STUDY OF COMMERCIAL GRADES OF CANADA WESTERN RED SPRING WHEAT BY DIGITAL IMAGE PROCESSING

by

Jürgen Max Kohler

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A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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To my parents

To my friend

Melvin Toews

and to a very special person

Lynne

Befiehl dem Herrn Deine Wege

und hoffe auf ihn

er wird's wohl machen

Psalm 37:5

Hamlet and Polonius demonstrating the need for objective measurement:

Hamlet: Do you see yonder cloud that's almost in shape of a camel?

Polonius: By th'mass, and 'tis like a camel, indeed.

Hamlet: Methinks it is like a weasel.

Polonius: It is backt like a weasel.

Hamlet: Or like a whale?

Polonius: Very like a whale.

from William Shakespeare's Hamlet, Prince of Denmark

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Jürgen Max Kohler
Winnipeg, Manitoba
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ABSTRACT

Canada's grading system is primarily based on the subjective interpretation of grading factors that influence end-use quality. Grade is determined by grain inspectors upon visual inspection and assessment of sampled grain relative to established standard grade samples. The lack of objective measurement of important grading factors has led to inconsistent grade determinations to the extent that anywhere from 10% to 14% of reinspected samples receive a higher grade from that originally assigned.

End-users will always prefer a precise and consistent measurement of quality characteristics, especially as wheat utilization and processing technology is increasing in sophistication. The present study uses digital image processing techniques for the objective measurement of kernel morphology and its uniformity in three commercial grades of Canada Western Red Spring (CWRS) wheat. A total of 32 variables quantified aspects of kernel size, kernel shape and kernel brightness, as well as their relative uniformity within each grade. The analysis is based on 103 carlot and 73 cargo samples that were obtained from the Grain Inspection Division of the Canadian Grain Commission (CGC). An evaluation of the computer-based methodology in terms of its ability to objectively distinguish between the three CWRS grades is also undertaken.

A preliminary experiment to determine an appropriate sample size revealed that the degree of variability within the sample and the tolerable measurement error set by the investigator are important factors to consider. Using the kernel contour length feature as an example and assuming a 95% certainty that the error of estimation does not exceed 0.10mm, the results indicated that the required sample sizes are 333, 362 and 416 kernels for the 1CWRS, 2CWRS and 3CWRS grade, respectively.

The average coefficient of variation (C.V.) for 16 morphological features

in the carlot samples progressively increased as grade dropped, from 3.33% for the No.1 to 3.67% for the No.2 and to 4.13% for the No.3 grade. The No.3 grade was also the least uniform among the cargo grades, reflecting the fact that the highest levels of weather-related degrading factors such as bleached, immature, frosted and sprouted kernels are allowed in this grade. Each cargo grade was also found to be considerably more uniform compared to its corresponding carlot grade, with average C.V.'s decreasing by 58%, 63% and 64% for the No.1, No.2 and No.3 grade, respectively. Similar results were obtained from the thousand kernel weight determinations, providing objective evidence that Canada's grain grading and bulk handling system is very effective in enhancing uniformity within the top grades of CWRS wheat as it is moved into export position. The observed uniformity differences between the cargo and carlot grades are also indicative of the more stringent grade specifications under the export standard as compared to the primary standard.

Stepwise discriminant analysis and canonical discriminant analysis were used as analytical and graphical techniques to examine the level of grade discrimination that could be achieved with the morphological data. While the three carlot grades could not be clearly separated, an excellent level of discrimination was achieved among the three cargo grades based on a 32-variable linear discriminant model. The improved level of discrimination in the cargo samples was due to the greater number of variables that tested "significantly different" for the pairwise grade comparisons using Duncan's New Multiple Range Test. Overall, the variance variables were found to be just as important as the mean feature variables themselves in terms of their contribution to the three-way grade discrimination.

An experiment to test the reproducibility of the measuring system confirmed that a high and satisfactory level of precision was used in the extraction and measurement of kernel morphology. Measurement errors were insignificant (C.V.'s < 1.5%), as sample variance was anywhere from 5.5 to 17.5 times greater than instrumental variance, depending on grade and measurement feature.

The study concludes with a brief discussion of the various factors that contribute to the overall uniformity of quality in CWRS wheat and its importance in terms of commanding price premiums over Australian Prime Hard, U.S. Dark Northern Spring and U.S. Hard Red Winter wheats in the international wheat market.

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I. INTRODUCTION

Canadian wheat grades are established under the authority of the Canada Grain Act, which is administered by the Canadian Grain Commission (CGC). This Act charges the Commission with the responsibility of ensuring that the interests of grain producers are protected during the marketing of their grain. To meet this objective, the CGC is directed to establish and maintain standards of quality for Canadian grains and oilseeds as well as to regulate the handling of such grains.

Wheat shipped by rail is graded by government inspectors at primary inspection points from samples obtained from the railroad cars at convenient points of interception. The final grade of each carload of wheat is established by the inspector based on the visual assessment of a sample drawn mechanically as the car is unloading at the terminal elevator. The largely subjective nature of this grading method commonly leads to problems and inconsistencies with regard to accurate grade determinations in Canada Western Red Spring (CWRS) wheats. As a result of the overall importance of this class of wheat to the Prairie economy, the grain industry, in cooperation with the federal government, has been encouraging research efforts to focus on the development of more objective and thus more consistent methods for wheat inspection and grading.

The purpose of this study is to investigate the feasibility of using digital image analysis (DIA) as an instrumental method for objective assessment of certain quality factors in CWRS wheat. The approach taken will be to examine if DIA is capable to distinguish between three commercial grades of CWRS wheat on the basis of certain physical characteristics. The focus will be on the quantification of kernel size, shape and brightness attributes and their respective uniformity in commercial grades of both carlot unload and cargo samples of CWRS wheat. The reproducibility of the measuring system and practical implications in terms of the overall feasibility for objective determination of grade will also be discussed.

II. LITERATURE REVIEW

A. Introduction

The major objective of this thesis project was to use digital image analysis (DIA) as an instrumental method for objective measurement of certain kernel size, shape and brightness features that contribute to wheat quality. The ultimate aim is to examine the relationship between this set of physical quality characteristics and three CWRS grade levels, to permit an objective evaluation of the performance of the Canadian wheat grading system. Therefore, the following review of the literature will cover in greater detail those publications that are pertinent to this research project, especially those identifying the various physical characteristics of wheat that determine its quality. In addition, the degree to which the Canadian wheat grading system objectively measures these characteristics will be examined, as well as studies that have already used DIA for wheat inspection purposes.

B. Definition of Wheat Quality

When used in reference to wheat, the meaning of "quality" is not easy to define. Clark (1936) argued that the miller, the chemist and the baker all have their own conception of wheat quality:

> Quality wheat to the operative miller frequently means clean, sound wheat, free of screenings, of medium hardness, of a plump berry, heavy in test weight, whose bran cleans up easily while going through the mill. Its yield in bushels and pounds required to make a barrel of flour should be low, its flour should bolt freely, and its bran should not shatter into fine particles but remain in large flakes, thereby making a well dressed flour. Such is the picture that mention of quality brings to the mind of the miller.
>
> To this picture the mill chemist would add his ideas of ash content not only in the wheat but he would prefer to have this ash distributed so that the patent flours would run proportionally low in ash. The chemist would be called upon to classify the wheat according to protein content so quality to him includes protein. His picture includes flour

> color so wheat producing an easily bleached flour would be of interest. Finally, the chemist might be interested to know how flour milled from the wheat would bake according to his treatment.
>
> The baker understands baking characteristics. He directs his help by telling them what baking qualities to observe. He does not regulate his shop according to the flour's ash, protein, hydrogen-ion concentration, acidity, flour yield, or color. He is not concerned with what the test weight of the wheat might have been from which his flour was made. He does not care whether the bran cleaned up or not. He is, however, tremendously concerned about how much water the flour demands, to make a dough of the consistency necessary for proper development. He is vitally interested in how long he should mix his flour and other ingredients to make a good dough. He likewise wants to know how long the dough batch should be fermented to produce his type of bread. The picture of quality to the baker, therefore, is painted in terms of baking characteristics.

The author further argues that since flour is consumed in baking, the quality picture of paramount importance is that of the baker or the consumer. If the baker's demands are not met, the flour is of poor quality and the wheat inferior. If the flour bakes successfully it demonstrates quality to the baker and the wheat from which it was made becomes good quality wheat.

Finney and Yamazaki (1967) indicate that the basic definition of wheat quality usually varies from one class of wheat to another and is dependent on the wheat's suitability for a given product. For example, the quality of a soft winter or white wheat variety is defined in terms of its suitability for soft wheat milling and for the production of cakes, cookies, and crackers. The quality of a durum wheat is defined in terms of its suitability for semolina and macaroni production. Hard red winter and spring wheat quality is defined in terms of specific milling and baking properties that determine the suitability of a wheat for hard wheat milling and bread production. The authors stress that quality of any kind of wheat cannot be expressed in terms of a single property, but depends on several milling, baking, processing, and physical dough characteristics, each important in the production of bread or pastry products.

Tipples (1985) distinguishes between two categories of quality factors when defining wheat quality: (1) "type determining" factors such as bran color, hardness, protein content and gluten strength, as opposed to (2) "quality acceptability" factors such as flour yield, flour color and alpha-amylase activity. He notes that specific combinations of the type-determining factors, such as hard strong high protein, or soft weak low protein, do not in themselves infer "good" or "poor" quality, but, rather, suitability for specific end-uses. By contrast, wheats that have low flour yield, poor flour color, high enzyme activity, etc. may be said to have poor quality regardless of the intended (food) end-use.

From these various definitions, there appears to be general agreement that the proper approach to assessing the overall quality of a particular variety of wheat should include an assessment of the various milling, baking and processing characteristics considered to be important quality attributes for the particular end-use for which the variety is intended.

C. Physical Characteristics that Contribute to Wheat Quality

The various physical characteristics reviewed in this section contribute to bread wheat quality mainly by influencing flour yield. As a result, the following review of the literature will mainly focus on how each of the various physical characteristics influence this milling property.

1. Weight per Unit Volume (Test Weight)

One of the most widely used and simplest criteria of wheat quality is the weight of the wheat per unit volume, or test weight. It is expressed in terms of pounds per bushel; in most countries using the metric system, kilograms per hectolitre is the unit of measurement. In the United States, the Winchester bushel (2,150.42 $in.^3$) is used to express test weight, whereas in Canada, the Imperial bushel (2,219.36 $in.^3$), or more commonly, the metric kilograms per hectolitre, is used (Halverson and Zeleny, 1988).

The basic factors that affect the weight per unit volume of grain are discussed by Hlynka and Bushuk (1959). They have shown that, contrary to popular opinion, kernel size as such has little, if any, influence on test weight. Kernel shape and uniformity of kernel size and shape were identified as important factors affecting test weight, inasmuch as they influence the manner in which the kernels orient themselves in a container. The other important factor influencing test weight is the density of the grain. Density, in turn, is determined by the biological structure of the grain and its chemical composition, including moisture content.

A general relationship between test weight and flour yield has been acknowledged in the literature, even though the relationship is rough and not always reliable (Bailey, 1916; Mangels and Sanderson, 1925; Mangels, 1934; Shuey, 1960; Baker et al., 1965; Barmore and Bequette, 1965; Shuey and Gilles, 1969; Baker and Golumbic, 1970; Dattaraj et al., 1975). It appears that above approximately 57 lb/bu (73.4 kg/hl), the test weight of wheat has relatively little influence on flour milling yield. With decreasing test weight, the milling yield usually falls off rather rapidly. Immature wheat or wheat that is badly shrivelled as a result of drought or disease usually has a low test weight and gives correspondingly poor yields of flour. The average test weight of U.S. wheat is approximately 60 lb/bu (77.2 kg/hl), but test weights of up to 64 lb/bu (82.4 kg/hl) are not uncommon. Badly shrivelled wheats may have test weights as low as 45 lb/bu (57.9 kg/hl) or less (Halverson and Zeleny, 1988).

There are various factors that influence the test weight-flour yield relationship, making test weight only a rough and often unreliable index of flour milling yield. Wheat samples may have as much as nine pounds per bushel difference in test weight, yet have the same milling yield (total flour extraction) (Shuey, 1960). This inconsistency is explained by Barmore and Bequette (1965) as follows. Test weight of wheat is dependent upon the packing characteristics and the density of the grain. Packing characteristics depend in turn upon kernel shape, uniformity of kernel size and shape, presence of brush, and condition of the kernel surface. The surface may be rough or smooth depending upon (1) the variety, (2) whether the grain was exposed to wetting and drying after maturation, and (3) the amount of handling it has undergone. Wetting and drying roughens the bran and decreases kernel density through internal fissuring. Moving grain scours or polishes the kernels allowing them to pack tighter in the test kettle. All in all, these changes affect test weight but generally do not alter the flour-yielding capacity of the wheat.

Several studies have provided experimental evidence for some of the factors causing an inconsistent test weight-flour yield relationship. Mangels (1934) found a significant varietal variation in flour yielding capacity as related to test weight. Baker et al. (1965) noted that correlations between test weight and flour yield also differed widely among different classes of wheat. The correlation was high only for hard red winter wheats (0.897); correlations for soft red winter (0.448), hard red spring (0.365) and white wheats (0.535), were significant but low. Barmore and Bequette (1965) observed that test weight gave poor estimates of flour yield from Pacific Northwest white wheats, particularly for the white club varieties which consistently produced high flour yields regardless of low test weights.

2. **Kernel Weight**

Kernel weight, usually expressed in terms of weight per thousand kernels, is another physical characteristic of wheat that may also be used as an index of milling quality. Thousand-kernel weight (TKW) simply measures the average weight of a kernel, with a factor of 1,000 included for the necessary precision of the determination. TKW is a function of kernel size and kernel density. For example, Dattaraj (1970) found that in the case of blending a sample of a single shrivelled wheat variety (Shawnee) with sound wheat, as the percentage of shrivelled wheat in the sample was increased, TKW decreased. Therefore, to the extent that TKW reflects the size of the kernels, it would not be expected to be related to the weight per bushel. However, to the extent that it reflects the density of the grain, it would be directly related to the weight per bushel (Hlynka and Bushuk, 1959).

The range in weight per 1,000 kernels for U.S. hard red winter and hard red spring wheat is normally from about 20 to 32g. Soft red winter, white, and durum wheat normally range from 30 to 40g per 1,000 kernels, averaging approximately 35g per 1,000 kernels (Halverson and Zeleny, 1988).

Inasmuch as large, dense wheat kernels normally have a higher ratio of endosperm to nonendosperm components than do smaller, less dense kernels, one might expect kernel weight to be a more reliable guide to flour yield than test weight. Although this subject does not appear to have been studied exhaustively (Zeleny, 1971), no advantage of the kernel weight determination over the simpler test weight determination has been demonstrated conclusively in commercial milling operations. However, Baker and Golumbic (1970) showed that kernel weight was superior to test weight in predicting milling yield for hard red spring wheat but not for other classes of wheat, when milling yield was determined by use of the Buhler experimental flour mill.

Johnson and Hartsing (1963) have also presented evidence that the number of kernels per unit of weight as determined by an electronic seed counter may be a useful index of potential milling yield. Kernel counts on 198 samples of hard red spring and hard red winter wheat were compared with flour yields as determined on a Buhler pneumatic experimental mill. Both kernel count and flour yields were corrected to a moisture-free basis. The correlation coefficient of -0.84 for kernel count and flour yield was highly significant. The standard error of the flour yield estimate was 0.842%. In order to compare the relative ability of kernel count and test weight to predict flour yield of hard red spring and hard red winter wheat, the authors also regressed flour yield on test weight. The regression equation showed that the correlation coefficient of +0.67 for these to be highly significant as well. The standard error of the flour yield estimate was 1.73%. The difference between the correlation coefficient for kernel count vs. flour yield and test weight vs. flour yield was also found to be statistically significant at the 1% level for all classes of wheat used in their study. The final conclusion was that the number of kernels in a fixed weight of wheat corrected to a common moisture basis would be a better indication of flour yield than the test weight.

3. Kernel Size and Shape

Kernel size and shape are perhaps among the most important of all the various physical characteristics used to evaluate milling quality in wheat. This is because kernel size and shape affect the proportion of endosperm in the mature kernel, which in turn determines flour yield (Marshall et al., 1984). For example, consider the simplest situation where the wheat kernel is assumed to be spherical in shape. Since Crewe and Jones (1951) found no significant difference in bran thickness between large kernels and small kernels, it is further assumed that the thickness of the bran layer remains constant as the size of the sphere changes. The question then becomes the following: What happens to the ratio of endosperm to bran content in wheat kernels that are assumed to differ in size only? The necessary calculations are summarized in Figure 1 and the results indicate that large wheat kernels have a higher ratio of endosperm to bran than small kernels. Shellenberger (1961) assumed the kernel to be an oblate ellipsoid and calculated the ratio of total volume of a wheat kernel to the total volume of the bran for both large and small kernels. He found that there is nearly a five percent increase in the ratio in favor of the larger kernels. These simplified calculations then effectively illustrate the economic significance of wheat kernel size and shape. Both the crude fiber and ash content of wheat are related to the amount of bran in the wheat and hence have rough inverse relationships to flour yield. Small or shrivelled kernels have more bran on a percentage basis and therefore more crude fiber and ash than large, plump kernels and consequently yield less flour (Halverson and Zeleny, 1988).

Shuey (1960, 1961, 1965) found that there is a better relationship between the percentage of wheat kernels falling into a particular size class and milling yield as compared to that of test weight and milling yield. Shuey's kernel-sizing technique consisted of a wheat sizer with a rolling action which upends kernels resting on the sieves, allowing the kernels to be graded according to cross-sectional area. Three sizes of wire mesh were used, and the percentage of wheat kernels that would not pass endwise through each sieve was determined. Potential flour yields were then calculated by a mathematical formula. Figure 2 shows the relatively poor correlation between test weight and milling yield for samples from three crop years, with a correlation coefficient of 0.744. On the other hand, a correlation of 0.957 was obtained between predicted milling yield (based on kernel size distribution) and actual commercial milling yield as seen in Figure 3. These findings have led some authors to conclude that some of the uncertainty in the test weight prediction of flour yield can be attributed to kernel size (Baker and Golumbic, 1970).

There now appears to be a considerable amount of experimental evidence that points to a fairly regular decrease in flour yield as wheat kernels decrease in size (Bailey, 1916; Pence, 1943; Shuey and Gilles, 1969; Dattaraj et al., 1975). It is important though to stress that this conclusion is true only within the same variety (Li and Posner, 1987).

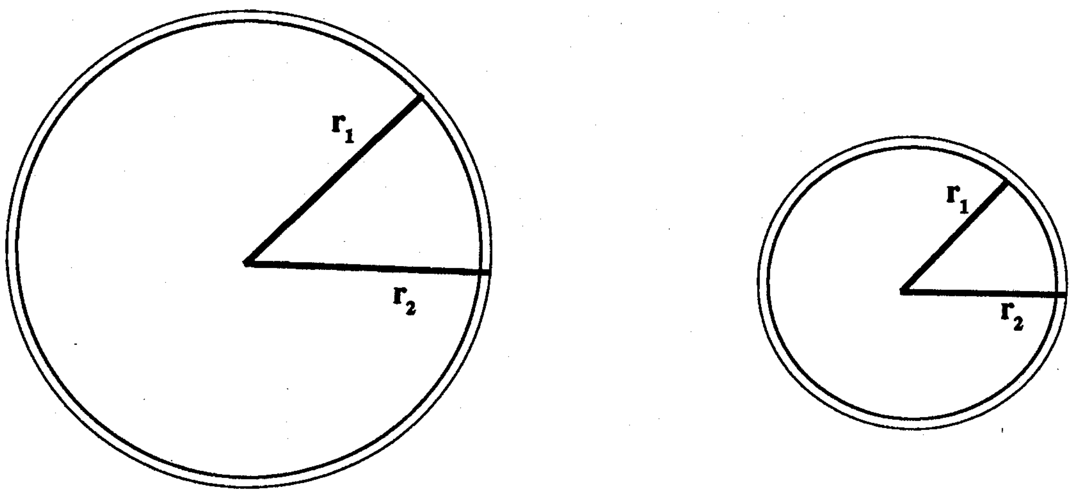
Shuey and Gilles (1969) showed that not only does the percent extraction decrease as the kernel size decreases, but the mineral content of the flour increases as well. Their data revealed that once small kernels are removed, the percent extraction usually increases and the mineral content of the flour decreases. The authors consequently suggest that the value of a wheat lot may be increased when the small kernels are removed and milled separately and the flours blended rather than blending the wheats. However, it is also noted that the percentage of small kernels, their mineral content, and variety are factors that need to be considered when determining how much of an advantage would be gained by sizing a wheat lot prior to milling.

Pence (1943) found that within the same wheat variety, large kernels possess a lower protein content than small kernels. The same tendency was observed in protein content of flour from different sized wheat.

Li and Posner (1987) probably carried out the most extensive study investigating the milling performances of different sized wheat kernels in the

Figure 1

Effect of kernel size on the volume of endosperm relative to bran for a wheat kernel assumed to be spherical in shape



Case A: $r_1 = 3.0$ cm
$r_2 = 3.2$ cm

Case B: $r_1 = 2.0$ cm
$r_2 = 2.2$ cm

Assumption: Thickness of bran layer ($r_2 - r_1$) remains constant

Volume of a sphere: 4/3 (pie) r^3

Case A:

$$\frac{\text{Volume of Endosperm}}{\text{Volume of Bran}} = \frac{V_1}{V_2 - V_1} = \frac{4/3\,(\text{pie})\,r^3_1}{4/3\,(\text{pie})\,r^3_2 - 4/3\,(\text{pie})\,r^3_1}$$

$$= \frac{r^3_1}{r^3_2 - r^3_1} = \frac{3^3}{(2.2)^3 - (2)^3} = \frac{27}{5.768} = \underline{\underline{4.68}}$$

Case B:

$$\frac{\text{Volume of Endosperm}}{\text{Volume of Bran}} = \frac{r^3_1}{r^3_2 - r^3_1} = \frac{(2)^3}{(2.2)^3 - (2)^3} = \frac{8}{2.648} = \underline{\underline{3.02}}$$

Figure 2

Relationship between test weight and actual commercial milling yield for U.S. wheat from crop years 1956-1958
(From Shuey, 1960, p. 72)

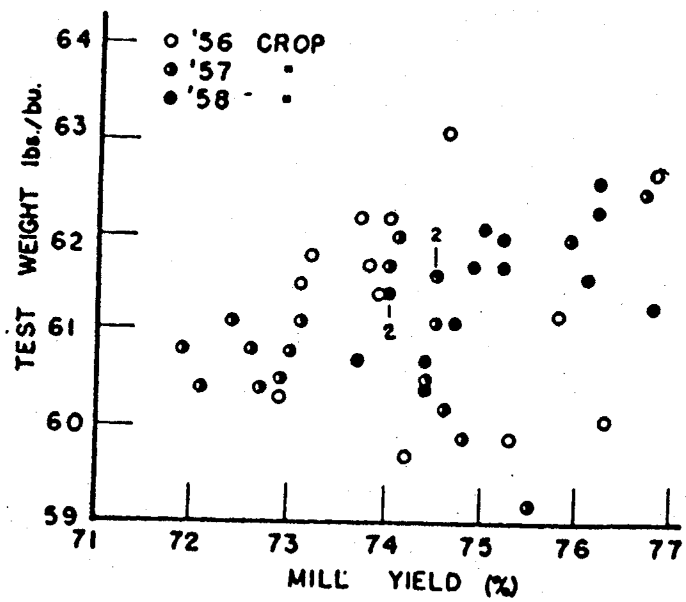
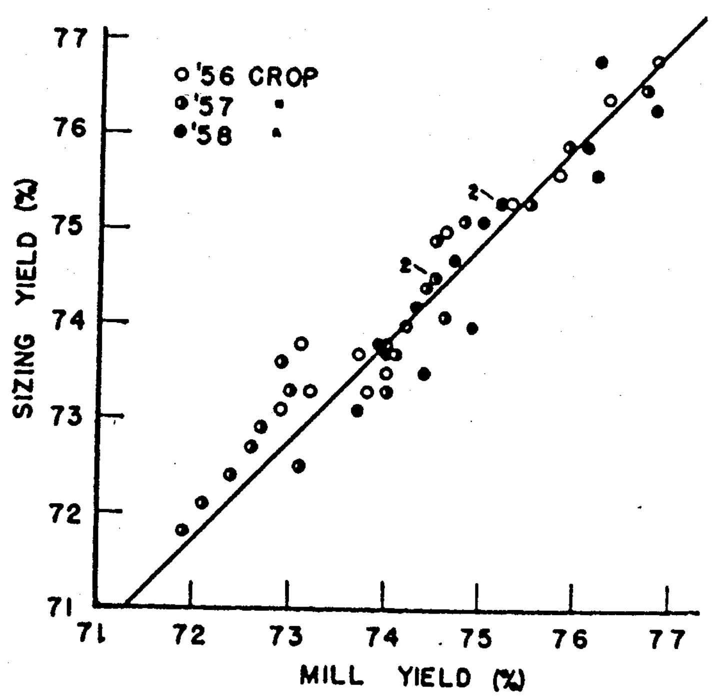


Figure 3

Relationship between milling yield predicted by a kernel-sizing technique and actual commercial milling yield for U.S. wheat from crop years 1956-1958
(From Shuey, 1960, p. 72)



same batch of commercial wheat. Their findings are summarized below.

1. Wheat size distribution plays an important role in influencing physical test results. Large wheat kernels give higher values of test weight and 1,000 kernel weight than small wheat kernels.

2. The smaller the wheat kernels, the higher the pearling value. Pearling values of wheats are comparable only when their kernel size distributions are similar.

3. Milling smaller wheat kernels results in a higher protein loss during milling.

4. The amount of water absorbed is negatively related to wheat kernel size.

5. At a given ash content, the same quantity of large wheat kernels can yield more flour than small wheat kernels. The yield of straight grade flour increases as wheat kernel size increases.

6. When milled with fixed milling systems, different wheat kernels behave quite differently in the break system in terms of break releases, cumulative break releases, and the yield of different sized intermediate milling stocks. The larger the wheat kernels, the higher the break releases in the early break systems. Large wheat kernels tend to release more milling stocks in the early break systems than small wheat kernels. The high sizing yield is thought to be favorable to the yield of low ash flour.

7. The flour milled from large wheat kernels has a higher water absorption and shows a longer peak time on the farinograph curves than the flour milled from medium and small wheat kernels.

8. Flour from small wheat kernels has the greatest mixing stability.

9. The flour of medium wheat kernels yields a significantly greater amount of wet and dry gluten than that of large and small wheat kernels.

In addition, it should be noted that the actual degree of uniformity of kernel size within a given lot of wheat plays an important role in milling stability. From the millers' standpoint, wheats that are uniform in kernel size are desirable in terms of the employment of technical specifications of milling equipment. This would seem to suggest that wheat kernel size distribution could be beneficial as a wheat grading criteria in grading systems (Li and Posner, 1987).

Marshall et al. (1984) used simple geometric models of wheat grains to determine the effects of changes in shape and size on volume per unit surface area and hence potential milling yield. Their analyses showed that both seed size and seed shape can significantly affect the volume per unit surface area of the wheat kernel, and therefore milling yield. Of the various shapes considered, spherical kernels had the highest volume per unit surface area. In theory, then, it was concluded that to maximize milling yield by maximizing volume per unit surface area, wheat grains should be as large as possible and spherical in shape. However, it was also observed that substantial changes in grain volume have a greater effect on milling yield than do changes in grain shape. Also, it was suggested that since grain volume appears to be much easier manipulated in plant breeding programs than seed shape, any efforts to increase milling yield by increasing the volume per unit surface area of the wheat grain should focus on increasing seed size to the maximum possible without sacrificing yield potential or other quality characteristics.

D. Other Characteristics that Contribute to Wheat Quality

There are several other characteristics of wheat that are taken into consideration when making quality assessments. Among those still classified as physical characteristics are kernel hardness, vitreousness, color, the level of damage to the kernel and impurities. In addition, there are botanical characteristics, such as species and variety, as well as chemical characteristics, such as moisture content, protein content, protein quality, alpha-amylase activity, fat acidity and crude fiber and ash content that are also known to be important determinants of overall wheat quality. A comprehensive treatment of how these characteristics influence quality is given by Halverson and Zeleny (1988).

E. Quality Control of Canadian Wheat

Wheat production in Canada involves roughly 35 to 40 million hectares of improved farmland, the bulk (>80%) of which is located in the three Prairie provinces of Manitoba, Saskatchewan and Alberta. In any given year, the actual area seeded to wheat can vary from 10 to 14 million hectares, yielding an annual production level anywhere from 20 to 30 million tonnes. Associated with this distribution of production is the fact that wheat generates a substantially higher proportion of the total farm cash receipts within the Prairies than anywhere else in Canada, making it a major contributor to the economic activity of the region. As approximately 80% of its production is exported, wheat continues to be one of Canada's largest earners of foreign exchange in the international market (Loyns and Carter, 1984).

Wheat produced over such a large geographic area is bound to show a considerable degree of variation in average quality from year to year and location to location, this being largely due to a variety of conditions and extremes of weather during the growing and harvesting season. With uniformity of physical characteristics progressively becoming more important as wheat utilization and processing technologies are increasing in sophistication, more emphasis will likely be given to quality control, especially if a major exporting country wishes to establish and maintain a competitive advantage in the international market.

The Canadian approach to quality control involves two important areas of federal government regulations: 1) licensing of new wheat varieties; and 2) the wheat grading system.

1. The Varietal Licensing System

Before a new Canadian variety can be licensed for commercial production, it must meet a number of legal requirements (Bushuk, 1986a). Firstly, it must conform to the regulations of the Canada Seeds Act (1928) in relation to purity, uniformity, and distinguishability. Secondly, it must meet the grading specifications described in the Canada Grains Act (1971). This Act specifies that to qualify for the top grades of the CWRS class of wheat, the new variety must be "equal to Marquis" (the Marquis quality standard has been replaced by Neepawa since August 1, 1987). It is generally interpreted that this specification applies to all characteristics, including milling and baking quality. Because the Canadian wheat grading system is based on visual distinguishability of wheat classes, varieties offered for the CWRS class must also be visually distinguishable from varieties of other classes such as Canada Western Red Winter (CWRW), Canada Utility (CU) and Canada Prairie Spring (CPS). If a new variety is not equal in quality to the CWRS standard variety, then it may only be licensed into a different quality class (e.g. CU or CPS) provided its kernels can be distinguished from the standard variety of the higher quality class (i.e. CWRS) by visual means. This requirement is unique to the Canadian system. Furthermore, Canadian statutory wheat grading regulations also require that the grain of a new variety be uniform in kernel size, shape , and color and have a consistently good test weight (Bushuk, 1986a).

A potentially new CWRS variety is extensively tested and screened under field conditions by comparing it to Neepawa, the statutory standard, as well as to other commercially grown varieties, in terms of yield, agronomic characteristics (e.g. disease resistance) and end-use quality. As the scope of testing progresses, only the best varieties are submitted to a testing procedure designed for that class of wheat. In the case of bread (CWRS) wheats, there are three testing levels. At the "A" test level, approximately 100 or more potentially new varieties are compared at several locations, while the "B" test sees only the more promising varieties tested. During the final phase of the testing program, the Bread Wheat Cooperative test, evaluation for yield, disease reaction and quality becomes most extensive. Data from this test are reviewed by three National Expert Committees (on grain breeding, grain diseases, and grain quality). A variety may be rejected from the test and thus from licensing consideration by any one Committee at any stage. Varieties may remain in the Cooperative Test for a total of three years. If, at that point, all three Committees still agree as to the quality of the variety and its contribution to Canada's grain industry, the variety is recommended for licensing and the plant breeder submits an application to the Plant Products and Quarantine Directorate of Agriculture Canada. A license may then be issued under authority of the Federal Minister of Agriculture (Loyns et al., 1985).

Critics of these stringent licensing regulations argue that many high yielding, medium quality strains (yet of adequate quality for a different end-use) are wasted by the application of these criteria (i.e. quality equal to the Neepawa standard and visual distinguishability). For example, the Agriculture Canada Research Station in Winnipeg may evaluate up to 8,000 new lines of wheat every year, yet only very few actually end up being licensed (Lukow, 1989). In fact, from 1923 to 1986 only 34 new CWRS varieties were released in Canada, roughly one new variety every two years. In the early 1980s, in contrast, 33 new varieties were released in North Dakota alone over a 5-year period, for an average of more than 6.5 varieties each year (Leisle, 1987) [cited in OTA, 1989a].

2. The Canadian Wheat Grading System

Once approved for commercial production, the next step in the quality control process is the actual grading of the wheat. Grading can be broadly defined as "the segregation of heterogeneous material into a series of grades reflecting different quality characteristics of significance to users" (Canada Grains Council, 1982). This definition implies that the characteristics which determine the separation of a particular commodity into grades should be those denoting value to end-users. The primary objective of grading is to enable the maximum net return from the grain to be extracted from the market. This will only be achieved where the grade becomes a means for the user to communicate with the producer (or seller) as to the quality of the grain which is considered most desirable for a particular purpose.

The grading of wheat in Canada is regulated by the Canadian Grain Commission (CGC), a government and regulatory agency whose legal mandate is established through the Canada Grains Act of 1971. This Act charges the Commission with the responsibility of protecting the interests of grain producers during the marketing of their grain. Specifically, the CGC is directed to establish and maintain standards of quality for Canadian grains and oilseeds as well as to regulate the handling of such grains to ensure a dependable commodity for domestic and export markets. To accomplish these objectives, the CGC has legislative authority for licensing grain-handling facilities, setting grade standards, providing official inspection and weighing services, handling foreign complaints, and ensuring that quality is maintained as grain is moving through the marketing system (Gosselin, 1982a,b). An excellent treatment of the history and evolution of the Western Canadian wheat grading and handling system is given by Irvine (1983).

a. **Grade classification and principal grading factors**. The various classes of wheat grown in Canada, for which grade specifications have been established, are outlined in Figure 4. Of these classes, the hard red spring and amber durum enter the export market in the most significant quantities. At present, Canada Western Red Spring (CWRS) wheats account for about 85% of Canadian wheat exports. Production of wheats of the CWRS class has averaged about 16 million tonnes over the last 10 years (Preston et al., 1988).

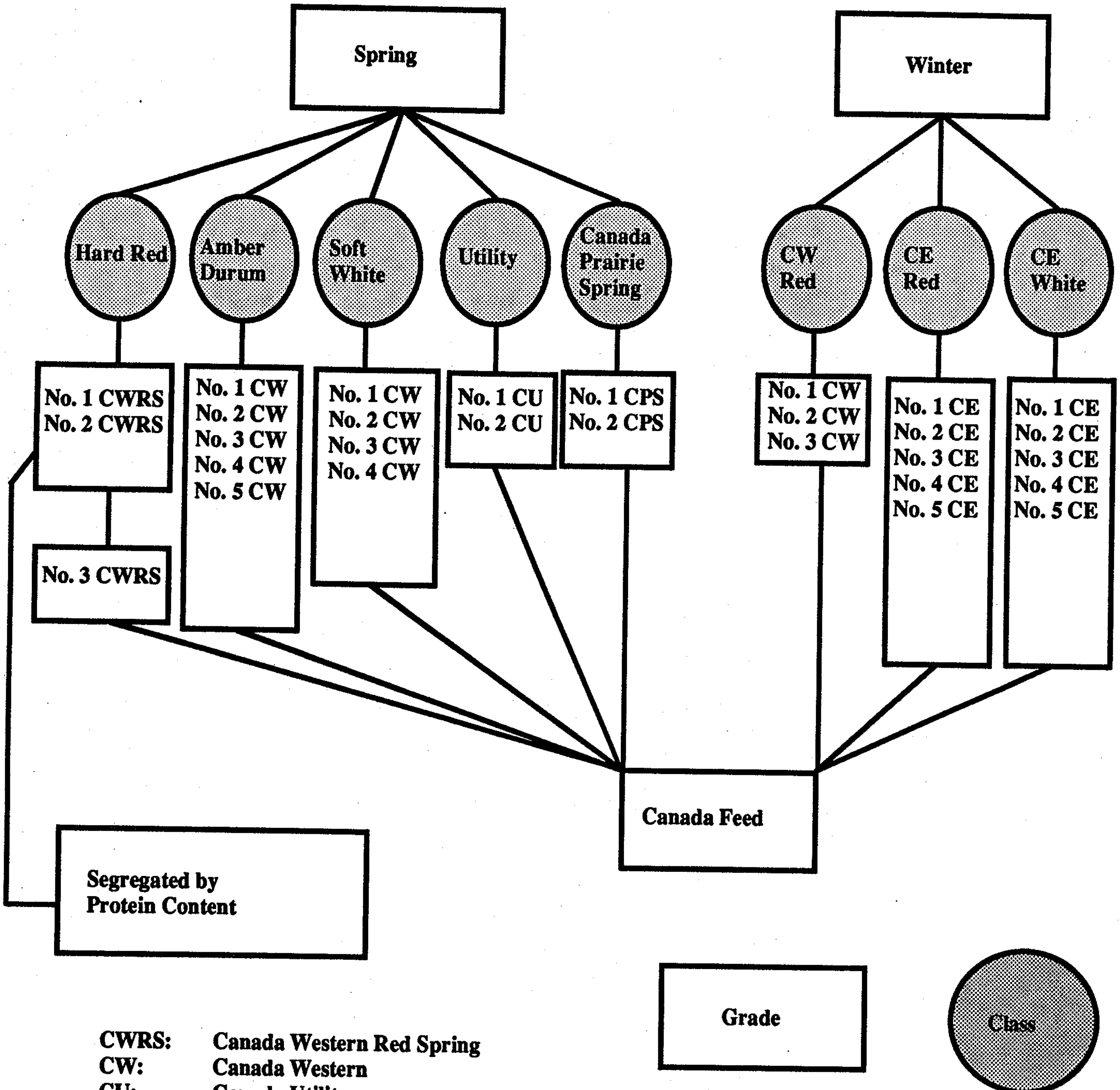
A distribution of the classes and grades of Canadian wheats at terminal elevators for three crop years is shown in Table 1. The CWRS grades (No.1, No.2 and No.3) typically constitute over 60% of the total terminal wheat receipts in any given year. As for the distribution among the three CWRS grades, it is to a large extent a reflection of prevailing environmental conditions, both shortly before and during the harvesting season. For example, during the 1988-89 crop year, the Prairies experienced extensive drought conditions and as a result over 50% of all wheat receipts graded No.1 CWRS.

There are five principal factors considered by grain inspectors when grading Canadian wheat (Bevilacqua, 1987):

1. Test weight
2. Varietal purity

Figure 4

Grade classification of Canadian Wheat (From Bushuk, 1982, p. 508)



CWRS: Canada Western Red Spring
CW: Canada Western
CU: Canada Utility
CE: Canada Eastern
CPS: Canada Prairie Spring

Table 1

Grade distribution of terminal elevator wheat receipts for three crop years
(From Canadian Grain Commission, Annual Reports)

Crop Year

	1986-87		1987-88		1988-89	
Class/Grade	'000t	% of all wheat	'000t	% of all wheat	'000t	% of all wheat
No.1 CWRS[a]	5,680	26.00	6,186	26.08	6,943	52.63
No.2 CWRS	3,101	14.37	7,548	31.83	2,792	21.16
No.3 CWRS	6,194	28.71	4,814	20.30	1,108	8.40
CPS[b]	177	.82	54	.23	30	.23
CU[c]	58	.27	24	.10	6	.05
CWF[d]	2,586	11.99	750	3.16	141	1.07
CWAD[e]	2,453	11.37	3,594	15.15	1,821	13.80
CWRW[f]	637	2.95	352	1.48	108	.82
CWSWS[g]	298	1.38	294	1.24	189	1.43
Other	462	2.14	101	.43	54	.41
Total All Western Wheats	21,574	100.00	23,717	100.00	13,192	100.00

[a] Canada Western Red Spring. [b] Canada Prairie Spring. [c] Canada Utility.
[d] Canada Western Feed. [e] Canada Western Amber Durum. [f] Canada Western Red Winter.
[g] Canada Western Soft White Spring.

3. Vitreousness
4. Soundness
5. Admixture of inseparable foreign material

These are sometimes referred to as degrading factors since a failure to meet the specified grade tolerance in any one factor will result in a lower grade (Gosselin, 1982b).

Under the grading system, grain that contains damaged kernels becomes degraded according to the type, degree and extent of the damage. In order to qualify for the top grade of No.1 CWRS wheat, a sample must contain licensed red spring wheat varieties of the Neepawa type and be "reasonably well matured and reasonably free from damaged kernels" (A summary of the various grade specifications for CWRS wheat is given in Appendix I). Other specifications, such as minimum test weight and maximum limits of foreign material, must also be met, but it is the visual assessment of the amount and severity of the damage relative to standard samples that is most important (Tipples, 1979).

To facilitate practical grading, the Chief Grain Inspector of the CGC prepares the Primary Standard samples for each grade of the new crop, after consultation with a Grain Standards Committee which includes representatives from all elements of the grain industry. The samples are prepared to reflect the degrading peculiarities of the crop. They are used only as visual guides to grading wheat before and on receipt at terminal elevators and shipments from terminal elevators when no Export Standard sample is established for a grade. The Export Standard samples are used for most grades of Western Canadian wheat to govern grading of shipments out of terminal, transfer and process elevators. They are prepared to represent the average of the grade rather than the minimum represented by the Primary Standard samples (Bushuk, 1986b).

Each of the wheat grades in Figure 4 is further subgraded according to moisture content as straight (below 14.5% moisture), tough (14.6-17.0%) or damp (over 17.0%). In addition, No.1 and No.2 CWRS are segregated by protein content upon arrival at terminal elevators. Protein segregation levels are set each year (or as required), according to the market demand and availability of wheat of specific protein content. Computerized methods have been developed to determine the protein boundaries based on the protein content of the subgrade and amount of production and protein content of the grade in question (Dunne, 1973). Protein content of samples is determined by on-line near infrared reflectance (NIR) techniques. After arrival at the terminal elevator, the grain is cleaned to conform with the grade specifications and, if necessary, dried to straight-grade requirements (Bushuk, 1986b).

b. Inconsistencies in current grading methods. Of all the principal grading factors, only one, test weight, is measured objectively. Even so, very seldom does test weight determine the actual grade that is assigned, since in almost all cases the actual test weight of No.3 CWRS wheat exceeds the minimum specified for No.1 CWRS (Preston et al., 1988; Canadian Grain Commission, 1989a). Many of the other grading factors are expressed as percentages in the grading guide (see Appendix I), but the actual percentage values are calculated from the amounts of components separated on the basis of visual examination and not from any direct objective measurement (Bushuk and Sapirstein, 1987). As for degree of soundness, qualifying adverbs such as "fairly", "moderately" and "reasonably" are judgemental factors which cannot be precisely measured. As a result, virtually all the grading factors must be visually evaluated by grain inspectors, using judgement derived from training and experience. Visual inspection of grain samples, however, is usually based on relative and not absolute judgements, as the physical characteristics which make each grading factor vary in degree are difficult if not impossible to quantify subjectively (Sapirstein and Bushuk, 1989).

The Grain Inspection Division of the CGC has centralized control over 165 grain inspectors and their assistants (Bevilacqua, 1987). Since there may well be differences in experience and therefore judgement from inspector to inspector, one would expect to see some inconsistencies in determination of grade. Table 2 confirms this hypothesis. Of a total of 9,111 grain samples reinspected at various locations across Western Canada during the 1988-89 crop year, there was a revision in grade in 13.1% of the samples: 12.9% of the reinspected samples received a higher grade, while 0.2% received a lower grade from that originally assigned. For the 1985-86, 1986-87 and 1987-88 crop years the numbers are 10.9%, 12.5% and 14.1%, respectively, for upward grade revisions, and 0.2%, 0.6% and 0.3%, respectively, for downward grade revisions. Speculation still remains about the 255,006 samples (96.6%) that were not reinspected: Would the percentage of upward grade revisions have been similar, lower, or perhaps even higher?

Of all the major grain companies, United Grain Growers (UGG) alone reported that audit results of its grain inventories showed a grade loss of $3.1 million during the 1986-87 crop year and $700,000 during the 1987-88 crop year (UGG, 1989).

From an economic perspective, the increased homogeneity of grades of wheat resulting from the grading process serves to increase both operational and pricing efficiency (Futz, 1989). In order for these two economic criteria to be realized, it is extremely important that samples of wheat of the same composition

Table 2

Grade revisions of Western grain after reinspection of carlots and trucklots at various locations for the 1988-89 crop year (From Canadian Grain Commission, Annual Report)

No. of Samples

Location	Inspected	Re-inspected	Un-changed	Grades raised	Grades lowered
Thunder Bay	99,716	3,653	3,162	444	4
Winnipeg	5,790	360	296	66	1
Churchill	972	27	21	6	-
Moose Jaw	3,084	306	206	70	11
Saskatoon	2,634	223	143	65	4
Calgary	2,610	9	8	1	-
Vancouver	114,973	3,421	3,130	261	2
Prince Rupert	34,338	1,112	844	264	1
TOTAL	264,117	9,111	7,810	1,177	23
Percentage of total carlots and trucklots	100.0	3.4	99.5	0.4	*
Percentage of reinspections	-	100.0	85.7	12.9	0.2

* less than 0.05%.

and of similar physical characteristics receive the same grade at every point of inspection.

F. Application of Digital Image Analysis for Wheat Inspection and Grading

Under Canada's wheat grading system the determination of grade depends completely on subjective assessments by experienced grain inspectors, who have been trained to skilfully recognize the characteristic patterns of the various grading factors. Standard grade samples are prepared each year and used as a reference for visual comparisons.

True measurement of quality characteristics by any objective means will always be preferred by end-users to the use of subjective measurements (Coudiere, 1990). One technology showing considerable promise for objective measurement of certain grain quality parameters is a computer-based methodology called digital image analysis (DIA). The primary reason for its potential application for wheat inspection and grading purposes lies in its capability to quantify, with precision, speed and consistency, the composition and physical characteristics of grain samples using parameters which form the basis of visual inspection (i.e. object size, shape, brightness, color and texture)(Sapirstein and Bushuk, 1989).

1. Principles of Digital Image Analysis

Computer-assisted DIA usually entails quantification and classification of images and of objects of interest within images (Joyce-Loebl, 1985). It basically involves the computer processing and mathematical analysis of images created by video cameras and other image-capturing devices. The technique is capable of distinguishing between objects on the basis of size, shape, brightness, texture or color. It can also be used to identify combinations of these attributes (Ronalds et al., 1987).

There are essentially four principal stages to the DIA methodology (Sapirstein and Bushuk, 1988):

1. Image acquisition, digitization and storage
2. Image segmentation and object detection
3. Feature extraction and measurement
4. Analysis

One of the first steps in DIA is the conversion of the analogue signal (i.e. the picture seen by the video camera) into digital form (i.e. numbers) so that the information can be processed and stored by the computer. This process is referred to as image digitization and is carried out by an electronic component called the analogue to digital converter. It involves dividing the video image into a large number of small elements called pixels (picture elements) and storing the screen location and tonal value of each pixel for subsequent computer analysis. The DIA system used by the Grain Industry Research Group (Food Science Department, University of Manitoba) has 640 x 480 = 307,200 picture elements and the tonal value of each element is stored as one of 256 shades of gray (gray levels), where black = 0 and white = 255. A typical gray level frequency distribution for a 1CWRS carlot sample of 405 kernels is depicted in Figure 5. The average gray level value (GLV) of all 885,358 pixels was computed to be 134.5. The average GLV is a measure of the light reflectance, not the true color, of the wheat sample. The threshold gray level value is set at 44, meaning that any pixel with a GLV of less than 44 is defined as dark background, whereas values between 44 and 255 represent the CWRS wheat kernels. Image segmentation and object detection are perhaps the most critical steps in DIA. Segmentation describes the act of separating the regions of interest within an

Figure 5

Digital image histogram showing a typical gray level frequency distribution for a 1CWRS carlot sample of 405 kernels

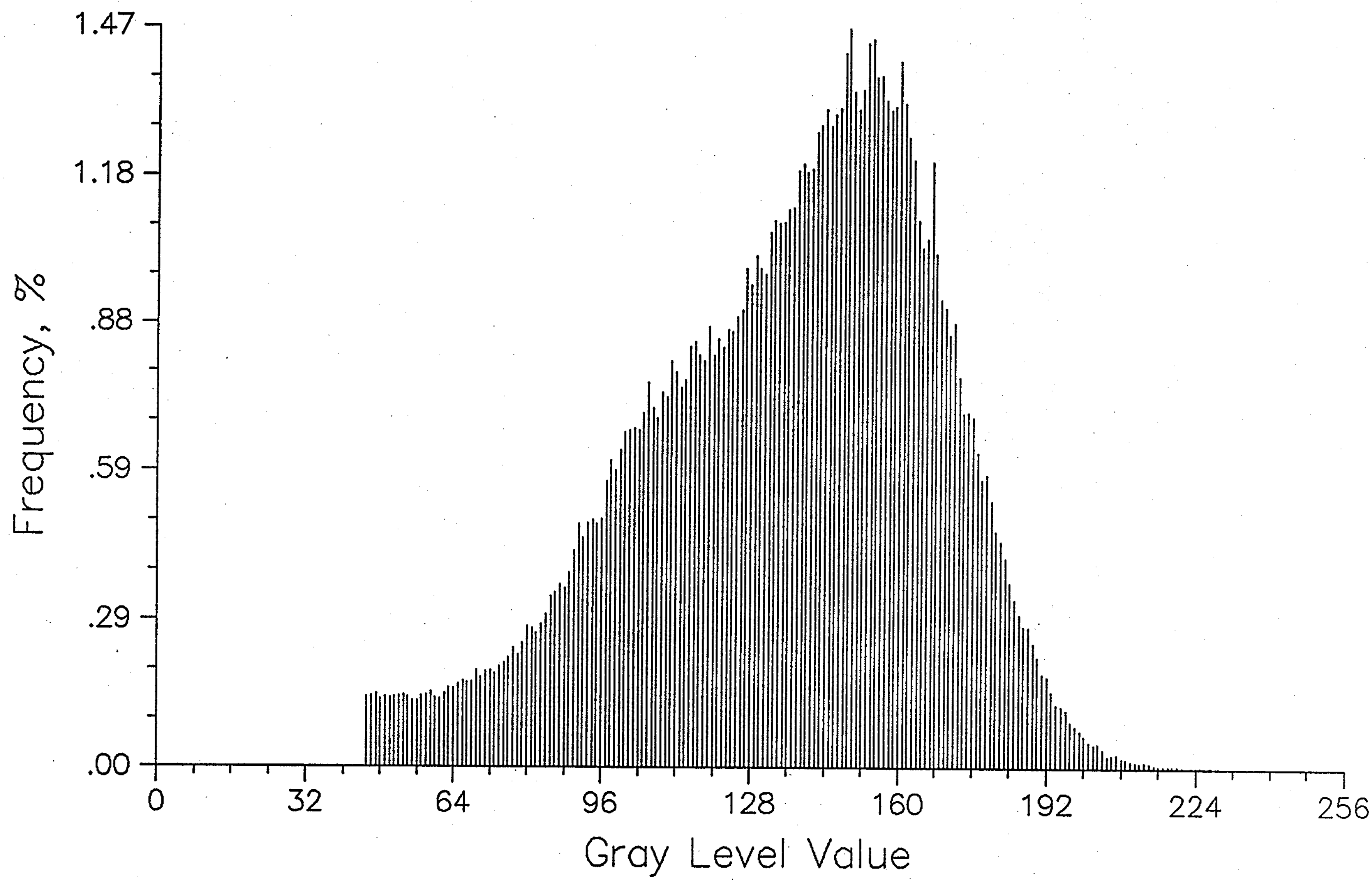


image from the background whereas object detection is a data-reduction step which produces a description of each object that is more compact than a list of co-ordinates of every pixel it encompasses (Joyce-Loebl, 1985). The aim is the perception of all relevant objects in the image and the exact specification of their locations and contours. They are necessary steps in any DIA system in order to provide data which allow subsequent analyses to be confined to individual regions of interest only (Sapirstein and Bushuk, 1988).

The ability of DIA systems to extract certain morphological features of objects and subsequently provide quantitative results undoubtedly are some of the more important reasons why they are being applied to such a wide range of scientific disciplines. Once the measurements have been made, the results can be analysed to make some sort of decision or classification. In the cereal science and technology area this has usually meant attempting to objectively classify the various cereal grains as well as to discriminate between the various wheat classes and varieties. As for this particular research project, the focus is on examining the feasibility of using DIA to distinguish between three commercial grades of CWRS wheat by measuring certain physical characteristics that are known to contribute to wheat quality. An objective assessment of the uniformity of these physical quality parameters within each CWRS grade will then also allow for an evaluation of the performance of the Canadian wheat grading system vis á vis the samples used in the study.

Most applications of DIA-specific technology have traditionally been in such fields as biomedical imaging, aerial and satellite photo interpretation, industrial robotics and artificial intelligence (Sapirstein et al., 1987). Recently some studies have started to use DIA to quantify important quality factors in various food products such as meat, cheese, pizza crusts, peanut butter and peach fruit (Newman, 1984a, b, 1987a, b; Hildebrandt and Hirst, 1985; Heyne et al., 1985; Wassenberg et al., 1986; Ruegg and Morr, 1987; Whitaker et al., 1987; Stutte, 1989). Common applications in the soil and crop sciences are reviewed by Yanuka and Elrick (1985).

The use of DIA to assess the composition and physical characteristics of grain samples represents a new discipline in cereal science and technology. Over the past few years, however, there have been many applications: to determine the physical dimensions of rice kernels (Goodman and Rao, 1984), to examine the variation in kernel morphology in populations of oat cultivars (Symons and Fulcher, 1988a), to characterize rudimentary seed shape in different crop and weed species (Draper and Travis, 1984; Travis and Draper, 1985) and to quantify the size-distribution of starch granules during endosperm development in hard red winter wheat (Bechtel et al., 1990). With respect to more specific grading applications, DIA has been used to discriminate among various cereal grains (Lai et al., 1986; Ronalds et al., 1987; Sapirstein et al., 1987), to specifically discriminate among wheat classes and varieties (Zayas et al., 1985,1986; Keefe and Draper, 1986,1988; Neuman et al., 1987, 1989a,b; Symons and Fulcher, 1988b,c; Myers and Edsall,1989), and, more recently, to discriminate among non-cereal constituents in wheat samples (Zayas et al., 1989).

III. MATERIALS AND METHODS

A. Wheat Samples

The wheat samples analysed in this study represented the three most important commercial grades of the Canada Western Red Spring (CWRS) class. All samples were obtained from the Inspection Division of the Canadian Grain Commission (CGC) who collected them during the May-August 1988 shipping period.

The samples were provided in three categories: (1) Primary elevator bin, (2) Pacific carlot unloads and (3) Pacific third quarter cargo loads. The primary elevator bin samples came from primary elevator managers as they were submitting wheat samples to the CGC for official grade and protein determination. The carlot unloads were samples of individual railcars (from various primary elevators) that unloaded at Pacific Coast terminal elevators. The cargo samples represented composites of wheat leaving Pacific Coast terminals, being loaded onto ocean-going vessels for export market destinations. Samples from both the carlot and cargo categories were taken from streams of grain moving on a belt or through a spout using automatic sampling devices.

Three CWRS grade levels were obtained for each sample category, giving a total of 258 samples, each containing roughly 450 to 500g of wheat (see Table 3). It is interesting to note that by far the bulk (78%) of all the carlot unload samples originated out of Saskatchewan. With respect to their particular grade distribution, 78% of all 1CWRS, 66% of all 2CWRS and 65% of all 3CWRS carlots came from that province. These percentage figures are not surprising since they are consistent with the fact that over 60% of all Prairie wheat is produced in Saskatchewan. The geographical distribution of the carlot samples is also shown in Figure 6.

Table 3

Geographic distribution of CWRS wheat samples by sample category and grade

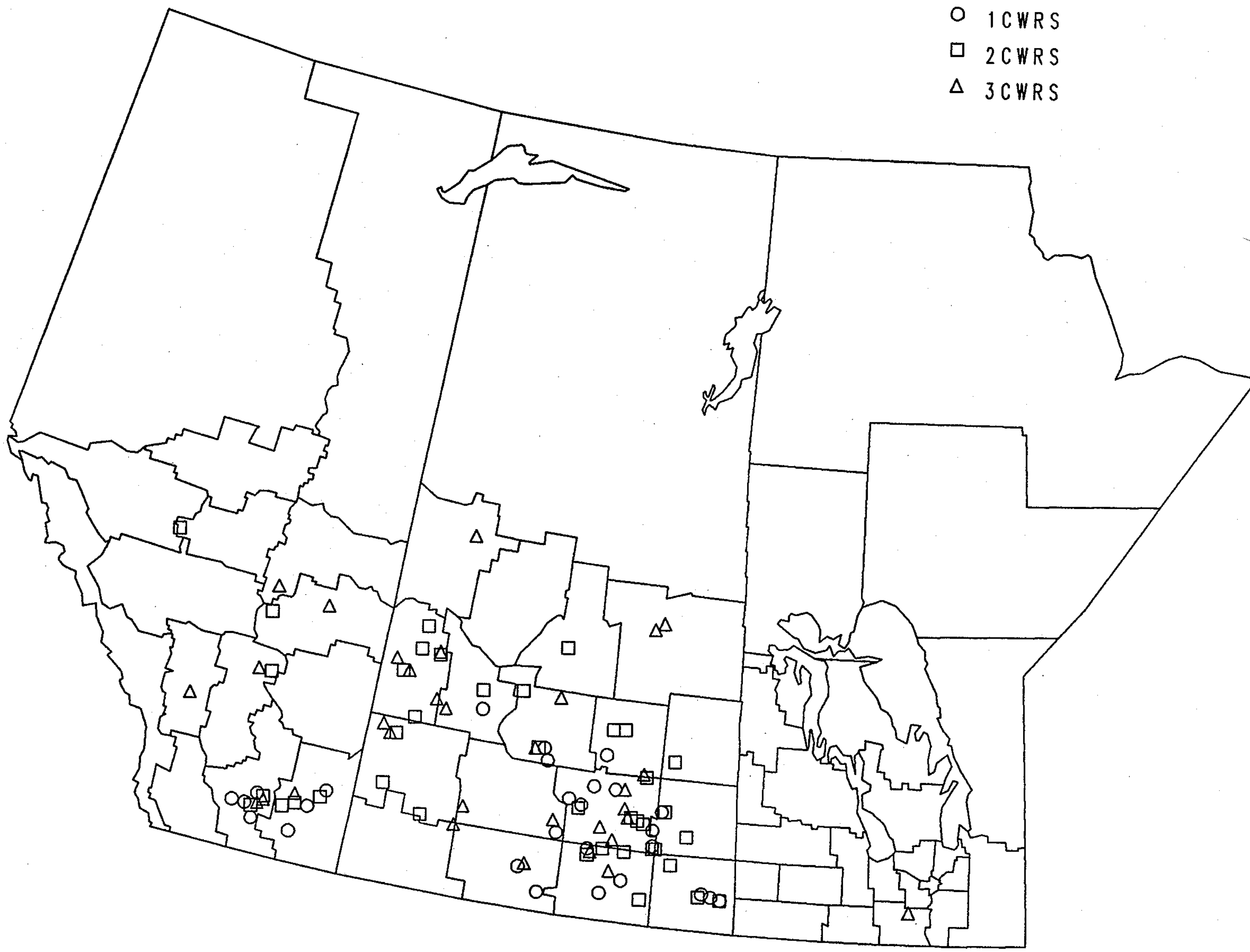
Sample category and province of origin

	Primary elevator bin				Carlot				Cargo	Grand total
	Man	Sask	Alta	Total	Man	Sask	Alta	Total	Prairies	
1CWRS	5[a]	21	0	26	0	20	7	27	25	78
2CWRS	15	12	0	27	0	32	8	40	25	92
3CWRS	14	14	1	29	1	28	7	36	23	88
All grades	34	47	1	82	1	80	22	103	73	258

[a] Number of samples, each representing from 450 to 500g of wheat.

Figure 6

A map showing the distribution of CWRS carlot samples by grade and province



B. Sampling Methods

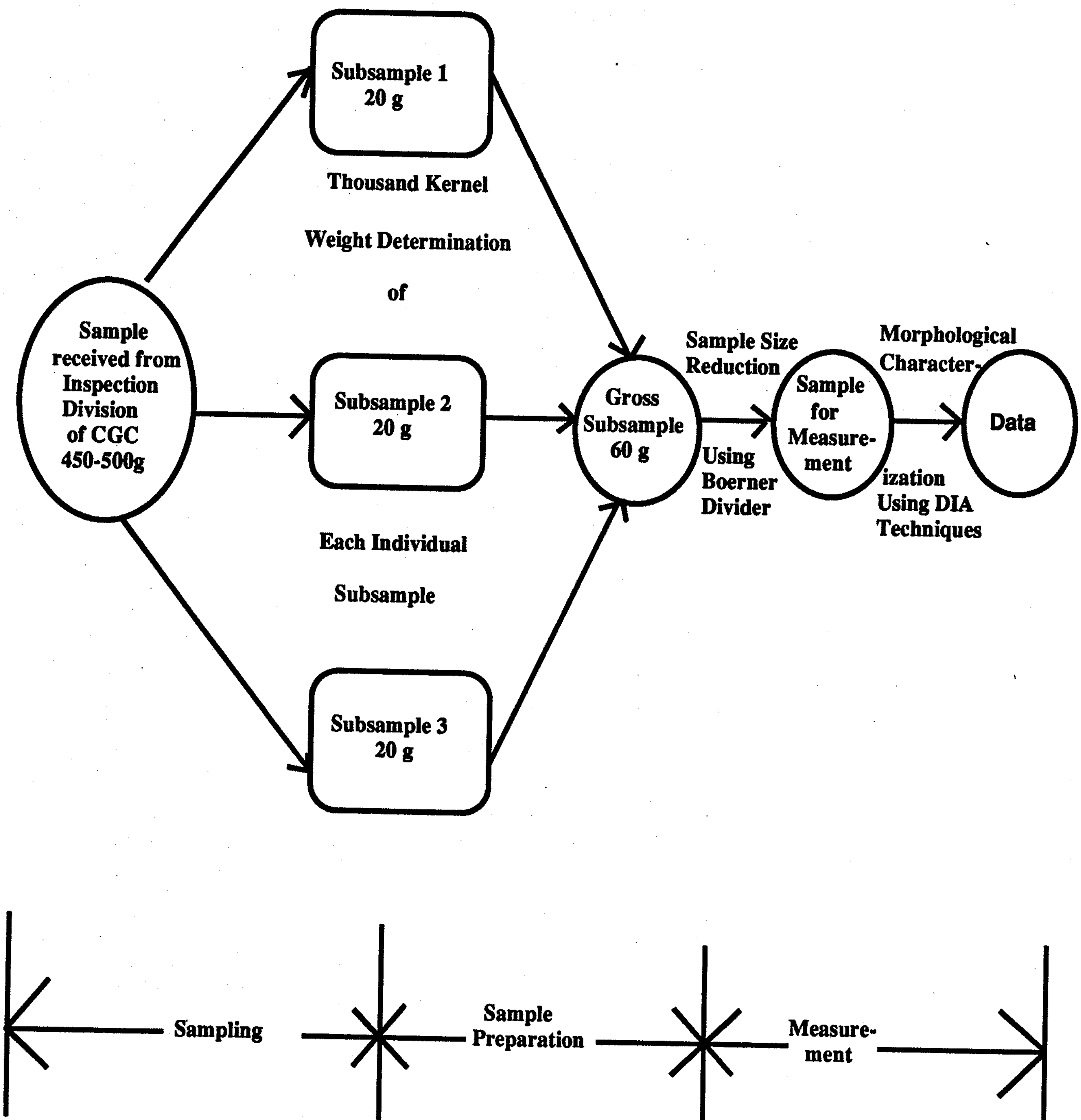
Fan et al. (1976) referred to the operation of sampling as being the withdrawal of small quantities from the bulk of a material in such a way that the withdrawn quantities are as closely representative of the whole and as similar in structure and consistency as may be practicable under the given circumstances. Sampling investigations are said to yield results in terms of the probability since all samples are subject to statistical variations. The authors also indicate that although experimental errors and operator bias are imposed on these variations, careful observation and analysis can result in the elimination of the latter and the reduction of the former.

The overall approach used in this study for preparing individual wheat samples for the characterization of morphological features (i.e. kernel size, shape, and brightness) is schematically outlined in Figure 7. All of the samples received were first stored in the laboratory at room temperature for a period of up to five months to allow for moisture content equilibration. Consequently, all test data are reported on an 'as is' moisture basis.

One of the first steps in the overall sampling process was to pour each individual sample (c.450-500g) into a large plastic container and then to mix it thoroughly. A scoop was used to withdraw grain from randomly selected areas within the container to give a c.21 to 22g subsample. All dockage and foreign material were then removed from the subsample by hand-picking so as to end up with 20g of clean wheat. The kernel count of the subsample was determined next with the aid of an electronic seed counter. Thousand kernel weight (TKW) was calculated and the subsample was then stored in a plastic petri dish. Before the withdrawal of the second subsample, the remaining wheat in the plastic container (i.e. the main sample) was re-mixed. The entire procedure was repeated until a

Figure 7

Flowsheet illustrating sampling and sample preparation methods used in this study



total of three subsamples of 20g each were obtained from each main sample. The TKW data from the subsamples was averaged to give a TKW value for the main sample.

The second step was to recombine the three subsamples to give a composite sample of 60g (Figure 7). The 60g subsample was thoroughly mixed by passing it through a Boerner Divider. The subsample was split by the divider into four portions of about 12 to 15 grams (400-500 kernels) each. One of the four portions was then randomly selected and was counted out (using a vacuum counting plate) to 400 kernels. This portion then became the measurement sample, being representative of the main sample. All 400 kernels in the measurement sample were then morphologically characterized using DIA techniques. The sample size of 400 kernels was selected based on results from a preliminary experiment, which will be discussed in the next chapter.

C. Experimental Equipment and Procedures

1. Thousand Kernel Weight Determination

An electronic seed counter (Model 850-2, The Old Mill Co., Savage Industrial Center, Savage, Maryland) was used to determine the weight per thousand kernels. The device consists of a vibrator, counting bowl, counter, electric eye, and associated electronic circuitry.

The vibrator causes the wheat kernels to move up a narrow spiral ledge in single file around the sides of the bowl. As the wheat kernels reach the exit at the top of the bowl they fall individually through the beam of an electric eye, and are recorded on a counter.

Instead of counting exactly 1,000 kernels and reporting this value as "1,000-kernel count," the kernel count in a specific weight of wheat was determined as follows:

1. Prepare three 20-gram (± 0.1 gram) subsamples with broken kernels and foreign material first removed by hand-picking.
2. Pour weighed subsample into the counting bowl and turn on the counter, and record count.
3. Reset counter to zero, and test the remaining two subsamples.
4. Average the count from the subsamples and calculate the weight of 1,000 kernels. This value then becomes the TKW for the main sample, reported on an 'as is' moisture basis.

TKW was determined in this fashion for 258 samples of CWRS wheat, representing three sample categories and three grade levels (Table 3).

The procedure for counting all of the kernels in a specified weight as outlined above is thought to be more accurate than weighing the 1,000 kernel count. Johnson and Hartsing (1963) argue that from a statistical viewpoint, error is reduced by counting all of the kernels in the bowl rather than counting the first 1,000 kernels which pass the electric eye. In the latter case, the vibrator in the counter may select certain kernels ahead of others. The procedure is also more convenient and quicker because when a fixed weight is counted, the bowl does not have to be emptied after each test.

2. Image Analysis System

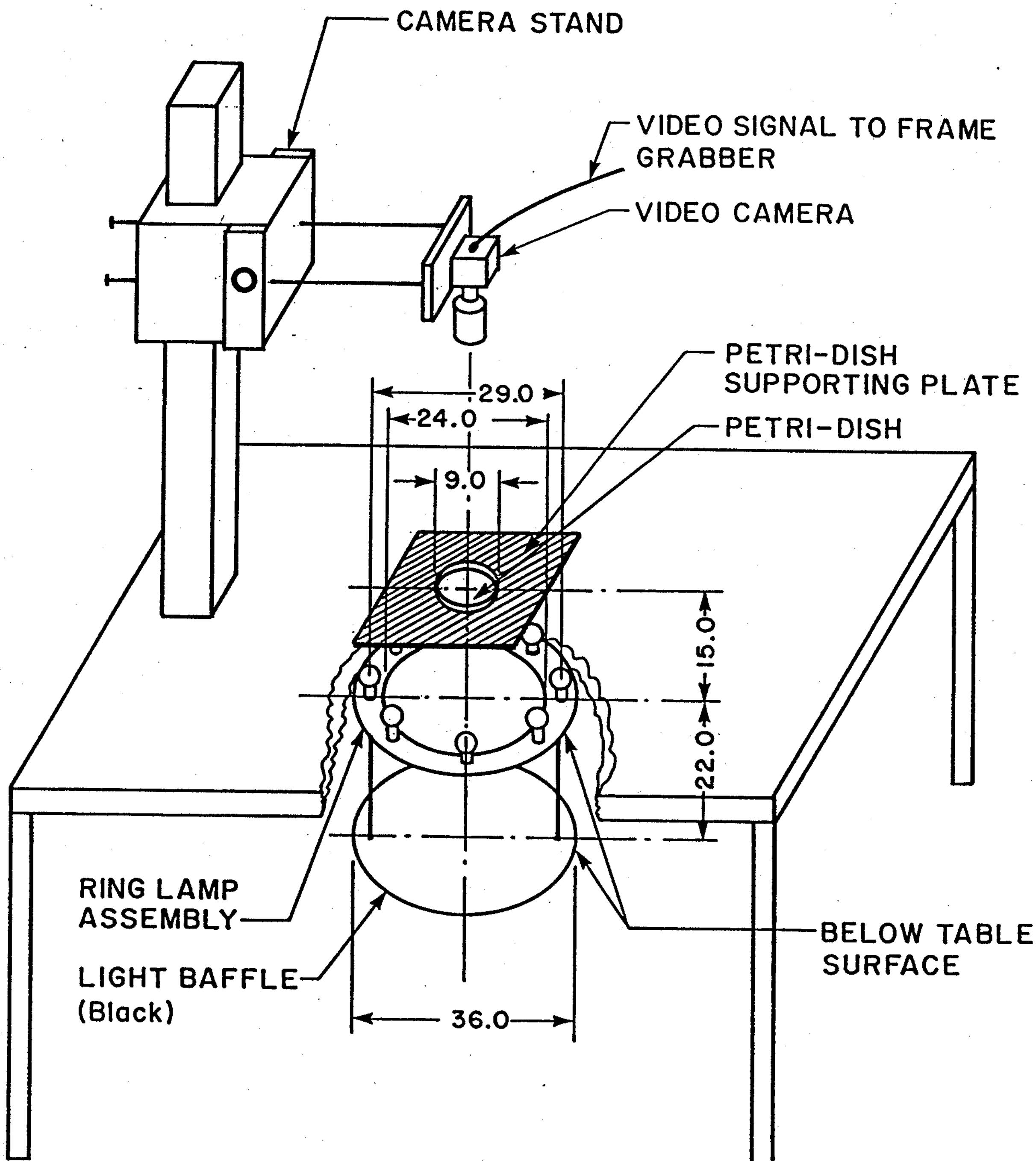
All quantitative measurements of grain morphology were carried out using the image analysis system of the Grain Industry Research Group (GIRG, Food Science Department, University of Manitoba). The following description of the various components of the system is adopted from Sapirstein et al. (1987) and Sapirstein and Bushuk (1989), with minor modifications, as basically the same system setup was used for this particular study.

a. System hardware components. A schematic representation of the customized image analysis workstation and its major components is given in Figure 8. The workstation table was designed to accommodate undisturbed viewing of grain samples in both reflected and transmitted light. The table was centre-cut and routed to support 100 x 15mm polystyrene petri dishes into which grain samples were placed for image acquisition. Lights positioned above and below the horizontal plane of the grain sample supply the required illumination. All grain sample images processed in this study were acquired using only reflected light (i.e. using the light source positioned above the horizontal plane of the grain sample). Video images were obtained using a monochrome charge-coupled device (CCD) camera (Panasonic WV-CD 50), fitted with a 50mm f-1.4 fixed focus C-mount lens (Fujinon Inc.) and a 11mm extension tube. Manual iris control for system calibration purposes was used throughout the image acquisition phase of the experiment. Horizontal and vertical camera positioning was accommodated using a Bencher M2 (Bencher Inc., Chicago) stand.

Digitization and pre-processing of the NTSC (National Television System Committee) video camera output was carried out using a PC-Vision Plus ("square pixel" option) image frame grabber (Imaging Technology Inc.). The digitization board provided 8-bit or 256 gray level digital images, each comprising 640 columns by 480 rows of picture elements (pixels) with equal vertical and horizontal densities (Sapirstein and Bushuk, 1989). The frame grabber also facilitated software control of video signal gain and offset before digitization. This feature was extremely useful to optimize the dynamic range of digital images, which was not possible using lens aperture control alone. Research via

Figure 8

Schematic diagram of customized image analysis workstation used in this study (PC hardware and color video monitor not shown) Courtesy Dr. H.D. Sapirstein, Grain Industry Research Group Department of Food Science, University of Manitoba



(All measurements in cm)

small-scale experiments by GIRG staff has revealed that the dynamic range of digital grain images appears to be optimized at a video signal gain and offset of 70 and 73, respectively. The frame grabber was implemented in an IBM-AT compatible personal computer (PC), with 2 megabytes of memory running under DOS 3.3, which provided system control and computational power. Essential PC hardware included a numeric co-processor to shorten processing time and a 150 megabyte hard disk used for program, temporary image and data storage. After acquisition and digitization, the digital images were viewed on a color video monitor (Sony PVM-1271Q). A tape cartridge system (Tecmar QIC-60) was used to permanently store all digitized images and their extracted feature data, each tape having a 60 megabyte capacity. The entire experiment encompassed 1,760 images digitized for a total of over 70,000 wheat kernels from 176 samples (the primary elevator bin samples were not used for reasons outlined in the discussion of the TKW results). This required a storage capacity of roughly 541 megabytes, or about 10 magnetic tapes.

b. Sample illumination and system calibration. The illumination system consisted of a light stand in combination with a ring lamp assembly positioned above the table surface (Figure 8). Reflected light images of grain samples were obtained using a conventional 90 degree detection - 45 degree illumination configuration. Diffuse incident light was provided by four incandescent tungsten filament frosted envelope lamps (Spectro 40 Watt, color temperature, 2750 K) in a ring configuration (24cm lamp envelope diameter). Images of grain samples with kernels positioned in dorsal orientation were routinely acquired from a distance (lens to object) of 30cm, which provided a spatial resolution of $0.0054mm^2$ per pixel.

A working standard for digital image acquisition consisted of a white opal acrylic sheet, 2mm in thickness, with a nominal light transmittance of 15% (Acrylite 015-FF, Chemacryl Plastics, Rexdale, ON). This material was convenient as a single 10 x 10cm sheet facilitated system calibration under reflected light conditions. This calibration step was performed prior to each grain image acquisition session in the following way: a small central area of interest of the white opal acrylic sheet was repeatedly digitized and the lens aperture manually adjusted (with constant frame grabber gain and offset values of 70 and 73, respectively) until a computed mean gray level (reflectance) value of 215 (± 0.5 gray level) was obtained. The latter represented a pre-determined reference target value that was shown to optimize the dynamic range of a set of samples (Sapirstein and Bushuk, 1989).

c. Object perception and feature extraction. Previously developed computer programs for object detection and measurement of kernel size, shape and brightness (i.e. reflectance) features were written in FORTRAN (Microsoft Fortran 4.1) and C (Microsoft C 5.1) languages, and implemented on the workstation personal computer. Individual objects within a digitized frame were identified using an iso-density contour following algorithm (Sapirstein and Bushuk, 1989) based on reflected light images of kernels. The image analysis system was capable of making over 40 separate measurements on each detected object. A listing of computed morphological features used in this study is given in Table 4, along with a geometrical representation of a wheat kernel as seen in Figure 9.

Digital image extracted features were invariant to kernel rotation, with the practical effect that there was no constraint to manually position and precisely orient individual kernels in a certain way. Nevertheless, individual

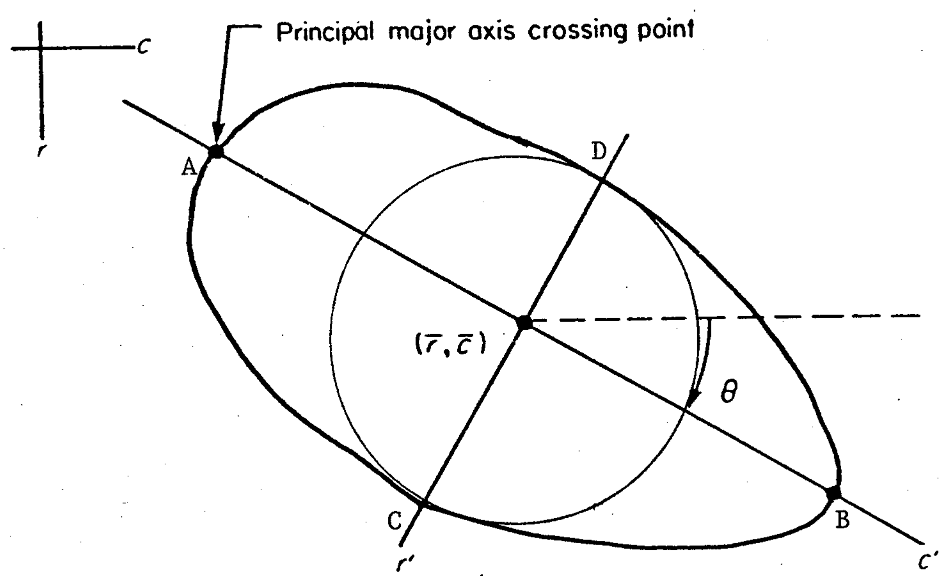
Table 4

Definition of kernel size, shape and brightness features computed by digital image analysis

Parameter	Definition
AREFL	Mean reflectance of pixels within kernel contour
CLEN	Contour length (mm)
AREA	Area enclosed by contour (mm^2)
LENGTH	Principal axis length (mm) [i.e. d(AB)]
WIDTH	Width of minimum enclosing rectangle (mm) [i.e. d(CD)]
RAR	Rectangular aspect ratio (LENGTH/WIDTH)
NCP	Number of pixels in object contour
MMAX	Principle major axis centroidal moment of inertia
MMIN	Principle minor axis centroidal moment of inertia
MAR	Moment aspect ratio (N20/N02)
THINN	Thinness ratio [4π(AREA)/$CLEN^2$]
AMEC	Area of minimum enclosing circle centered at centroid
N20, N02	Normalized low order central moments
M20, M02	Un-normalized low order central moments

Figure 9

Geometrical representation of a wheat kernel and morphological features quantified by digital image analysis



kernels needed to be spatially separated from each other as the contour following algorithm lacks the capability to identify the contour of two or more touching kernels. The N_{02} and N_{20} features are also invariant to object size and so correspond more directly to a shape characterization (Sapirstein et al., 1987; Sapirstein and Bushuk, 1989).

D. Statistical Analysis

Statistical analysis of extracted morphological feature data was performed using the SAS statistical package (Version 6.03), running under UNIX System V on the GIRG's HP 9000 Model 350 (Hewlett-Packard Co., Palo Alto, CA) mini-computer. The following statistical procedures (SAS Institute Inc., 1988) were used: (1) MEANS, for calculating univariate statistics, such as mean, variance, standard deviation and coefficient of variation; (2) ANOVA, for analysis of variance, to test for significance of mean feature differences for the three grade level comparisons (i.e. 1CWRS vs. 2CWRS, 2CWRS vs. 3CWRS and 1CWRS vs. 3CWRS); (3) REG for least-squares regression, to determine which subsets of independent variables "best" explain the variation in the dependent or response variable; (4) DISCRIM for discriminant analysis and classification, to develop and evaluate linear discriminant models; (5) STEPDISC, for stepwise discriminant analysis to evaluate the marginal contribution of each additional feature added to an existing feature set in the overall three-way grade level discrimination; and (6) CANDISC, for canonical discriminant analysis and classification, to graphically evaluate, in three dimensional space, the level of discrimination which exists in the data based on a discriminant model using all or certain combinations of kernel size, shape and brightness features. Units of spatial measurement for most morphological feature parameters are in pixels, except for those where a transformation was made from pixels to mm or mm^2 using an object of known size.

IV. RESULTS AND DISCUSSION

A. Relationship Between CWRS Grade and Thousand Kernel Weight

Depending on the grade and sample category, average thousand kernel weight (TKW) values typically ranged from 30 to 31.5g as summarized in Table 5. These numbers are in line with the 10-year (1978-87) averages reported by the Canadian Grain Commission (1989b). In order to determine statistical differences between the various CWRS grades, Duncan's New Multiple Range Test (Steel and Torrie, 1980) was run using the SAS statistical package. The results were as follows:

1. For the primary elevator bin samples, there was no significant difference in mean TKW for any of the three possible grade level comparisons (i.e. 1 vs. 2, 2 vs. 3 and 1 vs. 3CWRS).

2. For the carlot samples, there was no significant difference in mean TKW for any of the three grade level comparisons at the 1% level. At the 5% level, only the 2 vs. 3CWRS grade comparison gave significantly different mean TKW values.

3. For the cargo samples, there was a significant difference in mean TKW for the 1 vs. 2CWRS grade comparison only, at the 5% and 1% significance levels.

The variability in TKW, as measured by its coefficient of variation (C.V.) was highest in the No.3 grade for all three sample categories. Moreover, the expectation that there ought to be a progressive increase in TKW variability with lower grades was confirmed for both the carlot and cargo sample categories. However, this trend was not observed in the primary elevator bin sample category, where the results showed that on average the No.2 grade was more uniform in TKW than the No.1 grade. It is speculated that this reflects the ongoing blending between these two grades at primary elevators. For example, consider the following situation. An elevator having a considerable amount of 1CWRS wheat already in storage may blend it with incoming and otherwise 2CWRS deliveries,

Table 5

Relationship between grade and thousand kernel weight for three sample categories of CWRS wheat ('as is' moisture basis)

Grade	No. of Samples	Ave TKW(g)	Range (g)	Variance	Std. Dev.	C.V.	% Decrease in C.V. Cargo vs. Carlot
			I Primary Elevator Bin Samples				
1 CWRS	26	31.27	6.81	2.85	1.69	5.39	
2 CWRS	27	30.89	5.30	2.41	1.55	5.03	
3 CWRS	29	31.18	6.83	2.90	1.70	5.46	
			II Carlot Samples				
1 CWRS	27	30.88	4.48	2.03	1.42	4.61	
2 CWRS	40	30.58	8.57	3.33	1.82	5.96	
3 CWRS	36	31.53	7.96	4.72	2.17	6.89	
			III 3rd Quarter Cargo Samples				
1 CWRS	25	31.43	1.86	.35	.59	1.88	59.22
2 CWRS	25	30.01	2.40	.40	.63	2.10	64.77
3 CWRS	23	30.25	3.22	.66	.81	2.68	61.10

thereby being able to offer producers a higher grade. This would likely increase the elevator's handling percentage in the area. As a result, some or even all of the No.1 primary elevator bin samples could be coming from elevators where this type of blending occurred. The No.2 samples on the other hand may have originated from elevators where such blending was not possible for lack of 1CWRS supplies. This inter-grade blending (No.1 with No.2) as opposed to the intra-grade blending (No.2 with more No.2 producer deliveries) may then explain why the No.1 grade was less uniform in TKW than the No.2 grade. Accordingly, it was decided not to use the primary elevator bin samples for further morphological characterization using DIA.

From a grading system performance point of view, one of the more important results from the TKW determination perhaps is that TKW is much more uniform (i.e. it has lower C.V.'s) within each grade in the cargo samples when compared to the carlot samples. The increase in uniformity, as measured by the percent decrease in C.V.'s, is 59%, 65% and 61% for the No.1, No.2 and No.3 grade, respectively. In other words the data provide objective evidence showing that Canada's grain grading and bulk handling system promotes uniformity in at least one quality parameter as CWRS wheat is shipped from country positions to the export market. The uniformity of other CWRS quality factors, such as kernel size, shape and brightness features will be assessed with the aid of DIA technology.

B. Determination of Sample Size for Morphological Feature Characterization

1. The Importance of Sample Size

In order for statistical inference to lead to valid conclusions about a population it is essential that the sample from which the necessary statistics are derived is both representative and sufficient in size. A theoretical basis for selecting a suitable sample size in the case of grinding grain for the Hagberg falling number test (a test to measure the level of sprout damage in grain) is discussed by Tipples (1971). Experimental data were presented illustrating the magnitude of error inherent in the falling number determination for various sample sizes. A dramatic increase in standard error (from ± 14 sec. to ± 79 sec.) was observed as sample size taken for grinding was reduced from 250 to 25g. The author concluded that the recommended sample size for the falling number test should be increased to a minimum of 250g. Increasing the number of replicates of a smaller sample grind size was also cited as an effective way to reduce the error. This would, on the other hand, involve considerably more work.

To resolve the question of what an appropriate sample size might be for purposes of this study, a preliminary small-scale experiment was undertaken. The specific goal was to measure by DIA kernel features in samples of increasing size and then use the data to develop an analytical approach for the selection of a suitably-sized sample. The objective was to reduce sampling errors which might otherwise mask small differences between the grades.

2. What is an Appropriate Sample Size ?

Carlot unload samples received from the Inspection Division of the CGC were used to prepare composite wheat samples. Individual sample sizes (in number of kernels) for each composite were as follows:

For 1CWRS:10,27,81,135,189,243,324,405,513, for a total of n = 1927;
For 2CWRS:10,40,80,120,200,240,320,400,520, for a total of n = 1930;
For 3CWRS:10,36,72,144,180,253,324,396,504, for a total of n = 1919;

Kernel features measured for each carlot composite sample were contour length, kernel width, length and area. Results for the 1CWRS, 2CWRS and 3CWRS grades are summarized in Tables 6, 7 and 8, respectively. In general, the means for each

Table 6

Effect of sample size on DIA-computed kernel size features in 1 CWRS carlot composites

Size feature and Statistic

Sample size[a]	Contour length (mm)			Width (mm)			Length (mm)			Area (mm^2)		
	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.
10	13.95	1.06	7.56	3.06	.33	10.90	5.71	.36	6.35	21.74	3.51	16.16
27	14.07	.74	5.29	3.04	.21	6.74	5.81	.31	5.33	21.70	2.31	10.64
81	14.33	.94	6.58	3.08	.26	8.31	5.93	.43	7.28	22.54	2.87	12.72
135	14.20	.86	6.04	3.06	.27	8.73	5.88	.38	6.38	22.08	2.82	12.76
189	14.31	.98	6.82	3.09	.30	9.81	5.90	.43	7.26	22.48	3.14	13.96
243	14.38	.91	6.35	3.11	.25	8.18	5.94	.40	6.82	22.72	2.87	12.64
324	14.27	.96	6.73	3.07	.29	9.28	5.89	.43	7.22	22.36	3.06	13.70
405	14.25	.95	6.64	3.07	.29	9.27	5.89	.41	7.03	22.32	3.05	13.65
513	14.28	.90	6.28	3.09	.28	9.18	5.89	.41	6.94	22.43	2.92	13.01
for n= 1927	14.28	.93	6.49	3.08	.28	9.07	5.90	.41	6.98	22.40	2.97	13.27

[a] No. of kernels.

Table 7

Effect of sample size on DIA-computed kernel size features in 2 CWRS carlot composites

Size feature and Statistic

Sample size[a]	Contour length (mm)			Width (mm)			Length (mm)			Area (mm^2)		
	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.
10	14.81	1.06	7.16	3.21	.35	10.99	6.11	.46	7.58	24.13	3.36	13.93
40	14.76	.92	6.23	3.19	.28	8.72	6.12	.39	6.37	24.02	3.05	12.69
80	14.55	.99	6.79	3.13	.26	8.19	6.04	.47	7.76	23.27	3.12	13.42
120	14.59	.85	5.80	3.15	.28	8.90	6.01	.40	6.73	23.44	2.83	12.08
200	14.46	.96	6.66	3.09	.29	9.37	6.00	.42	7.05	22.81	3.14	13.78
240	14.38	.92	6.41	3.10	.29	9.23	5.95	.41	6.89	22.65	3.01	13.28
320	14.32	.98	6.87	3.09	.31	10.04	5.91	.44	7.36	22.51	3.26	14.47
400	14.55	.98	6.71	3.13	.28	9.03	6.01	.42	7.02	23.17	3.14	13.54
520	14.33	1.00	6.99	3.07	.29	9.46	5.94	.44	7.46	22.46	3.17	14.13
for n= 1930	14.43	.97	6.75	3.10	.29	9.38	5.97	.43	7.21	22.81	3.15	13.81

[a] No. of kernels.

Table 8

Effect of sample size on DIA-computed kernel size features in 3 CWRS carlot composites

Size feature and Statistic

Sample size[a]	Contour length (mm)			Width (mm)			Length (mm)			Area (mm^2)		
	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.
10	14.91	.73	4.93	3.22	.25	7.75	6.17	.27	4.32	24.23	2.53	10.43
36	14.53	.84	5.80	3.14	.25	8.05	6.00	.37	6.09	23.08	2.76	11.94
72	14.62	.88	6.00	3.15	.28	9.00	6.03	.38	6.24	23.28	2.98	12.81
144	14.72	.94	6.37	3.20	.30	9.28	6.04	.42	6.88	23.78	3.07	12.92
180	14.24	1.10	7.69	3.07	.34	11.16	5.88	.46	7.78	22.25	3.55	15.96
253	14.59	1.01	6.94	3.17	.31	9.88	6.01	.44	7.35	23.43	3.37	14.37
324	14.26	1.13	7.94	3.07	.34	11.17	5.91	.48	8.06	22.33	3.69	16.53
396	14.58	1.02	7.01	3.15	.30	9.66	6.05	.45	7.44	23.40	3.41	14.58
504	14.48	1.02	7.08	3.13	.33	10.67	5.99	.44	7.28	23.07	3.50	15.18
for n= 1919	14.48	1.04	7.20	3.13	.32	10.33	5.99	.45	7.46	23.05	3.47	15.04

[a] No. of kernels.

size feature remained relatively stable as sample size changed. However, the variability associated with each mean changed more irregularly with sample size as seen in Figures 10 and 11. Both suggest that the standard deviation and C.V. tend to stabilize at sample sizes in the neighbourhood of 350 to 400 kernels, depending on grade.

According to statistical theory (Bhattacharyya and Johnson, 1977), the key factors that determine an appropriate sample size for any experiment are the degree of variability displayed by the experimental units and the degree of error tolerated by the investigator. For example, suppose the standard deviation (σ) of a particular population of interest is known. Theory of statistics (Bhattacharyya and Johnson, 1977) then gives the formula for a $100(1-\alpha)\%$ error bound for the estimation of μ by X as

$$Z_{\alpha/2} \frac{\sigma}{\sqrt{n}} \tag{1.0}$$

In order to be $100(1-\alpha)\%$ sure that the error does not exceed an amount d, the investigator must have

$$Z_{\alpha/2} \frac{\sigma}{\sqrt{n}} = d \tag{1.1}$$

This gives an equation in which n is unknown. Solving for n gives

$$n = \left[\frac{Z_{\alpha/2}\, \sigma}{d} \right]^2 \tag{1.2}$$

Figure 10

Effect of sample size on the standard deviation of mean kernel contour length (mm)

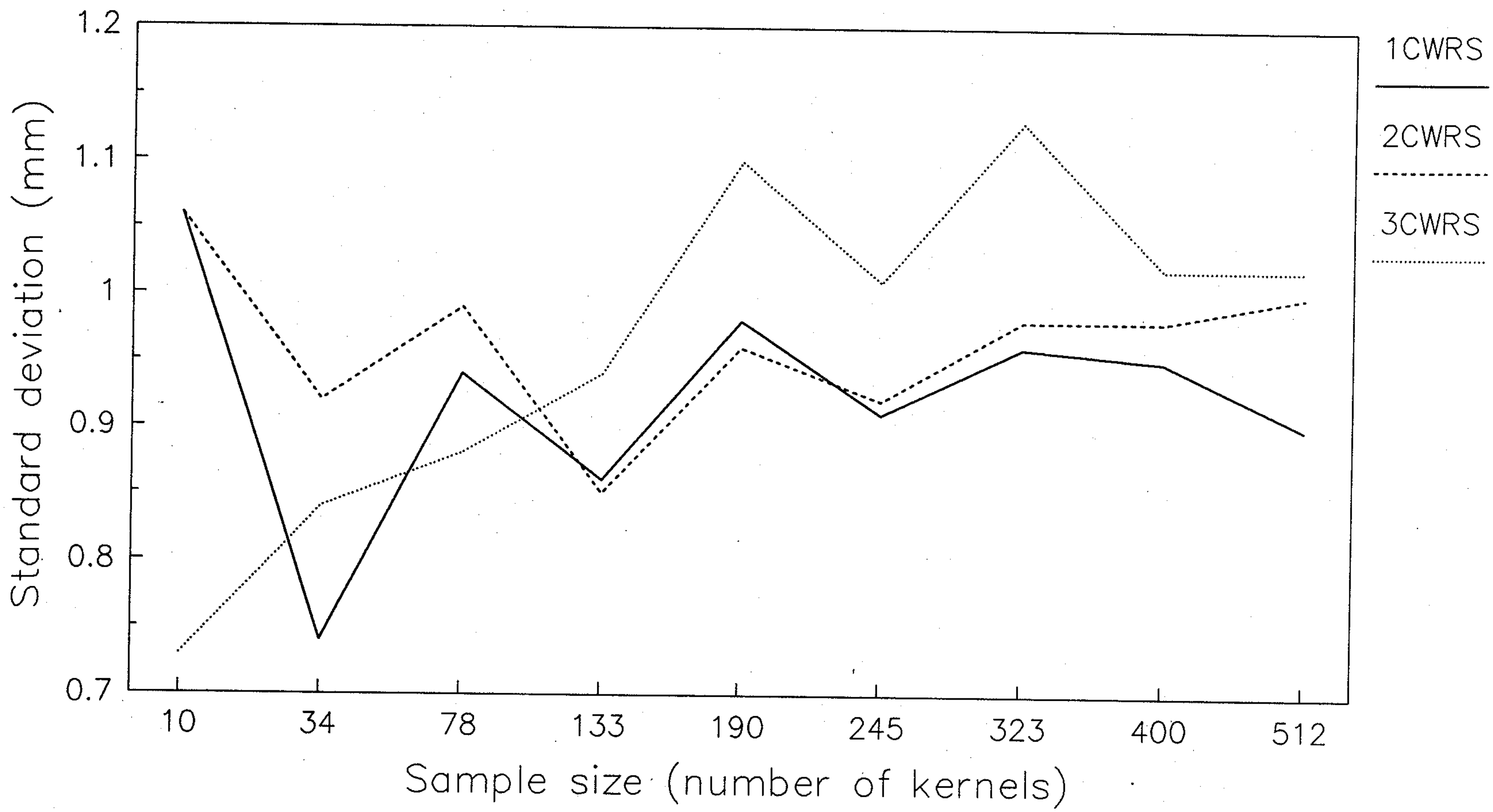
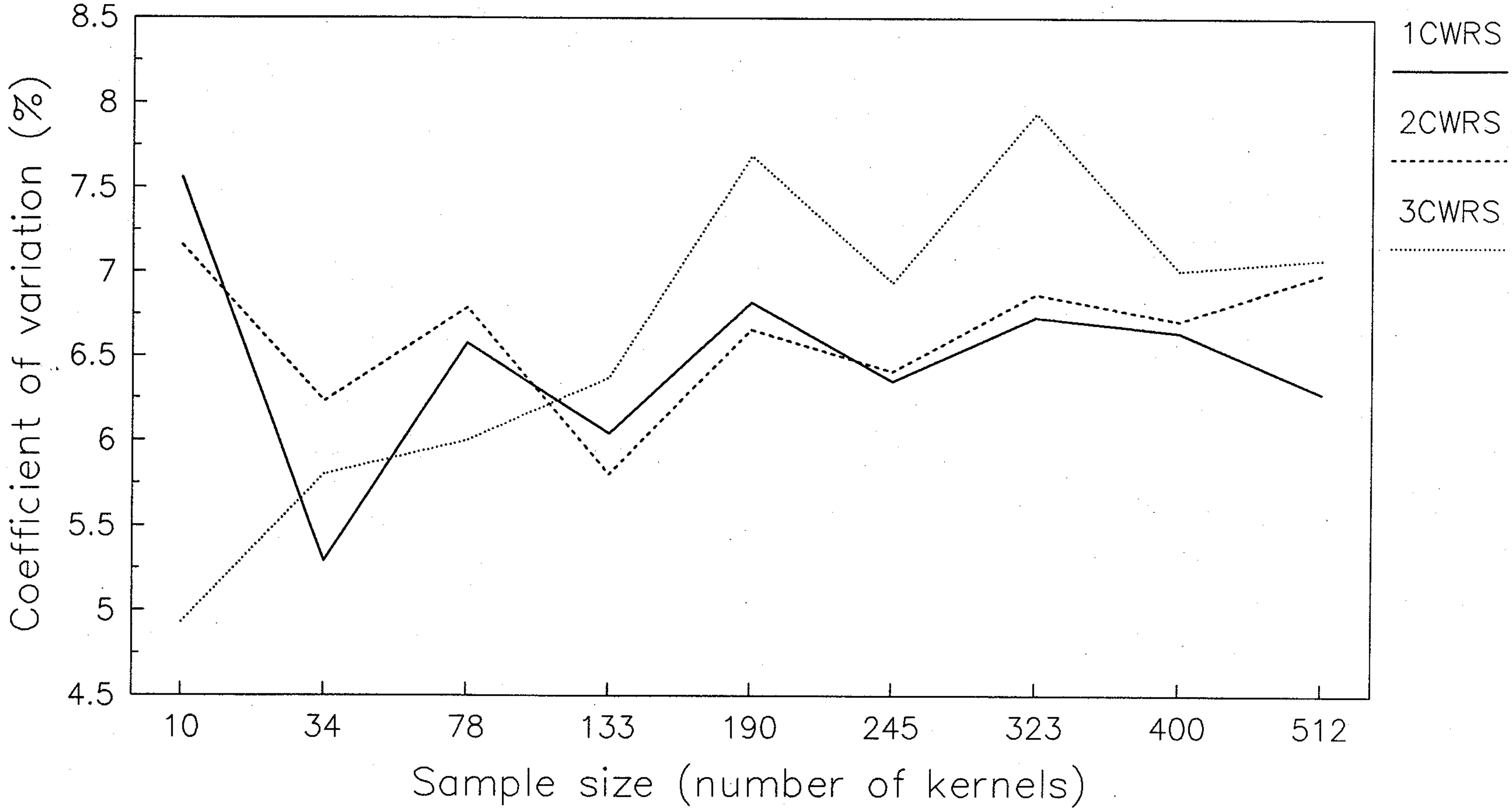


Figure 11

Effect of sample size on the coefficient of variation of mean kernel contour length (mm)



where: σ = the standard deviation of the population of interest;
d = the tolerable error;
$Z_{\alpha/2}$ = the upper $\alpha/2$ point of the standard normal distribution;
α = the level of significance, commonly .05;

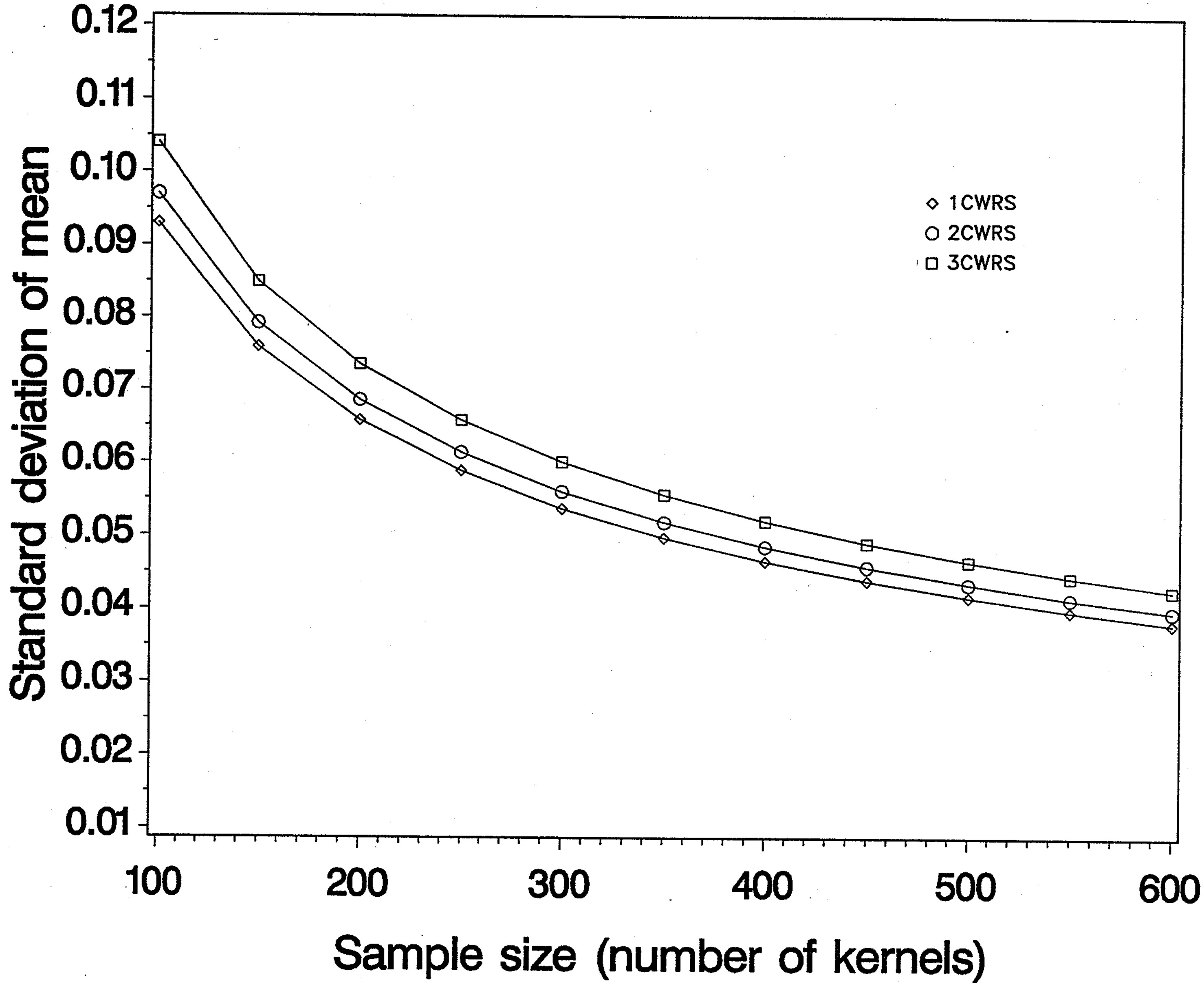
which determines the required sample size. At this point it should be noted that knowledge of σ or at least a close approximation of σ is required to compute n. If σ is completely unknown, a preliminary sampling experiment is necessary to obtain its estimate.

Estimates of σ for 1CWRS (n=1927), 2CWRS (n=1930) and 3CWRS (n=1919) for all four kernel size features are given in Tables 6, 7 and 8, respectively. Equation (1.2) was then used to calculate n for all three grades using the contour length feature as an example. Assuming a 95% certainty (i.e. α = .05) that the error of estimation does not exceed 0.10 (i.e. d = 0.10mm), the required sample sizes then are 333, 362 and 416 kernels for the 1CWRS, 2CWRS and 3CWRS grades, respectively.

Equation (1.2) also shows that the sample size n is directly related to σ (i.e. its estimate s) and inversely related to d. If σ increases, n increases; if d, the tolerable measurement error increases, then n decreases accordingly. These relationships are also illustrated graphically in Figure 12. Along the ordinate are values for the term $s/\sqrt{n}$ (i.e. the estimate of $\sigma/\sqrt{n}$) and along the abscissa are values for n. Using $Z_{.025}$ = 1.96 and d = 0.10, it follows from Equation (1.1) that $s/\sqrt{n}$ = .05. If a line is now drawn parallel to the abscissa until each of the three curves is intersected, the sample sizes of 333, 362 and 416 can then be read off. The higher sample sizes for the lower grades reflects a higher degree of variability in kernel size, which in turn is due to higher tolerances for the various grading factors. Therefore, in order to maintain the

Figure 12

Theoretical relationship between standard deviation of mean kernel contour length and sample size for three grades of CWRS wheat



same degree of error when estimating the sample distribution of kernel size, shape and brightness, sample size should be increased progressively as lower grade samples are being analyzed with DIA.

C. Relationship Between CWRS Grade and Uniformity of Morphological Features

Sixteen morphological features (see Table 4 for a more detailed description) were quantified on a kernel by kernel basis for both the carlot and cargo samples, as well as for an export standard sample. The export standard was obtained as a check against which the cargo results could then be compared. It was prepared by the CGC during the 1987-88 crop year to facilitate the grading of CWRS wheat leaving terminal, transfer and process elevators. Six of the sixteen features quantified aspects of kernel size (CLEN, AREA, LENGTH, WIDTH, NCP, AMEC), nine described elements of kernel shape (THINN, RAR, MMAX, MMIN, MAR, N20, N02, M20, M02) and one measured kernel brightness (AREFL). The distribution of each feature within each grade was estimated in terms of its mean value and standard deviation. A coefficient of variation (C.V.) was also calculated:

$$\text{C.V.}(\%) = \frac{\text{std.dev.}}{\text{sample mean}} \times 100 \qquad (1.3)$$

On the basis of this C.V., assessments were made as to the relative uniformity of each feature, within each grade, between different grades of the same sample category, and between two different sample categories (carlot vs. cargo) of the same grade.

1. Carlot Samples

A total of 103 carlot samples, of which 27 were graded as 1CWRS, 40 as 2CWRS and 36 as 3CWRS, were morphologically characterized by DIA. Values for the statistics describing the distribution of each morphological feature within each carlot grade are summarized in Table 9.

One characteristic which could be distinguished subjectively between the three grades was the proportion of bleached kernels in the sample and the variability in the degree to which individual kernels were bleached. The 1CWRS grade contained by far the largest proportion of mature, sound and dark (red) colored kernels with relatively little variability. The 3CWRS grade, on the other hand, consisted of very few such kernels, some of them appearing frost damaged, but the bulk being immature or weathered to varying degrees. The degree of bleaching among the kernels also appeared the least uniform. Most of these observations were indeed confirmed by the data in Table 9, with the 3CWRS samples, on average having a higher value for average reflectance when compared to the 1CWRS samples (138.38 vs. 136.33 pixels). Higher average reflectance values were due to the presence of relatively more bright objects which reflect more light than darker objects. As a result, higher values for average reflectance were indicative of a greater proportion of bleached kernels in the sample and vice versa.

It is interesting to note that the mean value for average reflectance was lower in the No.3 grade when compared to the No.2 grade (138.38 vs. 140.71). This appears to be inconsistent with the expectation that the No.3 grade should contain a relatively higher proportion of bleached kernels, leading to higher values for average reflectance. However, this result is probably indicative of grading factors other than bleached kernels (e.g. dark immature, smudge,

Table 9

Relationship between CWRS grade and morphological features in carlot wheat samples

	Carlot Grade and Statistic								
	1CWRS[b]			2CWRS[c]			3CWRS[d]		
Parameter[a]	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.
AREFL	136.33	4.23	3.11	140.71	4.84	3.44	138.38	4.74	3.43
THINN	.75	.011	1.46	.75	.013	1.70	.75	.012	1.61
AREA(mm^2)	22.25	.65	2.90	22.34	.68	3.05	22.75	.86	3.78
CLEN(mm)	13.95	.14	.99	14.01	.16	1.13	14.11	.21	1.49
NCP	166.30	1.48	.89	167.09	1.87	1.12	167.91	2.43	1.46
WIDTH(mm)	2.99	.08	2.82	2.98	.09	2.98	3.03	.10	3.45
LENGTH(mm)	5.80	.07	1.14	5.84	.08	1.31	5.85	.09	1.49
RAR	1.95	.06	3.09	1.97	.07	3.48	1.94	.07	3.65
MMAX	338.54	6.49	1.92	343.33	9.09	2.65	344.15	10.41	3.03
MMIN	90.45	5.09	5.62	89.93	5.36	5.96	93.07	6.27	6.74
MAR	3.86	.25	6.36	3.94	.28	7.14	3.83	.30	7.83
AMEC	862.63	57.62	6.68	856.35	59.51	6.95	891.92	69.67	7.81
N20	.16	.005	3.19	.16	.006	3.59	.16	.006	3.88
N02	.04	.0013	3.10	.04	.0014	3.50	.04	.0015	3.73
M20	1.17E08	3.00E06	2.57	1.18E08	3.68E06	3.13	1.19E08	4.57E06	3.86
M02	1.13E06	8.42E04	7.47	1.13E06	8.59E04	7.60	1.19E06	1.06E05	8.85
Average			3.33			3.67			4.13

[a] Units of measurement are in pixels, unless indicated otherwise.
[b] n=27. [c] n=40. [d] n=36.

blackpoint, grass green, mildew, ergot, etc.) that may have contributed to the determination of the No.3 grade. For example, maximum tolerances for grass green and dark immature kernels are increased, respectively, from 2.0% to 10.0% and from 2.5% to 10.0% when comparing the No.2 and the No.3 grades (see Appendix I, p.127). The presence of kernels with a darkened seed coat as a result of these factors would then lower the mean value for average reflectance.

Kernels from the 3CWRS samples were, in terms of area, on average 2.25% larger than those found in 1CWRS (22.75mm^2 vs. 22.25mm^2), but only 1.84% larger than those from the 2CWRS samples (22.75mm^2 vs. 22.34mm^2). The 3CWRS kernels were also the widest and the longest, which translates into the highest value for the contour length feature. Most of these size differences (especially between the No.3 and the No.1 grade) were likely due to extensive weathering (periods of wetting and drying) that CWRS wheat has been exposed to before harvest while still lying in windrows. Wet kernels will swell as they imbibe water. However, they will not return to their original size after a period of drying (Swanson, 1941), leaving them slightly larger than before. As a result of this phenomenon, CWRS wheat that has been downgraded to No.3 will be considerably more bleached and also slightly larger in size when compared to the No.1 and No.2 grades.

The No.3 grade was also the least uniform. Comparing the degree of variability in kernel area between the No.3 and No.1 grade, the C.V. increased from 2.90% for 1CWRS to 3.78% for 3CWRS. The No.2 grade was intermediate in uniformity. In terms of kernel area, it was slightly more uniform than the No.3 grade (3.05% vs. 3.78%), but still somewhat less uniform than the No.1 grade (3.05% vs. 2.90%)(see Table 9). Similar relationships between grade level and the degree of uniformity were also observed for the remaining morphological features. The average C.V. for all sixteen features progressively increased as grade drops, from 3.33% for 1CWRS to 3.67% for 2CWRS to 4.13% for 3CWRS.

Relative changes in uniformity with grade level for each feature are given in Table 10. With the exception of average reflectance (AREFL) and thinness ratio (THINN), there was a steady increase in the percent change in C.V. as grade dropped. For nine features (AREA, CLEN, NCP, WIDTH, LENGTH, MMIN, AMEC, M20, M02) the percent increase in C.V. from the No.1 to the No.3 grade was more than twice the percent increase in C.V. from the No.1 to the No.2 grade, while for five features (RAR, MMAX, MAR, N20, N02) it was between 1.4 and 1.9 times. Averaging over all features, there was a 13.42% increase in C.V. from the No.1 to the No.2 grade, a 13.68% increase from the No.2 to the No.3 grade, and a 29.06% increase from the No.1 to the No.3 grade.

Differences in the relative change in uniformity of morphological features from the top CWRS grade to the lowest CWRS grade were to a large extent a reflection of the relative changes in tolerance levels of pertinent grading factors. Tolerance levels for grading factors such as the maximum limits of wheats of other classes or varieties and the allowable proportion of sprouted, grass green, dark immature, and shrunken kernels are relaxed to a marginally greater extent in the grading guide from the No.2 to the No.3 grade compared to those from the No.1 to the No.2 grade. For example, there is no limit to the percentage of shrunken kernels allowed in the No.3 grade, whereas tolerances of 6.0% and 10.0% apply to the No.1 and No.2 grade, respectively (Canadian Grain Commission, 1989a). These relative changes in tolerance levels for the various grading factors affect the degree of uniformity of kernel size, shape and brightness features, with the No.3 grade becoming the least uniform and the No.1 grade the most uniform.

Table 10

Changes in uniformity of morphological features with carlot grades

Parameter[a]	% Change in C.V.		
	2CWRS vs. 1CWRS	3CWRS vs. 2CWRS	3CWRS vs. 1CWRS
AREFL	10.61	-0.29	10.29
THINN	16.44	-5.29	10.27
AREA (mm^2)	5.17	23.93	30.34
CLEN (mm)	14.14	31.86	50.51
NCP	25.84	30.36	64.04
WIDTH (mm)	5.67	15.77	22.34
LENGTH (mm)	14.91	13.74	30.70
RAR	12.62	4.89	18.12
MMAX	38.02	14.34	57.81
MMIN	6.05	13.09	19.93
MAR	12.26	9.66	23.11
AMEC	4.04	12.37	16.92
N20	12.54	8.08	21.63
N02	12.90	6.57	20.32
M20	21.79	23.32	50.19
M02	1.74	16.45	18.47
Average	13.42	13.68	29.06

[a] Units of measurement are in pixels, unless indicated otherwise.

2. 1987-88 Export Standard

Export standard samples are used for most grades of Western Canadian wheat to govern grading of shipments out of terminal, transfer and process elevators. They are prepared each year by a Western Standards Committee and approved by the CGC. The export standards are higher in quality than the original primary standards for the same grades because they are prepared to represent the average of the grade rather than the minimum that is represented by the primary standard samples (Bushuk, 1986b).

Foreign material and dockage were removed by hand-picking from each sample grade of the 1987-88 export standard obtained from the CGC's Inspection Division. The sample sizes were 1344 kernels for 1CWRS, 1434 kernels for 2CWRS, and 1382 kernels for 3CWRS, or an equivalent of 40 to 45g per grade. Each export standard grade was then morphologically characterized by DIA with the results presented in Table 11.

It should be noted that the quantitative results summarized in Table 11 are based on an average of between 1344 and 1434 kernels using only one sample per grade, whereas the carlot and cargo results were based on 400 kernels per sample, using anywhere from 23 (3CWRS Cargo) to 40 (2CWRS Carlot) samples, depending on grade and sample category (see Table 3). In other words, the carlot and cargo means are really means of sample means, whereas the export standard means are just means of one sample. Similarly, the coefficient of variation calculated for the carlot and cargo samples measures the variation among the various sample means within each grade, whereas in the export standard sample it measures the variation among individual observations (i.e. kernels). The variability among individual kernels in one sample is significantly greater than the variability among means of several samples. This is demonstrated by the fact that C.V.'s are

Table 11

Relationship between CWRS grade and morphological features in the 1987-88 export standard sample

Export Standard Grade and Statistic

Parameter[a]	1CWRS[b] Mean	1CWRS[b] Std.Dev.	1CWRS[b] C.V.	2CWRS[c] Mean	2CWRS[c] Std.Dev.	2CWRS[c] C.V.	3CWRS[d] Mean	3CWRS[d] Std.Dev.	3CWRS[d] C.V.
AREFL	141.15	11.31	8.01	144.66	11.67	8.06	143.39	12.34	8.60
THINN	.73	.0398	5.45	.72	.0430	5.97	.73	.0460	6.32
AREA(mm^2)	21.32	3.60	16.91	21.19	3.86	18.20	20.90	3.90	18.64
CLEN(mm)	13.72	1.08	7.88	13.76	1.15	8.34	13.60	1.14	8.39
NCP	164.72	12.97	7.87	165.45	13.69	8.28	163.48	13.58	8.31
WIDTH(mm)	2.83	.34	11.90	2.78	.35	12.71	2.79	.38	13.52
LENGTH(mm)	5.79	.46	7.89	5.84	.48	8.20	5.73	.49	8.56
RAR	2.06	.22	10.88	2.12	.23	10.96	2.08	.26	12.59
MMAX	339.38	51.07	10.88	347.52	53.11	15.28	335.25	53.40	15.93
MMIN	82.11	19.06	23.21	79.20	19.48	24.59	80.20	21.28	26.53
MAR	4.31	1.02	23.64	4.60	1.12	24.45	4.42	1.20	27.03
AMEC	768.65	210.44	27.38	736.52	217.47	29.53	746.64	234.65	31.43
N20	.16	.0188	11.43	.17	.0199	11.68	.17	.0220	13.18
N02	.04	.0041	10.42	.04	.0039	10.36	.04	.0047	12.11
M20	1.10E08	2.01E07	18.21	1.11E08	2.18E07	19.61	1.08E08	2.15E07	19.93
M02	9.74E05	3.57E05	36.63	9.49E05	3.67E05	38.64	9.38E05	3.91E05	41.63
Average			14.91			15.93			17.04

[a] Units of measurement are in pixels, unless indicated otherwise.
[b] n=1344 kernels. [c] n=1434 kernels. [d] n=1382 kernels.

on average about four times higher in the export standard compared to carlot samples and more than ten times higher when compared to cargo samples. As a result, any comparisons between C.V.'s of export standard features and C.V.'s of the same carlot and cargo features are not meaningful. However, variability differences in kernel features between the three export standard grades can still be analysed.

Although no consistent relationship was observed between the three grade levels and mean values for the various kernel size, shape and brightness features, their variability patterns with a lowering of grade were comparable to those found in the carlot samples. Variability progressively increased with decreasing grade level for fifteen of the sixteen features. The average C.V. for all features increased from a low of 14.91% for the No.1 grade, to 15.93% for the No.2 grade, and to a high of 17.04% for the No.3 grade.

The rate of change in uniformity within each grade as grade dropped is summarized in Table 12. Averaging over all features, there was a 7.05% increase in variability as grade was lowered from No.1 to No.2, a 6.86% increase from No.2 to No.3, and a 14.25% increase from No.1 to No.3. As expected, the percent increase in variability was highest from the No.1 to the No.3 grade, being slightly more than twice the percent increase from the No.1 to the No.2 and from the No.2 to the No.3 grade.

3. Cargo Samples

The CWRS cargo grades that were analysed consisted of 25 samples that graded No.1, 25 samples that graded No.2, and 23 samples that graded No.3. Quantitative measurements for each morphological feature are given in Table 13. Again, the 3CWRS samples, on average, had a higher average reflectance than the

Table 12

Changes in uniformity of morphological features with 1987-88 export standard grades

Parameter[a]	% Change in C.V. 2CWRS vs. 1CWRS	3CWRS vs. 2CWRS	3CWRS vs. 1CWRS
AREFL	0.62	6.70	7.37
THINN	9.54	5.86	15.96
AREA (mm^2)	7.63	2.42	10.23
CLEN (mm)	5.84	0.60	6.47
NCP	5.21	0.36	5.59
WIDTH (mm)	6.81	6.37	13.61
LENGTH (mm)	3.93	4.39	8.49
RAR	0.74	14.87	15.72
MMAX	40.44	4.25	46.42
MMIN	5.95	7.89	14.30
MAR	3.43	10.55	14.34
AMEC	7.85	6.43	14.79
N20	2.19	12.84	15.31
N02	-0.58	16.89	16.22
M20	7.69	1.63	9.45
M02	5.49	7.74	13.65
Average	7.05	6.86	14.25

[a] Units of measurement are in pixels, unless indicated otherwise.

Table 13

Relationship between CWRS grade and morphological features in cargo wheat samples

	Cargo Grade and Statistic								
	1CWRS[b]			2CWRS[c]			3CWRS[d]		
Parameter[a]	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.	Mean	Std.Dev.	C.V.
AREFL	137.81	1.13	.82	142.33	1.69	1.19	142.06	1.81	1.27
THINN	.76	.004	.47	.75	.004	.51	.75	.004	.54
AREA(mm^2)	21.96	.28	1.29	21.75	.27	1.25	21.95	.30	1.37
CLEN(mm)	13.71	.08	.59	13.70	.08	.57	13.75	.08	.61
NCP	164.52	.91	.56	164.57	.93	.56	165.17	.98	.59
WIDTH(mm)	2.96	.03	.95	2.91	.03	.97	2.93	.03	1.13
LENGTH(mm)	5.66	.04	.71	5.69	.04	.69	5.70	.04	.67
RAR	1.93	.02	.98	1.97	.02	.91	1.96	.02	1.14
MMAX	329.36	3.67	1.11	332.99	3.55	1.07	335.18	3.90	1.16
MMIN	89.37	1.67	1.87	86.85	1.65	1.90	87.95	1.99	2.26
MAR	3.79	.07	1.80	3.95	.07	1.74	3.95	.09	2.26
AMEC	844.23	17.96	2.13	815.86	18.86	2.31	827.60	21.12	2.55
N20	.15	.001	.90	.16	.001	.88	.16	.002	1.14
N02	.04	.0004	.85	.04	.0004	.88	.04	.0005	1.13
M20	1.14E08	2.09E06	1.82	1.14E08	1.71E06	1.50	1.14E08	2.27E06	1.99
M02	1.07E06	3.74E04	3.49	1.04E06	3.16E04	3.04	1.07E06	3.88E04	3.64
Average			1.27			1.25			1.47

[a] Units of measurement are in pixels, unless indicated otherwise.
[b] n=25. [c] n=25. [d] n=23.

1CWRS samples, indicating the presence of a larger proportion of bleached kernels in the 3CWRS grade. However, average reflectance was slightly lower when comparing the No.3 grade to the No.2 grade (142.06 vs. 142.33, respectively), even though one would expect the No.3 grade to contain the highest proportion of bleached kernels and accordingly give the highest value for average reflectance. Again, as was the case in the carlot samples, this result likely indicates that grading factors other than bleached kernels were operational during the grading process. Factors such as dark immature and grass green kernels would have had a darkening effect on the seed coat, making it reflect less light and thereby lower the average reflectance of the samples.

In terms of kernel size, there was little difference between the three grades, as indicated by the AREA, CLEN, NCP, WIDTH, and LENGTH features. Mean values for contour length, length, and number of contour pixels were only slightly (<1%) higher for 3CWRS. Kernels from the No.1 grade were on average 1% wider than those from the No.3 grade (2.96mm vs. 2.93mm).

The low average C.V.'s for the 1CWRS features indicates a high degree of uniformity. C.V.'s ranged from a low of .47% for thinness ratio (THINN) to a high of 3.49% for the unnormalized low order central moment along the minor axis (M02). The average C.V. for all sixteen features was 1.27% for the No.1 grade. There was very little difference in uniformity between the No.1 and the No.2 grade. In fact, nine of the sixteen morphological features were slightly more uniform in the 2CWRS grade, yielding an overall average C.V. of 1.25%. The No.3 grade was again the least uniform, with an average C.V. for all features of 1.47%.

Table 14 shows the percent change in uniformity for each feature as grade changes. Combining all features, there was a .83% increase in variability from

Table 14

Changes in uniformity of morphological features with cargo grades

	% Change in C.V.		
Parameter[a]	2CWRS vs. 1CWRS	3CWRS vs. 2CWRS	3CWRS vs. 1CWRS
AREFL	45.12	6.72	54.88
THINN	8.51	5.88	14.89
AREA(mm^2)	-3.10	9.60	6.20
CLEN(mm)	-3.39	7.02	3.39
NCP	0.00	5.36	5.36
WIDTH(mm)	2.11	16.49	18.95
LENGTH(mm)	-2.82	-2.90	-5.63
RAR	-7.14	25.27	16.33
MMAX	-3.60	8.41	4.50
MMIN	1.60	18.95	20.86
MAR	-3.33	29.89	25.56
AMEC	8.45	10.39	19.72
N20	-2.22	29.55	26.67
N02	3.53	28.41	32.94
M20	-17.58	32.67	9.34
M02	-12.89	19.74	4.30
Average	0.83	15.72	16.14

[a] Units of measurement are in pixels, unless indicated otherwise.

the No.1 to the No.2 grade, a 15.72% increase from the No.2 to the No.3 grade, and a 16.14% increase from the No.1 to the No.3 grade. As in the carlot samples, one of the main reasons that the No.3 grade was the least uniform was because the least stringent grading specifications generally apply to this grade. The highest levels of weather-related degrading factors such as bleached, immature, frosted and sprouted kernels are allowed in this grade, which is ultimately reflected in low uniformities for kernel size, shape and brightness features.

4. Cargo - Carlot Uniformity Differences

A comparison of the relative uniformity of each morphological feature in cargo as opposed to carlot grades is given in Table 15. The data point to a significant increase in uniformity (indicated by the negative percent changes in C.V.) for each of the sixteen features. Comparing cargo to carlot samples, the average C.V. for all features dropped by 57.64% for the 1CWRS, 63.45% for the 2CWRS, and 63.57% for the 3CWRS grade.

Changes in uniformity with grade level for both carlot and cargo samples are graphically displayed in Figures 13, 14, and 15 using a selected number of features. Figure 13, for example, shows the gradual decrease in uniformity in kernel width as grade dropped, for both sample categories, illustrated by the relative height differences in the bars. For kernel area (Figure 14), both sample categories again showed a decrease in uniformity with lower CWRS grades, although the relative changes in uniformity with grade were slightly more pronounced in the carlot samples. A similar trend was observed when comparing average C.V. values for all sixteen features, as shown in Figure 15. Note that for all three Figures the carlot bars are always higher than the cargo bars, indicating that each cargo grade is more uniform than its corresponding carlot grade.

Table 15

A comparison of the relative uniformity of morphological features in cargo and carlot grades

% Change in C.V.

Parameter[a]	1CWRS Cargo vs. 1CWRS Carlot	2CWRS Cargo vs. 2CWRS Carlot	3CWRS Cargo vs. 3CWRS Carlot
AREFL	-73.63	-65.41	-62.97
THINN	-67.81	-70.00	-66.46
AREA (mm^2)	-55.52	-59.02	-63.76
CLEN (mm)	-40.40	-49.56	-59.06
NCP	-37.08	-50.00	-59.59
WIDTH (mm)	-66.31	-67.45	-67.25
LENGTH (mm)	-37.72	-47.33	-55.03
RAR	-68.28	-73.85	-68.77
MMAX	-42.19	-59.62	-61.72
MMIN	-66.73	-68.12	-66.47
MAR	-71.70	-75.63	-71.14
AMEC	-68.11	-66.76	-67.35
N20	-71.79	-75.49	-70.62
N02	-72.58	-74.86	-69.71
M20	-29.18	-52.08	-48.45
M02	-53.28	-60.00	-58.87
Average	-57.64	-63.45	-63.57

[a] Units of measurement are in pixels, unless indicated otherwise.

Figure 13
Uniformity differences in kernel width between carlot and cargo grades

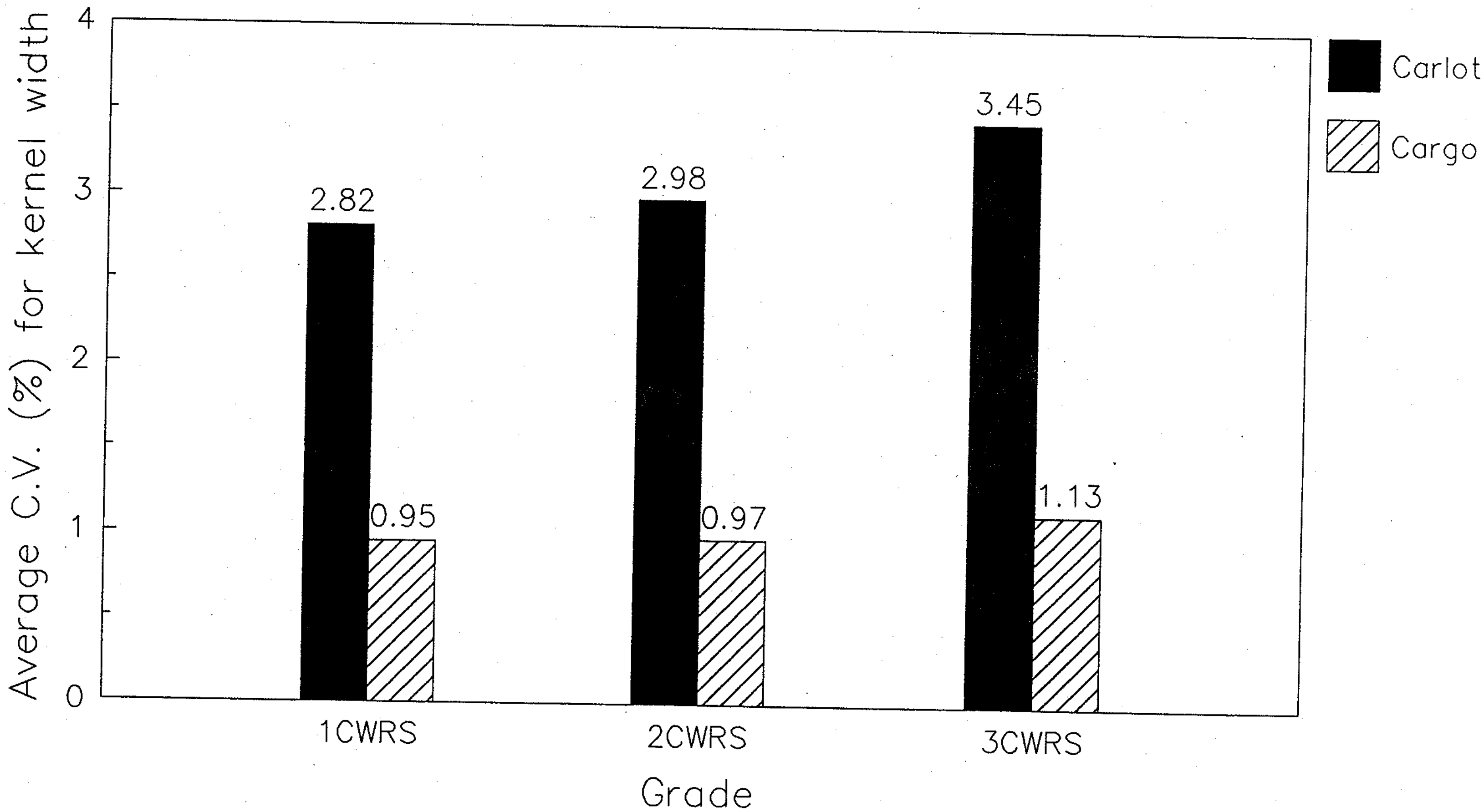


Figure 14

Uniformity differences in kernel area between carlot and cargo grades

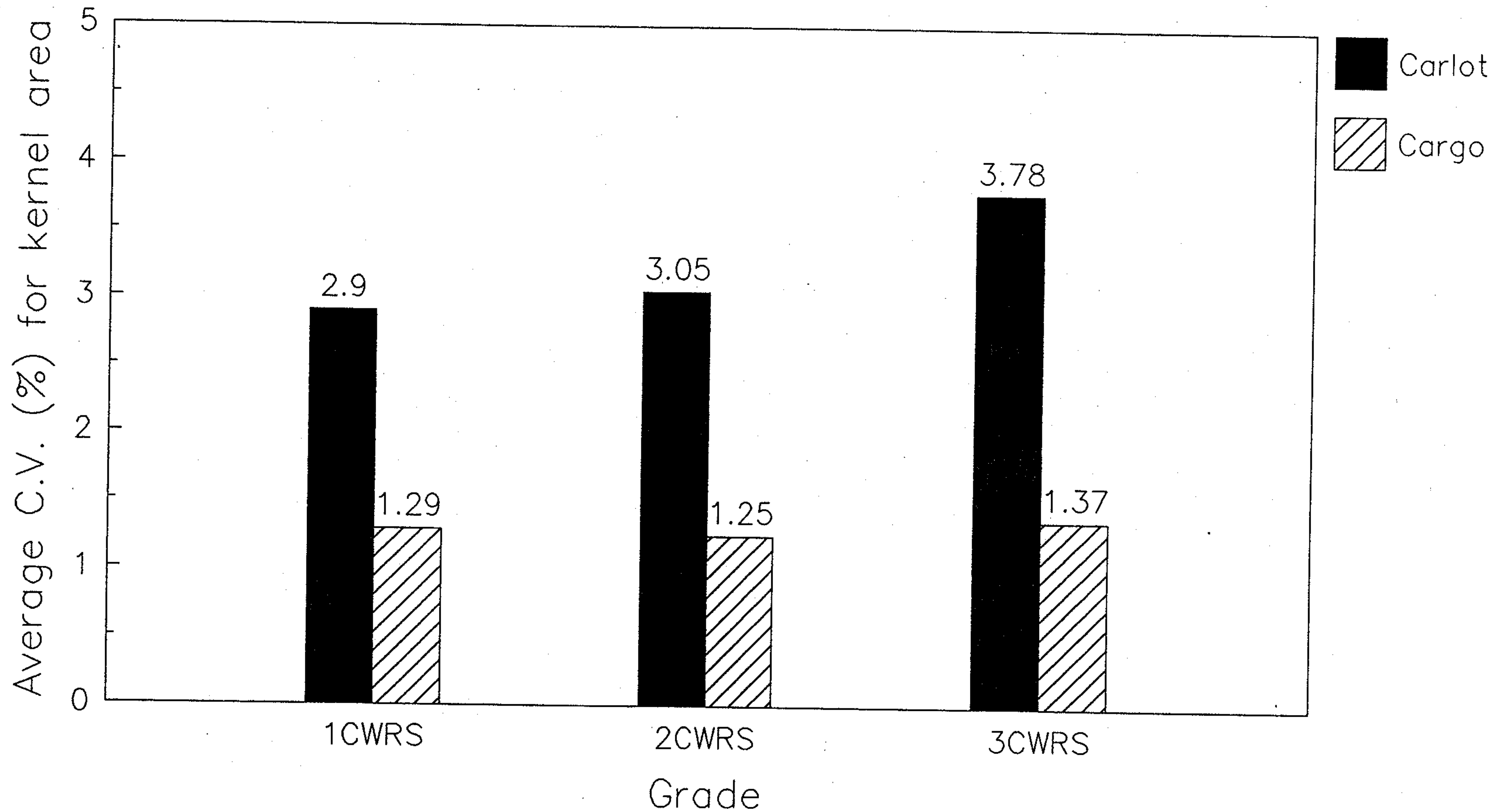
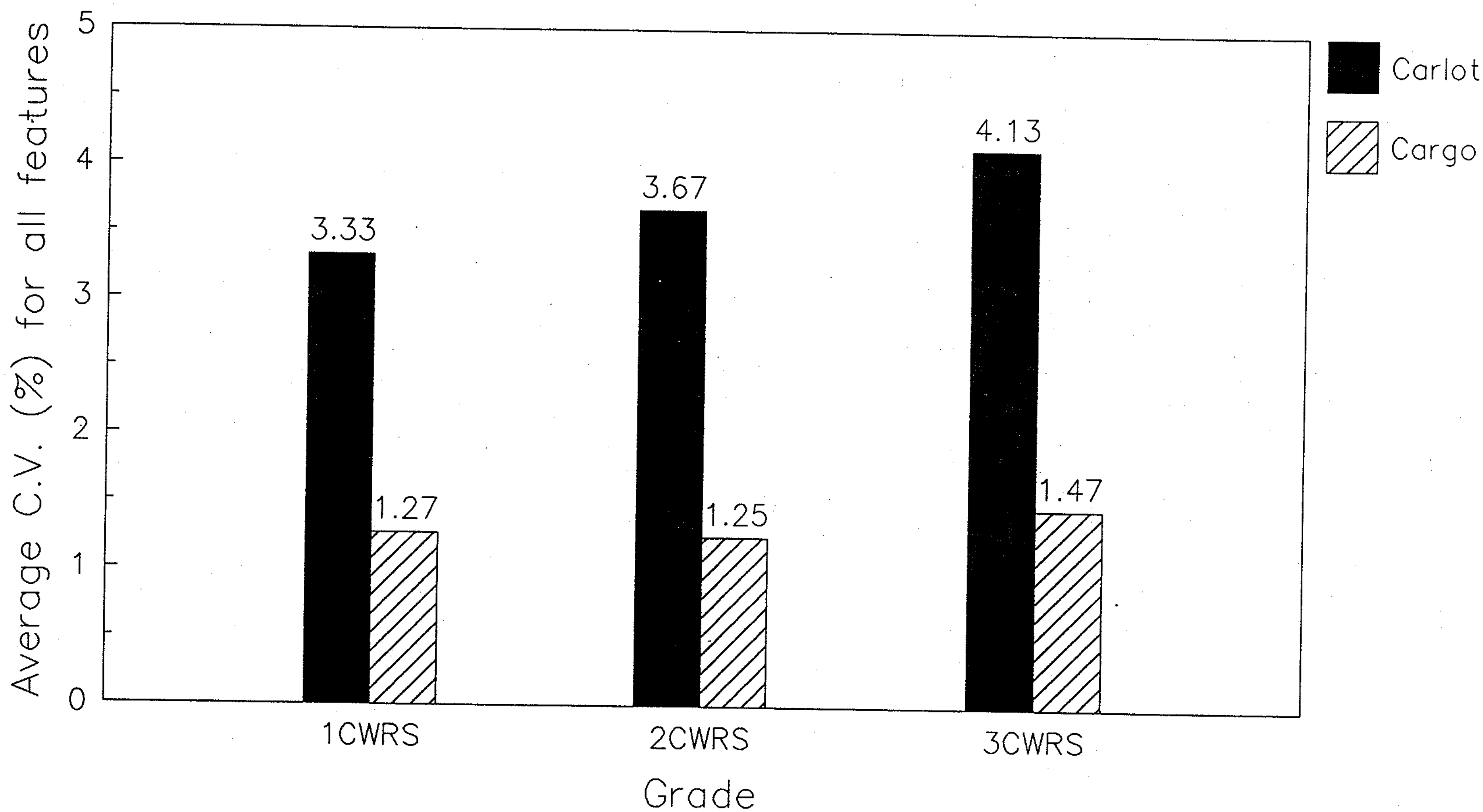


Figure 15

Uniformity differences between carlot and cargo grades averaging over all morphological features



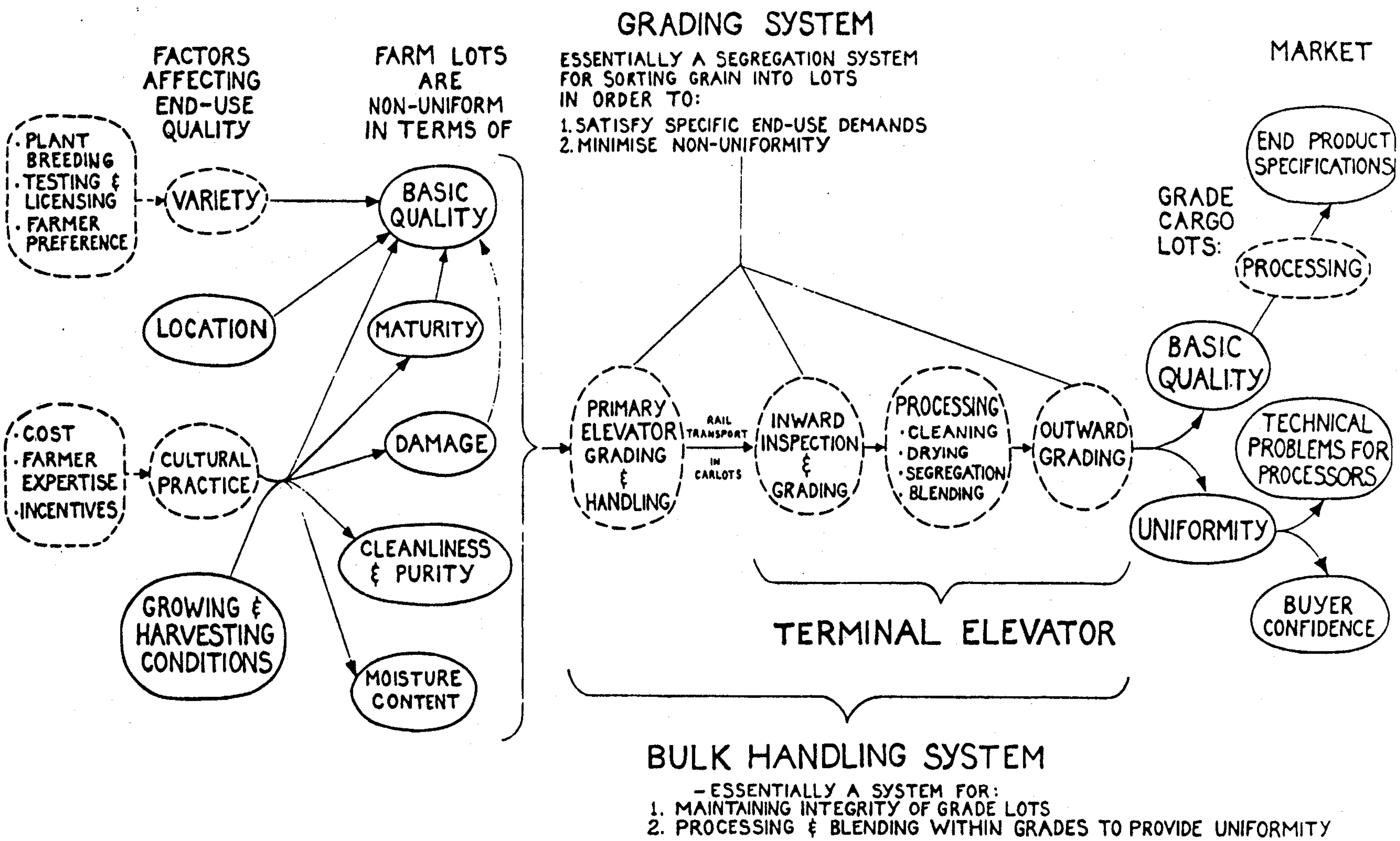
The more uniform cargo grades as opposed to their carlot counterparts provides direct support for the argument that Canada's grain grading and bulk handling system is effective in promoting uniformity as Canadian wheat is shipped from primary elevator to terminal elevator positions (Tipples, 1979).

A unique feature of the Canadian system is that a single parcel of wheat is graded three times (Bushuk, 1986b): (1) by the primary elevator operator at the time it is delivered into the country elevator or by the CGC if the offered grade, dockage or moisture content are disputed by the grower; (2) on arrival at the terminal elevator; and (3) during loading into a cargo vessel prior to export. These three stages of grading are integrated with the bulk handling system as shown in Figure 16.

Two quality standards are used to facilitate this three-stage grading process: the primary standard and the export standard. While a primary standard exists for all grains, an export standard applies only to certain grades of wheat, oats and barley. The primary standard is based on the grade specifications laid down by the CGC and represents the minimum requirements of the grade with respect to the visual grading factors. It is used only as a visual guide to grading grain before and on receipt at terminal elevators and shipments from terminal elevators when no export standard sample is established for a grade (Bushuk, 1986b). The requirements under the export standard are more stringent. This becomes possible since in meeting the primary standard a number of the characteristics of the grain normally exceed the minimum requirements. Consequently, when different lots of grain meeting the primary standard are mixed, the grain then exceeds the requirements in all respects (Canada Grains Council, 1982). Export standard samples are established to represent the average of the grade received and are used for most grades of Western Canadian wheat to

Figure 16

Effect of grading and bulk handling systems in promoting uniformity in shipments of Canadian grain
(From Tipples, 1979, p.586)



govern the grading of shipments out of terminal, transfer and process elevators.

The overall merits of having such a two standard system were questioned in two reports, both prepared by the Grain Grading Committee of the Canada Grains Council after having extensively studied and consulted with participants in Canada's grain grading system (Canada Grains Council, 1982; 1985). One of the recommendations put forward in both reports was to narrow the differences between the primary and the export standard for those grades to which both apply, with the ultimate goal of having only one standard for Canadian grain. The Committee argued that the degree of "improvement" called for in the individual characteristics in the export standard for a grade is not consistent as compared to the primary standard. It indicated that for some characteristics there is a significant difference in the requirements under the primary and the export standard while for others the requirements are the same.

A fundamental weakness with the Grain Grading Committee's recommendation is that it is based on an analysis which lacks objective detail. The Committee even admits to this by noting that " an in-depth assessment of the merits of the two standards would be difficult and time consuming" (Canada Grains Council, 1982, p.123). Secondly, based on objective evidence, this research project found no support for the Committee's argument. In fact, for each of the kernel size, shape and brightness features quantified with DIA, there was a consistent increase in uniformity (ranging anywhere from 37% to 75%) across all three grades from carlot to cargo samples (see Table 15). Although the blending of carlots within the same grade is probably more significant, the use of the export standard has also contributed to the consistent and substantial increase in kernel feature uniformity. Narrowing the differentials between the two standards by lowering requirements for the export standard as suggested by the Committee ought not to be pursued for the simple reason that it may otherwise seriously compromise on the uniformity of quality in export shipments of Canadian wheat. The use of export standard samples for the grading of wheat destined for the export market assures buyers that they will receive at least the average - not the minimum - quality of each grade. Certification by the Inspection Division of the CGC that export shipments have been subjected to this grading procedure has proven so dependable over the years that importers accept shipments of Canadian wheat on the basis of the Certificate Final accompanying the shipment, without requiring any samples of the wheat before shipment (Wilson, 1979).

D. Relationship Between Thousand Kernel Weight and Kernel Size and Shape

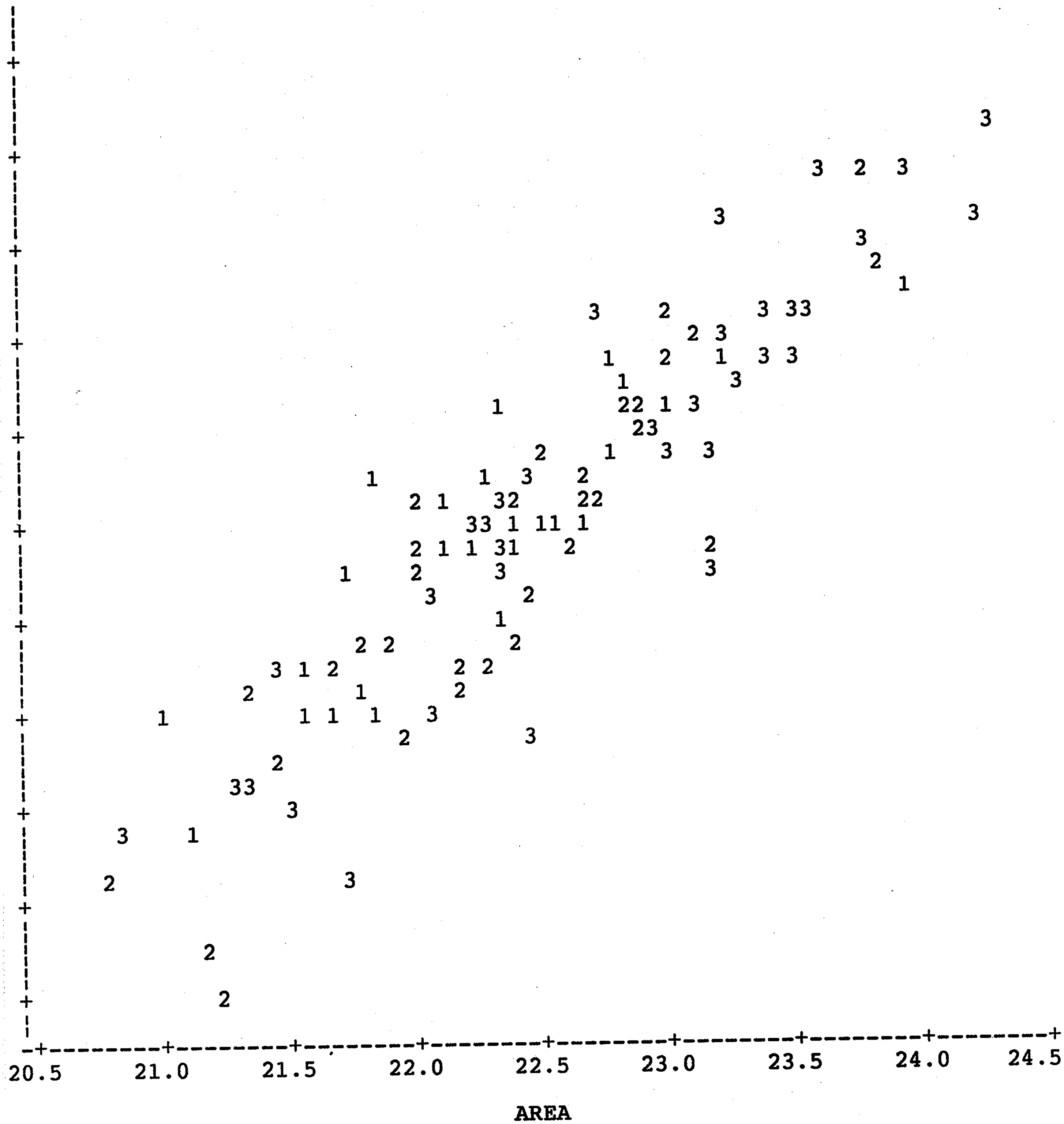
Regression analysis was used to estimate the influence of kernel size and shape features on thousand kernel weight (TKW). A plot of TKW vs. kernel area for 103 carlot wheat samples is shown in Figure 17, with the numerical values representing the CWRS grade that was assigned to each individual sample. The least squares regression line is estimated as

$$\underset{(\Pr>|t|=.0001)}{\underset{(t=20.69)}{TKW = -19.03 + 2.23\ AREA}} \qquad r^2 = 0.809 \qquad (1.4)$$

The coefficient 2.23 in Equation (1.4) is statistically significant given its large (>2) t value. The interpretation of the coefficient is as follows: for a $1mm^2$ increase in kernel area, TKW would on average, increase by 2.23g. The coefficient of determination (r^2) of 0.809 means that 81% of the variation in TKW can be explained by kernel area. The value for the coefficient of correlation (r) is +.90, while the standard error of the TKW estimate is 0.0819.

Figure 17

Relationship between thousand kernel weight (TKW, g) and kernel area (mm^2)



'E: 11 obs hidden.

Kernel shape can be measured through the relation of kernel length to kernel width together with the pattern or form of the kernel. As indicated in Figure 18, the most common kernel shapes for wheat can described as short, midlong or long, and as oval, ovate or elliptical when viewed from the dorsal side. An ovate kernel is broader at the germ end and has an egg-shaped appearance. An elliptical kernel is narrow in relation to length and is rounded at the ends. An oval kernel is broad across the center and tapered slightly toward both ends (Canadian Grain Commission, 1971).

The kernel shapes described above were quantified through the rectangular aspect ratio (RAR), which is simply the ratio of kernel length divided by kernel width. The observed inverse relationship between TKW and RAR is depicted in Figure 19, which can be described as

$$\underset{(Pr>|t|=.0001)}{\underset{(t=13.06)}{TKW = 73.93 - 21.94\ RAR}} \qquad r^2 = 0.628 \qquad (1.5)$$

The RAR coefficient is statistically significant and indicates that for a 0.1 unit increase in RAR, TKW would decrease by 2.19g. An increase in RAR would reflect an increase in kernel length relative to kernel width, or a tendency towards more of an elliptical kernel shape. Elliptical kernels with a RAR between 2.0 and 2.1 have TKW's ranging from 27 to 29g, whereas oval kernels with a RAR between 1.80 and 1.90 have TKW's ranging from 32 to 35g (Figure 19). According to Equation (1.5), kernel shape as measured through RAR can account for 63% of the variation in TKW.

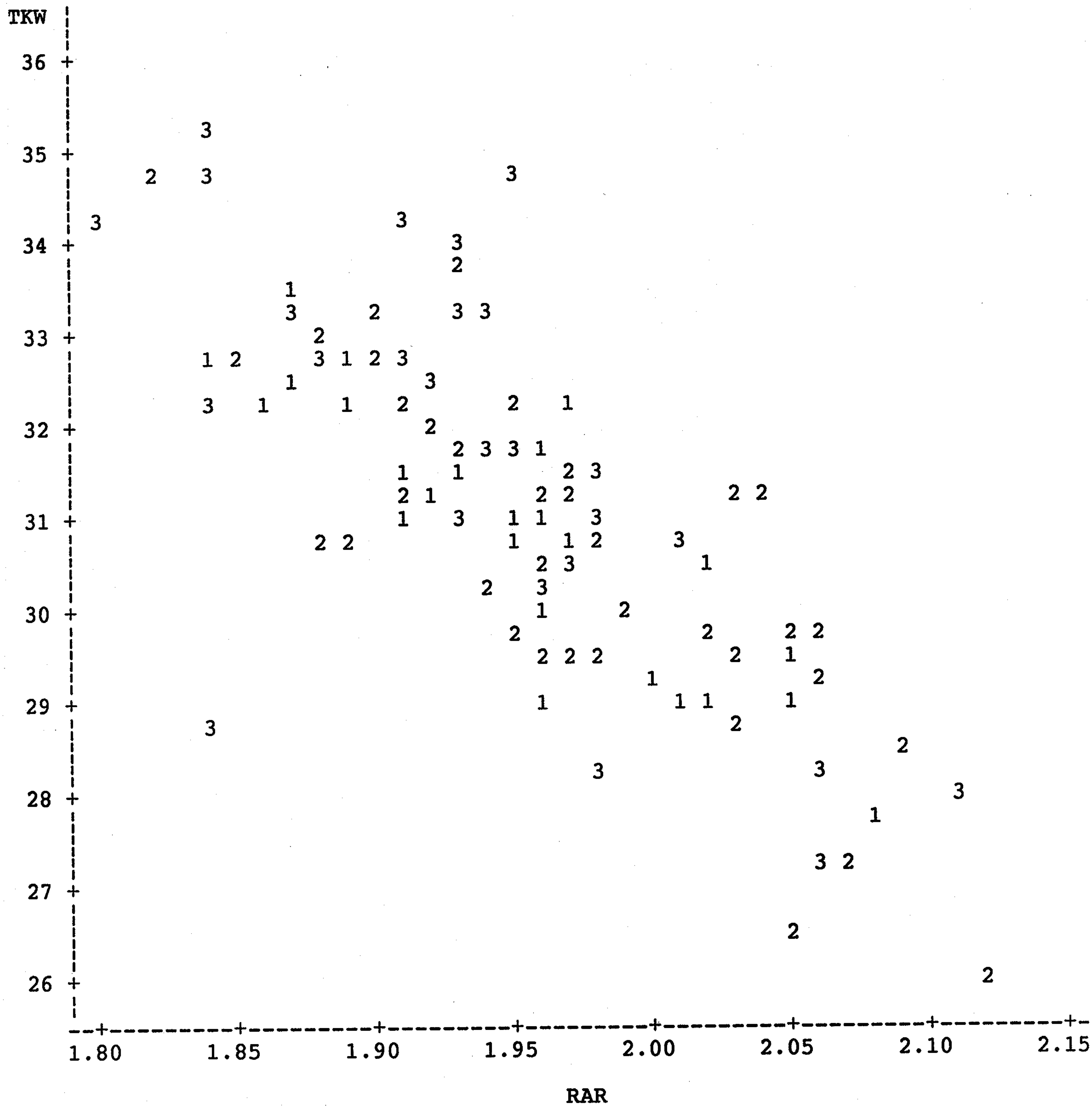
When the variables AREA and RAR were combined to estimate TKW, the following regression equation was obtained:

Figure 18

Classification of wheat kernel shape: dorsal view
(From Canadian Grain Commission, 1971, p. 57)

Elliptical Ovate Oval

Figure 19
Relationship between thousand kernel weight (TKW, g) and kernel shape as measured by the rectangular aspect ratio (RAR)



NOTE: 16 obs hidden.

$$\text{TKW} = 10.15 + 1.68\ \text{AREA} - 8.63\ \text{RAR} \qquad r^2 = 0.858 \qquad (1.6)$$
$$(t = 12.70) \quad (t = -5.84)$$
$$(Pr>|t|=.0001) \quad (Pr>|t|=.0001)$$

The regression model described by Equation (1.6) shows that for a $1mm^2$ increase in kernel area, TKW would increase by 1.68g. Similarly, a 0.1 unit decrease in RAR (say from 2.0 to 1.9) would increase TKW by 0.86g. Both independent variables contribute significantly to the model since the t values for testing the null hypothesis that their parameters equal zero are large (>2 for AREA and <-2 for RAR). Also, Pr>|t| values are .0001 for both parameters. Pr>|t| answers the following question (SAS Institute Inc., 1983): If the parameter is really equal to zero, what is the probability of getting a larger value of t? A very small value (ie. < .05) for this probability indicates that the value of the parameter is not likely to equal zero, and therefore that the independent variable contributes significantly to the model. The r^2 value of 0.86 implies that when combined, kernel size and shape can explain up to 86% of the variation in TKW. This represents a considerable improvement over the r^2 of 0.63 from the kernel shape model and somewhat of an improvement over the r^2 of 0.81 from the kernel size model. The remaining variation in TKW is explained by the density of the kernels (Hlynka and Bushuk, 1959).

Marshall et al (1986) studied the empirical relationship between grain size and milling yields in Australian milling wheats. Their experimental results showed that grain size, as measured by either grain weight or volume was highly and significantly correlated with flour yield. Linear correlation coefficients between flour yield and 100-grain weight (g) were +0.83 and +0.87 for the varieties Cook and Kite, respectively. For flour yield vs. 100-grain volume (cm^3), the reported correlation coefficients were +0.85 and +0.86 for the same varieties, respectively. Similar conclusions suggesting that kernel size does significantly influence milling yield in wheat were also reached by Shuey (1960), Shuey and Gilles (1969), and Baker and Golumbic (1970).

E. Evaluation of DIA System for Objective Wheat Grading

Although it has been 78 years since the Canada Grain Act became a federal statute in 1912, Canadian wheat grading has not yet been able to evolve to the point of becoming a predominantly objective system. As it exists today, the grading system is still to a large degree based on the subjective interpretation of grading factors by grain inspectors upon visual inspection of grain samples. This has in turn led to grading inconsistencies to the extent that after reinspections, it is not uncommon to find revisions in grade. For example, recent annual reports from the CGC for the crop years 1985-86 to 1988-89 indicate that anywhere from 10.9% to 14.1% of the reinspected samples received a higher grade, while from 0.2% to 0.6% received a lower grade from that originally assigned. In order to avoid these inconsistencies, it is therefore highly desirable to be able to grade wheat in the most objective manner possible.

The DIA system used in this study has generated a considerable amount of objective data on a single-kernel basis. In addition to the 16 image-extracted features measuring kernel size, shape, and brightness, 16 more variables were defined as their variance. The variance variables were used to quantify the level of uniformity that existed within each grade. To test the feasibility of being able to grade wheat objectively, the data was evaluated as to whether it could be used to differentiate between each of the three CWRS grades. For this purpose, the following approach was taken:

1. Using an appropriate multiple comparison procedure, to test for mean differences in the variables for each of the following three pairwise grade level comparisons: 1CWRS vs. 2CWRS, 2CWRS vs. 3CWRS, and 1CWRS vs. 3CWRS.

2. To use SAS statistical procedures (SAS Institute Inc., 1988), such as stepwise discriminant analysis and canonical discriminant analysis, in order to graphically evaluate, in three dimensional space, the level of discrimination which exists in the data based on a discriminant model using all or a certain subset of the 32 variables.

Before proceeding with the actual analysis, however, a brief overview of the basic ideas of discriminant analysis is in order. For a more comprehensive treatment of the subject, the reader is referred to specialist texts, such as those by Lachenbruch (1975), Goldstein and Dillon (1978), Hand (1981), Dillon and Goldstein (1984), and Krzanowski (1988).

Dillon and Goldstein (1984) describe discriminant analysis as a statistical technique for classifying individuals or objects into mutually exclusive and exhaustive groups on the basis of a set of independent variables. The technique involves deriving linear combinations of the independent variables that will discriminate between the priori defined groups in such a way that the misclassification error rates are minimized. This is accomplished by maximizing the between-group variance relative to the within-group variance.

Extending the above definition to the grading problem at hand, the individuals or objects are the carlot and cargo wheat samples, the groups are the three CWRS grades, and the independent variables are the image-extracted grain features (ie. 16 morphometric variables and their variances, for a total of 32 variables). Within this context discriminant analysis will be used as a technique to evaluate the level of CWRS grade discrimination that can be achieved with the kernel size, shape, brightness, and uniformity features quantified via DIA, for both the carlot unload and cargo wheat samples. Sapirstein et al. (1987) and Neuman et al. (1987) have used this approach to test to what extent kernel size and shape data could discriminate between different cereal grains (ie. wheat, barley, oats, rye), as well as between wheats of different classes (ie. HRS, SWS, Durum) and varieties.

1. Carlot Grade Discrimination

Duncan's New Multiple Range Test (Steel and Torrie, 1980) was run at both the 1% and 5% significance level to test for mean variable differences for each of the three possible pairwise grade level comparisons in the carlot samples (n=103). The results summarized in Table 16 indicate that for the 1CWRS vs. 2CWRS comparison there were 3 mean and 2 variance variables showing significant difference at the 5% level. For the 2 CWRS vs. 3 CWRS comparison it was 7 means and 6 variances, whereas for the 1CWRS vs. 3CWRS comparison it was 6 means and 7 variances that were significantly different at the 5% level. For the test results at the 1% significance level, it was interesting to note that the ratio of significant variance variables to significant mean variables increased relative to the 5% results, from 0.67 to 1.00, from 0.86 to 4.00 and from 1.17 to 1.75 for the 1CWRS vs. 2CWRS, 2CWRS vs. 3CWRS, and 1CWRS vs. 3CWRS comparison, respectively.

Stepwise discriminant analysis was used to determine the relative contribution of each kernel feature parameter for discrimination of the 1CWRS, 2CWRS, and 3CWRS carlot grades. Table 17 gives the summary ranking of the kernel features according to their incremental influence to distinguish between the three grades. One of the more common statistics that gives an indication of the overall degree of discrimination achieved is the average squared canonical

Table 16

Pairwise grade level comparisons of morphological features in carlot wheat samples

Parameter[a]	Grade Comparisons[b] 1CWRS vs. 2CWRS	2CWRS vs. 3CWRS	1CWRS vs. 3CWRS
Means:			
MAREFL	**	*	ns
MTHINN	ns	ns	ns
MAREA	ns	*	**
MCLEN	ns	*	**
MNCP	ns	ns	**
MWIDTH	ns	*	ns
MLENGTH	*	ns	*
MRAR	ns	ns	ns
MMMAX	*	ns	*
MMMIN	ns	*	ns
MMAR	ns	ns	ns
MAMEC	ns	*	ns
MN20	ns	ns	ns
MN02	ns	ns	ns
MM20	ns	ns	ns
MM02	ns	**	**
Variances:			
VAREFL	**	*	**
VTHINN	ns	ns	ns
VAREA	ns	*	**
VCLEN	ns	ns	ns
VNCP	ns	ns	ns
VWIDTH	ns	**	**
VLENGTH	ns	ns	ns
VRAR	ns	ns	ns
VMMAX	ns	ns	ns
VMMIN	ns	**	**
VMAR	ns	ns	ns
VAMEC	ns	**	**
VN20	ns	ns	ns
VN02	ns	ns	ns
VM20	*	ns	**
VM02	ns	**	**
No. of variables showing significance at 5% level (1% level):			
Means:	3 (1)	7 (1)	6 (4)
Variances:	2 (1)	6 (4)	7 (7)
Total:	5 (2)	13 (5)	13 (11)

[a] Prefix "M" and "V" denote means and variances, respectively.
[b] Carlot grades: 1CWRS (n=27), 2CWRS (n=40), 3CWRS (n=36).
* P < 0.05. ** P < 0.01.
ns = not significant at P < 0.05.

Table 17

Summary of ranking of kernel features by stepwise discriminant analysis of carlot wheat grades

Variable[a]	Number in	Partial R^2	F Statistic	Prob>F	ASCC[b]
VAREFL	1	0.2890	20.33	0.0001	0.1445
VM02	2	0.1560	9.15	0.0002	0.2078
MAREFL	3	0.1082	5.95	0.0037	0.2555
VN02	4	0.0594	3.07	0.0512	0.2740
VTHINN	5	0.0334	1.66	0.1960	0.2835
VMMAX	6	0.0419	2.08	0.1306	0.2974
VLENGTH	7	0.0562	2.80	0.0658	0.3218
MCLEN	8	0.0201	0.95	0.3897	0.3297
MM20	9	0.0528	2.57	0.0823	0.3459
MLENGTH	10	0.0321	1.51	0.2270	0.3553
MAREA	11	0.0471	2.23	0.1139	0.3691
MNCP	12	0.0188	0.85	0.4307	0.3738
VAREA	13	0.0364	1.66	0.1958	0.3825
VWIDTH	14	0.0640	2.97	0.0564	0.4043
MAMEC	15	0.0340	1.51	0.2260	0.4152
VCLEN	16	0.0227	0.99	0.3766	0.4206
MTHINN	17	0.0172	0.74	0.4825	0.4258
MM02	18	0.0199	0.84	0.4338	0.4328
VMMIN	19	0.0137	0.57	0.5680	0.4358
VN20	20	0.0196	0.81	0.4479	0.4419
VMAR	21	0.1002	4.46	0.0146	0.4761
MRAR	22	0.0136	0.54	0.5824	0.4797
VAMEC	23	0.0214	0.85	0.4295	0.4850
VNCP	24	0.0065	0.25	0.7770	0.4864
MMMAX	25	0.0011	0.04	0.9602	0.4867
MMAR	26	0.0045	0.17	0.8459	0.4880
MN20	27	0.0348	1.34	0.2695	0.4955
MWIDTH	28	0.0189	0.70	0.4983	0.5009
VRAR	29	0.0044	0.16	0.8528	0.5023
MMMIN	30	0.0026	0.09	0.9125	0.5028
MN02	31	0.0325	1.18	0.3142	0.5092
VM20	32	0.0003	0.01	0.9911	0.5093

[a] Prefix "M" and "V" denote means and variances of variables, respectively.
[b] ASCC, average squared canonical correlation.

correlation (ASCC). The ASCC is a trace criterion measuring the within class separability compared to the total (Sapirstein et al., 1987). An ASCC close to 1 means all groups are well separated and all or most directions in the discriminant space show good separation for at least two groups (SAS Institute Inc., 1988). An ASCC equal to 1 corresponds to perfect discrimination with no within class scatter.

The ASCC values in Table 17 reveal that the best two variable model accounted only for 40.8% [40.8% = (0.2078/0.5093)100] of the clustering of the three grades in the discriminant space, whereas the best three, four and five variable models accounted for 50.2%, 53.8%, and 55.7% of the clustering, respectively.

The level of discrimination which exists in the data is evident from the cluster diagram represented by Figure 20, which is a graphic result of a canonical discriminant analysis on the carlot grade samples ("training set") where kernel size, shape, reflectance and uniformity features were quantified. The result demonstrates that the machine vision system was not able to clearly separate the three CWRS grades based on a discriminant model using all 32 measured features. As expected, the 1CWRS and 3CWRS grades were the best separated groups. However, significant confusion existed between the 1CWRS and 2CWRS as well as between the 2CWRS and 3CWRS grades, although the extent of the confusion is unclear from the perspective of the three-dimensional clustering.

2. Cargo Grade Discrimination

Cargo results from Duncan's New Multiple Range Test at both the 5% and 1% significance level are given in Table 18. When compared to the carlot results (Table 16), there is a substantial increase in the number of variables

Figure 20

Clustering of 1CWRS, 2CWRS and 3CWRS carlot wheat kernels by canonical discriminant analysis using size, shape, reflectance and uniformity features. The plotted symbols (n=103) correspond to scores on the first three canonical variables derived from an original set of 32 measured features

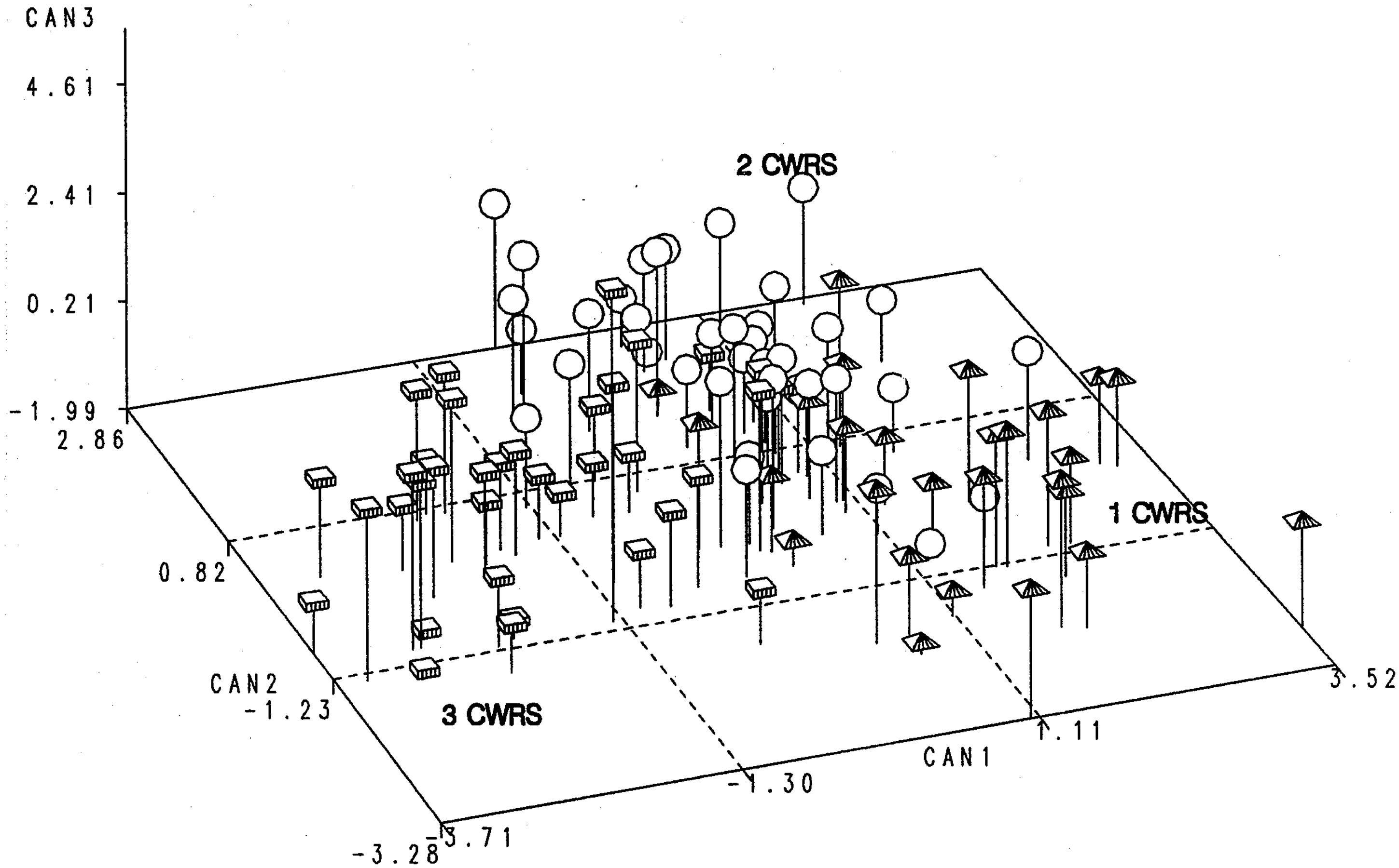


Table 18

Pairwise grade level comparisons of morphological features in cargo wheat samples

Parameter[a]	Grade Comparisons[b] 1CWRS vs. 2CWRS	2CWRS vs. 3CWRS	1CWRS vs. 3CWRS
Means:			
MAREFL	**	ns	**
MTHINN	**	ns	**
MAREA	*	*	ns
MCLEN	ns	*	ns
MNCP	ns	*	*
MWIDTH	**	*	**
MLENGTH	*	ns	**
MRAR	**	ns	**
MMMAX	**	*	**
MMMIN	**	*	**
MMAR	**	ns	**
MAMEC	**	*	**
MN20	**	ns	**
MN02	**	ns	**
MM20	ns	ns	ns
MM02	**	**	ns
Variances:			
VAREFL	**	ns	**
VTHINN	**	**	**
VAREA	**	**	**
VCLEN	**	*	**
VNCP	**	ns	**
VWIDTH	*	**	**
VLENGTH	**	ns	**
VRAR	**	**	**
VMMAX	**	ns	**
VMMIN	ns	**	**
VMAR	**	**	**
VAMEC	ns	**	**
VN20	**	**	**
VN02	ns	**	**
VM20	**	**	**
VM02	ns	**	**
No. of variables showing significance at 5% level (1% level):			
Means:	13 (11)	8 (1)	12 (11)
Variances:	12 (11)	12 (11)	16 (16)
Total:	25 (22)	20 (12)	28 (27)

[a] Prefix "M" and "V" denote means and variances, respectively.
[b] Cargo grades: 1CWRS (n=25), 2CWRS (n=25), 3CWRS (n=23).
* P < 0.05. ** P < 0.01.
ns = not significant at P < 0.05.

(especially in the variances) that tested "significantly different" at both levels. At the 5% (1%) level, there were respectively 13(11) means and 12(11) variances, 8(1) means and 12(11) variances, and 12(11) means and 16(16) variances that were significant for the 1CWRS vs. 2CWRS, 2CWRS vs. 3CWRS, and 1CWRS vs. 3CWRS grade comparison.

The results from Duncan's test would seem to indicate that the cargo grades should be more readily distinguished from one another as compared to their carlot counterparts. This is essentially confirmed by the results from the stepwise discriminant analysis, which yielded higher values for ASCC (Table 19). The ASCC column in Table 19 reveals that the best two, three, four, and five variable models accounted for respectively 60.8%, 70.8%, 73.7% and 75.4% of the clustering of the 1CWRS, 2CWRS, and 3CWRS grades. This represents a considerable improvement over the carlot results of respectively 40.8%, 50.2%, 53.8%, and 55.7%.

As shown in Figure 21, an excellent level of discrimination was achieved among the three cargo grades. All three grades were essentially disjoint with 1CWRS and 3CWRS being especially well separated along the first canonical component axis, which characteristically possess the largest range of values (Sapirstein et al., 1987). The three grades can essentially be seen as three distinct clusters in the three-dimensional discriminant space.

The importance of kernel feature uniformity in the overall grading process is demonstrated in Figure 22. With the variances of all feature variables removed from the data set (i.e. the discrimination was based on only 16 variables), significant confusion existed between the No.2 and the No.3 grade as seen by the amount of overlap in the clustering. The absence of variance variables had no apparent effect on the level of discrimination between the No.1 and the No.2 or

Table 19

Summary of ranking of kernel features by stepwise discriminant analysis of cargo wheat grades

Variable[a]	Number in	Partial R^2	F Statistic	Prob>F	ASCC[b]
MAREFL	1	0.6499	64.97	0.0001	0.3249
VMMIN	2	0.6437	62.33	0.0001	0.5316
VAREFL	3	0.1765	7.29	0.0014	0.5637
MMMAX	4	0.1537	6.08	0.0037	0.5862
VAREA	5	0.1544	6.03	0.0039	0.6001
VMAR	6	0.1032	3.74	0.0290	0.6230
MRAR	7	0.1047	3.74	0.0291	0.6556
MLENGTH	8	0.0872	3.01	0.0565	0.6602
MTHINN	9	0.0930	3.18	0.0486	0.6815
VCLEN	10	0.0654	2.14	0.1269	0.6874
VMMAX	11	0.1800	6.59	0.0026	0.7026
MMAR	12	0.0693	2.20	0.1201	0.7087
MM20	13	0.0603	1.86	0.1645	0.7199
MM02	14	0.1467	4.90	0.0109	0.7289
VN20	15	0.0568	1.69	0.1946	0.7409
MAREA	16	0.0432	1.24	0.2972	0.7442
MN02	17	0.0506	1.44	0.2463	0.7555
VWIDTH	18	0.0603	1.70	0.1927	0.7685
MWIDTH	19	0.0465	1.27	0.2900	0.7718
VN02	20	0.0332	0.88	0.4223	0.7785
VAMEC	21	0.0180	0.46	0.6354	0.7793
MN20	22	0.0156	0.39	0.6801	0.7823
VRAR	23	0.0130	0.32	0.7299	0.7843
VTHINN	24	0.0151	0.36	0.7000	0.7871
MMMIN	25	0.0144	0.34	0.7168	0.7890
MNCP	26	0.0250	0.58	0.5660	0.7922
VLENGTH	27	0.0140	0.31	0.7340	0.7937
VM20	28	0.0111	0.24	0.7860	0.7941
VM02	29	0.0079	0.17	0.8473	0.7954
VNCP	30	0.0060	0.12	0.8845	0.7958
MAMEC	31	0.0033	0.07	0.9366	0.7959
MCLEN	32	0.0013	0.03	0.9747	0.7959

[a] Prefix "M" and "V" denote means and variances of variables, respectively.
[b] ASCC, average squared canonical correlation.

Figure 21

Clustering of 1CWRS, 2CWRS and 3CWRS cargo wheat kernels by canonical discriminant analysis using size, shape, reflectance and uniformity features. The plotted symbols (n=73) correspond to scores on the first three canonical variables derived from an original set of 32 measured features

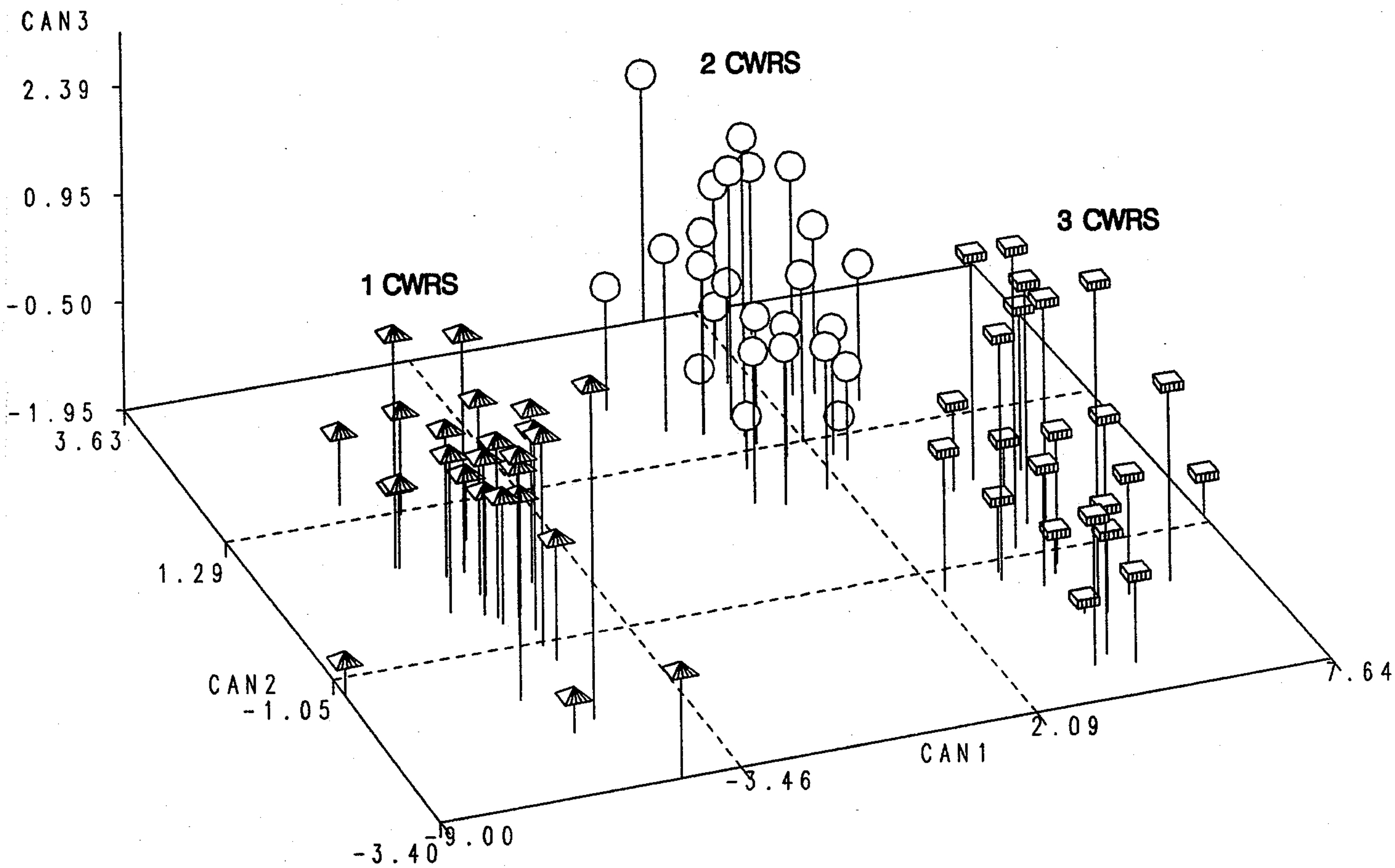
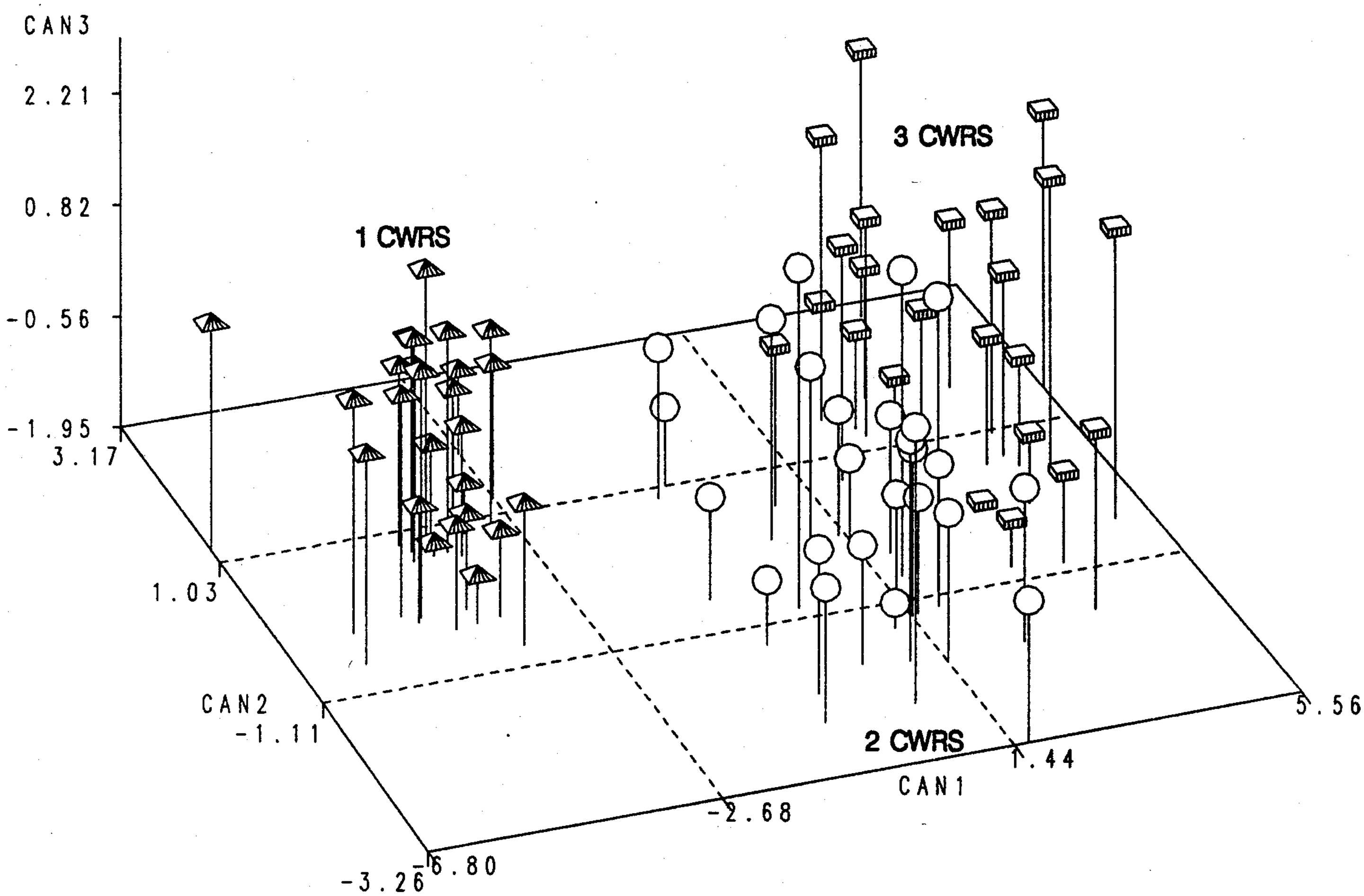


Figure 22

Clustering of 1CWRS, 2CWRS and 3CWRS cargo wheat kernels by canonical discriminant analysis having removed the variance variables from the data set. The plotted symbols (n=73) correspond to scores on the first three canonical variables derived from an original set of 16 measured features



between the No.1 and the No.3 grade, suggesting the No.1 grade is really "in a class of its own."

Figure 23 illustrates the effect of removing the reflectance features (i.e. both mean and variance) from the data set (i.e. leaving 30 variables in the discriminant model). When compared to Figure 21, not only is the overall level of grade discrimination lower, but it also appears that there is one particular sample that should now (based on kernel size and shape) grade 2CWRS instead of 1CWRS. This result shows the relative importance of kernel brightness (i.e. the level of bleaching) and its uniformity in the wheat inspection and grading process.

3. Cargo - Carlot Differences

To quantitatively assess the relative differences in the level of grade discrimination in the cargo as compared to the carlot samples, respective ASCC's were plotted against the number of variables in the respective discriminant models. As summarized in Figure 24, ASCC's for the cargo models were consistently and significantly higher than those for the carlot models. With all 32 variables included, the cargo model yielded an ASCC of 0.80, whereas an ASCC of only 0.51 was obtained in the carlot model. This difference in the ASCC reflects the results obtained from Duncan's test, namely that in the cargo samples there were considerably more variables that tested "significantly different" for each of the three pairwise grade comparisons when compared to the carlot samples. Overall, this means an improved separation of the three CWRS grades as seen in the cargo cluster diagrams (see Figure 21 versus Figure 20). Figure 24 also reveals that as new variables are being added to the discriminant models, increases in ASCC start to become less pronounced after addition of the 15th variable and virtually

Figure 23

Clustering of 1CWRS, 2CWRS and 3CWRS cargo wheat kernels by canonical discriminant analysis having removed average and variance of reflectance from the data set. The plotted symbols (n=73) correspond to scores on the first three canonical variables derived from an original set of 30 measured features

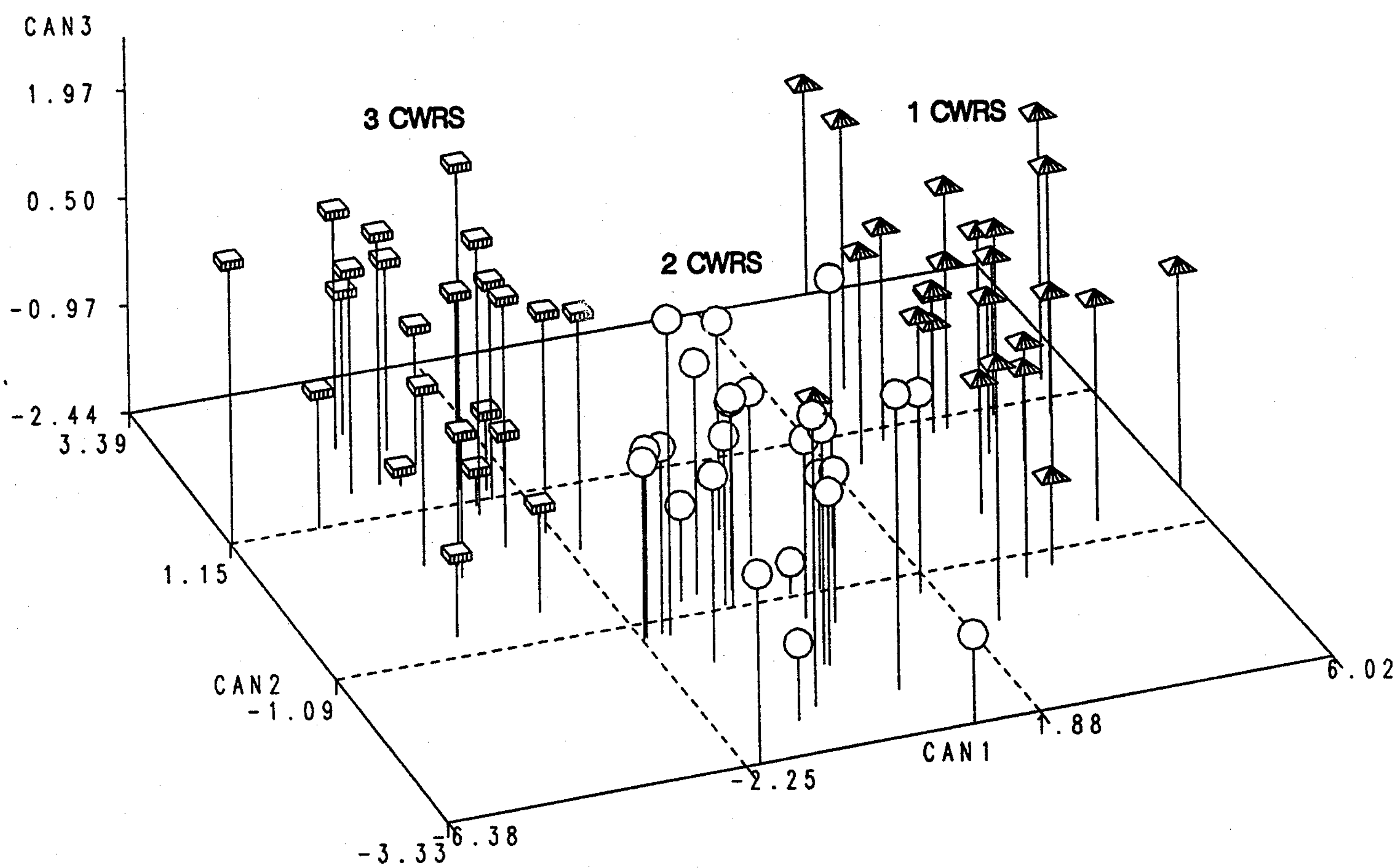
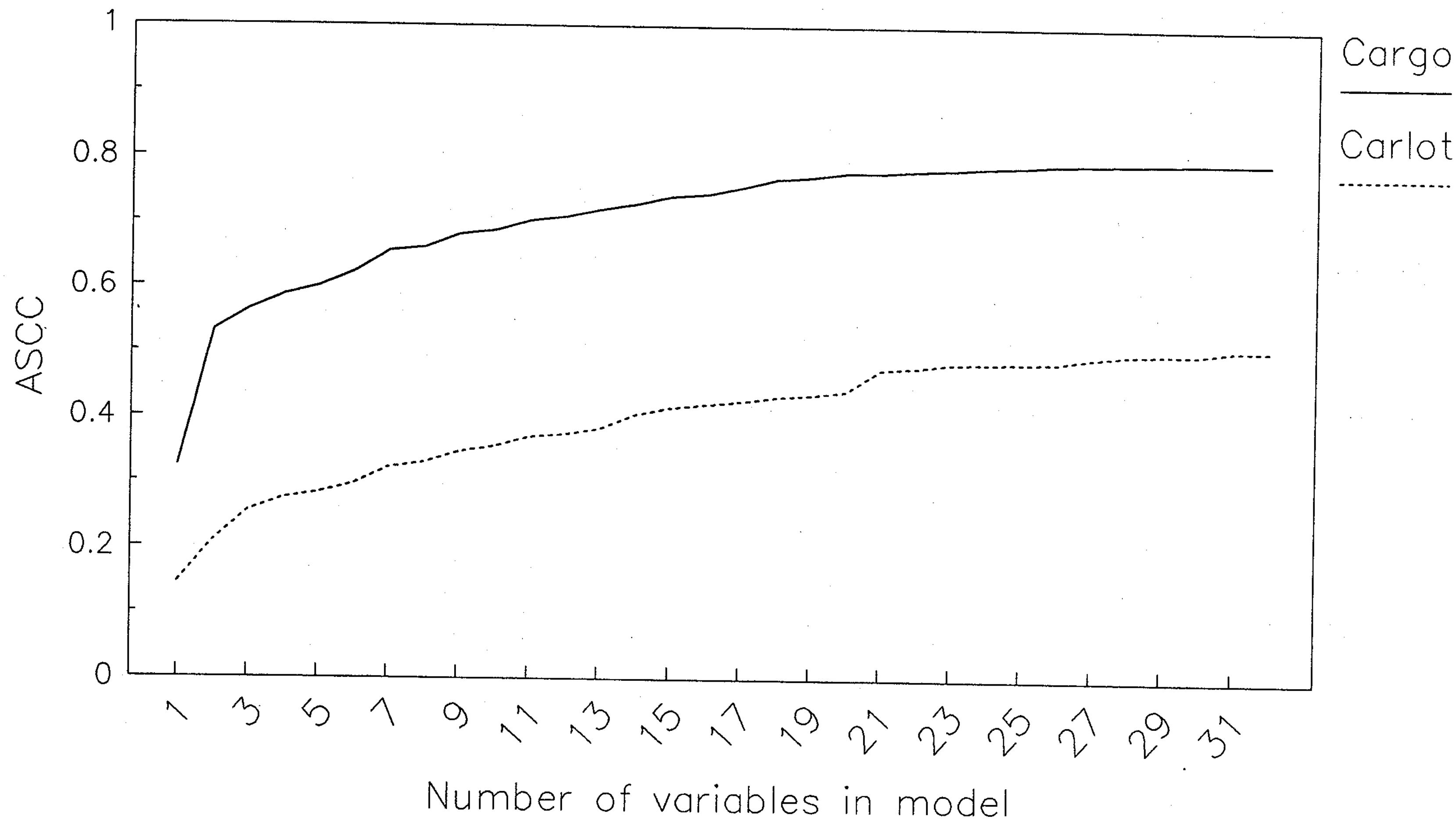


Figure 24

Plot of ASCC versus number of variables in carlot and cargo discriminant models



level off after the 21st variable was added.

The carlot and cargo discriminant models also differ in the type of variables and their ranking, given the objective of determining an optimal subset of kernel features that can be routinely extracted by digital image processing. For example, the composition and ranking of the 15 variable models were as follows:

	Carlot Model	Cargo Model
1.	VAREFL	MAREFL
2.	VM02	VMMIN
3.	MAREFL	VAREFL
4.	VN02	MMMAX
5.	VTHINN	VAREA
6.	VMMAX	VMAR
7.	VLENGTH	MRAR
8.	MCLEN	MLENGTH
9.	MM20	MTHINN
10.	MLENGTH	VCLEN
11.	MAREA	VMMAX
12.	MNCP	MMAR
13.	VAREA	MM20
14.	VWIDTH	MM02
15.	MAMEC	VN20

Out of the first 10 variables included, 6 were variance variables in the carlot model compared to 5 variance variables in the cargo model. Similarly, out of the first 15 variables, 8 were variance variables in the carlot model compared to 7 variance variables in the cargo model. It appears then that the variance variables are just as important as the morphological features themselves in objectively discriminating among the three grades. Average reflectance as well as the uniformity of average reflectance were included in both carlot and cargo models among the top three variables.

F. Reproducibility of the Measuring System

Some common sources of error in a digital image analysis system when used to measure volume and surface area in sweet potatoes were identified by Tappan et al. (1987). Gray levels in the digitized image of an object were found to change with the object's position. Changes in the vertical positioning had a greater effect than horizontal changes. As only the central pixel columns were used in their study, changes from just above center to just below center were measured. It was found that the pixel count for the lower position was consistently larger. Expressed as a percent of the average count for the two positions, the variation ranged from ± 1.2% to ± 1.7%, depending on the threshold level.

Symons and Fulcher (1988b) used repeated measurements on single wheat kernels to determine variability of measurements due to camera focus, kernel position and segmentation. For ten measurements with each of three parameters (focus, kernel position and segmentation), interactively adjusted, an insignificant degree of variability (i.e. less than the 3% variability described by the manufacturers for their imaging system) was detected for five variables: area (C.V.=1.5%), perimeter (C.V.=0.5%), convex perimeter (C.V.=1.3%), kernel length (C.V.=0.8%) and kernel width (C.V.=0.7%).

The precision of the image analysis system used in this study for extracting and measuring kernel features was evaluated by processing individual images of a single wheat kernel placed dorsally at 9 different positions within the viewing window. At each position, the kernel was also rotated 180 degrees after the previous image was grabbed and stored. All 18 treatments were processed under the same experimental conditions used for the carlot and cargo experiments. Coefficients of variation were then calculated for kernel contour length, width, length and area as illustrated in Table 20. C.V.'s ranged from 0.76% for kernel area to 1.18% for contour length. Also shown in Table 20 are the C.V.'s for the same four size features that were quantified for a 1CWRS carlot composite sample of 1927 kernels (Table 6). Comparing these variabilities inherent in the sample (ie. sample variance) to the measurement variabilities inherent in the image analysis system (ie. instrumental variance), it is evident that the latter are indeed insignificant. Sample C.V.'s were considerably higher than instrumental C.V.'s, ranging from 5.5 times higher for contour length to 17.5 times higher for kernel area. These results reflect the overall level of measurement reproducibility, and demonstrate that a high and satisfactory level of precision was used in the extraction and measurement of the various morphological features and their subsequent use in CWRS grade discrimination.

G. Factors Contributing to Uniformity of Quality in CWRS Wheat

The interaction between the grain grading system and the bulk handling system to promote uniformity of quality as CWRS wheat is shipped from primary to terminal elevator positions has already been discussed in conjunction with Figure 16. The basic objective of the grading system is to ensure that the 1CWRS grade is consistently the most uniform grade with respect to the range of variation in quality caused by environmental effects and admixture of foreign material. Through the process of melding like grades and restricting the blending of unlike grades the bulk handling system further maximizes uniformity within the top grade at export positions. The relative effects on uniformity from both systems have been quantified in this study (Tables 9 - 15 and Figures 13 - 15).

The high degree of uniformity within the No.1 grade cannot, however solely be attributed to the grading and bulk handling systems. The regulations in place

Table 20

Variability of DIA-computed size measurements as a result of repositioning and rotating wheat kernel in the imaging field: instrumental versus sample variance

	Size feature			
Statistic	Contour length[a]	Width[a]	Length[a]	Area[b]
n	18	18	18	18
Mean	14.93	3.57	5.76	25.96
Std.Dev.	0.1755	0.0396	0.0497	0.1980
C.V. (DIA)[c]	1.18%	1.11%	0.86%	0.76%
C.V. (1CWRS)[d]	6.49%	9.07%	6.98%	13.27%
C.V. (1CWRS) / C.V. (DIA)	5.5	8.17	8.12	17.46

[a] Measurement units in mm.

[b] Measurement units in mm^2.

[c] Instrumental variance.

[d] Sample variance.

for developing, testing and licensing new wheat varieties also has a very significant impact. For a new variety of wheat to be eligible for marketing under the CWRS class and, more specifically, qualify for any of its three grades, it must have demonstrated at least an equal performance to the variety Neepawa, the CWRS standard, in the various milling and baking quality tests. The new variety must also be visually distinguishable from wheats of other classes. As a result of these stringent regulations, only a small number of new varieties have been licensed for commercial production during the last ten years.

Predominant bread wheat varieties, commercially grown in the Prairie Provinces from 1981 to 1990 are listed in Table 21. The three CWRS varieties Neepawa, Columbus, and Katepwa accounted for 79.7%, 84.5%, 87.3%, 88.5%, 85.8% and 73.9% of the annual seeded acreage, from 1985 to 1990, respectively. From 1981 to 1984 over 50% of the bread wheat acreage was seeded to Neepawa. After 1984 the Neepawa acreage started to decrease with the introduction of Columbus and Katepwa. The variety Katepwa has been the most popular choice amongst Prairie farmers over the last four years at over 40% of the seeded acreage. Since these three varieties have close genetic relationships, they possess very similar kernel size and shape characteristics, which is the "built in" uniformity within the CWRS class.

H. Historic Price Differentials for CWRS Grades

Final prices for the various CWRS grades for the crop years 1969/70 to 1988/89, obtained from Canadian Wheat Board (CWB) Annual Reports, were used to calculate price differentials. Each of the three price differentials calculated in Table 22 were expressed as a percentage of the 2CWRS final price as this grade is generally indicative of the average dollar value (basis in store Vancouver or

Table 21

Ten-year summary of predominant bread wheat varieties grown in the Prairie Provinces[a]
(From Manitoba Seed Growers Association, 1990, p.42)

Bread wheat variety	Percent of total bread wheat acreage seeded									
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Benito	1.0	6.6	6.6	4.7	2.7	2.0	1.6	1.4	1.1	1.0
Columbus	0.0	0.0	8.1	17.6	20.7	20.0	18.3	18.0	17.0	16.1
Conway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	4.4
Glenlea	2.9	0.8	2.7	2.2	1.5	0.8	0.6	0.4	0.3	0.3
Katepwa	0.0	0.0	0.0	1.7	17.9	33.2	43.7	49.3	50.2	44.3
Laura	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	9.5
Neepawa	64.6	65.2	61.8	52.6	41.1	31.3	25.3	21.2	18.6	13.5
Park	3.9	4.5	4.0	3.5	3.3	2.9	2.7	2.8	2.3	1.9
Roblin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	4.3
Others	27.6	22.9	16.8	17.7	12.8	9.8	7.8	6.9	5.3	4.7

[a] Based on a survey of grain varieties seeded on the Pairies conducted jointly by Alberta Wheat Pool, Saskatchewan Wheat Pool and Manitoba Pool Elevators.

Table 22

Canadian Wheat Board final prices and price differentials
for CWRS wheat grades, crop years 1969/70 - 1988/89
(From Canadian Wheat Board, Annual Reports)

Crop Year	Final Price ($/t)			Price Differentials					
	1CWRS	2CWRS	3CWRS	1CWRS-2CWRS	% of 2CWRS Price	2CWRS-3CWRS	% of 2CWRS Price	1CWRS-3CWRS	% of 2CWRS Price
1969/70	60.81	57.91	53.35	2.90	5.01	4.56	7.87	7.46	12.88
1970/71	60.67	58.83	54.34	1.84	3.13	4.49	7.63	6.33	10.76
1971/72	58.64	56.40	49.75	2.24	3.97	6.65	11.79	8.89	15.76
1972/73	79.15	77.68	73.27	1.47	1.89	4.41	5.68	5.88	7.57
1973/74	168.21	165.33	160.68	2.88	1.74	4.65	2.81	7.53	4.55
1974/75	164.39	158.22	156.60	6.17	3.90	1.62	1.02	7.79	4.92
1975/76	146.28	141.43	132.79	4.85	3.43	8.64	6.11	13.49	9.54
1976/77	117.15	109.90	104.35	7.25	6.60	5.55	5.05	12.80	11.65
1977/78	120.30	113.81	107.17	6.49	5.70	6.64	5.83	13.13	11.54
1978/79	160.53	151.80	150.11	8.73	5.75	1.69	1.11	10.42	6.86
1979/80	196.43	187.64	179.18	8.79	4.68	8.46	4.51	17.25	9.19
1980/81	222.12	217.96	209.42	4.16	1.91	8.54	3.92	12.70	5.83
1981/82	199.62	197.03	187.76	2.59	1.31	9.27	4.70	11.86	6.02
1982/83	192.34	185.39	180.39	6.95	3.75	5.00	2.70	11.95	6.45
1983/84	193.98	190.23	178.56	3.75	1.97	11.67	6.13	15.42	8.11
1984/85	186.37	184.11	171.51	2.26	1.23	12.60	6.84	14.86	8.07
1985/86	160.00	154.21	146.21	5.79	3.75	8.00	5.19	13.79	8.94
1986/87	130.00	124.21	110.21	5.79	4.66	14.00	11.27	19.79	15.93
1987/88	134.02	127.87	115.78	6.15	4.81	12.09	9.45	18.24	14.26
1988/89	197.14	191.19	182.11	5.95	3.11	9.08	4.75	15.03	7.86
Ave. 1969/70 - 1973/74				2.27	3.15	4.95	7.16	7.22	10.31
Ave. 1974/75 - 1978/79				6.70	5.08	4.83	3.83	11.53	8.90
Ave. 1979/80 - 1983/84				5.25	2.73	8.59	4.39	13.84	7.12
Ave. 1984/85 - 1988/89				5.19	3.51	11.15	7.50	16.34	11.01
All years:									
Mean				4.85	3.62	7.38	5.72	12.23	9.34
Variance				5.18	2.49	12.15	8.41	15.95	11.72
Std.Dev.				2.27	1.58	3.49	2.90	3.99	3.42
C.V.				46.91	43.62	47.23	50.71	32.66	36.67

Thunder Bay) of CWRS wheat. Under normal weather conditions during harvest the No.2 grade is also the most predominant CWRS grade being handled annually by terminal elevators.

Over the 20-year period, the 1CWRS-2CWRS price differential was the most stable, averaging at 3.62% of the 2CWRS price, with a standard deviation of 1.58%. The 2CWRS-3CWRS and 1CWRS-3CWRS price differentials were comparatively more volatile and have gradually increased since the early 1980's. For example, from the 5-year period 1979/80-1983/84 to the 5-year period 1984/85-1988/89 the 2CWRS-3CWRS price differential increased from 4.39% to 7.50%. Over the same time period the 1CWRS-3CWRS price differential widened from 7.12% to 11.01% (see Table 22). These increases can be partly explained by increasing market competition from wheats of quality equivalent to the 3CWRS grade, but also by increasing value differences as perceived by end-users, such as domestic and overseas millers (Coudiere, 1990; OTA, 1989b).

The various price differentials do for the most part reflect the objectively measured physical characteristics and their uniformity differences between the CWRS grades as quantified in this study. However, it appears as though the 1CWRS-2CWRS price spread of between $5 and $6 per tonne during the late 1980's may have somewhat overstated the actual differences observed. For both the carlot and cargo samples there was very little difference in terms of the uniformity of physical characteristics between these two grades:

Sample category	C.V. for 1CWRS	C.V. for 2CWRS
Carlot (Table 9)	3.33%	3.67%
Cargo (Table 13)	1.27%	1.25%

Futz (1989) arrived at a similar conclusion when he studied the relationship between CWRS grade and processing quality characteristics. Based on quarterly information published by the CGC from 1975/76 to 1985/86, an analysis of Pacific cargo quality data indicated that the 1CWRS 13.5% vs. 2CWRS 13.5% and the 1CWRS 12.5% vs. 2CWRS 12.5% grade comparisons had the least number of significantly different processing quality characteristics.

I. Importance of Uniformity of Quality in the International Wheat Market

In 1986 the Office of Technology Assessment (OTA) of the U.S. Congress initiated a two-year study (OTA, 1989a, b) covering major issues in U.S. grain quality. One of its objectives was to determine which quality attributes are considered important by domestic and overseas processing industries. Results from a wheat survey showed that domestic and overseas millers considered uniformity between shipments as being as important as the quality attributes themselves. The respondents were also asked to rank their preference for bread, soft, and durum wheats from all countries exporting these types of wheat, assuming that price, transportation, and other related costs were equal. For bread wheats the preferences were as follows:

1. Canada Western Red Spring (CWRS)
2. Australian Prime Hard (APH)
3. U.S. Dark Northern Spring (DNS)
4. U.S. Hard Red Winter (HRW)
5. Australian Hard
6. Argentinean Hard
7. E.C. Soft
8. U.S. Soft Red

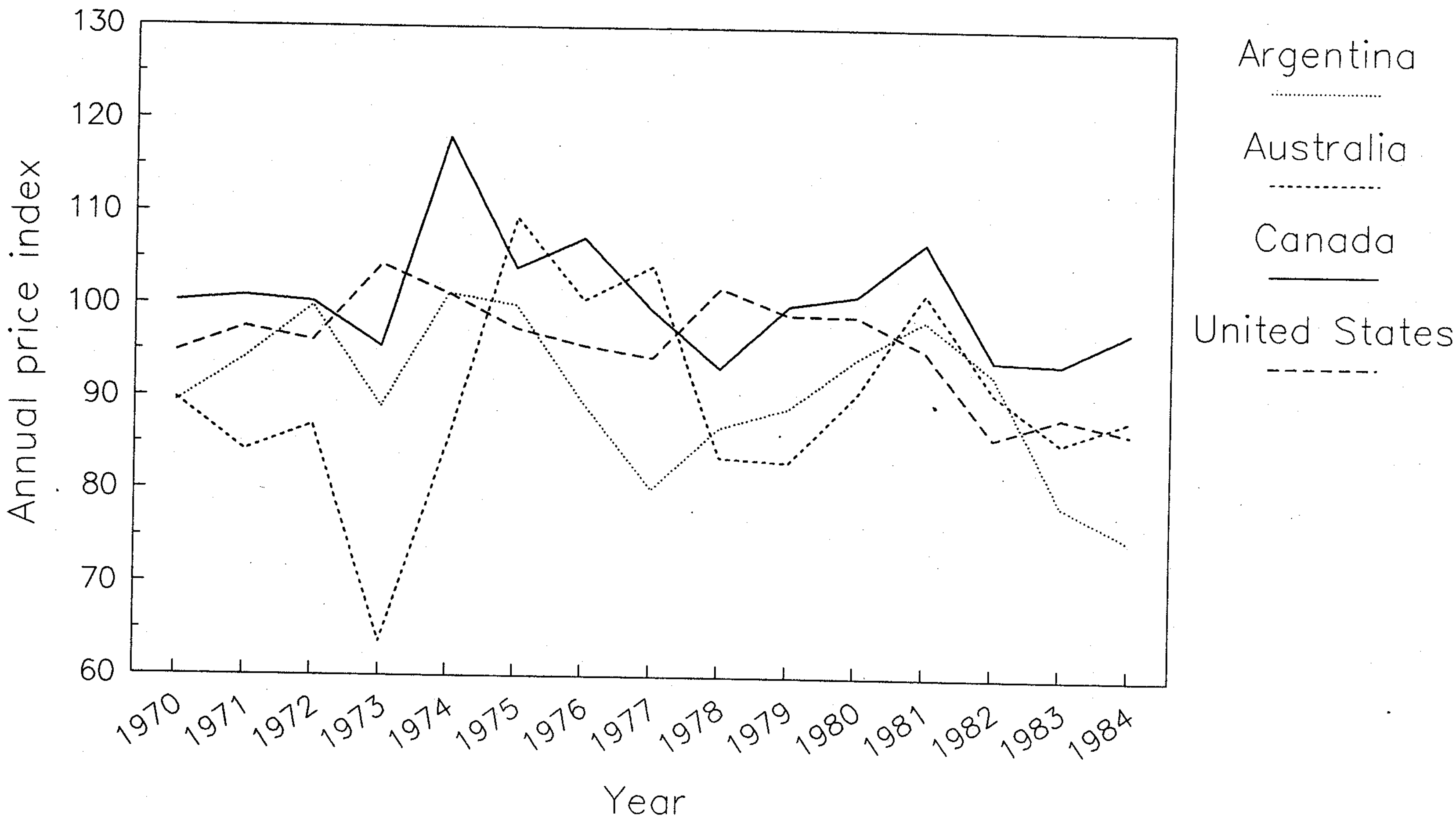
Given the frequent number of complaints over the wide quality fluctuations in U.S. wheat shipments in recent years (OTA, 1989b; Agweek, 1989; Western Producer, 1990; Hill, 1990), foreign buyers in search for uniform or consistent quality wheat for breadmaking and blending purposes pick Canada Western Red Spring (CWRS) and Australian Prime Hard (APH) wheats before turning to U.S. Dark Northern Spring (DNS) and U.S. Hard Red Winter (HRW).

The reputation Canada has developed for selling wheat of uniform and predictable quality has allowed the CWB to continue to charge a premium over the Australian, U.S. and Argentinean wheats (Figure 25). For example, between 1980/81 and 1984/85 import prices for No.1 CWRS 13.5 dropped approximately 20%, from $264 to $212 per tonne, with prices for other classes of wheat showing similar declines. However, the premium received for No.1 CWRS wheat has held its own, while the discount on U.S. HRW wheat has increased (OTA, 1989a). This seems contrary to the conventional wisdom of the early 1980's that the spread between Canadian and U.S. wheat was narrowing (Canada Grains Council, 1985). The Canadian price premium spiked up in 1974, 1976, and 1981 (Figure 25), when temporary shortages of high-protein wheat occurred.

A more recent study of international wheat prices (Larue, 1990) has also concluded that country specific policies relating to wheat quality, such as grading and inspection services and the licensing of new varieties are reflected in price premiums. Based on an econometric model using price and wheat quality data covering the period starting in 1980/81 and ending in 1988/89, Canadian wheat was also found to command a premium over Australian and U.S. wheat. These results were interpreted to imply that Canada's marketing strategy during the 1980's achieved its objective, maintaining its reputation as a reliable supplier of wheat of consistent quality.

Figure 25

Annual price indices for the major wheat exporters, 1970–84 (dollars per tonne)



Source: OTA, 1989a, p.92.

V. GENERAL DISCUSSION

Of the various types of wheat produced in Canada, the Canada Western Red Spring (CWRS) class is by far the most important. It accounts for roughly 85% of total annual Canadian wheat exports, a reflection of its overall significance to the Prairie economy. CWRS wheats possess very desirable milling and baking properties, such as hardness, high protein content, good protein "quality," strong gluten, and a high water absorption. These unique physico-chemical properties make these wheats ideal for the production of pan and hearth breads, as well as for blending with lower quality wheats for importers wishing to improve the milling and baking performance of their domestic wheats.

The grading of CWRS wheat in Canada represents a significant value-added activity which facilitates its marketing once it leaves the farm gate and enters into commercial channels. Under Canada's grading system a single parcel of wheat is graded and inspected three times: (1) at the time it is delivered by producers into the country elevator; (2) on arrival at the terminal elevator; and (3) during loading into a cargo vessel prior to export. This system is based on the subjective interpretation of grading factors by grain inspectors upon visual inspection of sampled grain relative to established standard grade samples. The five factors considered when grading CWRS wheat are test weight, varietal purity, vitreousness, soundness, and admixture of inseparable foreign material. The only grading factor determined through objective measurement is test weight. However, very seldom does test weight determine grade since in almost all cases the actual test weight of No.3 CWRS exceeds the minimum specified for No.1 CWRS (Preston et al., 1988; Canadian Grain Commission, 1989a). Many of the other grading factors are expressed as percentages in the inspector's grading guide (see Appendix I), but their actual percentage values are calculated from the amounts of components separated on the basis of visual examination and not from any direct objective measurement (Bushuk and Sapirstein, 1987). As for degree of soundness, grade requirements for No.1 CWRS such as being "reasonably well matured and reasonably free from damaged kernels" cannot be precisely measured and as such are open to subjective interpretation.

The lack of objective measurement of important grading factors has led to grading inconsistencies to the extent that after reinspections it is not uncommon to find revisions in grade. According to recent annual reports from the CGC for the crop years 1985-86 to 1988-89, 10.9% to 14.1% of reinspected samples received a higher grade, while from 0.2% to 0.4% received a lower grade from that originally assigned. With uniformity in grain quality progressively becoming more important as wheat utilization and processing technology increases in sophistication (Smart, 1990), end-users will always prefer a precise and consistent measurement of quality characteristics. With these considerations in mind, the present research was undertaken to evaluate a computer-based methodology called digital image analysis (DIA) in its ability to distinguish between three commercial grades of CWRS wheat solely based on objective measurement of kernel size, kernel shape and kernel brightness, as well as the uniformity of these features within each grade.

A total of 103 carlot and 73 cargo samples were used for the analysis. The samples were graded by the Grain Inspection Division of the CGC, each containing from 450 to 500g of wheat. As a first step in the research, thousand kernel weight (TKW) was determined for each sample based on three replicates. The replicates were then recombined into a gross subsample from which kernels were to be sampled for morphological characterization by DIA. To empirically determine an appropriate sample size, DIA was used in a preliminary experiment measuring kernel size features in composite samples ranging from 10 to 520 kernels in size. Assuming a 95% certainty that the error of estimation does not exceed 0.10mm, the results indicated that the required sample sizes are 333, 362 and 416 kernels for the 1CWRS, 2CWRS and 3CWRS grade, respectively. The increase in sample size as grade dropped was due to a progressively increasing variability in kernel size. Based on these results it was decided to use a sample size of 400 kernels for all three grade levels.

Although there were virtually no significant differences in mean TKW values between the three grades, a progressive increase in the variability in TKW, as measured by its coefficient of variation (C.V.), was observed as grade level decreased. For the carlot samples C.V.'s were 4.61%, 5.96% and 6.89% for the 1CWRS, 2CWRS and 3CWRS grade, respectively. The cargo grades had significantly lower C.V.'s, but still displayed a similar variability pattern with a decrease in grade: 1.88%, 2.10% and 2.68% for 1CWRS, 2CWRS and 3CWRS, respectively. The increase in uniformity of TKW (measured by the percent decrease in C.V.) was 59%, 65% and 61% for the No.1, No.2, and No.3 grade, respectively.

The characterization of kernel morphology using DIA saw a total of 16 features measured on a kernel by kernel basis for both the carlot and cargo samples, as well as for an export standard sample. Six features quantified aspects of kernel size, nine described elements of kernel shape and one estimated kernel brightness. For the carlot samples the average C.V. for all 16 features increased as grade dropped, from 3.33% for 1CWRS to 3.67% for 2CWRS to 4.13% for 3CWRS. These increases in average C.V. reflect the relative changes in tolerance levels of pertinent grading factors. Tolerances for grading factors such as the maximum limits of wheats of other classes or varieties and the allowable proportion of sprouted, grass green, dark immature, and shrunken kernels are relaxed to a marginally greater extent from the No.2 to the No.3 grade as compared to those from the No.1 to the No.2 grade (see Appendix I). Using the percentage of shrunken kernels as an example, there is no limit for the No.3 grade, whereas tolerances of 6.0% and 10.0% apply to the No.1 and No.2 grade, respectively.

Each of the 16 morphological features measured was found to be considerably more uniform in the cargo grades. Average C.V.'s dropped by 58%, 63% and 64% for the 1CWRS, 2CWRS and 3CWRS grade, respectively, when compared to the carlot C.V.'s. These results agree with those obtained from the TKW determinations, providing objective evidence that Canada's grain grading and bulk handling system is very effective in promoting uniformity within the top grades as Canadian wheat is shipped from primary elevator to terminal elevator positions. The observed uniformity differences between the cargo and carlot grades also reflect the more stringent grading requirements called for under the export standard as compared to the primary standard.

Regression analysis was used to elucidate the relationship between kernel size and shape and TKW. The regression results confirmed the influence of kernel size and shape as noted by Hlynka and Bushuk (1959). Kernel size and shape, quantified by DIA through kernel area and the rectangular aspect ratio (length/width), respectively, were able to explain up to 86% of the variation in TKW.

An evaluation of the DIA system for objective wheat grading purposes was carried out by using SAS statistical procedures such as stepwise discriminant analysis and canonical discriminant analysis. These procedures were used as analytical and graphical techniques to examine the level of grade discrimination that could be achieved with the morphological data. In addition to the 16 extracted features measuring kernel size, shape, and brightness, 16 more variables were defined as their variance.

A relatively lower level of discrimination was achieved among the three carlot grades based on a 32-variable discriminant model, with an average squared canonical correlation (ASCC) of 0.51 (an ASCC of 1 indicates perfect discrimination with no within class scatter). Considerable overlap existed between the 1CWRS and 2CWRS as well as between the 2CWRS and 3CWRS grades, although the extent of the overlap was unclear from the perspective of the three-dimensional cluster diagram. The low level of discrimination between the three carlot grades was due to the small number of variables that tested "significantly different" (Duncan's New Multiple Range Test) for the three pairwise grade comparisons.

When compared to the carlot results, an excellent level of discrimination was achieved among the three cargo grades, with an ASCC of 0.80 for the 32-variable discriminant model. The three CWRS grades could essentially be seen as three distinct clusters in the three-dimensional discriminant space. This improved level of discrimination reflects the greater number of variables that were significantly different for each of the three pairwise grade comparisons. Overall, the variance variables were found to be just as important as the mean feature variables in terms of their contribution to the three-way grade discrimination. Furthermore, average reflectance as well as the uniformity of average reflectance were among the top three variables, indicating their relative importance in the overall grading process.

The reproducibility of the measuring system was evaluated by processing images on the same kernel at different positions within the viewing window. The C.V.'s were all less than 1.5% for the following four variables: contour length

(C.V.=1.18%), width (C.V.=1.11%), length (C.V.=0.86%) and area (C.V.=0.76%). In comparison, the No.1 CWRS sample C.V.'s were 5.5, 8.2, 8.1, and 17.5 times higher, respectively, for the same four variables. These differences in C.V.'s are a good indication of the difference between sample variance and instrumental variance, confirming that a high and satisfactory level of precision was used in the extraction and measurement of morphological features and their subsequent use in CWRS grade discrimination.

VI. CONTRIBUTIONS TO KNOWLEDGE

This investigation into the feasibility of instrumental wheat grading has revealed several significant findings that should be of value not only to end-users of CWRS wheats, but also to policy makers involved in shaping the future of the Canadian wheat grading system. The following conclusions are drawn from the present study:

1. Digital image analysis is an instrumental methodology that is capable of measuring physical grain characteristics of wheat with a high degree of accuracy and consistency. Since many of the morphological features quantified in this study are also important factors contributing to the overall milling quality of wheat, the instrument has potential for use in the grain grading and inspection process.

2. The highly detailed information on kernel morphology and its uniformity within each of the three CWRS grades provided by this research should help the modern processor to improve upon his industrial transformation of wheat into useful and attractive end products. For example, results from studies by Pence (1943) and Li and Posner (1987) indicated that if a sample of wheat contained a considerable amount of shrivelled and therefore smaller kernels, not only would there be a decrease in flour yield, but also a higher protein loss during milling. While a 0.1% loss in protein content may not appear statistically significant, according to a senior milling executive of a highly automated U.K. flour mill it could cost his company up to $152,000 in mill profitability (Smart, 1990). As a result, the modern miller may wish to know more about a sample of wheat

than just grade and protein content as determined by the present grading system. It is suggested that wheat kernel size distribution be included as a wheat grading criteria in the Canadian grading system.

3. Objective evidence showed that Canada's grain grading and bulk handling system is effective in promoting uniformity of physical grain attributes in top grade export shipments of CWRS wheat. The influence of Canada's varietal licensing system was also noted.

4. The excellent level of grade discrimination obtained with the morphological data extracted from the cargo samples would suggest the most effective use of the image analysis system to be at the terminal elevator level. While the methodology may not immediately replace existing grading methods, it would nevertheless improve upon their consistency. Digitized images from cargo samples could represent an efficient way of storing important quality information of export wheat shipments.

5. Image analysis may also find a useful application in breeding programs for evaluating early-generation milling yield potential. Precise measurement of kernel size and shape features through non-destructive means would be an attractive alternative where sample size is limited.

6. Recent studies have commented on the importance of uniformity of quality in the international wheat market. The price premium that CWRS wheat commands over Australian Prime Hard and U.S. Dark Northern Spring reflects Canada's policies relating to wheat quality. This would suggest that

Canada's approach to the licensing and grading of new varieties may not have been as inefficient as originally thought. The uniform and predictable quality of No.1 CWRS wheat has allowed the Canadian Wheat Board to make inroads into several important markets such as Japan, Thailand, Venezuela, Indonesia and Western Europe because buyers there have been dissatisfied with the quality fluctuations in U.S. shipments of hard red spring wheat.

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APPENDICES

APPENDIX I. Primary Grade Determinants for CWRS Wheat

(From Canadian Grain Commission, Official Grain Grading Guide, 1987)

RED SPRING WHEAT (Canada Western) - PRIMARY GRADE DETERMINANTS

	Standard of Quality				Maximum Limits of			
					Foreign Material		Wheats of Other Classes or Varieties	
Grade Name	Minimum Test Weight kg/hL	Variety	Minimum Hard Vitreous Kernels	Degree of Soundness	Matter Other Than Cereal Grains	Total Including Cereal Grains	Contrasting Classes	Total Including Contrasting Classes
No. 1 Canada Western Red Spring	75.0	Any variety of red spring wheat equal to Neepawa	65.0%	Reasonably well matured, reasonably free from damaged kernels	About 0.2%	0.75%	1.0%	3.0%
No. 2 Canada Western Red Spring	72.0	Any variety of red spring wheat equal to Neepawa	35.0%	Fairly well matured, may be moderately bleached or frost damaged, but reasonably free from severely damaged kernels	About 0.3%	1.5%	3.0%	6.0%
No. 3 Canada Western Red Spring	69.0	Any variety of red spring wheat equal to Neepawa	-	May be frost damaged, immature or weathered, but moderately free from severely damaged kernels	About 0.5%	3.5%	5.0%	10.0%
Canada Western Feed	No Minimum	Any type or variety of wheat excluding amber durum	No Minimum	Excluded from other grades of wheat on account of light weight or damaged kernels, but shall be reasonably sweet	1.0%	10.0%	No Limit 10.0% amber durum only	
Final Grade Name	Canada Western Feed		No. 3 C.W. Red Spring		Over 1.0% grade Wheat, Sample C.W. Account Admixture	Over 10.0% grade Mixed Grain, C.W. Wheat	Canada Western Feed Over 10.0% amber durum grade Wheat, Sample C.W. Account Admixture	

RED SPRING WHEAT - PRIMARY GRADE DETERMINANTS

Grade Name	Sprouted: Severe	Sprouted: Total Incl. Severe Sprouted	Binburnt Severe Mildew Rotted Mouldy	Heated Incl. Binburnt	Fireburnt	Stones	Ergot	Sclerotinia	Smudge	Total Smudge and Blackpoint
No. 1 C.W. Red Spring	0.1%	0.5%	2K	0.1%	Nil	3K	3K	3K	30K	10.0%
No. 2 C.W. Red Spring	-	1.5%	5K	0.75%	Nil	3K	6K	6K	1.0%	20.0%
No. 3 C.W. Red Spring	-	5.0%	10K	2.0%	Nil	5K	24K	24K	5.0%	35.0%
Canada Western Feed	No Limit		10.0%	10.0%	2.0%	10K	0.25%	0.25%	No Limit	No Limit
Final Grade Name	Canada Western Feed		Over 10.0% grade Wheat, Sample C.W. Account Heated		Over 2.0% grade Wheat, Sample C.W. Account Fireburnt	Over grade tolerance up to 2.5% grade Rejected "grade" Account Stones. Over 2.5% grade Wheat, Sample Salvage	Over 0.25% grade Wheat, Sample C.W. Account Ergot	Over 0.25% grade Wheat, Sample C.W. Account Admixture	Canada Western Feed	Canada Western Feed

Grade Name	Shrunken and Broken: Shrunken	Shrunken and Broken: Broken	Shrunken and Broken: Total	* Degermed	** Grass Green	Pink Kernels	Artificial Stain No Residue	Natural Stain	*** Insect Damage: Sawfly Midge	*** Insect Damage: Grasshopper Army Worm	Dark Immature
No. 1 C.W. Red Spring	6.0%	6.0%	7.0%	4.0%	0.75%	1.5%	Nil	0.5%	2.0%	1.0%	1.0%
No. 2 C.W. Red Spring	10.0%	10.0%	11.0%	7.0%	2.0%	5.0%	5K	2.0%	8.0%	3.0%	2.5%
No. 3 C.W. Red Spring	No Limit	15.0%	No Limit Providing Broken Tolerances Not Exceeded	13.0%	10.0%	10.0%	10K	5.0%	25.0%	8.0%	10.0%
Canada Western Feed	No Limit	50.0%		No Limit	No Limit	No Limit	2.0%	No Limit	No Limit	No Limit	No Limit
Final Grade Name	No. 3 C.W. Red Spring	Over 50.0% grade Sample Broken Grain		Canada Western Feed	Canada Western Feed	Canada Western Feed	Over 2.0% grade Wheat, Sample C.W. Account Stained Kernels	Canada Western Feed	Canada Western Feed	Canada Western Feed	Canada Western Feed

*Degermed: Tolerances apply to kernels not classed as sprouted.

**Grass Green Kernels: Tolerances are given as a general guide and may be increased or reduced in the judgment of the inspector after consideration of the overall quality of a sample.

***Insect Damage: Tolerances are not absolute maximums. Inspectors must consider the degree of damage in conjunction with the overall quality of the sample.

NOTE: THE LETTER "K" IN THESE TABLES REFERS TO KERNEL SIZE PIECES IN 500 GRAMS.