identified using color features extracted from bulk

samples of clean grain (Visen et al. 2004; Majumdar and Jayas 1999). Both the studies have used the entire visible spectrum to capture images. However, there is a possibility that a single or a few wavelengths in and beyond the visible spectrum could play a predominant role in identifying grain types. Different types of filters that attenuate a particular range of wavelengths can be used for better performance in identification and would substantially improve the classification process. The reflectance properties of vegetables and fruits have been studied using spectrophotometers and the relevant spectral bands chosen were isolated using filters in image acquiring devices to improve the efficiency of classification by narrowing the wavelength range (Howarth et al. 1990; Howarth and Searcy 1989; Upchurch et al. 1990; Delwiche et al. 1990; Casady et al. 1993).

A spectrophotometer uses wavelengths from the infrared (IR), near-infrared (NIR), visible, and ultraviolet (UV) spectrum to measure the reflectance, absorption, and transmission characteristics of objects. These spectral properties have been used to identify grains and oilseeds. They have also been used to determine protein and moisture contents, identify damage by molds and pathogens, and detect insect infestations in seeds (Dowell 1992; Casady et al. 1993; Delwiche 2003; Stermer et al. 1977; Massie and Norris 1965; Delwiche and Norris 1993; Williams 1975). The visible spectrum with wavelengths ranging from 400 – 750 nm was used to classify cereal grains, oilseeds, and specialty crops and identify damaged soybean and peanuts (Hawk et al. 1970; Casady et al. 1993; Majumdar et al. 1996). Quality, ripeness, and bruise detection in fruits and vegetables, adulteration in food products, and soil moisture estimation are made possible by using spectral reflectance (Bittner and Norris 1968; Bilanski et al. 1984; Upchurch et al. 1990; Park et al. 2002; Lu and Ariana 2002; Scanlon et al. 1999; Ventura et al. 1998; Slaughter et al. 2001; Irudayaraj and Sivakesava 2001).

In this study, it was hypothesized that the reflectance characteristics of bulk seeds could be used for rapid nondestructive identification. This, as a feature, could then be used for automation in railcar unloading and binning of seeds in grain-handling facilities.

Grain arriving at primary elevators comes from different growing regions and hence grain will have different moisture and foreign material contents. Moisture content is one of the key parameters determining grain quality. At present, moisture meters are used at elevators to determine moisture contents of incoming grain. Studies have been conducted to classify cereal grains based on their moisture contents using ground samples (Law 1977). Due to differences in climatic conditions and soil composition, grains from different growing regions may have variations in color, morphology, and chemical characteristics. Specific characteristics of these factors could influence the quality leading to a value added crop from that growing region. To determine the amount of foreign material present in a representative sample, incoming grain at elevators is inspected manually and sieved. This information is then used for optimal selection of sieves to adjust the cleaning machines and to increase the recovery of salvageable grains. Over-cleaning or under-cleaning benefits either the buyer or the seller, respectively. Manual sieving involves sifting followed by weighing of foreign material in grain and hence is a laborious and time consuming task. For an automated railcar unloading, the influence of the above mentioned characteristics and their interference on the identification of the grain types has to be tested.

Hence, the objectives of this study were to determine: (i) the reflectance characteristics of various bulk seed samples in the visible and near-infrared spectrum using a spectrophotometer; (ii) the potential of using reflectance data to classify various bulk samples; (iii) the effects of growing regions, moisture content, and foreign material content on the reflectance characteristics of Canadian Western Red Spring (CWRS) wheat; and (iv) one or more wavelengths that contribute significantly to the identification of grain samples.

MATERIALS and METHODS

Spectrophotometer

The spectrophotometer (Model: Cary 5, Varian Canada Inc., Mississauga, ON) was equipped with a diffuse reflectance accessory consisting of an integrating sphere with five ports and coated with polytetrafluoroethylene. The sphere had two detectors, a photomultiplier tube that collected signals in visible and UV regions and a lead-sulphide detector to collect signals in NIR regions of the spectrum. A personal computer loaded with Varian, a Windows-based software acted as an interface with the spectrophotometer. The machine was calibrated using a disc coated with polytetrafluoroethylene and the base and zero reflectance lines were recorded (Labsphere, North Sutton, NH). Diffuse reflectance of samples with respect to the base and zero reflectance line were recorded as percent reflectance (herein after reflectance refers to percent reflectance values, R'). Tkachuk (1987) defines the relationship between reflectance and apparent absorbance, A' as: $R' = R_{\text{sample}}/R_{\text{standard}}$ and $A' = \log(1/R')$. Machine and random noise was filtered using a built-in Savitzky-Golay smoothing algorithm with a set wavelength (10 nm) interval for the entire spectrum. Savitzky-Golay filters random noise effectively and preserves essential features of the data like peak heights in the spectrum.

A scan usually propagates from the higher to the lower wavelengths. During scanning, if the wavelength range encompasses the 800 nm wavelength, the machine introduces a shift in the reflectance recordings at 800 nm. This was due to the change of the detectors and face change of the grating mirror during the scanning as a result of the change in the spectrum. The shift in the reflectance recording was nullified by changing the detectors at 870 nm instead of 800 nm. The 870 nm wavelength was found during preliminary testing.

Grain samples

Bulk grain samples of seven cereals namely, Canada Western Red Spring (CWRS) wheat, Canada Western Amber Durum (CWAD) wheat, Canada Western Soft White Spring (CWSWS) wheat, 2-row barley, 6-row barley, oats, and rye were procured with the assistance from Industry Services Division of the Canadian Grain Commission. The samples were stored at -18°C in a freezer and were equilibrated to room temperature before use.

To test the effect of the different growing environments on reflectance characteristics of wheat, CWRS wheat was collected from 15 different geographical regions in western Canada. The CWRS wheat samples were collected from three boreal, three sub-boreal regions, six sub-humid-prairie, and three semi arid regions based on the climatic subdivisions of the Canadian prairies (Putnam and Putnam 1970).

To test the effect of moisture content (m.c.) on reflectance characteristics, wheat samples from one of the regions, namely North Battleford, Saskatchewan was conditioned to 10, 12, 14, 16, and 18% m.c. For rapid determination of moisture content that is independent of particle size, this study was carried out using whole grain samples. The samples were conditioned to the required moisture content by adding the appropriate amount of water, mixing it thoroughly, and leaving the sample airtight for a period of at least 12 h for the moisture to penetrate uniformly through the grain sample. Moisture contents of the wheat samples were determined by drying triplicate samples of 10 g each at 130°C for 19 h in a convection oven (ASAE 2001). The final moisture contents of the prepared samples were 9.8, 11.8, 14.1, 15.9, and 17.7%.

The wheat sample from Estevan, Saskatchewan was conditioned to have 3, 6, 9, 12, and 15% foreign material (collected by screening uncleaned wheat), to determine whether foreign material content influences reflectance characteristics. The initial samples were hand cleaned and were considered clean. The samples were prepared on a mass basis, i.e. adding 3 g of foreign material to 97 g of the pure sample to give a sample containing 3% foreign material.

Data collection and analysis

Cereal grains weighing about 500 g were obtained for testing. Samples weighing 3-5 g were randomly selected and packed tightly into the powder cell. Variation in the sample size was due to the varying sizes and shapes of different seeds. Particle size of ground samples markedly influence reflectance characteristics of cereal grains and oilseeds (Williams 1975). The particle size is dependant on the machine used to grind the samples thereby limiting real time application in the grain industry. Hence, in this study whole grain kernels were used. Variations in packing of samples into the cells is a major factor affecting reflectance, which can be controlled by over filling the cell and striking the surface before capping it, resulting in compaction (Williams and Norris 1987). The powder cell was fixed to the sample port of the integrating sphere. The spectrophotometer collected the reflectance data at a preset interval of 0.33 nm over a range of 400 to 1850 nm.

The machine scanned each sample three times and the average value was recorded. The raw data were then filtered and interpolated to obtain percent reflectance at intervals of 10 nm. The variation in reflectance for an undisturbed sample scanned consecutively for 30 times was found to be within ± 0.3 percentage points. Personal bias resulting from the same person setting the sample in the port during the experiment was evaluated. Two volunteers were instructed to position the sample holder and the recorded reflectance was compared. There was no appreciable difference when three different people were allowed to collect the data. Thirty samples were drawn from the 500 g bulk grain randomly and reflectance was recorded.

Reflectance data, two-wavelength ratios, and two-wavelength slopes were extracted and used as features for the classification of cereal grains. Majumdar et al. (1996) suggest the use of reflectance data is not a good practice to be used in real-time industrial applications because reflectance is affected by light intensity, dust, and aging of the light source. These factors affecting the reflectance can be reduced by using ratio and slope features. These features have been used in different

studies for quality evaluation of fruits and vegetables (Delwiche 2003; Upchurch et al. 1990; Hehn et al. 1991; Beckmann and Bulley 1980).

For data analysis, the direct reflectance, the two-wavelength ratios, and two-wavelength slopes were defined as:

Direct reflectance i = Reflectance at wavelength n

Ratio i = Reflectance at wavelength n / Reflectance at wavelength $(n + 10)$

Slope i = (Reflectance at wavelength n - Reflectance at wavelength $(n + 10)$) / 10

where i represents the feature numbers (1, 2, ...) and n represents the wavelengths (400, 410, ... 1840).

To determine the effects of the visible and NIR wavelengths in identifying seeds, the reflectance, ratios, and slope features were segregated in the different spectrum regions. Thirty-six reflectance, 35 ratio and slope features from the visible and 110 reflectance, and 109 ratio and slope features from the NIR spectrum were derived. Procedure STEPDISC (SAS 2002) was used to rank the features contributing significantly to the identification process. The best two, five, and ten features were selected and used in assessing the classification accuracies. During preliminary analysis, classification accuracies of more than 90% were achieved using two and five features. Hence classification results obtained using 10 features were not included in this manuscript. Procedure DISCRIM using linear parametric classifier and 4-layer back propagation neural network (BPNN) were used to determine the classification percentages (SAS 2002; Neuroshell 2, Ward Systems Group, Frederick, MD). Linear parametric classifier and BPNN are commonly used in quality inspection and classification of agricultural products (Jayas et al. 2000; Paliwal et al. 2001; Zayas and Flinn 1998). Two-thirds of the data set selected randomly was used as a training set and the remaining one-third was used as the independent test set. This process was repeated three times and the classification percentage was recorded as the average of the three trials.

RESULTS and DISCUSSION

Reflectance characteristics in the visible spectrum

Figure 1 shows the mean reflectance of all 30 samples of cereal grains in the visible spectrum. Rye had the lowest reflectance and 6-row barley had the highest reflectance along the wavelength range among all cereals. The CWSWS wheat had a higher reflectance than CWAD and CWRS wheat. Majumdar et al. (1996) determined CWRS and CWAD wheat had overlapping characteristics. It was observed that the greatest differences in reflectance values occurred beyond 450 nm for all cereals and agreed with the observations by Hawk et al. (1970). They determined the greatest difference in reflectance of cereal grains occurred between 450 and 700 nm. Reflectance characteristics determined in this study were similar to the reflectance measured using a spectroradiometer by Majumdar et al. (1996). As the wavelength increased, the differences in reflectance among the cereals increased. This is due to the change in the spectrum from violet to red regions in the visible spectrum. Red was determined to be the predominant color in identifying cereal grains using visible images from bulk grain samples (Visen 2002; Majumdar and Jayas 1999). More than

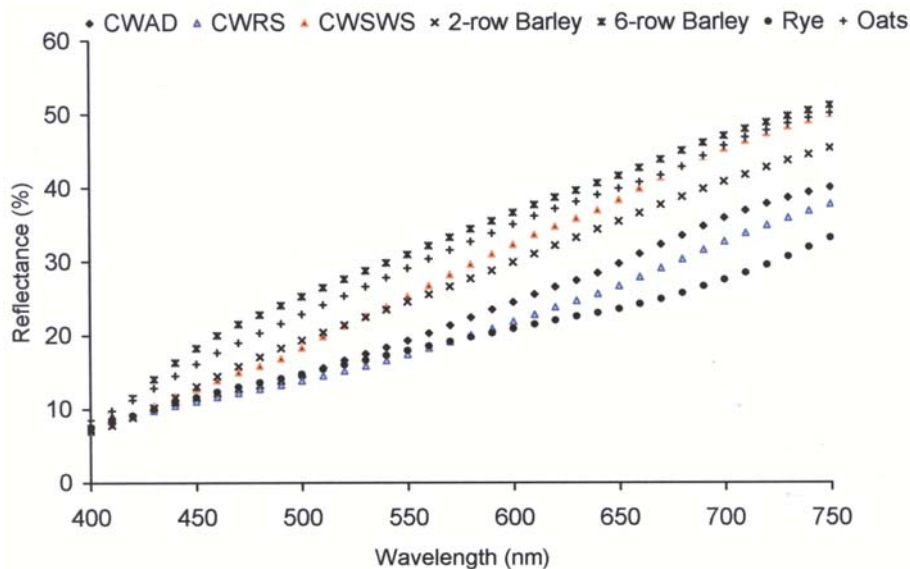


Fig. 1. Diffuse reflectance properties of cereal grains in the visible spectrum.

97% of cereal grains tested by them were correctly identified using color information.

When reflectance data were used as features for identification, the STEPDISC procedure selected 720, 500, 480, 580, and 400 nm as the top five significant features. Using the top five features, all cereal grains were correctly identified by the linear parametric classifier. When the top two wavelengths were used, 92.4% of all cereals were correctly identified. The misclassification occurred with the 2-row and 6-row barley classified as oats, CWRS wheat identified as CWAD wheat and 2-row barley, and oats identified as 2-row and 6-row barley. Similar misclassifications were reported by Hawk et al. (1970) on misidentification between barley and oats. The canonical correlation also showed the grouping of 2-row barley and oats

groups close to each other. This misclassification could be attributed to 6-row barley and oats having similar reflectance around the selected wavelengths. When BPNN was used, wavelengths 500, 410, 490, 510 and 480 nm were selected as the top five significant features contributing to the classification. Using the top five features, cereal grains were identified with a mean accuracy of 78.6%. The main misclassifications were due to 6% of CWSWS wheat identified as 2-row barley and oats, 5.7% of CWAD identified as rye, and 3.8% of oats classified as 2-row barley. When the features were reduced to the top two wavelengths, as expected the mean classification accuracy dropped drastically to 55.7%.

The STEPDISC procedure selected features 2, 11, 9, 35, and 24 as the top five features contributing significantly for classification. The wavelengths corresponding with the selected ratio features had similarities with the wavelengths selected for direct reflectance. For example, feature 2 has 410 and 420 nm, and 400 nm was selected as one of the features when direct reflectance values were used by the linear parametric classifier. The mean classification accuracies of 88.6 and 98.6% were obtained when the top two and five features, respectively, were used. Misclassification of 2-row, 6-row barley, oats, and CWRS wheat were similar to misclassifications when direct reflectance was used with the top two features. When five features were used, 6.6% of CWAD was misclassified as CWRS wheat. The BPNN classifier using the top two and five features gave mean classification accuracies of 81.4 and 97.1%, respectively.

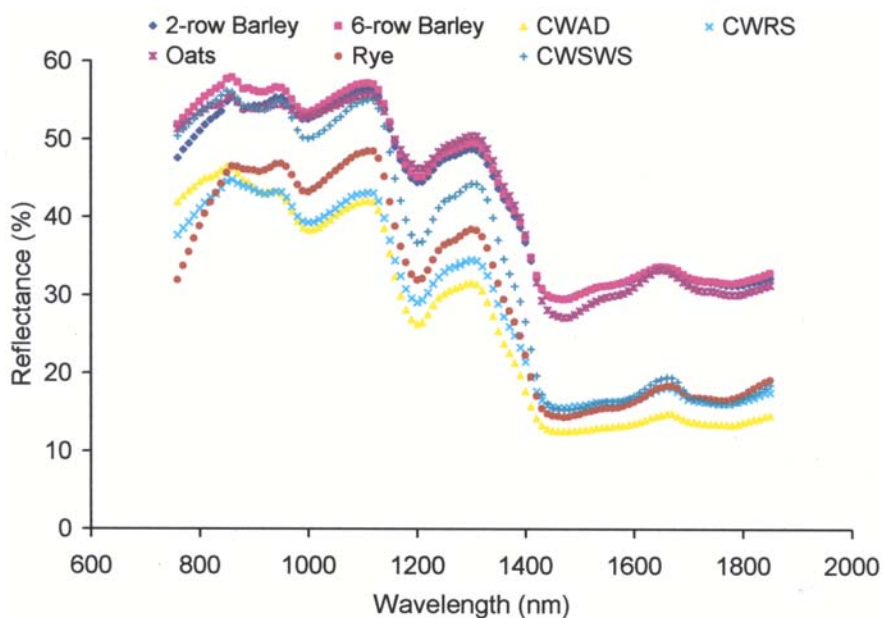


Fig. 2. Diffuse reflectance properties of cereal grains in the NIR spectrum.

The 35 slope features extracted from the reflectance of all cereals revealed the distinct differences among various cereals. Features 5, 17, 8, 35, and 15 were selected as the top five features and the wavelengths selected were considerably different from that of the wavelengths selected using ratio and direct reflectance values. Mean classification percentages of 89.1 and 99.1% were obtained when two and five features, respectively, were used by the linear parametric classifier. The BPNN classifier using the top five slope features gave a mean accuracy of 92.4%.

Reflectance characteristics in NIR spectrum

Mean reflectance values of all cereals in the NIR spectrum are shown in Fig. 2. Reflectance values in the NIR region were higher than in the visible region. The deflection points determined using second derivatives occurred at 970, 1160, 1340, 1400, and 1680 nm.

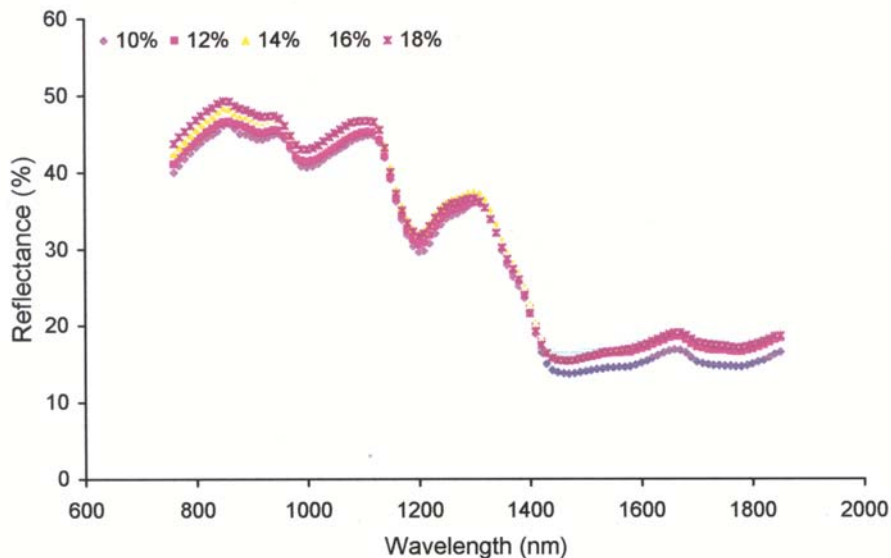


Fig. 3. Effect of moisture content on the diffuse reflectance properties of CWRS wheat in the NIR spectrum.

Wavelengths 1840, 760, 910, 1430, and 1250 nm were selected by the STEPDISC procedure as the best five features, when direct reflectance values were used. The selected wavelengths 910, 1250, and 1430 correspond to absorption values for protein and starch (Williams and Norris 1987). All cereals were correctly identified by the linear parametric classifier even when two wavelengths were used for the classification. Single kernels of red and white wheat were correctly classified with 97.0% accuracy using the entire 700 – 1688 nm NIR spectrum (Dowell 1992). Delwiche (2003) determined wavelengths 1182 and 1242 nm as the top two wavelengths for identifying scab and mold-damaged wheat kernels with an accuracy of 95%.

The top five selected ratio features by the STEPDISC procedure were 46, 5, 67, 64, and 42. These features correspond to wavelengths 1210 and 1220; 800 and 810; 1420 and 1430; 1390 and 1400; and 1170 and 1180 nm. The wavelengths selected correspond to the protein, starch, oil, and water absorption bands (Williams and Norris 1987). When the top two features were used, the mean classification percentage by the linear parametric classifier was 91.4% for cereal grains. Misclassifications occurred mainly within the 2-row and 6-row barleys, CWAD wheat misclassified as rye, and 20% of oats misclassified as barley. However, when the top five features were used, the mean classification accuracies rose to 99.5% and 0.5% misclassification occurred within the two barleys.

The STEPDISC procedure selected the slope features 42, 67, 5, 64, and 40 as the five best features. These features correspond to the wavelengths selected by using the ratio as features except feature 40 which corresponds to 1150 and 1160 nm which lies in the starch absorption band. Using the top two and five wavelengths means classification accuracies of 91.9 and 99.5%, respectively, were obtained by the linear parametric classifier. When the top two features were used for the classification, the major misclassification occurred within the 2-row and 6-row barley accounting for 4.8% of the mean classification inaccuracy. The same error was repeated when five features were used but by a far lesser degree.

The statistical linear parametric classifier gave better classification using slope features in the NIR spectrum. So BPNN was tested using only the slope features in the NIR spectrum. Wavelengths 1420 and 1430; 1120 and 1130; 1670 and 1680; 960 and 970; and 1020 and 1030 nm were selected as the best five features contributing to the classification. The classification accuracies by the BPNN were 70 – 90% and 50 – 70% when five and two features were used, respectively.

Further data analysis through out the manuscript was carried out using only the slope features in the NIR spectrum.

Reflectance characteristics of CWRS wheat with different moisture contents

A difference in moisture content would not have a substantial influence on visual qualities of the cereal grains. Hence, reflectance data in the NIR region was used to differentiate different moisture content samples in this study. Law (1977) determined the effectiveness of the NIR spectrum for classification of grains based on their moisture contents on ground samples. Figure 3 shows the reflectance characteristics of different moisture content CWRS wheat in the NIR spectrum.

The selected wavelengths by the STEPDISC procedure were in the range from 1200 – 1440 nm. These wavelengths were derived from the slope values of the reflectance data. Using the top two selected slope values (1300 and 1310; 1330 and 1340 nm) classification accuracies ranging from 75 – 100% were achieved using the linear parametric classifier. The drier samples with moisture contents 10 and 12% were always correctly identified. Misclassification occurred when the moisture contents of the samples were 14, 16, and 18%. The misclassifications were not random but occurred as the adjacent moisture content sample. For example, in 14% m.c. wheat, 3.3 and 16.7% samples were misclassified as 12 and 16% m.c. wheat, respectively. To determine if more wavelengths would contribute to a better classification, the top five features were used (1300 and 1310; 1330 and 1340; 1430 and 1440; 1290 and 1300; 1210 and 1220 nm). The classification accuracies remained the same as when lower wavelengths were used. The 4-layer BPNN (109-34-34-5 nodes) selected wavelengths 1090 and 1110; 990 and 1000; 1580 and 1590; 1110 and 1120; and 1210 and 1220 nm as the top five features. Using the top two and five features, classification accuracies ranging from 60 – 100% were achieved. Misclassification was predominant in the higher moisture content samples (> 14% m.c.). Downey (1985) determined the efficiency of the NIR method to differentiate different moisture contents ranging from 13.6 to 20% in whole grain to be less efficient than ground samples. However, he indicated that the NIR classification method would be useful for commercial purposes for rapid identification of moisture content. This could be attributed to the fact that elevators are interested in the dryness of grain.

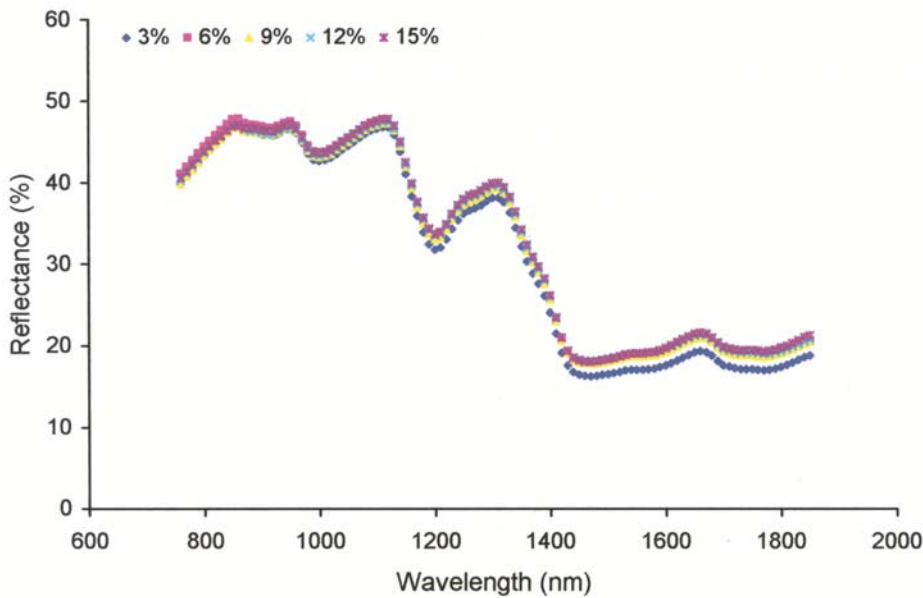


Fig. 4. Effect of foreign material content on the diffuse reflectance properties of CWRS wheat in the NIR spectrum.

Reflectance characteristics of CWRS wheat with varying concentrations of foreign material

The NIR spectrum was used to determine the foreign material content and to study the feasibility of using the same for rapid identification. Figure 4 shows the NIR reflectance values of CWRS wheat containing varying quantities of foreign material. The selected wavelengths by the STEPDISC procedure were between 930 and 1840 nm for the 3, 6, 9, 12, and 15% foreign material content CWRS wheat samples. The top five features encompassed the wavelengths 1210 and 1220; 1800 and 1810;

1830 and 1840; 940 and 950; and 930 and 940 nm. Using the top two and five selected slope values, classification accuracies ranging from 0 – 40% were achieved by the linear parametric classifier. The 4-layer BPNN (109-34-34-5 nodes) selected 1710 and 1720; 1020 and 1030; 1810 and 1820; 1560 and 1570; and 800 and 810 nm as the most significant features contributing to the classification. Using these selected wavelengths, classification accuracies of 20-50% were achieved. The classification accuracies were also tested using both the visible and the NIR spectrum. However, no increase in classification accuracies was observed. The reason for inaccurate classification could have been due to the difference in the uniformity of distribution of the foreign material content in the sample. When smaller samples were drawn, the foreign material content in them would not be proportional to the sample. Hence, it can be concluded that in this study, the foreign material content did not affect the identification of grain types.

Reflectance characteristics of CWRS wheat from different growing regions

This study determines if there is a significant difference among cereal grains collected from different growing regions. The NIR spectrum was used to test the classification of the cereal grain, CWRS wheat from 15 growing regions (Fig. 5). The slope features, when ranked using the STEPDISC procedure, determined features 54, 77, 56, 44, and 53 as the top five features. These features correspond to 1290 and 1300; 1520 and 1530; 1310 and 1320; 1190 and 1200; and 1300 and 1310 nm, respectively.

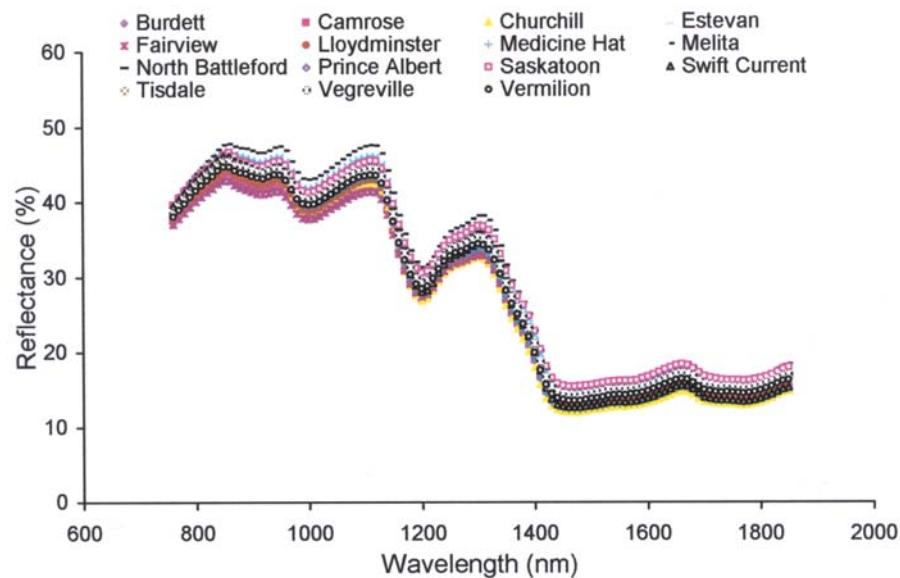


Fig. 5. Effect of growing regions on the diffuse reflectance properties of CWRS wheat in the NIR spectrum.

The fourth best feature corresponds to the cellulose absorption band. Wavelengths 1300 and 1310; 1290 and 1300; 950 and 960; 960 and 970; and 870 and 880 nm were selected as the best features for classification by BPNN (109-42-42-15 nodes); but no other relation could be inferred. Neither the linear parametric classifier nor the BPNN could categorize the grains based on the growing locations, as the classification accuracies were 0–30%. Majumdar et al. (2000d) determined that the growing regions had no significant effect on color and morphological features of cereal grain which is in agreement with this study.

Combined effect of moisture, foreign material content, and growing locations on identification of cereal grains

To determine the combined effect of external variables (moisture content, foreign material content, and growing locations) on identification of cereal grains, further analysis was done by pooling NIR reflectance data collected for individual testing (i.e. NIR reflectance values of CWRS wheat with different moisture, foreign material contents, and different growing regions were added to the clean and dry cereal grains). When dry, clean CWRS wheat and CWRS wheat with external variables were treated as one class, the mean identification accuracy of all grains was reduced by 5.6%. However, the identification was 99.9% when the CWRS wheat with external variables was treated as their corresponding individual classes. For automated railcar unloading and binning decisions, 100% identification accuracy is warranted. Hence, it can be inferred that reducing the influence of external variables, by treating the external variables as different classes will decrease the chances of grain misclassification.

CONCLUSIONS

Reflectance characteristics of cereal grains were studied in the visible and NIR spectrum. The wavelengths that correspond to the NIR spectrum identified the cereal grains better than the wavelengths in the visible region. The classification accuracies were higher when the slope features were used. Using five features, classification accuracies of 99.5% were achieved by the linear parametric and BPNN classifiers. The use of five features corresponds to 10 wavelengths which were scattered in the NIR region. Moisture content, foreign material content, and growing locations affected the reflectance characteristics of CWRS wheat when treated as a single entity; but when the variables were segregated as individual classes the cereals were correctly classified. No single wavelength contributed enough to correctly identify all cereal grains. A band pass filter allowing 800 – 1430 nm could be used for objective identification of cereal grains. Reflectance characteristics in the NIR region alone cannot be used to determine moisture content, foreign material content, and growing regions of cereal grains. The NIR reflectance values of CWRS wheat samples of different moisture and foreign material contents and from different growing regions, when added to other cereal grains, did not affect the identification efficiency.

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