STRATEGIES TO INCREASE WHEAT VALUE THROUGH SEGREGATING BY KERNEL SIZE AND UNIFORMITY

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CHAPTER I

CONCEPTUAL FRAMEWORK, OBJECTIVES, AND OVERVIEW OF THESIS

Problem Statement

One of the central features of agricultural production and marketing is continuing industrialization through technological advances (Urban). This industrialization process includes increasing technological ability to measure and supply quality to meet customer needs. Processors and marketers are continually producing and designing products to meet high value niche markets. In the wheat industry this leads to an increasing expectation and ability to supply improved quality wheat that meets specific customer needs. Meeting these higher standards is, however, difficult to achieve in the current wheat marketing system.

The current marketing system is based on generic grades and hence works well for the production of commodities, but is becoming outmoded in an increasingly specialized food market (Barkema, Drabenstott, and Welch). The United States Department of Agriculture has carefully stipulated wheat producers' quality factors. They include such factors as wheat class, percentage of damaged kernels, percentage of foreign material, percentage of shrunken and broken kernels, total defects, heat damaged kernels, dockage, and test weight.

Judging by these characteristics, the wheat that farmers deliver to country elevators is given a grade and then becomes a commodity. This idea of quality is driven more by facilitation of the large amounts of production rather than the consumer. Grading has been limited to these factors in part due to the previous lack of technology to grade for factors that millers are beginning to consider more important.

Current wheat marketing is largely based on these federally established quality factors, which are a somewhat outdated criterion for judging wheat quality. Not only is wheat quality multifaceted with many quality characteristics, but different levels in the marketing system have different goals and benefits from quality. According to Mark Hodges, Executive Director of the Oklahoma Wheat Commission, a key new customer demand relates to kernel size and uniformity because these higher quality factors will lead to increased milling efficiency and flour particle size uniformity.

The majority of wheat produced is used in the milling of flour, which is then used for some sort of baking (Barkley and Porter). However, the processors' concept of quality is different than that of the producer and includes such non-grades and standards variables as cleanliness, kernel size, kernel size and shape uniformity, response to conditioning, thickness of bran, behavior during milling, protein content, and flour yield. These characteristics determine the quality and quantity of the final product, and therefore are ultimately demanded by the consumer.

In general, there are several potential methods that could be used to improve performance in meeting customer needs for kernel size and uniformity. These strategies should logically focus on country elevators because they currently play a key role in the marketing of wheat. Implementation of segregation strategies at the elevator level may be able to take advantage of quality that already exists. Ninety percent of wheat is collected and sold at country elevators (Baker). Because elevators have already been sorting to increase the grade, it seems feasible that elevators can increase the value of wheat to processors by sorting the wheat by the quality factors that the end users desire.

Producers currently select varieties on criteria such as yield, and resistance to disease. There is currently little incentive to adopt varieties with a higher milling yield unless reflected by current grade factor. In order for the producers to better meet the needs of the processors, bakers, and consumers, important changes should be made in the marketing system. Currently country elevators sort and blend the wheat that is delivered to them in order to meet the standards set by the USDA. The primary focus of the elevators is to increase the overall grade of the commodity or contract specification in order to capture a premium for their wheat. However, it is possible to segregate wheat by different quality characteristics, and increase the value of the overall commodity (Attaway).

Sorting by varieties that have the same physical characteristics, creating more uniformity within each category, could also increase the value to processors. As kernel size and uniformity increase, processing time should decrease and milling yield increase. This is the driving factor behind the potential value of uniformity to processors.

The levels of uniformity in Oklahoma wheat, as well as the potential to increase uniformity through segregation, are new issues for the Oklahoma wheat industry. New technologies, such as near infra-red technology and the single kernel characterization systems, are in place and can determine the protein content, kernel hardness and kernel size uniformity of a sample of wheat on site. There is a demand by processors for these desired characteristics. Therefore, the next step is to develop a marketing plan that puts this technology to use and increases the value of production.

Currently, it is known that there is demand for quality variables such as kernel size and uniformity in the wheat market. There are technologies in existence that have the ability to measure kernel size and uniformity. The SKCS 4100 measures a 300-kernel sample of wheat for variables such as kernel weight, diameter, and hardness. The Ro-tap sieving system separates a sample of wheat into three sub-samples, from which the percentage of large, medium, and small kernels are calculated. The wheat industry needs a fast, accurate, cost effective measure of uniformity to use in marketing.

Objectives

The overall goal of this study is to increase the Oklahoma wheat industry's responsiveness to customer needs, relating to kernel size and uniformity. The specific objectives for achieving the overall objective are:

1) Determine the existing levels of uniformity in Oklahoma wheat truckloads, varieties, elevators, and regions, as measured by the SKCS and Ro-tap sieve.
2) Develop and determine the effectiveness of segregation strategies to increase levels of kernel size uniformity.

Conceptual Framework

In order for the Oklahoma wheat industry to increase their responsiveness to customer's kernel size uniformity needs, several steps must take place. First of all it is important to realize that the processors' demand for inputs is ultimately derived from the consumer's demand for the finished product. Therefore, the consumer's preference for a high quality and low cost product should lead the processor to prefer inputs that process with greater efficiency, and result in a higher quality product.

Research has shown that greater kernel size uniformity will increase milling yield and flour quality (Li). Because this higher quality wheat will possibly yield higher quality flour that requires less processing time, it will be of greater financial value to the processor. Based on this it would be expected millers will be interested in buying wheat that is more uniform in kernel size. This would send a market signal to producers.

If the elevators can capture a premium for selling more uniform wheat, then they have an economic incentive to be willing to pay producers for uniform varieties. The elevator should also be willing to implement segregation strategies that increase the overall uniformity of the wheat that is stored on site. Currently there is no market signal for elevators to segregate to increase uniformity. Because there is no incentive given by processors, adoption of new measurement technology has yet to take place.

Preliminary research has shown that standard deviation of kernel size is lower per truckload of wheat than it is per elevator of wheat. Standard deviation is also lower for individual varieties than it is for commingled varieties. Therefore, segregation strategies that group together truckloads and/or varieties with similar kernel size characteristics should result in greater uniformity. Anytime additional commingling takes place kernel size uniformity will likely decrease. Based on this, the following can be hypothesized:

1) Uniformity will be higher for wheat that has had less commingling.
2) Segregation strategies that sort wheat into groups with similar characteristics should increase uniformity and milling yield.
3) Because they are based on more precise measurements, segregation strategies that are based on variables measured by the SKCS 4100 should create the greatest uniformity.

<u>Procedure</u>

In order to meet the goals of the proposed research several samples of wheat will be taken from major wheat-producing region in Oklahoma. Official grades, protein content, and two measures of uniformity will be collected on the samples. Standard deviations of single kernel weight will be used to measure current levels of uniformity, and also used in the evaluation of the segregation strategies. A measure of the effect of kernel size and uniformity on milling yield developed at Kansas State University will be used to evaluate the segregation strategies (Baker).

Current Levels of Uniformity

Before developing strategies to increase uniformity it is important to determine the current levels of uniformity in existence. Two measures of uniformity will be conducted on the samples taken in order to determine the levels of uniformity at different levels of the marketing system. These two uniformity measurements will be fundamental to the development and implementation of segregation strategies.

To determine the existing levels of uniformity in Oklahoma wheat varieties, elevators, and regions, all samples will have three hundred kernels tested by the SKCS 4100. Kernel weight means will be determined for every variety, elevator, and region sampled. Kernel weight standard deviations will also be obtained, and used as a measure of uniformity.

Ro-tap sieving will also be used as a criterion to judge the levels of uniformity of kernel size for the samples. The Ro-tap unit of analysis, as conceived in this analysis, is a sieve that separates a sample into three sub-samples based on the size of the kernels being sieved. Percentages are then calculated for each sub-sample. A sample with a large percentage of the kernels in one sub-sample would be a uniform sample of that sub-samples' screen size.

The above mentioned tests will be used as segregation criteria for the country elevator strategies. Segregation strategies are simply ways of sorting wheat. The goal of these strategies is to sort wheat into groups with similar kernel characteristics, thereby increasing overall uniformity. The first general strategy is to eliminate some of the commingling in the current marketing system, and look at the uniformity benefits of purchasing wheat from a single elevator or region of elevators. Another strategy is to segregate at each elevator into separate bins based on some single kernel variable.

A dough factor equation, developed at Kansas State University, which determines the amount of flour water dough that can be produced from a particular sample of wheat will be the criterion from which to judge the effectiveness of the segregation strategies. Dough factor is a function of kernel weight, kernel weight standard deviation, protein content, and test weight.

Segregation by Elevator and Region

One of the easiest ways to segregate wheat would be on the basis of elevator or region. It is believed that some uniformity exists in each elevator and in each region, and that commingling of wheat at terminal elevators currently reduces this uniformity. This strategy analyzes the benefit of reducing some of the commingling. An overall dough factor will be calculated for the state of Oklahoma using all of the samples collected during the 1998 harvest. These samples will then be sorted (using SAS) by elevator and region in order to determine the benefit of this segregation strategy.

Segregation by Variety

Segregation by variety has already been adopted to a certain extent in several grains including wheat and is called identity preservation. This is a simple concept with good potential benefits due to the fact that there is a significant difference in kernel size between varieties. However, to adopt this strategy on a statewide level would present major challenges.

Several varieties are produced in Oklahoma, and most elevator facilities would not have enough bins to segregate every variety. Knowing which of these varieties performs the best, and the potential benefits of segregating these varieties is an important part of this research. Dough factor and milling yield will be calculated for the most popular Oklahoma varieties in order to determine this.

Segregation by Kernel Weight

Segregation by kernel weight looks at the potential benefit of segregating wheat at an elevator by kernel weight. Mean kernel weight quartiles will be established based on the samples taken from each elevator. Each sample in the elevator will then be assigned to one of four bins. Dough factor and milling yield (per segregated bin) will be calculated and potential increases determined.

The increase in dough factor and milling yield per strategy will be compared in order to determine which one is the most effective strategy. The most effective strategy will be the one that increases the dough factor and/or the milling yield by the greatest percentage. While all strategies are being analyzed, it is important to consider which strategies can be realistically implemented. Evaluation of the potential implementation is the final step of this research.

Evaluation of Potential Implementation

Before any strategy can be adopted it must be profitable to the business that is implementing it. While it is not part of this research to implement these strategies at elevators a simple evaluation of the implementation is useful. The costs to elevators would consist of capital expenditures on either of the grading systems, Ro-Tap or SKCS 4100, and any additional storage capacity required by the strategies. Increase in overhead and opportunity cost due to time required for grading could also be considered.

The benefits of these strategies will be different at every level of the marketing system. The increase in milling yield or dough multiplied by the value of the dough will give a good estimate of the benefit of uniform wheat to processors. It is hard to determine what this will mean for the other levels of the marketing chain. Whatever net benefit will exist for the processors may be shared with producers, marketers, and consumers in the form of premiums for quality and cheaper finished products.

Outline/Structure

The research will be presented in the following manner. The next chapter is a literature review that summarizes previous relevant research. Chapter three provides data on current levels and distribution of such quality factors as kernel size uniformity and Ro-tap sieve percentages from Oklahoma regions, elevators, and varieties. In chapter four strategies to increase kernel size and uniformity are evaluated in order to determine the relative benefit of each segregation strategy alternative. In chapter five key points of the research will be highlighted.

CHAPTER II

LITERATURE REVIEW

Quality in wheat is a complex issue for many reasons including the fact that definitions of quality vary among different levels of the marketing system. The trend towards more effectively meeting consumer driven demands through new products and technologies lead to demand for wheat that is more easily processed and provides better baking quality. Many technological advances have been made in wheat breeding, testing equipment, and management that have helped develop these changes and potential for further advances in the wheat marketing industry.

The following chapter discusses the many factors that have influenced the need for and the adoption of new management practices and technology in commodities marketing. Research that looks at quality in wheat to both the producer and the processor is first discussed in order to understand what has historically driven these industries. The current trends in wheat marketing are then discussed. The increase in contractual agreements and vertical integration, as well as what is driving them, are discussed in this section. The final section looks at a new technology called the SKCS 4100. Research on this technology's capabilities as well as its potential for the use in segregation strategies are discussed.

Quality in Wheat

The issue of quality in wheat has been an important, longstanding issue. Early research on this topic stated in 1941 that quality to the farmer is associated with yield and grade, to the miller quality is associated with flour yield and ease of milling, and to the baker quality refers to bread yield and the ease of processing (Geddes). The increase in the number of varieties on the market, which were developed to increase the yield and disease resistance for the wheat producer, are decreasing the overall uniformity to the miller, as well as baking strength to the baker.

Geddes stressed that from the standpoint of the entire grain trade, the fewer the number of varieties the better. As new varieties are introduced it becomes more difficult for the miller to maintain smooth operation of the mill and to produce uniform flour. However, it is possible to develop new varieties that will reduce the losses of wheat to producers and at the same time will be satisfactory to the millers and bakers. He concluded that the industrial quality of hard wheats depends on their milling quality and the value of the flour for bread making purposes. The efficiency of the grading system would be greater if it evaluated wheat on the basis of its intrinsic value, such as plump, uniform kernels, and ready separation from foreign material.

Variety Selection by Producers

While there has been significant progress made in the breeding of wheat for increased milling and baking characteristics, these varieties have not been adopted for that purpose by the producer as the processors may have hoped. Although these varieties provide better quality to processors on selected attributes, they often lack the traits that are desirable to producers such as higher yield and disease resistance. This approach by farmers is consistent with the rewards they face for improving quality.

In the wheat marketing system, wheat is collected and sold at country elevators with prices typically based on physical characteristics established by the Federal Grain Inspection Service rather than the characteristics that are valuable to the processor. Prices received by farmers are adjusted based on grade factors such as test weight, moisture content, foreign matter, and protein content.

Because this pricing scheme does not greatly reflect the quality needs of the processor, there continues to be potential pricing inefficiency between wheat producers and processors. In order to motivate producers to adopt higher quality varieties and produce wheat that is of greater value to the processor, there must be a reward system for these quality needs. If producers see that they can capture a premium by producing wheat that is of higher quality in the eyes of the processor then this will provide powerful incentives to produce varieties of this nature from seed merchants.

Evidence of this market inefficiency is shown by Barkley and Porter who conducted a study on the determinants of wheat variety selection in Kansas from 1974 to 1993. They measured the percentage of planted wheat acres to each variety, and found that varietal decisions are strongly responsive to past production decisions, relative yields, and yield stability. Economic considerations lead farmers to plant higher-yielding varieties, which are sometimes characterized by low milling and baking qualities. Barkley and Porter further concluded that while some varieties are being developed that enhance both average yield to producer and baking and milling quality, these varieties could take up to fifteen years before full adjustment could take place.

Wheat producers, like any other businessman, are driven by economic factors in their production decisions. If producers where able to capture a premium in the current market for wheat that had greater baking and milling quality, it would make sense that they would adopt these varieties much faster. In order for this to happen at all, the reward system needs to be in place.

Milling Quality and Baking Strength

The primary use for wheat is for flour and baking. Flour, put very simply, is made from the endosperm of the kernel after its separation from the pericarp and germ. The more exact the separation of these components makes the milling performance more desirable. Because flour is the most valuable product of the milling process, it is obvious that kernels that yield the highest percent of flour are the most desired kernels. The average wheat kernel consists of approximately 14.5% bran, 1.5% germ, and 84% endosperm. However in average commercial milling 70-72% flour is obtained from the milling of wheat, which means that 12 % of the endosperm goes into feed (Swanson and Kroeker). The tradeoff for higher percentage flour extraction is usually a higher percentage ash content, which results from processing some of the bran.

Swanson and Kroeker characterized good milling wheat as having fairly easy separation of bran from endosperm in order to produce a good yield of flour of low ash content. The endosperm should not be so hard that excessive power is required to process it into flour, and should have a minimum of yellow coloring matter. Larmour, Working, and Ofelt defined baking strength as the capacity of flour to produce large loaves of good texture and the ability to confer this property to blends with softer wheats. They concluded that baking strength was in large a result of protein content which was a product of the environment the wheat was produced to a greater extent than a hereditary or genetic selection.

The idea of the kernel size as a factor of the overall milling quality has been around for a long time. For instance, Bailey conducted a study in which the millability of wheat was evaluated on the basis of kernel volume, kernel density, and endosperm density as early as 1915. In his study milling quality was defined as the potential yield of edible flour from wheat when milled by the usual roller process. Bailey found that a plump well-filled kernel yields more flour than does a shriveled one, and therefore a regular decrease in flour yield is observed as kernels decrease in size. He also found that when estimating the relative percentage of flour, which can be milled from different samples of wheat, the kernel volume and the density, more precisely that of the endosperm, are better indicators than weight per bushel.

Li found in his study on the influence of kernel size on the millability of wheat that the uniformity of wheat kernel size plays an important role in the stability of milling. Wheat kernels that are smaller have higher pearling value and protein content, and kernels that are larger yield more flour per kernel and have higher water absorption. Li also found a disagreement in flours from different size wheat kernels, suggesting possible difference in the chemical composition of the flour protein and quality for bread making. From the miller's point of view, wheats with more uniform larger kernel size are more desirable in terms of technical efficiency and consequential economic benefit. He concluded that wheat kernel size distribution should become a wheat grading criteria.

Many of these past studies suggest that there is an inefficiency in the current marketing system because the wheat produced by the farmers lacks certain physical quality characteristics that are important to processors. The food system is changing from a commodity-based market to an ingredient-based market, and profits to processors can be increased by uniformity in the grain they purchase. While it would take many years for the adoption of varieties that provide the millers and bakers with the characteristics they want and need, current levels of quality can be taken advantage of by changes in current practices. New management and grain grading technologies are currently in place to enable this to happen. Because they are already positioned at the front of the marketing system, Oklahoma country elevators have an opportunity to take advantage of the current quality levels and meet these quality demands.

Current Trends in Wheat Marketing

There have been significant advances in management and technology in the past years that have led to changes in marketing in the food industry. An important element in change is opportunity. As these advances are made there is an opportunity for key players to capture premiums by providing what is demanded by consumers. It is important that producers and processors coordinate in order to meet consumers needs more favorably.

Agricultural Industrialization

Agriculture is undergoing an industrialization in which the process by which goods are produced is being restructured under the pressures of increasing levels of capital and technology (Urban). In this process, production agriculture is becoming part of an industrialized food system in which uniformity and predictability in the food system are keys to efficient operations. As this process continues in the grain industry, it will become increasingly important for processors of wheat that their inputs are of greater quality. This has lead to opportunities for producers.

Producers are beginning to realize the difficulty in surviving the cyclical nature of the commodities market and are looking for special market niches. These producers need to look beyond production into the marketing system. Commodity producers can alter their marketing methods to contribute quality in the food marketing system. If they take into account the demands of the processors, and ultimately the consumer, they will realize the opportunity that is facing them, and tailor their production and marketing to meet these demands (Peterson and Swinton). The vulnerability to market prices of the producer can be reduced if their output is no longer a commodity but an ingredient.

Changes in Commodities Marketing

The traditional market structure for a farm product has been termed open production because in this system the production process is completed before any marketing commitments are made (Barkema, Drabenstott, and Welch). This structure leads to risks on both sides of the market. Producers have price risk caused by unexpected large supplies of commodities, which can drive prices down. Processors on the other hand, are exposed to price, quantity, and quality risks of the commodities market. Low supplies cause input prices to increase and quantities harder to obtain; further, the grading system and environmental factors expose them to quality variability and risk. This open production method has historically been used for many generic commodities markets, but it has become increasingly outdated as changes take place in the food market.

Barkema, Drabenstott, and Welch state that the food market is changing from a mass market to many niche or specialty markets in which production and marketing demands of the consumer are being met by promising new technologies. They further state that the commodity markets are becoming obsolete as food processors aim their products at a growing number of smaller consumer niches. As this takes place contractual agreements and vertical integration among producers and processors are becoming increasingly common.

Before this shift in marketing practices can take place, grading technology must be in place that can guarantee processors the quality they demand. Technological advances in grain grading technology, such as the SKCS, will enable marketers to sort commodities into a wide range of quality categories. This combined with advances in production and processing technologies will allow for more contracting in the grain industry. As contracting in the wheat industry increases, there is an opportunity for elevators to capture a premium and reduce pricing risk by providing wheat that reduces the quality risks of the processor.

As levels of management and technology increase, the needs of product users will drive demand of higher quality wheat to the level of the producer. Oklahoma wheat producers have an opportunity to meet this demand by adding value to wheat sold to processors. As this opportunity is realized, increases in expenditures on capital that will enable such value added activities will follow. The agricultural industrialization and the necessary marketing changes that are necessary for this to happen are already underway. It is now time for elevators to take advantage of this opportunity and through better marketing provide processors with what they demand.

Adding Value Through Segregation

The opportunity that faces elevators, as discussed earlier, can be partly met through improved segregation strategies. Country elevators currently segregate wheat in order to meet the Federal Grain Inspection Service's guidelines of higher grade wheat. As more elevators realize the opportunity that is presented by technologies such as the SKCS, more investment in such equipment will take place and coordination between producers and processors will increase. This coordination will result in higher quality and/or lower cost food products for the consumer.

The Single Kernel Characterization System

The single-kernel characterization system 4100 was developed to provide an automated objective means of classifying wheat into U.S. grades. A three hundred kernel sample is deposited into a hopper where a rotating wheel picks up individual kernels with a vacuum and places them one at a time into a weighing boat. The kernels are then sent down an inclined crescent where the diameter is measured and the kernel is crushed between the crescent and a toothed rotar. A load cell measures and records the crush force profile while the conductivity of the crushed kernel is measured. The total test time of this procedure is three to five minutes (Osborne et al.). Means and standard deviations are recorded for kernel weights, diameters, hardness indices, and moisture contents for each sample.

Because the SKCS is such a quick testing system that requires little time and only a small sample, it has the potential to provide information that could improve wheat-sorting strategies at country elevators. In their study Osborne et al. found that the SKCS 4100 was shown to produce accurate and reproducible measurements of kernel weight, diameter, hardness, and moisture content on as few as 50 individual kernels of wheat. They further found that the test was rapid enough for use at country elevators and that the test generated uniformity data that was not otherwise available.

The usefulness of this technology as an instrument of prediction may be of perticular importance when applied in on site situations at country elevators. Gaines, Finney, Fleege, and Andrews successfully generated a hardness prediction equation using single kernel data from the SKCS 4100. Information such as this may be important to processors who are looking to increase milling efficiency. Milling efficiency may also be increased through uniformity of kernel size.

In his thesis on the influence of kernel size on the millability of wheat, Li found that wheat size distribution plays an important role in influencing wheat physical test results. Large wheat kernels give higher values of test weight than small wheat kernels, and as wheat kernel size increases, the ash content and protein content of the wheat decreases. Furthermore, when different size groups of wheats are milled under the same milling conditions, the protein content of the flour milled from smaller wheat kernels is higher than that milled from larger wheat kernels. Most importantly, the yield of straight grade flour increases as wheat kernel size increases. Therefore, it seems reasonable that the single kernel measurements of kernel diameter would be very useful when considering segregation strategies at country elevators because overall milling yield could be increased by uniformity in wheat kernels.

Deyoe et al. conducted a study in which the potential uses of the SKCS 4100 for quality assessment and for mill quality control applications were reported. Data was collected during the hard red winter wheat crop survey of 1995 and 1996 and used to investigate the use of the SKCS to evaluate variation found in the physical attributes of wheat harvested in different years and when subjected to the environmental conditions existing during different years. The data indicated that differences in milling performance can be determined quite well and that proper application of this data could result in savings or increased returns in the order of thousands of dollars during processing periods.

<u>Application of the SKCS/Segregation Strategies</u>

A very important application of this technology is its use as a quality control tool for elevators and mills, and its use in segregation strategies. Baker conducted research at Kansas State University that focused on the development of a segregation system that used the single kernel characterization system and a whole grain near infra-red analyzer to evaluate the milling and baking quality of wheat as a single value called "dough factor." Results of Baker's research conducted over the 1995 and 1996 harvests indicated that kernel weight, kernel weight standard deviation, protein content, and test weight where the most important characteristics in predicting dough factor. In his study, dough factor was the amount of flour water dough produced by a given quantity of wheat.

Because this research has been conducted, and these variables were found to be of the greatest importance in determining what higher quality wheat is to the processor, it seems important that segregation strategies at country elevators should be evaluated in order to determine the value of such strategies. There has been some previous research to determine the on-site costs of segregating wheat at country elevators, although none have applied single kernel technology.

Hinchy conducted a study in which increasing the overall number of grades of wheat was looked at in New South Wales. The overall focus of Hinchy's research was to determine the overall costs and benefits of increased segregation at country elevators. He determined that an additional segregation would increase average operating costs of an elevator by about 4.8 percent. The increase in storage capacity required for a further segregation did not factor into the decision due to the fact that all elevators in the study already had excess capacity. Most elevators already perform some sort of segregation strategy; therefore it should be possible to segregate by a single kernel criteria.

Although technological advances such as the SKCS have yet to be applied to wheat segregation strategies at country elevators, there has been some application of similar technology in the segregation of soybeans. Hurburgh conducted a study in which a whole grain near-infrared transmission analyzer was used at a large Iowa elevator to measure oil and protein content of unground soybeans. In the third year of the study, soybeans were physically sorted on the basis of the sum of protein and oil. The top 23% of soybeans were isolated from the lower 77%. The high value beans were segregated for future sale to a processor. The analyzer performed accurately and required about 1.5

minutes per test. Compared to the normal 1 minute per test for moisture measurement, this caused additional delay of 30 seconds, which is a substantial amount of time over 300 truckloads. The segregated beans captured a premium of $0.10/bushel while segregation increased costs by $0.03/bushel. This cost benefit analysis of the application of near-infrared technology is very important in order to determine the practicality of its use. This is why further research must be conducted using the single kernel characterization system in order to determine the costs and benefits of its application.

Much research has been conducted in order to determine the capabilities of the Single Kernel Characterization System. Many of the capabilities and uses of this technology are now known. However, the overall benefit of this technology and its effectiveness as a segregation criteria in the marketing system have yet to be determined. As competition becomes increasingly fierce, the desire to increase premiums and decrease risk in the food industry will become more and more important. The use of this technology along with better management at country elevators should give wheat producers and marketers an edge as well as improving system performance through delivering higher quality goods to consumers.

<u>Summary</u>

For many years the marketing system has delivered wheat from producers to processors who then delivered food to the consumer. However, there has been an inconsistency in the goals of each step of the marketing chain. Producers had goals of increasing the amount of wheat that they could grow with limited resources because they were rewarded largely on the basis of yield, while processors instead needed high quality milling wheat. To address this need, research has been conducted to maximize both production yield and milling yield. However, there has been a lack of incentive for these varieties to actually be adopted due to a lack of cost effective grading technology and an appropriate incentive structure.

As the current trends in wheat marketing continue, the needs of the miller and ultimately the consumer will drive producers' decisions. The food industry as well as all of agriculture is undergoing an industrialization in which the process of how agricultural and food products are produced is being restructured under increasing levels of management and technology. Current advances in technology, such as the SKCS 4100, present producers and marketers with good opportunity. By segregating wheat at country elevators into classes that are more valuable to processors and consumers, demand for high quality wheat will be more effectively met.

CHAPTER III

1998 OKLAHOMA WHEAT KERNEL SIZE AND UNIFORMITY ESTIMATES

Kernel size and uniformity[1] are of increasing importance to the wheat industry because of increasing competition in the domestic and world market and the need for greater processing efficiency. An important step in improving the current wheat marketing system through increasing uniformity would be to determine current levels of kernel size and kernel size uniformity. This chapter discusses the importance of uniformity as a quality issue in wheat and examines the wheat marketing system, especially as it relates to uniformity. Data collection methods and current levels of uniformity are also discussed.

This chapter begins with a discussion of the importance of uniformity as a grain grading criteria as well as the benefits of uniformity in the wheat marketing system. An explanation and discussion of two uniformity measurements are then given. Data collection and results of the kernel size and uniformity analysis of Oklahoma regions, elevators, and varieties are then described.

Uniformity as a Quality Issue

Kernel size and uniformity are cutting edge issues in grain processing. Anecdotal evidence indicates that some domestic millers are already paying premiums for grain of specific known varieties. Surveys of major wheat importing nations indicate clearly that kernel size uniformity is one of the most important concerns in purchasing U.S. wheat.

[1] Uniformity refers to uniform kernel size.

However, the U.S. wheat industry does not market wheat on the basis of this important quality issue.

This industry need for kernel size uniformity is based on the fact that uniform kernel size is more desirable in terms of technical efficiency and consequential economic benefit. When there is a great deal of variation in the size of the kernels, smaller kernels are missed or only partially broken by the initial milling process, thus requiring further processing. This further processing increases costs and decreases the overall quality of the flour due to higher ash content (Li 1989). Uniformity in wheat thus allows for easier separation of the bran and endosperm by the mill, which then yields a greater quantity and quality of flour. Easier separation means less milling time, energy expense, and greater overall efficiency, while lower ash content means a higher quality flour. As kernel size increases the volume of the endosperm increases as well, yielding a higher quantity of flour per kernel of wheat.

While there are potential benefits to millers from improved kernel size and uniformity, benefits to bakers and consumers would likely result. As milling yield and processing efficiency increases then some of the benefit will likely be transferred through the marketing chain in the form of lower flour prices which would benefit wheat users, e.g. bakers and consumers. Furthermore, the wheat would yield higher quality flour due to its lower ash content, which should provide benefits to flour users.

Measures of Kernel Size and Uniformity

Currently kernel size and uniformity are not included in U.S. grades and standards. Because kernel size and uniformity are new potential criteria for which to grade wheat, a problem is presented to the industry of how to grade and market wheat on the basis on uniformity. A kernel size and uniformity measurement technique is needed that is fast, effective, and consistently accurate in order to grade and market wheat on this basis. With this goal in mind, two criteria to measure kernel size and uniformity were used in this study.

The first criterion was a Ro-tap sieving system. The Ro-tap sieve is a manual testing mechanism that, in the method used, segregates a sample of wheat into three different categories by putting the sample in the sieve and then shaking it. The sieving system has three screens, each smaller than the previous one, thus allowing smaller kernels to pass into the next screens resulting in three sub-samples of the original sample. These sub-samples are then weighed, and the sampler then calculates the percentage of the sample in each sub-sample. These measurements are then used as a representative percentage of the amount of small, medium, and large kernels in a truckload of wheat. Because this system is based on a simple sieving system, it is fairly inexpensive to use; however, its effectiveness has not been established for this purpose.

The second criteria used to measure kernel size and uniformity in this study is the Single Kernel Characterization System (SKCS 4100), also known as the single kernel hardness tester. This technology was developed at Kansas State University specifically to measure kernel size and uniformity. This machine takes a three hundred kernel sample of wheat, and measures every kernel individually for variables such as kernel weight, kernel diameter, and kernel hardness. The machine also calculates means and standard deviations for each particular sample.

The SKCS 4100 gives an accurate estimate of kernel size for a truckload of wheat in three to five minutes. Standard deviations of these kernel size variables can be used as a measure of uniformity. While this testing approach is technically fairly accurate, it is expensive.

The Current Wheat Marketing System

The wheat marketing system currently measures and evaluates wheat on the basis of federally developed grades and standards, and other key measurements. These quality measurements focus on physical quality attributes, such as, test weight, protein, foreign material, dockage, etc. However, trade has not traditionally been based on kernel size and uniformity. Because kernel size and uniformity are not measured in the current system parts of the wheat marketing chain find it difficult to respond to this need.

Producers choose their seed input primarily on the basis of yield and disease resistance, because if minimal quality levels are met, they are rewarded on the basis of yield. Since they are not rewarded for uniformity when they deliver their wheat to elevators, uniform varieties are not a key criteria demanded by producers.

Similarly, elevators market wheat on the basis of grades and standards, so their typical goal it to blend wheat in order to increase the overall grade. During this blending process wheat of different varieties and kernel sizes is commingled and forms a commodity defined by U.S. grades and standards. This blending may raise the overall grade of the stored commodity, but it may decrease the uniformity and typically eliminate identity preservation. These country elevators, which are the delivery site for ninety percent of the wheat produced, ship their grain to terminal elevators where this blending process is repeated and uniformity decreased further.

Millers, key wheat processors, buy their grain from these terminal elevators and are guaranteed the quality of the grade that they buy according to mutually agreed specifications. These specifications have not traditionally focused on kernel size and uniformity. However, the commingled wheat is of several different varieties and may lack uniformity. Ultimately, a signal needs to be sent through the marketing chain from the millers of the grain to the input suppliers, so they can produce varieties that are more uniform as well as high yielding.

Country elevators, as first handlers of wheat, can play a key role of any effort to increase kernel size and uniformity in the current marketing system. They could segregate wheat to increase the overall uniformity of the wheat and be rewarded by a premium from processors for delivering a more valuable and consistently uniform product. This would in turn allow elevators to pay a premium to producers for planting and delivering grain of desired varieties and quality levels. However, much work needs to be accomplished to establish this.

Data Collection

In order to do kernel size and uniformity analysis for the Oklahoma wheat industry several procedures were used. Data was collected from participating elevators throughout the state. Official grades for each sample were then obtained from the Federal Grain Inspection Service. Two measures of uniformity, the SKCS 4100 and the Ro-tap sieving system, were applied at Oklahoma State University.

The data used for this study were taken from all Oklahoma trade areas, including areas that draw on Texas and Kansas production. Growing conditions varied for all regions sampled due to weather and production practices, causing variability in yield and quality of the wheat crop across the state. The sampling consisted of approximately 1,200 tailgate truck samples collected at 12 different elevators in the Oklahoma wheat producing regions, as well as 300 samples taken from Oklahoma State University variety trials. The samples where collected at or near peak harvest days for the participating elevators during the 1998 wheat harvest.

The samples were obtained using the truck sampling procedures recommended by the Federal Grain Inspection Service. Approximately six sub-samples (cuts across the flowing grain) were taken from each truck. The sampling containers were pulled through the entire flowing grain stream in a continuous motion, and the sub-samples were taken at random intervals throughout the entire dumping process. These sub-samples where then combined to approximately form a 1,200 gram sample for each truck. Each sample was identified by a scale ticket, and stored in a sealed container.

These samples where then taken to Enid, OK where official grading factors such as test weight, moisture content, and protein content were determined (see table 3.1). The samples were then taken to Oklahoma State University where two measures of uniformity where conducted (see table 3.2). The Ro-tap sieving measurements where conducted by placing a 200 gram sample in the sieve and shaking until the sample is separated into three sub-samples. The Ro-tap screen numbers seven, ten, and fourteen, with openings of 2.80, 2.00, and 1.68mm. respectively, where used in the measuring process. The weights of the sub-samples in every screen where recorded, and the percentages for each size screen calculated.

The second measure of uniformity consisted of the Single Kernel Characterization System (SKCS 4100). Three hundred kernels from every sample where analyzed and measurements of kernel weight, kernel hardness, and kernel diameter where obtained. The averages of these variables were then calculated for every sample.

Kernel Size and Uniformity Analysis

Due to favorable weather conditions for the growing period, the 1998 wheat crop for the state of Oklahoma was exceptional, with over eighty percent of the crop receiving a grade of No. 1 (see figure 3.1). Although the crop for the entire state was exceptional, there was variation in kernel size and uniformity between elevators, regions, and varieties. These variations are important to address for future marketing strategies. The following section discusses the differences found among elevators, regions, and varieties by conducting the Duncan's multiple range test with a significance level of .95.

Regions

The Oklahoma wheat producing regions' growing conditions vary greatly. Average rainfall ranges from 16 inches in the western panhandle to over 54 inches in the southeast. Elevations range from 300 feet above sea level in the southeast to 4,900 feet in the panhandle. Production practices such as winter grazing of livestock and irrigation also vary across the regions.

A multiple range test showed that average kernel weights were significantly different ($F = 62.18$) between regions. The north central region had the highest average kernel weight of 31.5 mg., and the northwest region the smallest with an average of 26.4 mg. The west central region had the most uniform kernels with a standard deviation in kernel weight of 7.82 mg., while the north central had the greatest variation with a standard deviation in kernel weight of 8.78 mg (see table 3.3).

The Ro-tap sieve system also found statistical differences ($F = 88.71$) in uniformity among regions. The north central and west central regions were found to be the most uniform, and statistically different than the other regions as judged by percentage of kernels captured. The northwest region was found to be the least uniform, as judged by the Ro-tap criteria, with the smallest kernels.

The Ro-tap criteria consistently ranked the regions into the three statistically different groups. The north central and west central regions had the highest percentages of big kernels, and the smallest percentages of small kernels. The northwest region, which includes the Oklahoma panhandle, had the largest percentage of small kernels, and the smallest percentage of large kernels. This ranking is consistent with that of the kernel weight, which had the north central ranked the highest followed by the west central, and the northwest was the smallest (see table 3.3).

The results of these regional analysis shows that the north central and the west central regions had the largest kernels as judged by both measures. The kernel weight analysis showed a significant difference (F = 51.36) in uniformity between regions, as judged by standard deviation, with the west central and southwest as the most uniform. In addition, the regions that had average kernel weights close to the state average were found to be the most uniform as judged by kernel weight standard deviation. The Ro-tap system showed both the north central and west central regions as the most uniform.

Elevators

The elevators chosen for this study were selected as a cross-section of the state. Both cooperatives and private elevators were used in the study. Kernel size and uniformity analysis is important to conduct at the elevator level due to the fact that 90% of all wheat produced is delivered to elevators. Therefore, elevators are in a position to implement strategies to increase uniformity.

The Duncan's multiple range test showed that the twelve elevators sampled in this study could be grouped together in four groups that were statistically different (F = 29.08) from one another based on average kernel weight. These groups contained elevators from different regions with kernel weight means that were not significantly different from each other. The elevators with the largest average kernel weights were Alva, Perry, and Canton. Hooker in the Northwest region had the smallest average kernel weight.

Uniformity of kernel size per elevator ranged from a standard deviation of kernel weight of 7.53 mg. for Weatherford to 9.30 mg. for Perry. The Perry and Alva elevators, which had the highest average kernel weights, also had the highest standard deviation in kernel weight. Weatherford, which had the lowest standard deviation of kernel weight, had the eighth highest average kernel weight. Kernel weight standard deviations were high for elevators at both ends of the kernel weight range (see table 3.4). Elevators with an average kernel size that was close to the state average were more uniform, as judged by standard deviation. Standard deviations were higher for elevators with an average kernel weight that was well above or below the state average.

Statistical differences (F = 41.08) in kernel size and uniformity were also found between elevators, as judged by the Ro-tap sieving system. Canton, Perry, and Alva were found to have the largest and most uniform kernels in the study, with an average of 75% captured by the No. 7 sieve. Hooker was found to have the smallest and least uniform with 44.4% large kernels and 1.2% small kernels (see table 3.4).

The results of this analysis show that Alva, Perry, and Canton had the largest average kernels, as judged by the SKCS. The elevators in the middle of the kernel weight range had the greatest uniformity, as standard deviation of kernel weight was higher for the largest and smallest average kernel weights. The Ro-tap sieve found the elevators in the largest group to be the most uniform.

Varieties

It is important to analyze the differences in kernel size and uniformity by variety in order to determine superior varieties[1]. This will be a necessary step in the adoption of

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[1] This data is only for one year, so more years of data will be necessary to establish real variety differences under varying environmental conditions.

these varieties by producers. The variety data used for this study was collected from 300 variety trials grown by Oklahoma State University.

The average kernel weight for the varieties studied ranged from 31.30 to 24.31 mg., and were found to be statistically different (F = 3.59). Statistical differences (F = 3.28) were also found for standard deviations of kernel weight. While regions and elevators were typically more uniform when average kernel weights were close to the state average; this was not true for varieties. Ogallala, which had the lowest average kernel weight, had the most uniform kernels, as judged by standard deviation of kernel weight (see table 3.5). Coronado had the least uniform kernels, as judged by kernel weight standard deviation, and ranked fourth highest in average kernel weight.

The Ro-tap analysis showed Coronado as the most uniform variety with 67.03% of the kernels captured by the No. 7 screen. This measure of uniformity contradicted the standard deviation method, which ranked Coronado last. None of the varieties were found to be statistically different as judged by the Ro-tap screens, with the exception of the number fourteen screen. This smallest screen found Karl92 to be statistically different from all others, with 9.2% of kernels captured by the smallest screen (see table 3.5).

The results of this variety analysis show that statistically there are differences in kernel size and uniformity between varieties. There was also a different relationship between kernel size and uniformity among varieties than there was among elevators and regions. The variety with the lowest average kernel weight also had the lowest standard deviation of kernel weight.

Summary

Before attempting to increase average kernel size and uniformity, it would be useful to understand current levels of kernel size and uniformity. This chapter has shown that judging by two different criteria, differences in kernel size and uniformity among regions, elevators, and varieties do exist. A direct relationship between large average kernel weight and high standard deviation was also discovered among regions, and elevators. However, some varieties have proven to be able to provide both high average kernel weight and low standard deviation. Both of these results are important when trying to determine strategies to increase kernel size and uniformity because these results indicate that potential strategies to sort wheat could increase kernel size and uniformity by region, elevator, and variety.

Table 3.1 1998 Wheat Quality Summary Statistics

Year	Test Weight Lbs./Bu.	Dockage	Damage	Foreign Material	SBK	Total Defects	Protein
1990-97	59.18	1.36%	0.67%	0.26%	1.79%	2.5%	12.31%
1998	61.72	1.17%	0.03%	0.10%	1.17%	1.3%	11.41%

Sources: 1990-94--Oklahoma Agricultural Statistics and Oklahoma Wheat Commission
1995-98--FGIS Grades on OSU Truck Tailgate Grain Quality Samples

Table 3.2 Estimates of Kernel Size and Uniformity
1998 Wheat Harvest: Single Kernel Weight and Ro-Tap

Variable	Mean	Standard Deviation	Minimum	Maximum
Kernel Weight (mg.)	30.18	3.23	17.85	39.69
Kernel Weight Standard Deviation	7.67	0.89	4.80	11.14
Protein	11.41	1.25	7.9	16.4
Test Weight	61.72	1.79	51.0	67.2
Ro-Tap Seven %	66.63	15.55	2.84	96.32
Ro-Tap Ten %	32.67	15.27	0.80	96.53
Ro-Tap Fourteen %	0.71	0.92	0.01	25.15

Table 3.3 Estimates of Uniformity by Region: Single Kernel Weight and Ro-Tap

Region	Mean Kernel Weight	Kernel Weight Std. Dev.	Ro-Tap Seven	Ro-Tap Ten	Ro-Tap Fourteen
North Central	31.48	8.78	72.7%	26.7%	0.6%
West Central	30.82	7.82	71.1%	28.3%	0.6%
Central	30.16	8.13	66.1%	33.1%	0.8%
Southwest	29.40	8.10	63.6%	35.7%	0.7%
Northwest	26.37	8.42	44.4%	54.4%	1.2%

Table 3.4 Estimates of Uniformity by Elevator: Single Kernel Weight and Ro-Tap

Elevator	Mean Kernel Weight (mg.)	Kernel Weight Standard Deviation	Ro-Tap Seven	Ro-Tap Ten	Ro-Tap Fourteen
Alva	32.08	8.54	74.5%	25.0%	0.5%
Perry	31.84	9.30	74.5%	25.9%	0.6%
Canton	31.40	8.31	76.3%	23.2%	0.5%
Cordell	31.09	7.58	70.4%	29.0%	0.6%
Omega	30.95	8.20	70.7%	28.5%	0.8%
Pondcreek	30.42	8.37	68.9%	30.4%	0.6%
Apache	30.33	8.00	67.7%	31.4%	1.0%
Weatherford	30.07	7.53	67.1%	32.3%	0.6%
Kingfisher	29.35	7.98	61.4%	37.8%	0.8%
Chattanooga	29.28	8.11	62.6%	36.8%	0.6%
Frederick	28.56	8.08	60.1%	39.3%	0.6%
Hooker	26.37	8.42	44.4%	54.4%	1.2%

Table 3.5 Estimates of Uniformity by Variety: Single Kernel Weight and Ro-Tap

Variety	Mean Kernel Weight (mg.)	Kernel Weight Standard Deviation	Ro-Tap Seven	Ro-Tap Ten	Ro-Tap Fourteen
Agseco7853	31.30	9.01	59.74%	39.25%	1.0%
Tonkawa	30.74	8.49	61.93%	36.77%	1.3%
Chisholm	29.67	8.78	52.32%	46.41%	1.3%
Coronado	29.54	9.36	67.03%	31.74%	1.2%
2137	29.53	8.94	61.09%	37.50%	1.4%
Custer	29.42	8.79	61.94%	36.97%	1.1%
Longhorn	28.82	9.09	59.24%	39.22%	1.5%
2174	28.44	8.22	58.91%	39.83%	1.3%
Cimarron	28.25	7.95	46.78%	52.08%	1.1%
Champ	28.24	8.52	55.70%	42.96%	1.3%
Karl92	28.07	7.99	47.78%	43.07%	9.2%
Jagger	27.57	8.68	48.62%	50.11%	1.3%
Dominator	27.14	8.06	41.05%	57.27%	1.7%
Tomahawk	27.11	9.08	55.37%	42.49%	2.1%
2163	26.61	8.54	63.47%	34.82%	1.7%
Ike	26.58	8.31	46.73%	51.64%	1.6%
Oroblanco	25.54	8.29	45.56%	52.55%	1.9%
Ogallala	24.31	7.70	46.46%	51.55%	2.0%

Figure 3.1
Grade Distribution for 1998 Wheat Harvest

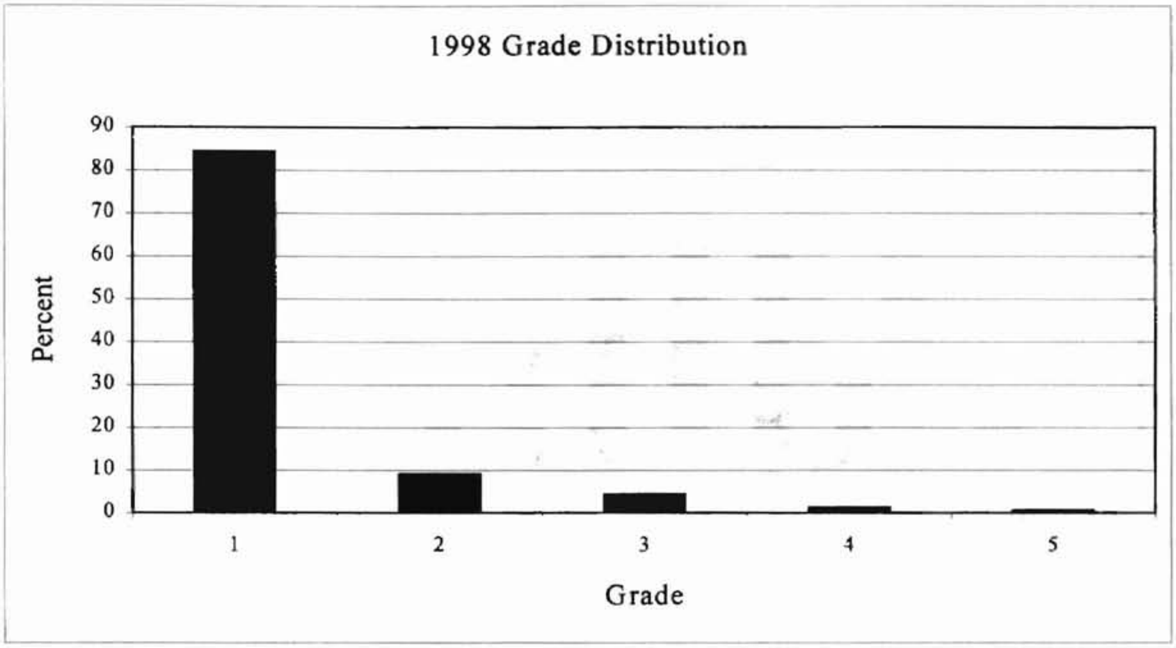


Figure 3.2
Kernel Weight Distribution for 1998 Wheat Harvest

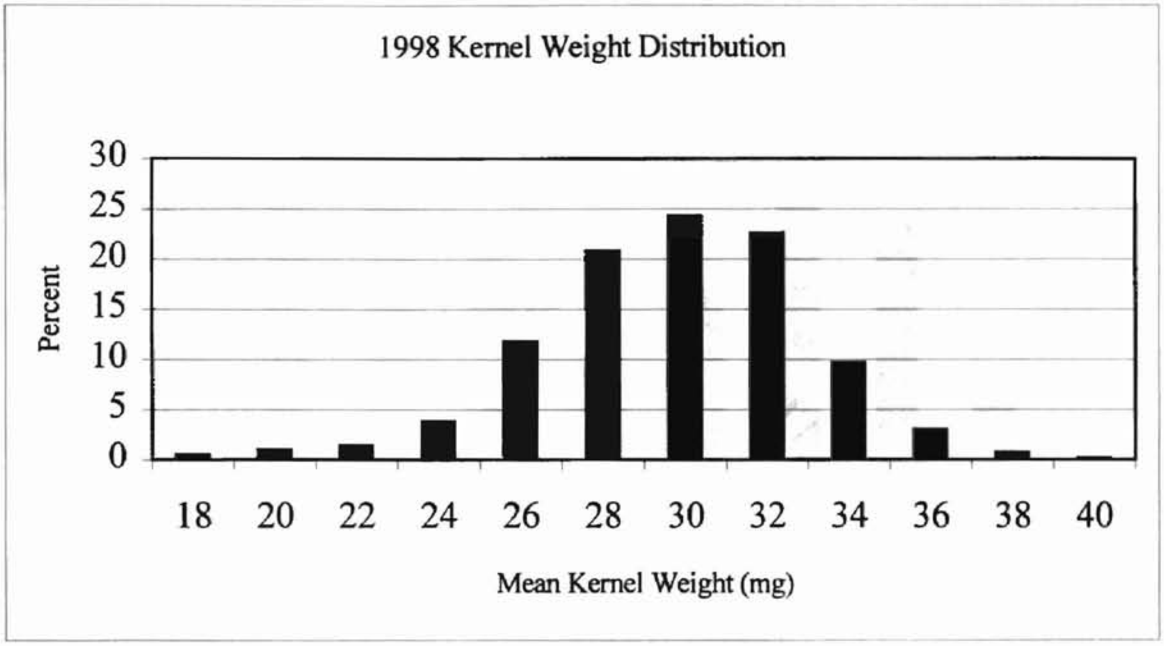


Figure 3.3
Ro-Tap Sieve Seven Distribution for 1998 Wheat Harvest

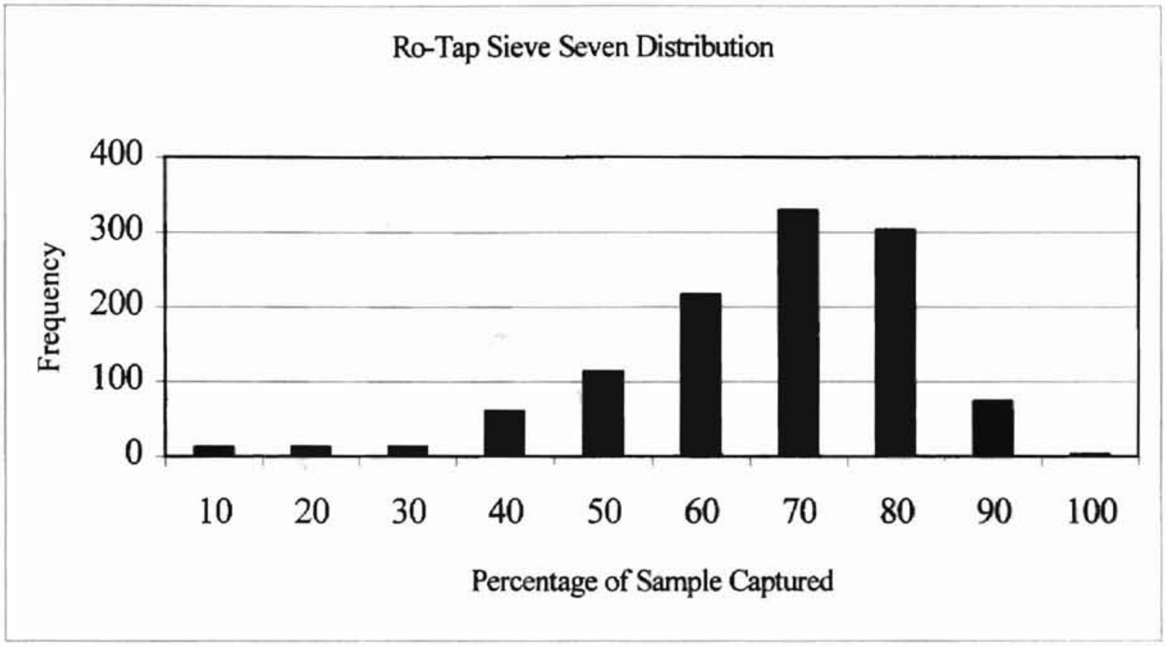


Figure 3.4
Ro-Tap Sieve Ten Distribution for 1998 Wheat Harvest

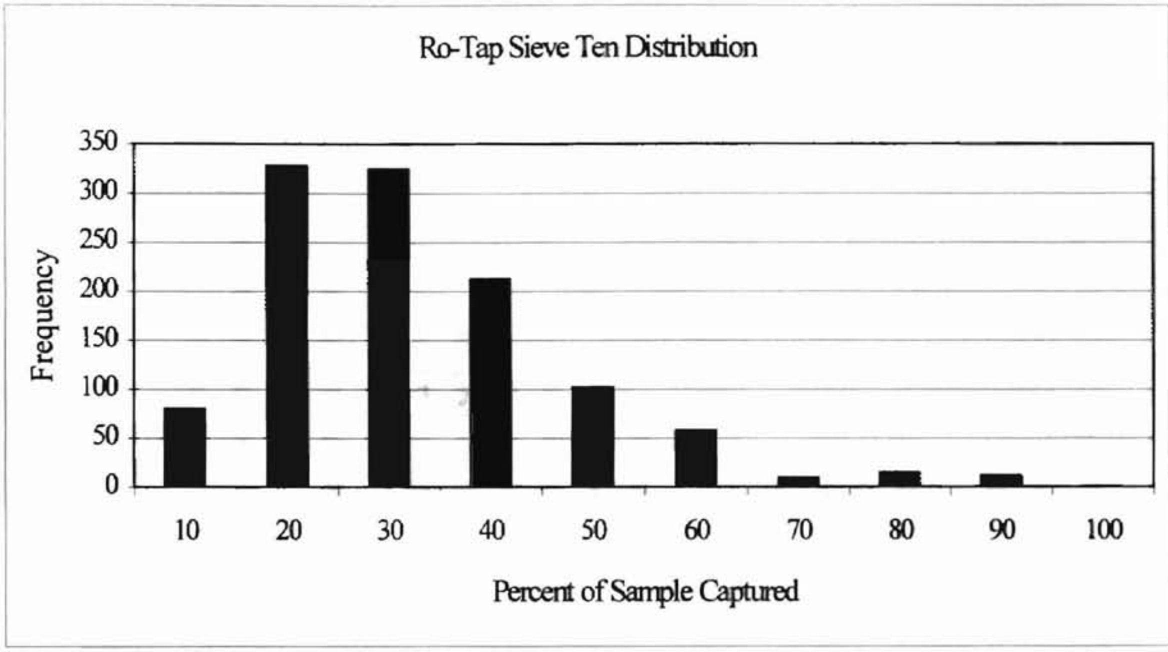
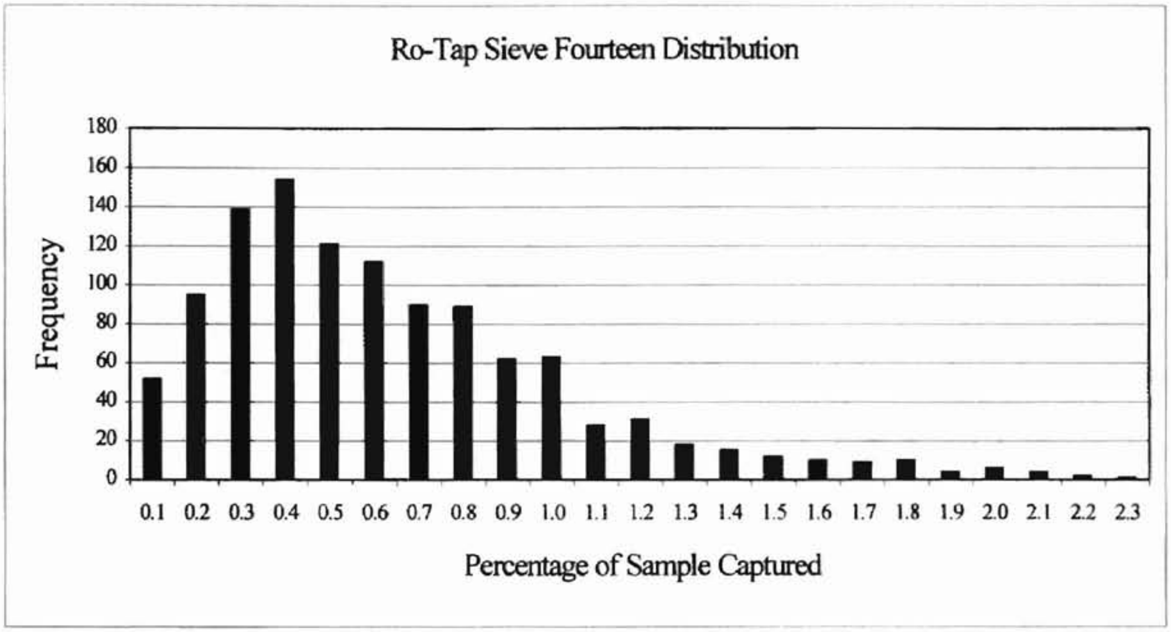


Figure 3.5
Ro-Tap Sieve Fourteen Distribution for 1998 Wheat Harvest



CHAPTER IV

KERNEL SIZE AND UNIFORMITY SEGREGATION STRATEGIES TO INCREASE DOUGH FACTOR

One of the central features of agricultural industrialization is the introduction of new technologies. New grain grading technologies that measure variables such as kernel size and uniformity have been developed and are on the verge of being introduced to the grain marketing system. Before these new technologies can benefit the marketing system they have to be proven to provide benefits.

The potential benefits of these new technologies could result from several different methods of implementation. In the current marketing system, grain-grading technologies are used in different ways. Technologies that measure federal grades and standards are often used to measure total value, and thus are used in segregation strategies that attempt to increase total value. Other segregation strategies apply the use of technologies in an attempt to segregate out a unique portion of the crop with desired characteristics. In both cases there is use of a technology that provides a quality measurement as a segregation criterion.

Two approaches to implementing new technologies are analyzed in this chapter. First, strategies are considered that attempt to increase the total value of the stored commodity at an elevator or region of elevators. By segregating all wheat produced into groups with similar kernel size characteristics, it is hypothesized that the total value of the wheat to processors will increase. This approach will be termed the total value approach. The second approach looks at segregating out a small portion of the crop with characteristics desirable to processors, and capturing a premium for this portion without discounting the remainder of the crop by an offsetting amount. This approach is termed the premium approach.

The following chapter looks at the effectiveness of two grain measurement devices that can be used in efforts to provide more uniform wheat with expected improved processing. The SKCS and Ro-tap sieving system can both be used to measure uniformity in wheat. Information from these devices can be used as a basis of the segregation strategies to increase the value.

<u>Strategies to Increase Total Value</u>

The first type of segregation strategies considered look at ways to increase the total value of the wheat crop on a state level. Attempts to increase total value are made by either changing the way the wheat is marketed or by sorting at county elevators. It is believed that as wheat is co-mingled the overall uniformity decreases. The first strategies look for an increase in dough factor if the wheat is marketed on a regional or country elevator basis. By doing this, the amount of co-mingling is decreased.

Other approaches to increase the total value involve segregation strategies on-site at country elevators. The first elevator segregation strategy is to segregate on the basis of variety. While this is simple in theory, it would present major challenges to elevators in practice. The idea behind this is that identity preserved wheat will have a higher dough factor due to greater uniformity and be more valuable to processors.

The second approach to increasing the total value at the elevator is to segregate wheat with similar characteristics into quartiles. This approach is used because of its similarity to current elevator segregation practices. The quartile strategy requires four bins, which is reasonable for most elevator facilities in Oklahoma and other states. By segregating wheat into quartiles that are of similar kernel size and uniformity, it is hypothesized that the overall dough factor for the elevator will increase even if some quartiles are discounted because of small kernel size.

Segregation by Region

Because of variable production practices and weather factors, kernel size and uniformity, as well as other quality factors, vary across wheat producing regions. The concept behind this strategy is very simple. By decreasing the co-mingling of wheat from different regions, it may be possible to increase the overall average dough factor for the state. More simply, this strategy looks at the increase in total value to the processor if wheat is segregated and purchased by region.

The results of this strategy showed that there were significant differences in dough factor by region (see table 4.2). However, the segregation strategy as a whole actually decreased average dough factor by 0.03% (see table 4.5). Overall dough factor for the processor would not increase do to segregating and processing by region, but processors could benefit by purchasing grain from superior regions.

Segregation by Elevator

The concept behind this strategy is similar to that of the region strategy. By decreasing co-mingling by focusing on the elevator level it is hypothesized that uniformity and dough factor will increase. There are several elevators per region in Oklahoma; therefore if processors were to purchase wheat from these elevators directly co-mingling would be decreased substantially.

The results of this strategy were similar to that of the region strategy. There was significant difference in dough factor between elevators (see table 4.3). However, some elevators had dough factors below the state average. Therefore, this strategy, if followed in all areas, decreased the overall average dough factor by 0.04% (see table 4.5). Once again, processors would benefit from purchasing wheat from elevators with high dough factors, such as Weatherford and Cordell. However, the overall value to the processor would not increase due to segregation by elevator.

Segregation by Variety

This strategy of segregation by variety is simple in theory, but complex in practice due to the number of varieties currently produced in Oklahoma. There were significant differences found in kernel size and uniformity between varieties. Therefore, when they are co-mingled the uniformity that exists is eliminated. The concept of this strategy would be to segregate each variety from one another or to segregate and reward proven high performing varieties. Because there are eighteen varieties analyzed in this study, actually implementing such an approach could be logistically challenging.

There is a wide range in dough factor between varieties (table 4.4), and there are superior and inadequate varieties, as judged by dough factor, currently being produced in Oklahoma. This analysis showed that there are superior varieties, and that processors would benefit from greater adoption of these varieties. This strategy as a whole was beneficial to processors. Segregation by Variety increased dough factor by 0.14%. While this benefit is only marginal, it is important to note that the percentage change of dough factor ranged from –2.33% to 2.25% across varieties (see table 4.4). This shows strong potential effects form variety selection to increase kernel size and uniformity.

Quartile Segregation Strategies

A final method that attempts to increase the total value is segregation strategies that sort wheat into quartiles at country elevators. The practice of sorting wheat at country elevators is not uncommon. Many country elevators currently sort wheat in order to raise the overall grade and value. In this study, the purpose of segregating wheat into quartiles is to increase uniformity by storing grain with similar characteristics together.

In order to segregate into quartiles elevators must have four separate bins, which is a reasonable amount of bins for most Oklahoma elevators. Four criteria were examined as the basis for sorting in this simulation. The first two were the SKCS and Ro-Tap measurements. The concept of segregating by these kernel size measurements was to group kernels of similar size together in order to increase overall uniformity.

The last two criteria were based on two measurements that are already taken at the majority of Oklahoma elevators, they were test weight and dockage. These two measurements are currently used as criteria by which to sort wheat at country elevators to increase grade. Their use in this study as criteria for segregation to increase uniformity was useful for comparison with the two new technologies.

All of these quartile strategies failed to increase the total value of the average elevators' inventory (see table 4.5) even when uniformity increased. There was found to be a high negative correlation between kernel size and protein content (-.44). Because the dough factors were figured for each bin independently, this relationship offset the benefit of greater uniformity. In the dough factor equation (see table 4.11) the variables that had the greatest range of influence were the kernel weight squared, and protein squared terms (see table 4.12). Even though a change in the overall average protein content and average kernel weight did not result from the segregations, the inverse relationship and range of influence of these variables affected dough factor per bin negatively (see table 4.6).

However there were some elevators that did benefit slightly. Hooker showed increases in both the kernel weight and Ro-tap quartile strategies (see tables 4.6 and 4.7).

More importantly, the forth quartile for the Hooker elevator in both the kernel weight and Ro-tap quartile strategies showed a 2.21% and 1.94% increase respectively. Hooker was an elevator from the northwest region with the lowest average kernel weight of all elevators. These results indicate that this approach may be useful in years where the crop is bad or closer to average, and all elevators have lower average kernel weights.

While there were some benefits found in these strategies to increase the overall value, only the variety strategy showed an increase in overall average dough factor. However, these strategies did yield some important results. There are superior wheat producing regions, elevators, and most importantly varieties in Oklahoma. The wheat marketing system can benefit from the adoption of these superior varieties.

The inverse relationship between kernel size and protein is another important result of this section. These variables counteracted each other in the quartile strategies, and uniformity did not increase enough to raise dough factor. The fact that large kernels typically have low protein content is the basis for another strategy in the next section.

Premium Approaches

The concept behind the premium approaches is to sort out a portion of the stored commodity that meets some certain criteria without discounting the rest of the stored crop. Some Oklahoma elevators currently implement segregation strategies in which wheat that is high in protein is segregated from the rest of the crop. Elevators have been able to capture a premium for this higher protein wheat without discounting the rest of the stored commodity. This is the concept behind the last two segregation strategies.

The first segregation strategies discussed in the previous section revealed two important characteristics, which are the basis for the last two strategies. The first is that there is a great deal of variation in dough factor across varieties. Therefore, the first segregation strategy in this section looks at segregating the top five varieties, based on dough factor, from the rest of the varieties.

The second characteristic of the first section was that any benefit caused by the segregation of higher kernel size was offset by a decrease in protein content. The last segregation strategy looks at the benefit of segregating the portion of the crop that is above average kernel weight and uniformity, while being above average protein content as well. By including three variables as the basis for which to sort, the number of loads that qualify is decreased. This leads to a small portion of premium wheat that is segregated from the rest of the commodity.

Segregating the Top Five Varieties

This segregation strategy is simple in theory, and could be easily implemented at an elevator. The strategy only requires the use of two bins, and communication between the elevator and producers on variety identification. Five varieties, from the variety trials, were substantially higher in dough factor than the rest of those grown in Oklahoma. The concept of this strategy is to segregate these five varieties from the rest, in order to capture any benefit without discounting the rest of the stored grain by an offsetting amount.

The results of this strategy showed that the top five varieties segregated together would yield a dough factor that is 1.52% higher than the state variety trial average (see table 4.8). The remaining varieties produced a dough factor 0.58% lower than the state average.

These results indicate that this strategy could provide net benefits to the marketing system. More importantly, this strategy shows once again the difference in the quality of varieties grown in Oklahoma. The top five varieties milled together would likely produce 1.52% more dough than the state average.

Segregating by Kernel Weight, Uniformity, and Protein Content

As the previous section showed, in many cases any benefit due to larger kernel size is offset by lower protein content. This characteristic is fundamental to this last strategy. This strategy segregates out the wheat that is above average in kernel size and uniformity, while at the same time above average in protein content. On average, this leads to about ten percent of the delivered crop at any particular elevator. This top ten percent of the crop should be more valuable to processors and should be considered premium wheat. Once again, the benefit of this wheat will likely not be offset by the discount of the remaining wheat.

The results of this strategy showed that by segregating out wheat that met these characteristics dough factor could be increased on average by 1.82% (see table 4.9). The reduction of dough factor by the rest of the crop was found to be minimal. A weighted average of the premium and discounted wheat showed dough factor increasing by 0.03%. This strategy showed the most potential, due to the fact that it yielded the most benefit and could be realistically implemented.

Summary

The benefits of these premium strategies were found to be substantially higher than those of the total value strategies. By segregating out the cream of the crop, a higher value product can be developed. Generally this can be done without negatively effecting the overall value of the rest of the stored commodity. In most cases these strategies can be easily accomplished because they require minimal excess storage. However, the strategies discussed in this section would require the implementation of both the SKCS and protein analyzer as well as greater coordination between producers and elevator managers.

The results of these strategies do have important implications for the marketing system. The top five varieties are superior, as judged by dough factor, to other varieties produced in Oklahoma. By implementing simple strategies the benefits of these varieties can be captured, and a market signal can be sent to producers. The same can be said about the potential implementation of the SKCS. When used along side a protein analyzer there is potential to capture a premium for superior processing wheat. If these premium approaches can increase value by 2%, then at $2.50/bu. this premium wheat is worth 5 cents more per bushel.

Conclusion

This chapter had looked at two approaches to increase the dough factor of the Oklahoma wheat crop. The first approach was to attempt to implement new grain grading technologies as criteria to segregate wheat. The concept was to decrease co-mingling of wheat that is of different characteristics, and by doing so increase the uniformity and dough factor of the overall stored commodity. These first approaches failed to increase the overall dough factor. However, important traits of the crop were realized such as the differences among varieties, and the relationship between kernel size and protein content.

The second approach to increase dough factor was by the segregation of a premium portion of the total crop. These strategies were successful in increasing dough factor, and showed that this could be done without discounting the rest of the stored commodity by an offsetting amount. The results of these strategies also indicated the potential benefit of the adoption of superior varieties, as well as the adoption of the SKCS used along side a protein analyzer.

Table 4.1 1998 Oklahoma Wheat Harvest Overall Dough Factor

Oklahoma	Kernel Weight (mg.)	Kernel Weight Standard Deviation	Protein Content %	Test Weight	Dough Factor
1998	30.18	8.35	11.42	61.72	108.54

Table 4.2 Dough Factor by Region

Region	Kernel Weight (mg.)	Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From State Average
West Central	30.82	7.82	11.62	109.86	1.22
Central	30.16	8.13	11.16	108.76	0.21
Southwest	29.40	8.10	11.30	108.48	-0.05
North Central	31.48	8.78	11.04	107.58	-0.89
Northwest	26.37	8.42	12.77	106.70	-1.70
State Average	30.18	8.35	11.42	108.54	0.00

Table 4.3 Dough Factor by Elevator

Elevator	Kernel Weight (mg.)	Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From State Average
Weatherford	30.07	7.53	11.68	110.33	1.65
Cordell	31.09	7.58	11.56	109.96	1.31
Apache	30.33	8.00	11.55	109.38	0.78
Canton	31.40	8.31	11.60	109.36	0.76
Kingfisher	29.35	7.97	11.31	108.89	0.32
Omega	30.95	8.20	11.01	108.67	0.13
Pondcreek	30.42	8.37	11.57	108.59	0.04
Frederick	28.56	8.08	11.34	108.09	-0.41
Chattanooga	29.28	8.11	10.99	107.87	-0.61
Alva	32.08	8.54	10.71	107.32	-1.12
Perry	31.84	9.30	10.90	106.90	-1.51
Hooker	26.37	8.42	12.77	106.70	-1.70
State Average	30.18	8.35	11.42	108.54	0.00

Table 4.4 Dough Factor by Variety

Variety	Kernel Weight (mg.)	Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From State Average
Tonkawa	30.74	8.49	13.25	110.32	2.25
Karl92	28.07	7.99	12.89	109.60	1.58
AgSeco78	31.30	9.01	12.59	109.50	1.49
2174	28.44	8.22	12.63	109.36	1.35
Cimarron	28.25	7.95	12.28	109.32	1.32
Dominator	27.14	8.06	12.62	108.79	0.82
Custer	29.42	8.79	12.62	108.76	0.80
Chisholm	29.67	8.78	12.13	108.46	0.52
Longhorn	28.82	9.09	12.74	107.96	0.06
Champ	28.24	8.52	12.50	107.92	0.02
2137	29.52	8.94	11.83	107.69	-0.19
Jagger	27.57	8.68	12.48	107.50	-0.37
Ogallala	24.31	7.70	12.65	107.32	-0.53
Ike	26.58	8.31	12.42	107.23	-0.62
Coronado	29.54	9.36	12.16	107.22	-0.63
Oroblanco	25.54	8.29	12.29	106.57	-1.23
Tomahawk	27.11	9.08	12.57	105.96	-1.80
2163	26.61	8.54	11.67	105.39	-2.33
Variety Trial Average	28.13	8.74	12.47	107.90	0.00

Table 4.5 Results of Strategies to Increase Total Value

Strategy	Average Protein Content	Average Kernel Weight	Average Kernel Weight Standard Deviation	Average Dough Factor	Percent Change in Dough Factor
Region	11.42	30.18	8.25	108.50	-0.03
Elevator	11.42	30.18	8.20	108.51	-0.04
Kernel Weight Quartile	11.42	30.18	7.75	108.46	-0.07
Ro-Tap Quartile	11.42	30.18	7.88	108.47	-0.06
Test Weight Quartile	11.42	30.18	8.08	108.41	-0.11
Dockage Quartile	11.42	30.18	8.09	108.52	-0.02
State Average	11.42	30.18	8.35	108.54	0.00
Variety	12.46	28.16	8.55	108.05	0.14
Variety Trial Average	12.46	28.16	8.74	107.90	0.00

Table 4.6 Results of Kernel Weight Strategy by Quartile for Alva

Kernel Weight	Kernel Weight (mg.)	Average Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From Elevator Average
Quartile 1	28.28	8.56	11.16	106.54	-0.73
Quartile 2	31.18	8.14	11.10	108.30	0.91
Quartile 3	33.09	8.11	10.23	106.63	-0.65
Quartile 4	35.61	7.69	10.29	106.26	-1.00
					Average % Change
Alva	32.08	8.54	10.71	107.32	-0.38

Table 4.7 Results of Kernel Weight Strategy by Quartile for Hooker

Kernel Weight	Kernel Weight (mg.)	Average Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From Elevator Average
Quartile 1	20.81	6.78	13.26	104.47	-2.08
Quartile 2	25.21	7.76	13.77	107.49	0.75
Quartile 3	28.03	7.80	12.51	108.77	1.94
Quartile 4	31.44	7.41	11.39	109.05	2.21
					Average % Change
Hooker	26.37	8.42	12.77	106.70	0.71

Table 4.8 Results of Ro-Tap Strategy by Quartile for Hooker

Ro-Tap	Kernel Weight (mg.)	Average Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From Elevator Dough Factor
Quartile 1	21.85	7.36	13.76	104.70	-1.87
Quartile 2	25.18	7.82	13.85	107.21	0.48
Quartile 3	28.17	7.82	11.73	107.83	1.06
Quartile 4	30.94	7.76	11.49	108.76	1.94
					Average % Change
Hooker	26.37	8.42	12.77	106.70	0.40

Table 4.9 Results of Top Five Varieties Strategy

Strategy	Kernel Weight (mg.)	Average Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From Elevator Average
Top Five Varieties	29.36	8.45	12.73	109.53	1.52
Remaining Varieties	27.67	8.80	12.36	107.27	-0.58
Variety Trial Average	28.13	8.74	12.47	107.9	Average % Change 0.003

Table 4.10 Results of Kernel Weight, Uniformity, and Protein Strategy

Elevator	Kernel Weight (mg.)	Average Kernel Weight Standard Deviation	Protein Content %	Dough Factor	Percent Change From Elevator Average
Hooker	28.14	7.86	13.76	109.50	2.63
Pondcreek	32.35	7.47	12.32	111.15	2.36
Frederick	30.38	7.50	11.95	110.26	2.01
Kingfisher	31.50	7.35	12.08	111.04	1.97
Apache	31.80	7.48	12.30	111.44	1.88
Weatherford	31.87	6.86	12.84	112.25	1.74
Perry	35.41	8.28	11.56	108.75	1.72
Cordell	32.45	6.54	12.34	111.81	1.69
Omega	32.94	7.90	11.77	110.39	1.58
Canton	33.57	7.57	12.40	110.97	1.47
Chattanooga	31.56	7.67	11.41	109.45	1.46
Alva	34.03	7.34	11.23	108.75	1.33
Overall Average of Premium Strategy	32.17	7.48	12.16	110.48	Average % Change 1.82

Table 4.11 Equation Estimating Dough Factor

	Parameter Estimate	Standard Error	*P*
Intercept	22.45	9.84	0.0228
Kernel Weight	2.94	0.56	0.0001
Kernel Weight Std	-6.87	1.19	0.0001
Protein	6.81	1.21	0.0001
Kernel $Weight^2$	-0.07	0.01	0.0001
$Protein^2$	-0.23	0.05	0.0001
Kernel Weight x Kernel Weight Std	0.19	0.04	0.0001
Test Weight	0.37	0.06	0.0001

$R^2 = 0.42$ Mean Square Error = 8.56

Table 4.12 Individual Influence of Dough Factor Variables

Variable	Coefficient	Minimum Influence	Maximum Influence	Range
Kernel Weight (mg.)	2.94	52.48	116.72	64.24
Kernel Weight Standard Deviation	-6.87	-33.00	-76.55	43.55
Protein	6.81	53.80	111.68	57.88
Test Weight	0.37	18.87	24.86	5.99
Protein Squared	-0.23	-14.35	-61.86	47.51
Kernel Weight Squared	-0.07	-22.31	-110.32	88.02
Kernel Weight* Kernel Weight Standard Deviation	0.19	20.00	65.05	45.06

Table 4.13 Correlation Matrix of Dough Factor Variables

Variable	Kernel Wt.	Kernel Wt. Std.	Protein	Test Wt.	$Protein^2$	Kernel $Wt.^2$	Kernel Wt* Kernel Wt. Std.
Kernel Wt.	1	0.073	-0.44	0.44	-0.45	0.996	0.69
Kernel Wt. Std.	0.073	1	-0.12	-0.24	-0.13	0.05	0.77
Protein	-0.44	-0.12	1	-0.25	0.997	-0.43	-0.37
Test Wt.	0.44	-0.24	-0.25	1	-0.27	0.42	0.11
$Protein^2$	-0.45	-0.13	0.997	-0.27	1	-0.44	-0.38
Kernel $Wt.^2$	0.996	0.05	-0.43	0.42	-0.44	1	0.67
Kernel Wt* Kernel Wt. Std.	0.69	0.77	-0.37	0.11	-0.38	0.67	1

CHAPTER V

HIGHLIGHTS OF RESEARCH, SUMMARY, AND CONCLUSIONS

The overall goal of this study was to increase the Oklahoma wheat industry's ability to respond to customer needs, relating to kernel size and uniformity. Domestic consumers and the export market ultimately drive the concept of providing more uniform wheat to the market.

The first step taken to meet this need was to determine the current levels of kernel size and uniformity among Oklahoma regions, elevators, and varieties. This was a necessary step in the development of strategies to increase uniformity. The analysis showed that there were differences in kernel size and uniformity.

The research then looked at strategies to increase value through greater kernel size and uniformity. These strategies were developed in two general approaches. The first approach was to implement strategies that attempted to increase the total value of the Oklahoma wheat crop through segregation to increase kernel size and uniformity. The second approach, termed the premium approach, was to segregated a smaller portion of the crop that met a certain quality criteria without discounting the remainder of the stored commodity. These approaches met with some success.

The kernel size and uniformity measurements used in this study were the result of two grain grading technologies, the SKCS 4100 and the Ro-tap sieve system. It was the consumer demand for greater uniformity that prompted the development of these technologies. An important aspect of this research was the effectiveness of their use as a criteria for which to segregate and grade wheat.

The final chapter of this study will address these issues in the following manner. First, the effectiveness of the strategies to increase uniformity will be reviewed, and strategies with potential highlighted. The choice of which technology would be the most cost-effective as an on-site criteria to segregate will then be discussed. Next, the distribution of the benefits provided by these technologies, and the necessary incentives for their adoption will be addressed. The final section of the chapter will highlight the important findings of the research as well as give suggestions for further research.

Strategies with Potential

Overall, there were several strategies to increase uniformity and dough factor addressed in this study. They included 'total value' strategies such as segregating by region, elevator, or variety, as well as 'premium' approaches which included segregating the top five varieties, and segregating by kernel weight, kernel weight standard deviation, and protein content. These strategies looked at both changing the way the grain is marketed by reducing co-mingling between regions and elevators, and also segregation on-site at elevators. The strategies resulted in some success. The ones that showed the greatest promise are highlighted here.

The strategies that looked at segregating by region or elevator showed that while the overall dough factor for the state would not increase, superior elevators and regions did exist. The elevator quartile strategies showed that the overall value of the stored commodity could increase for some elevators, but on average there was no benefit to such strategies. This was due in part to the inverse relationship between kernel weight and protein content.

There were two strategies that showed significant potential to increase value. Both of these premium strategies segregated out a portion of the stored crop. The top five varieties segregated from the rest of the stored commodity showed an increase in dough factor by 1.5%. The other strategy with the greatest potential segregated wheat on-site that was both high in average kernel weight and uniformity as well as protein content. This strategy showed an average increase in dough factor of 1.8%.

The results of these strategies and the degree of their effectiveness are important in order to determine the economic feasibility of adopting a uniformity measurement technology. An on-site measure of uniformity or knowledge of varieties would be essential to the implementation of these on-site strategies.

Technologies: SKCS 4100 vs. Ro-Tap

Segregation strategies that are based on kernel size and uniformity criteria require some form of technology to measure kernel size and uniformity on-site. This research looked at the use of two such technologies, the SKCS 4100 and the Ro-tap sieving system. While there are substantial differences in the cost of these two technologies, one of the aspects of this study is the difference in performance of these two technologies.

The SKCS 4100 can analyze a 300 kernel sample of wheat, and provide data on average kernel weight, kernel weight standard deviation, and related factors in less than three minutes. However, the SKCS does require a higher investment (approximately $25,000) than the sieving system. The Ro-tap sieving system determines kernel size and uniformity of a sample in a few minutes by determining the percentage of large, medium, and small kernels in a sample. The Ro-tap sieve system can be purchased for less than $1,000. Obviously, if using the Ro-tap system was effective, this would substantially decrease the costs of adoption.

While the procedures each of these technologies uses to determine kernel size and uniformity are very different there results are correlated in some cases. The percentage of kernels in the Ro-tap number seven sieve is highly correlated (.85) with the average kernel weight measurement given by the SKCS 4100. This indicates that the Ro-tap sieve could be close to the same effectiveness of the SKCS 4100 at a much lower cost. This indicates that the Ro-tap system could be used to sort for kernel size. However, there was not a high correlation between the Ro-tap percentages and kernel weight standard deviation which means that it is not likely to be effective to sort for kernel uniformity.

The benefit provided by either of these technologies must be able to pay for the measurement system. Therefore, the correlation between the two measurements, as well as the costs, are important factors. The Ro-tap sieving system may be able to provide close to the same measurement as the SKCS 4100 for kernel weight, but uniformity is not well measured by the Ro-tap system.

Distribution of Processing Benefits

The driving factor behind the adoption of new technology is that it will provide benefits that offset that technology's expense. The segregation strategies discussed in this study were designed to increase uniformity, and ultimately dough factor. By yielding more dough these strategies make the wheat more valuable to processors. Before adoption of either of the technologies discussed can take place there must be an incentive in place for each stage of the marketing chain involved.

This incentive must begin with the buyers of the wheat. Because importers and domestic processors have stated that greater uniformity is desired, they must be willing to pay a premium for this quality. The segregation strategies in this study were judged by how much they can increase dough yield. This percentage increase is a direct benefit to processors. If the wheat produces 2% more dough, then that wheat is 2% more valuable (about 5 cents with today's wheat price of $2.50) to processors, and a premium must be in place that will provide adequate incentive to sort, store, and market for this factor.

Elevators must have this incentive to segregate to increase uniformity before they will be willing to purchase new technology to measure uniformity. The cost of the new technology is not the only cost factored in for elevators. Segregation strategies generally require greater coordination, increased overhead and training as well. There may also be a need for elevators to provide an incentive to producers to produce varieties with desired characteristics to implement some of the strategies.

Producers may not respond to small incentives. Many producers set back seed from one years' production to plant for the next year. Therefore, it often takes several years for new varieties to be adopted on a widespread basis. Persuading producers to adopt varieties with greater kernel size and uniformity would be more effective with an incentive in place. If there is a premium for the delivery of specific varieties at the elevator, adoption of these varieties will more likely occur, but this would require some ability to verify specific varieties delivered.

The wheat marketing system is complex and has many independently operating players. It will require the coordination of all levels to provide incentives for the adoption of superior varieties and new grain grading technology that will yield strong benefits.

Conclusions

The research accomplished several objectives. It determined the existing levels of uniformity, as measured by the SKCS 4100 and Ro-tap sieving system, for Oklahoma wheat truckloads, varieties, elevators, and regions. In addition, the research developed segregation strategies to increase levels of kernel size and uniformity, and evaluated the effectiveness of these strategies.

The methods that accomplished each objective are: (1) Duncan's multiple range test for statistical differences measured the levels of uniformity among elevators, regions, and varieties and looked for statistical differences, (2) a segregation model sorted wheat on the basis of kernel size and uniformity measurements to increase dough factor.

The results of the first objective found that statistical differences in average kernel weight and uniformity do exist among regions, elevator, and varieties in Oklahoma. The results further indicated that there are superior elevators, regions, and varieties in Oklahoma.

The results of the second objective indicated that segregation strategies based on kernel size and uniformity measurements that attempt to increase the total value were unsuccessful on average. However, strategies that segregate a portion of the stored crop showed some benefit. Segregating the top five varieties increased dough factor by 1.52%. The high negative correlation between protein content and kernel size resulted in another segregation strategy based on both criteria that was able to raise dough factor on average by 1.82%.

The results of this study are important to the entire wheat industry because they indicate that there are differences in kernel size and uniformity in wheat. Currently, there is no measure of kernel size and uniformity commonly used in grades and standards on most grain transactions. As a result there is little or no incentive for investment in superior varieties and grain grading technology.

Wheat importers as well as domestic processors have expressed the need for more uniform wheat. If the U.S. wheat industry fails to respond to these needs, their competitiveness in the world wheat market will suffer. Because most of the wheat produced in Oklahoma is delivered to country elevators they have an opportunity to implement strategies that increase uniformity. However, an incentive program that rewards uniformity must first be in place.

Suggestions for future research include cost-benefit analysis of the implementation of the SKCS 4100 and Ro-tap sieving systems on-site. This is a necessary step before adoption of either of these technologies can take place. Furthermore, more data is needed to verify the results of this study. The data used in this study was taken from an above average crop. As samples are taken from different growing conditions more sound conclusions can be drawn.

The future of research in this area should focus on protein content as an important quality characteristic as well as kernel size and uniformity. There are already elevators that capture premiums for high protein wheat. High protein content has become a criteria by which to segregate in other commodities such as soybeans. Because of the trade off between kernel size and protein content, these two quality characteristics may need to be analyzed together.

Future regression analysis should also be done in order to develop a relationship between the Ro-tap measurements and flour yield. The Ro-tap technology has shown potential to measure kernel size with accuracy close to that of the SKCS 4100. This technology is moderately priced and would be more realistically adopted by the industry. Therefore, benefits of segregation strategies based on this criteria should be determined and evaluated.

Additional years' data are also needed in order to further this research. Data collected over several harvests is essential to establishing a reliable regression relationship between quality factors and milling yield because factors such as growing conditions vary greatly from year to year.

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