Factors concerning development of electronic systems for grading grains and seeds in Canada

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Introduction

This paper will document the concept of grading grains for value determination and marketing by electronic methods, with particular reference to near infrared (NIR) spectroscopy. The factors necessary to the development of an electronic grading system are summarised in Table 1 (not in order of importance). The paper will provide a short commentary on each factor, together with the methods used to date. Most of the work to be described concerns wheat, but extensive research has also involved barley, oats and the oilseed and pulse crops.

Establish reasons for development of electronic grading *vis-à-vis* "Status Quo" systems

The present visual system works, so why change it?

Grain will increasingly be purchased on quality specifications, rather than on grades. Add to this the increasing proclivity of Canadian marketing agencies to seek and service "Niche" markets and the looming threat of segregation of Genetically Modified wheat. The complexities of these changes in marketing strategy, combined with the already progressing changes in the elevator system and grain

Table 1. Factors to consider in the development of electronic systems for grading grains and seeds.

1	Establish reasons for development of electronic grading *vis-à-vis* "Status quo" systems
2	Identify factors that affect end-product quality and the value of commodities
3	Identify factors that should be predictable by NIR spectroscopy
4	Define method of expression of efficiency of NIR estimations and establish limits of acceptable accuracy
5	Identify instruments for application in appropriate settings
6	Evaluate software for calibration development and monitoring
7	Develop calibrations for grading of grains and seeds on the basis of functionality and end-value
8	Evaluate calibrations for electronic grading for application in grain-handling and processing
9	Advertise proposed electronic grading systems among potential user and their clients
10	Implement systems for electronic grading

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transportation, will make it extremely difficult for the present system of visual grading to meet the demands of future grain marketing.

Canada's Prairie provinces annually produce about 50 million tonnes of grain, of which about 80% is exported. This volume embraces 17 different crops (crops grown to a significant extent). Each crop is graded visually into at least two grades, so that a country (called Primary) elevator would require nearly 40 bins or cells to enable it to segregate all grades of all grains and seeds. Add to this the need to segregate the top two millings of CWRS wheat into at least two protein levels. In times of a wet harvest period, still further cells are needed to keep high moisture grains separate until the grain could be dried, or efficiently blended with other grain of the same type and grade of moisture content sufficiently low as to render it safe for shipping or further storage.

Binning of the eight classes of wheat is further complicated by the fact that some classes, such as western Canadian Red Winter (WCRW) and white Canada Prairie Spring (CPSW) wheat, are only produced in relatively small volumes. This means that an elevator may be obliged to tie up a 2000 tonne cell with only two or three railcar-loads (about 270 tonnes) of one of these classes until sufficient has been accumulated to market it. Combining the present six grades of western Canadian red and white classes [all classes other than Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD)] into no more than four classes would ease some of these binning stresses.

The need for electronic grading in western Canada (as well as testing for composition) was recognised as long ago as 1994, around the time when the western Canadian Grain-handling industry was exhorted to double grain-handling throughput within the following 10 years or so. At that time it was recognised that such a metamorphosis would not be possible without the application of electronics in grain-handling and the concept of Electronic Grading was spawned at the Canadian Grain Commission (CGC) Grain Research Laboratory (GRL) mainly in recognition of the above mandate.

The portended introduction of new wheat classes, such as a Hard White Spring class, will create even more demands for bin-space on the elevator system. During the past 20 years, the elevator system has been undergoing major changes, epitomised by reduction in the number (from over 5,200 in the mid-1960s to less than 550 at present) and increases in capacity (of individual elevators) and throughput potential. This development has coincided with a gradual emergence of extensive storage capacity on farms, sufficient in most cases to accommodate the full year's harvest.

These items formed the basis for the concept of an electronic system for identifying, at farm level, grains and seeds of the grades and composition required for shipments internationally and domestically. The concept is based on retaining the present visual system for the Hard Red Spring (CWRS) and durum (CWAD) classes and "streamlining" the classes of all other types of wheat by electronic grading. The electronic system would differ fundamentally from the present method, which is based on visual evaluation. It would be based on functionality—how will the grain **perform**, rather than what does it look like. For example, the main "grade" characteristics of wheat would stem from colour, texture, water absorption and gluten strength (protein content would still be used to segregate wheat of different classes). Visually assessed factors, such as sprouting and frost damage, would also be incorporated. Electronic systems for assessing this type of damage could also be used to improve the precision and reduce the time per test of grading the CWRS and CWAD classes.

A second objective of the electronic grading concept has been the development of systems for identification of wheat gluten "strength" for use in wheat-breeding. Prediction of recognised "strength" parameters, such as Farinograph development and stability times, Extensigraph peak height and area and Alveograph "W" value on whole kernels, would enable breeders to screen material in early generations, to avoid the expense of maintaining inferior lines. In later generations that are tested for environment/genotype interaction by growing them on several growing locations, the calibrations would identify lines that were most susceptible to genotype/environment interactions. Lines of this type should be rejected.

Identify factors that affect end-product quality and the value of the commodity

Weather-induced factors such as vitreous kernel %, frost, wet harvest conditions and growing conditions that favour the prolification of fungi and other hazards have been thoroughly researched, for example references 1 and 2. Functionality factors, such as kernel colour and texture and gluten "strength" would be added to these electronic gradings.

Identify factors that should be predictable by NIR spectroscopy

Factors such as sprouting, frost damage and *Fusarium* head blight affect kernel texture (degree of hardness or softness) in different ways. Sprout and *Fusarium* cause slight softening of the kernels, while frost makes the kernels appreciably harder. NIR spectroscopy has been found to be capable of detecting these subtle differences in texture. Significant differences in texture have been demonstrated among some wheat classes, such as Red Canada Prairie Spring (CPSR) and Canada Western Extra Strong (CWES) wheat. Both the texture and gluten characteristics of Canada Western Red Winter (CWRW) and CPSR wheat types are sufficiently close to each other that they could be incorporated into a single class for marketing. The white classes, Canada Prairie Spring White (CPSW), Canada Western Soft White Spring (CWSWS) and Canada Western Hard White Spring classes can be differentiated from the red classes on the basis of colour and from each other on the basis of kernel texture.

Both colour and texture can be measured by modern NIR instruments. Figure 1 illustrates spectra of four wheat classes of different kernel texture. Durum wheat is the hardest and Soft White Spring the softest.

The percentage of hard vitreous kernels (HVK) is an important parameter in establishing grades of durum wheat. The assessment of this by visual methods is subjective. A "pinpoint" of starchiness is sufficient for a grain inspector to regard the kernel as non-vitreous when, in fact, that pinpoint is not likely to have any influence on the functionality of the wheat. The HVK percentage can be predicted with accuracy by NIR as well as by digital imaging. Figure 2 illustrates spectra of six samples (three pairs) of durum wheat, each pair having different HVK % from the other two. The HVK % of each pair was clearly distinguishable.

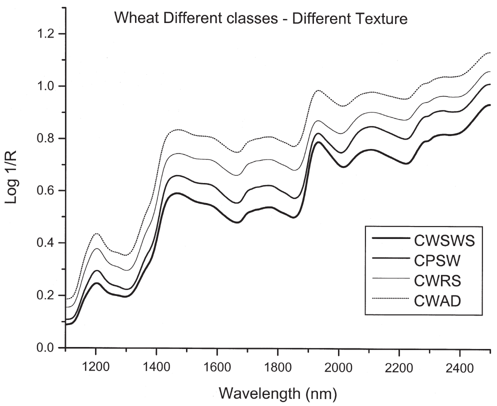

Figure 1. Spectra of four wheat classes of different kernel texture.

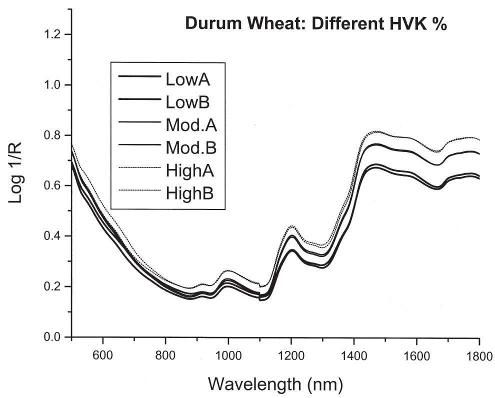

Figure 2. Spectra of six samples (three pairs) of durum wheat with different HVK % values.

Define method of expression of efficiency of NIR estimation and establish limits of acceptable accuracy

The time-honored statistics of coefficient of correlation (*r*), standard error of prediction (*SEP*) and bias have been used in the evaluation of calibrations developed for prediction of electronic grading parameters. Other important statistics include the slope and the relative standard deviations of the reference and NIR-predicted data of the validation sample set, which should be close to identical. The RPD statistic (ratio of *SEP* to standard deviation of reference data of the validation sample set) has also been found useful in "summarising" calibration validation statistics. Several parameters used as reference data (in calibration development) were based on visually-assessed characteristics and such parameters as the Falling Number values. Most of these parameters lack the degree of precision in reference data normally encountered with composition factors, such as protein content. Accordingly, RPD values upwards of 2.5 have been regarded as adequate for the establishment of electronic grading systems.

Identify instruments for application in appropriate settings (including on-farm)

Identification of suitable instruments for application at elevator and farm level have to be evaluated from the aspects of economic as well as technical efficiency. It would be inefficient to assemble and scan several thousand samples to calibrate an instrument that is likely to be superseded by one that is more efficient and/or of lower cost, for the same efficiency. The Foss/NIRSystems Model 6500 visible/NIR scanning spectrophotometer is regarded as the standard by which other instruments can be evaluated. This instrument operates over a wavelength range of 400 – 2500 nm. Several other instruments are under evaluation for possible application in electronic grading. The ideal NIR instrument will combine suitable accuracy and precision with consistent and reliable sample presentation, compact size, simple operation (from the aspect of software and transferability of calibrations and moderate cost). The capability of networking to assist with monitoring would be another asset.

Evaluate software for calibration development, regular analysis and monitoring

Software should be evaluated from aspects of user-friendliness in operation and effectiveness in resolving non-linearity, outliers and other features that detract from accurate and reproducible analysis. Evaluation includes generic software, such as Unscrambler and Grams, as well as dedicated software developed by instrument companies for calibration, operation and instrument diagnostics. Too often, the manufacturing companies' operators' manuals fall short of efficiency. Essential steps in the operation are overlooked by compilers of manuals and it is left to the user to locate such deficiencies and insert the missing steps.

Develop calibrations for electronic grading of grains and seeds on the basis of functionality and end-value

Modern software options, such as artificial neural networks (ANN) and the "Local" option of InfraSoft International's WINISI are most effective with large sample sets. The assembly of sample sets with several thousand samples can best be achieved by arranging for samples of railway carloads or farmers' deliveries to be forwarded to the central laboratory responsible for calibration development. Electronic grading is aimed at all levels of elevator and farm operation. Large terminal elevators may process over 1000 railway carloads in a week, while Primary elevators may process hundreds of farm deliveries in the same time-frame. A very wide range of diversity is represented by both railway and farm deliveries. All of this variance has to be incorporated into reliable calibrations. This is further complicated by the variance in the reference data. The "frowned-upon" practice of splitting large populations into calibration and validation sample sets is acceptable in this type of calibration, because of the wide variance inherent in the very large populations of railway carloads and, on a more regional basis, farmers' deliveries to Primary elevators.

In Canada, because of the handling system, the abrupt changes in grain quality that can occur from season to season usually have less immediate impact than in countries where farmers are able to deliver all of their newly harvested grain immediately. Grain arriving at terminal elevators from Primary elevators has undergone variable degrees of blending and individual carloads may contain grain from more than one season. Similarly, farmers may elect to retain new crop grain when it is of low moisture content and deliver grain from their storage bins from a previous season.

After calibration development, the efficiency of the calibrations has to be tested by setting up the instruments on-location at elevators. Here, the operating conditions may reveal areas where modifications to the operating procedure have to be introduced. Modern elevators can discharge railway hopper-cars in about 2–3 minutes and most elevators have more than one receiving line. At the same time, the elevator may be loading one or more vessels and operating conditions are very intensive. Systems have to be developed for monitoring instrument performance. Above all, the NIR instruments must be capable of efficient throughput with no inconvenience to the elevator staff, while retaining the integrity of the grades.

The chief difficulty in development of NIR calibrations for grade factors lies in the subjectivity of the data used as reference for calibration development. Most of the factors rely on the opinions of individual grain inspectors as to the degree of damage caused by factors such as frost and *Fusarium.* The Falling Number (FN) test is used in place of % sprouted kernels, but even this test has been found to show a standard error of about 30 seconds (including sample preparation). To put this in context, the 95% confidence limits stretch to +/– 60 seconds, so that an apparent result of, for example, 340 seconds for the FN of a sample used in calibration could, in fact, lie between 280 and 400 seconds. Precision of prediction of FN by NIR is only 14.7 seconds, including sample cell reload. The precision of the instrument on re-scanning a sample without re-loading is only six seconds.

Evaluate calibrations for electronic grading for application in grain-handling and processing

The development and evaluation of calibrations for electronic grading has been in process at the Grain Research Laboratory (GRL), Winnipeg, during the past four years. The process has been carried out as a collaborative project between the CGC Industry Services division and the GRL. Methods are as follows:

Sample accumulation

Samples of railway carloads have been forwarded from terminal elevators, together with cargo-loading increments and cargo composite samples. These have been augmented with samples submitted by farmers in response to the annual harvest surveys conducted by the GRL and further augmented by samples of pure varieties and breeders' lines submitted by plant breeders from over 30 Prairie growing locations over eight growing seasons. The total database contains over 4,000 spectra.

Near infrared analysis

All samples were scanned at, or close to, the time of receipt on a Foss/NIRSystems Model 6500 visible/NIR scanning spectrophotometer. All scans were carried out using whole grains and the Foss/NIRSystems Natural Products sample cell. Check samples of the respective classes of wheat were used and of samples of CWRS wheat with well-defined weather damage (sprouting and frost). Software included Foss/NIRSystems NSAS and WINISI. The very rapid NSAS software was used to optimise mathematical treatments of the log 1/*R* signals. Data-sets processed by the optimum mathematical treatment were transposed to WINISI for evaluation of the influence of scatter correction (SNV/Detrend and Multiplicative Scatter Correction). Details of mathematical treatments are available.

Reference methods

Reference methods used in calibration development for composition, kernel texture and physical dough characteristics were Approved Methods of the American Association of Cereal Chemists.[3] Grade factors such as % Frost were determined by experienced inspectors of the CGC, using the Official Grain-Grading Guidelines. The Falling Number test was used in place of % sprouted kernels.

Results

The preliminary results are summarised in Table 2. Data are presented in Table 2A for parameters to be used in an electronic system, based on kernel colour and texture and gluten strength. Data are also included for calibrations developed for some barley and oat functionality parameters. Table 2B includes results for prediction by NIR spectroscopy of parameters used in the present visual grading system.

Discussion

All of the wheat parameters were predictable with accuracy and precision suitable for the development of an electronic grading system for classes of wheat other than CWRS and CWAD. The grades would be based mainly on kernel colour and texture. Wheat gluten strength parameters could be used to "fine-tune" the red wheat calibration. For example, the Farinograph stability of the CPSR usually lies between 5–8 minutes, while that of CWES wheat usually lies between 25–35 minutes. The *SEP* of 1.9 minutes would clearly serve to differentiate between these two classes. The Farinograph stability time and kernel texture of CWRW wheat are similar to those of CPSR wheat and these two existing classes could effectively be marketed as a single class.

Prediction of factors such as sprout, frost, % hard vitreous kernels and *Fusarium* damage would assist in establishing grades of all classes of wheat, including the CWRS and CWAD classes. Assessment of these grade factors is time-consuming. Inspectors have to divide a 1–2 kg sample down to about 30 g. The sample is weighed accurately and examined visually to identify the presence and degree of damaged kernels. These are hand-separated and the damaged kernels weighed and reported as "% sprouted", % severe sprouted", etc. This exercise takes about 10–15 minutes for all similar grade factors. The procedure is also subjective, because the results depend on the opinions of individual inspectors. An NIR calibration could reduce the time to the usual 40–50 seconds and provide a higher degree of precision. Calibrations for both % Frost and Falling Number have proved to be significantly superior in precision to the visual method and also to the precision of the Falling Number test.

Turning to wheat gluten "Strength" calibrations developed to date have been developed on whole wheat kernels and preliminary results, based on two growing seasons, have been reported elsewhere.[4] The Foss/NIRSystems Natural Product sample cell can be used at only ¼-full, which is equivalent to about 30 g of wheat. This would enable plant breeders to screen for gluten strength at as early as F3 and still retain selected lines for planting.

Advertise proposed electronic grading systems among potential users and their clients

All concerned agencies should be made fully aware of all aspects of the proposed electronic system well in advance (at least one and, preferably, two years) of its projected implementation. This includes the reasons, the methods to be employed, accountability, economics, potential benefits and potential pitfalls. This can be carried out via the media and by workshops and presentations at Town Halls and

Table 2. Results of prediction of grading factors using NIR spectroscopy.

A. Electronic system	r^2	*SEP*	Potential for use
Kernel colour1 (Minolta b*)[1]	0.96	0.30	Excellent
Kernel texture (PSI %)[1]	0.94	2.38	Excellent
Farinograph water abs. %[1]	0.91	1.43	Excellent
Gluten Strength[1]			
a. Farinograph dev. time	0.71	1.2	Good
b. Farinograph stab. time	0.80	1.9	Good
c. Farinograph mix. tol.	0.92	17.7	Very good
d. Extensigraph max. ht.	0.72	85	Good
e. CSP mixing energy	0.76	2.5	Good
HVK % (Durum wheat)	0.83	4.22	Very Good
Protein content (All)	—	—	Excellent
Moisture content (All)	—	—	Excellent
Malt fine HWE3 (barley)	0.52	1.00	Fair
True met. energy (barley)	0.61	0.15	Fair
Groat % (oats)	0.82	0.95	Good

[1]wheat only

B. Present (visual) system	r^2	*SEP*	Potential for use
Falling number (seconds)	0.85	42.5	Fair
Fusarium “Scab” (DON) ppm	0.76	1.10	Not recommended
Frost-damaged kernels %	0.82	4.62	Good
Plump kernel % (barley)	0.83	11.5	Good
Chlorophyll ppm (canola)	0.96	2.06	Excellent
Oil content (canola seed)	0.95	0.70	Excellent
Seed size (lentil)	0.92	9.58	Excellent
“Greenness: (lentil)	0.99	0.014	Excellent

other meetings. Feed-back from concerned people can be employed to introduce improvements before actual day-to-day use.

Implement systems for electronic grading

The new system would be best introduced via a small-volume crop. This would enable operational pitfalls to be resolved with minimal economic consequences. In Canada, a crop such as western white wheat would be suitable. The crop will exist in at least two distinct classes (Hard and Soft White Spring wheats), neither of which will be grown in high volume but high enough to enable all aspects of the electronic system to become apparent. Another suitable crop would be canola seed. This is quite a high volume crop, but grading on the basis of electronically-determined chlorophyll content and segregation/marketing by oil content would rapidly realise the potential economic benefits of such a system.

Conclusions

(1) The visible/NIR spectra of grains and seeds contain enough information to enable these commodities to be classified on the basis of functionality
(2) A classification system could be developed to establish price in relation to the functionality of the commodities, rather than to their appearance
(3) Such a system, using NIR spectroscopy, would be faster and less subjective in operation than grading/pricing systems based on visual evaluation
(4) An electronic system that incorporated reduction in the number of classes of wheat would improve the efficiency of bin-space utilisation at elevators in Canada
(5) An electronic grading system would be attractive to wheat breeders (particularly in Canada), since the requirement for the kernel shapes of wheat classes to be visually distinguishable from one another would be eliminated and material could be selected on the basis of gluten strength in early generations.

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