EARLY PREDICTION OF PROTEIN IN THE WHEAT CROP

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KUSUM M. PATEL
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Approved by:

John A. Johnson
Major Professor

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INTRODUCTION

On the basis of information gathered by FAO, it has been reported that one third of the world's population is either undernourished or malnourished. Especially protein malnutrition is the most serious problem today in the lesser developed countries (22). Cereal protein is the most important protein, because it is most readily available and most economical. Of the cereals, wheat protein with rice is most widely produced. Wheat is one of the world's most important products of agriculture. In some parts of the world wheat provides 80 percent of the diet.

Considering the nutrients furnished by wheat, it is the most economical of foods. Although wheat has fair quality of protein, it is low in lysine, particularly. The nutritive quality of protein may be improved by supplementation with milk or other protein foods, particularly soybean protein. In a study of food consumption patterns in Latin America, Far Eastern and Middle Eastern countries, it has been shown that of all cereals, wheat alone could meet minimum protein requirements (22).

The protein content of wheat may vary widely depending upon variety, class and environment. In marketing of wheat while classes are segregated, variety, within a class usually loses its distinction because of blending. Therefore, within each class, protein content is the most important quality factor available in wheat marketing. Protein content is the most significant single factor influencing the baking behavior of sound flours. Since protein content is influenced mainly by environment, it is extremely desirable that the protein of wheat be known before it is marketed. Still better would be if means were available to accurately predict the protein content of wheat by areas before harvest. If such information were available, much more efficient marketing plans could be devised. The buyer of wheat could plan to purchase wheat from areas of known protein content.

During the last few years much attention has been directed to the protein of wheat as a measure of baking quality. Since protein content is the most significant single factor influencing baking behavior of sound flours, it is used in the evaluation of wheat both by flour milling and baking industries. Premiums are paid for high protein content.

The object of this research was to seek means of predicting protein content of wheat before harvest and to gain a better understanding of the effects of variety and environment on wheat quality.

REVIEW OF LITERATURE

The importance of environment upon protein content of wheat has been recognized for years. Like other living organisms, wheat, a living thing, is affected by a variety of factors. The main factors which influence wheat quality are climate, soil and variety. Plants are so sensitive to a change of the environment that it is difficult to say which of the environmental factors have the greatest influence. They may influence each other. Sometimes a single factor may be so strong that it minimizes the effects of others. For instance, lack of moisture at critical periods of growth may have a stronger influence on quality than varietal characteristics or the amount of available nutrients in the soil (54).

Climate may be defined as the atmospheric condition which prevails within a place or region in regard to temperature, rainfall and prevailing winds. How these conditions affect growth and quality of wheat is dependent upon the degree to which they prevail during the growing period (20, 61). Soil is the storehouse of the mineral elements necessary for the plant growth. The importance of soil factors as related to wheat quality is being recognized more and more. Water in the soil is the chief transporting medium for nutrients from the soil to the plant. About 300 pounds of water must pass from the soil to the plant for every pound of dry material constructed (54). Available soil moisture frequently determines the quality characteristics of wheat. Limiting moisture generally increases the protein content while decreasing the yield.

Variety is a type of wheat within a larger class. It has been recognized that approximately 80 percent of the variation in quality of Hard Red Winter wheat grown in Kansas, primarily for breadmaking is accounted for by protein content alone, while 20 percent of the variation in baking is due to variety and other quality factors (31).

The crude protein content of wheat and flour has become increasingly significant in the merchandising of Hard Spring and Hard Winter wheat crops. The correlation between protein content of wheat and baking strength and baking quality of flour has accordingly become of interest to all branches of trade. Several extensive studies of wheat composition to baking quality have been reported in recent literature. In a majority of instances, a positive correlation has been detected between percentage of protein and breadmaking value (5).

Zinn (61) found a positive coefficient of correlation between loaf volume and crude protein content. Similar findings were reported by Mangles and Sanderson (38), Blish and Sandstedt (8) and Grewe (25) for three crops of North Dakota wheat.

Reporting on series of Kansas grown wheat varieties of the 1938 crop, Larmour et al. (35) demonstrated that within a given season the potential strength of the principal Hard Red Winter varieties is related to protein content in linear fashion, and is very highly correlated with it. Bell and Simmonds (7) found that there was a general tendency for baking quality to rise with increasing total nitrogen in 26 Australian flours. A positive but less highly significant correlation also was observed between the formic acid soluble nitrogen and the baking score.

Many organizations have made elaborate and thorough surveys of the quality of the wheat in various states for years. This has permitted the classifying of wheat for quality characteristics according to locality. These surveys have been performed after the wheat has been harvested. Sometimes the wheat has been marketed and mixed in central terminals before full advantage can be taken of the survey information (31). If the survey information could be made available, the variation in the breadmaking quality of the wheat could be established and millions of dollars can be saved by the processor.

The composition of wheat is not to any great extent, hereditary. Protein, ash, size of berry and weight per bushel are found dependent upon climatic conditions, prevailing during growing period of plant. Seed of Kansas wheat having 20 percent protein and seed of California wheat having 13 percent protein when grown side by side in South Dakota, yielded crops of identical composition and physical appearance (37).

It is known that environmental factors play a big role in influencing wheat quality. Protein content of wheat is subject to great variation. It varies in the various world wheat growing regions, in different sections of the same region, in adjacent countries and farms. It varies from season to season (54, 34).

Climate: The term climate includes many factors, such as, precipitation, temperature, barometric pressure, humidity, wind velocity and hours of sunshine.

The greater importance of climate than variety or soil on determining protein content was emphasized by well-known Tri-Local experiments conducted by LeClerc and Leavitt (36). Soil was transferred from state to state in such a way that in each state, there was soil from each of the two other states along side the local soil. Soil was dug up in 3" layers and then put down in original order. This was also done with each local soil so that all would have the same effect of physical handling. Wheat from the same variety was grown in all three states. In this way, factors of soil and variety were eliminated and climate was the main variable. Kansas was in each of three sets of experiments conducted over a series of years. Part of the results are presented in Table 1. It is apparent from these figures that protein content was influenced both by climate and soil. It was the highest in Kansas and lowest in Maryland due to climate. While rainfall figures were not available, it might be assumed that rainfall was probably the greatest climatic factor influencing protein content. Within each state the soil caused a variation of 1.1 in Maryland, 2.2 in Kansas and 3.5 in California.

From these experiments, it was concluded that wheat of any one variety from any one source and absolutely alike in physical and chemical characteristics, when grown in different localities having different climatic conditions, yields crops of very widely different appearance and very different in chemical composition (37). From latter studies made by LeClerc and Yoder (37), they concluded that the environment rather than heredity was the major factor influencing the protein content of wheat. The soils studied exerted little influence compared to climate.

Harris, et al, (26) studied 56 long-patent flours of Hard Red Spring wheat grown in North Dakota and found that very significant variations

Table 1. Protein Content of Wheat Grown on Uniform Soil in Three States (1909-1912)

	Grown in Calif. on soil from			Grown in Kansas on soil from			Grown in Maryland on soil from		
	Calif.	Ks.	Md.	Calif.	Ks.	Md.	Calif.	Ks.	Md.
Protein %	13.2	11.3	14.8	17.5	19.3	19.7	11.8	12.5	12.9
Variation in each state due to soil		(3.5)			(2.2)			(1.1)	

in flour protein content, absorption, loaf volume and mixing properties existed between varieties and environment, with environment exerting the major influence. Significant differences in loaf volume were also shown at uniform protein level, indicating difference in protein quality, due to both varietal and station influences. Mixograms secured at uniform protein level showed significant variations between varieties and environment for dough development stages, range of dough stability, curve height and width.

Sandstedt and Fortmann (44), showed that large differences in test weight, protein content, absorption, loaf volume and mixing properties existed in Nebraska Hard Red Winter wheats grown in different locations. In some instances, these differences were larger than those due to variety.

Thatcher (55), pointed out that three factors of climate, of importance as related to wheat quality were 1) rainfall, 2) length of growing season and 3) temperature during growing season. It was assumed that wheat quality is primarily affected by protein content.

Length of growing season: Climate exerts important influence upon composition of crop by lengthening or shortening the growing period, particularly that portion during which kernel is developing. Thatcher (55), was of the opinion that it is not the length of total growing period but only that portion of it during which kernels are formed which influences the final composition of grain, particularly the protein-carbohydrate ratio. Similar observations were made by Shutt and Hamilton (49), supporting Thatcher's view. The effect of temperature during the maturing period was studied by Finney and Fryer (30). They found that subnormal loaf volumes were consistently associated with high temperatures (above 90°F.) during the last 15 days before harvest. In the absence of high temperatures during the last two weeks before harvest, other environmental factors such as rainfall and the chemical and physical composition of the soil appear to have relatively minor effects on protein quality. Protein content accounted for about 95 percent of the variations in loaf volume if temperature during the fruiting period was not a limiting factor.

Thatcher ((55), concluded from experimental evidence that high temperatures during ripening may produce high protein and that the percentage of nitrogen in kernel varies inversely with the length of this period. High temperature and absence of excessive moisture during the latter stage of kernel development shorten this period, hasten ripening, resulting in a high protein wheat. On the other hand, cool and wet weather in the latter part of the season prolong the development period, retard ripening and result in a starchy grain (49).

Thatcher's (55) conclusion that length of ripening period determines carbohydrate-protein ratio is based on the following explanation. Proteins of wheat are largely elaborated early in the plant growth and particularly cease to increase in amount after plant blooms, while manufacture of starch continues as long as any part of plant remains green, therefore, lengthening the period after blooming, by any climatic condition increases the elaboration of starch, resulting in starchy grain, low in protein.

Analysis of samples of wheat at different stages of maturity by several investigators (10, 13, 15, 16, 28), showed a higher protein content in immature kernels which decreased as maturity progressed. Changes in physical and baking characteristics of wheat protein, in relation to the development of wheat kernel during maturation, were studied by Scott et al. (46) in Kansas from 1948-1954, using hard winter wheat varieties. Protein quality, as measured by baking and physical dough properties, strongly indicated that the wheat plant is physiologically ripe with optimum quality characteristics about one or two weeks before it is suitable for combining.

According to Swanson (53), a climate having dry winters, cool springs with moderate rainfall and hot, fairly dry summers usually produces a hard, strong wheat characterized by a high protein content. A winter climate relatively warm, with a high rainfall in spring and summer, produces a soft wheat with relatively high starch content.

The temperature prevailing at the time of ripening with moisture supply at that time apparently are two of the most important factors which affect both yield of grain and quality of protein. In England, and to a large extent in northwestern Europe, the ripening takes place when the general air temperatures are decreasing. There also is an ample amount of rainfall at this time. The wheat in these areas is prevailingly soft with low protein and large yield. In western Canada, the ripening takes place when the temperature has passed its peak, but the climate conditions as a whole are much drier than in England and western Europe. In the southern plains area of the United States, the wheat usually ripens before the peak of the heat period. The fact that hard wheats are produced both in western Canada and in the plains area of the United States indicate that the moisture supply is a predominant factor (53).

Shutt and Hamilton (49) presented data from wheat grown in two western and two maritime Canadian provinces. The comparison extending from 1912-1932, showed western stations to have a July and August temperature of 8°F. above the maritime, but with a precipitation of approximately one-half that of the maritime provinces. With these differences, the western wheat had an average protein content of 17.4 percent versus 13.3 percent for the maritime province wheats.

From a study by Waldron et al. (57) of high prevailing temperatures for the 10-day pre-heading period with spring wheats, it was shown that only high maximum temperatures were associated with high protein content of the mature wheat. High-day temperatures from 10 days before heading until about the middle of July were found to be conducive to high protein while night temperatures did not modify the amount of protein. Also, the temperatures during the last two weeks of maturity had a very minor influence upon the protein content of the resulting crop.

In areas with hot summers and scanty rainfall, protein content tends to be high in wheat. Alsberg's (3) explanation for this is that it may be due in part to the fact that hot weather favors nitrification and accumulation of an abundant supply of nitrates in the earlier growth stages. Hot weather, by evaporation at the surface of the soil, tends to draw soluble soil constituents to the surface by capilarity. Also, high-air temperatures increase transpiration and thus may favor absorption of nutrients from the soil (3).

Rainfall: Rainfall is the most important factor that determines soil moisture content and supply of available plant food. That the amount of moisture in the soil has an influence on the protein content has been observed frequently.

Rainfall during the growing season is important, but benefits with respect to growth and maturity depend on how and when it is received. Distribution of rainfall during the growing period is important. Limited rainfall in a semi-arid region may produce a high protein content crop if it comes at a time when the plant can use it.

Moderate precipitation during major growth periods at frequent intervals usually results in a lower protein percentage than the same amount of precipitation in a few heavy rains. This may be due to the fact that the moderate rains provide more moisture for plant growth and that some of the nitrates may be leached out of the upper layers of the soil by heavy rains. Light rainfall and heavy evaporation which concentrate the nitrates in the upper portion of the soil, where they may be readily obtained by the plant, seem to favor the formation of hard glutinous wheat (37, 56). Under these conditions, yield of wheat is reduced but high protein content results.

Soule and Vanatter (51) found that the protein content was highest when rainfall was less than normal during the ripening period. Less rainfall resulted in a short, quick ripening period which retarded the elaboration and translocation of carbohydrates from stem to the grain and therefore produced a higher percentage of protein content.

Hopkins (27) found a slightly negative correlation between the amount of rainfall during the growing season and the nitrogen content of wheat. Early rainfall stimulates tillering and vegetative development generally. The production of carbohydrates was simultaneously increased by high rainfall, resulting in a relatively lower protein content in mature wheat. An inverse relationship between protein content and precipitation during the growing season also was reported by Eva and Birchard (12).

Soil: Soil is the medium through which the climate affects the plant since this is its home during growth and ripening. Type of soil is of primary importance from the point of view that soils vary in their capacity to retain water and they therefore can be said to govern the availability of rainfall for crop growth. Weather conditions at the time of formation and ripening are more important in their effect on quality than at other periods. At the time of head and seed formation, the physiological activities are at the maximum; particularly, in the transfer of material from soil, leaves and stem to the forming seeds. Water is the chief transporting medium and about 300 pounds must pass from the soil up through the plant for every pound of dry material constructed. Hence, the supply of moisture in the soil must be ample and the movement in the soil to the roots must be sufficiently rapid to supply needs. Rate of movement of moisture is affected mostly by soil texture; water moves more rapidly in light than in heavy soils. Because of different water movement, wheat grown on the different textured soils varies in quality because of the variation in amount of moisture which comes to the roots.

With continuous use of soil, fertility may be depleted, particularly in nitrogen and organic matter. The loss of organic matter lessens the water-holding capacity of soil and a decrease in nitrogen means lower protein content of the crop (43, 54).

It is not only the amount of moisture which is the determining factor of protein in wheat, but moisture in conjunction with nitrate supply, length of growing period and general temperature level, particularly at the time of head formation. An abundance of moisture, together with other favorable growth factors, results in large yields. Yields with high or low protein content are determined mostly by the amount of available nitrates at the time of head formation. If nitrates are abundant, together with other favorable growth factors, then a fairly high protein wheat with a large yield will be the result (54).

Continuous growing of a crop exhausts the soil of nitrogen content and organic matter, hence it is necessary to use fertilizers to replenish the depleted stock of essential elements. Nitrogen is absorbed from soil in the form of nitrates. The amount of nitrates is one of the most potent factors in influencing both yield and protein content. Thus, the amount of nitrate in soil at the time when most needed is the principal factor in determining the total amount of protein in wheat crops. Concentration of soil solution in available nitrogen and the amount of this solution are the two most important factors which determine yield and protein percentage. The climate owes its importance to the fact that it influences the soil solution. Swanson (54) stated that the greatest demand for nitrates from the soil is at the time of kernel formation. Davidson and Leclerc (11) studied the effect of nitrates on yield and protein content. Sodium nitrate was applied at three different stages of growth: 1) when the crop was two inches high, 2) at the time of heading and 3) in the milk stage. Results show that sodium nitrate, added during early stages of growth, stimulated vegetative growth and consequently produced a greater yield. Addition at the time of heading gave better quality grain protein, but the yield was not affected. Addition at milk stage neither affected yield not protein content. Striking increases in crude protein content (4.4%) by single spraying with urea at the time of flowering, and a number of sprayings throughout the fruiting period were reported by Finney et al. (21). The increase in protein content declined as the wheat kernel developed; the quality also deteriorated with increased concentration and number of sprayings. Subnormal loaf volumes, indicating a large increase in the water-soluble proteins, were associated with an incomplete glutenprotein synthesis.

One of the most complete experiments on the effects of available nitrogen in the soil on the protein content of wheat was reported by Neidig and Snyder (41). They found that cumulative additions of sodium nitrate throughout the growing period gave a greater yield as well as increased protein content over that obtained when the addition of nitrate was made at the time of planting. When there was a sufficient amount of nitrogen in the soil to insure a maximum plant growth during the early period, high yield was obtained.

Assuming that the growth factors in connection with soil and climate are favorable, the effects of moisture and nitrates may be summarized as follows:

1. When neither moisture nor nitrates are the limiting factors, both yield and protein percentage will be high.

2. When moisture is the limiting factor, but not the nitrates, the yield will be low, but the protein content higher than under 1.

3. When the supply of nitrates is the limiting factor but not the moisture, especially during kernel formation, the yield will be high but the protein content low.

4. When moisture and nitrates are both limiting factors, both the yield and the protein content will be low.

Snyder (50) showed that by proper application of fertilizer, the quality of wheat could be improved and thus increase the protein content by at least one percent. Protein content of wheat was the highest when nitrogen fertilizer was used and the lowest when phosphate fertilizer was used.

Fernandez and Laird (15) reported the influence of available soil moisture and nitrogen fertilization on percentage protein and yield.

Application of smaller amounts of nitrogen/acre under wetter soil moisture regimes, reduced the protein percentage, whereas larger applications of nitrogen fertilizer produced a larger yield as well as increases in protein content in all moisture treatments. The lower protein content of grain from wheat fertilized with small quantities of fertilizer probably was due to a greatly increased vegetative growth and a relatively small increase in the amount of nitrogen available for grain.

Fajerson (14) made a very extensive survey on the effect of nitrogen fertilization on wheat quality for five years (1949-1953) in Sweden. He reported that late application of nitrogen resulted in higher protein content than early application. Nitrogen fertilization at the time of heading had the most favorable effect on the protein content. Increasing fertilization had a more favorable effect on the glutin content than flour and grain protein content, and the water absorption and loaf volume increase were greater when fertilized with nitrogen in split application than with the application in one heavy dosage.

Supplying water by irrigation has an advantage that the supply can be controlled as to time and amount. Different quantities of irrigation water were supplied by Widstoe (58), to various plots. The protein percentage and yield varied inversely, indicating that the nitrate supply was the limiting factor in building protein. When the amount of water was too great so as to decrease yield, there also was an increase in percentage protein. As a rule, the practice of dry farming causes wheat to have a higher protein content than wheat which is irrigated. Irrigation increases the yield compared to dry farming and decreases the amount of nitrogen or protein content. The low protein content of wheat grown on irrigated land often is due to the fact that these soils are low in organic matter, containing little available nitrogen. Leclerc (37) stated that the protein content of wheat grown on arid land was higher than that grown on irrigated land. The protein content was 17.7 percent in dry land and 11.1 percent in irrigated land.

Shutt and Hamilton (49) studied wheat from irrigated and non-irrigated areas extending from 1916 to 1931. Considering averages, irrigated wheat was four percent lower in protein, had a higher test weight and a growing period 12 days longer than dry land wheat.

Variety: Schnelle (45), in research relating to quality of wheat as dependent on variety and environment, was able to determine that the relative difference between varieties remains constant even though grown under different environmental conditions. According to Gericke (23), varieties differ in: specific soil nutrient requirements, absorbing capacity for the soil nutrients at various growth stages of the crop, and the index of segregation of the total production of varieties into that of different parts; i.e., grain, leaves and straw roots. These three factors probably account for differences in yield and composition of different varieties of wheat.

Climate is generally regarded as more important than variety in determining protein content. While this is true, there also may be a correlation between wheat variety and quality. It may be possible to develop varieties that will give relatively high protein content wheats in regions where the wheat commonly grown is soft and weak (35). The superiority of one variety, as compared to another, is principally in adaptation to a certain environment so as to produce high yields of good quality wheat.

Kansas has long been a leading bread-wheat production state. Varieties of wheat not only affect the quantity of wheat produced in Kansas, but also affect the quality. The varieties of wheat respond differently to the milling and bread-making processes. The number and extent of varieties grown and their response to the growth environment are the chief contributing factors governing the quality of Kansas wheat as a whole (32).

The quality of Kansas wheat, besides being dependent upon the varieties grown and their response to environment, also was affected by the extent of varietal distribution. The acreage distribution of varieties changes from one year to the next, depending upon the availability of new and improved varieties (33).

One of the projects of the Kansas Agricultural Experiment Station is to grow all standard wheat varieties each year at various experiment stations and experiment fields in the state, and to compare these with the new crosses that are being studied. Thus, it is possible to evaluate accurately the response of the different wheat varieties to growing conditions at each station.

Shellenberger et al. (47) studied the importance of variety upon the Kansas wheat quality. From the three (1950, 1951, 1952) quality comparisons of Kiowa and Ponca (two newest varieties) with Turkey and Comanche, it was evident that the new varieties tended to have higher protein content and lower mineral content than the older varieties. Kiowa and Ponca, when grown beside Comanche, Turkey or any of the other older varieties, represent improvement both agronomically and in ability to produce satisfactory bread.

Variety plays an important role in influencing the bread-making characteristics; i.e., absorption, mixing and loaf volume. As the protein content increases, so does the absorption. However, some varieties consistently have greater absorption capacity than others when compared at comparable protein levels. Varieties have inherent properties that produce different mixing curves. Some varieties mix to the point of minimum mobility (peak of curve) in a relatively short time, while others require a longer mixing period. Loaf volume also is affected by variety. Some varieties consistently give greater loaf volume than others for any given protein content (35, 40).

Johnson et al. (32) studied the effect of environment and varieties on Kansas wheat quality from 1958 to 1962. The results were subjected to analysis of variance. They concluded that wheat variety had a significant effect on the quality of Kansas wheat. It was evident also that variety of wheat caused a significant effect on the protein content of the flour, and variety of wheat had a greater effect on the dough-mixing time than environment. Although environment played a dominant role, variety effect on both loaf volume and quality score was highly significant. They stated that the response of different varieties to locations of growth, as measured by quality, might be expected to be altered some, depending upon conditions prevailing during maturation. However, the response of all varieties to the condition of growth was generally very similar.

The varieties of wheat grown in Kansas are changing constantly because of changes in relative popularity of the established varieties. These changes are a sign of progress in wheat development work which has resulted in making better wheat varieties available to the growers in the state.

The changes in the composition of the wheat kernel during maturation have been studied recently (42, 46, 49). Previous study of the relationship of protein content of mature wheat to the immature plant has shown that the protein content of mature wheat can be estimated from the nitrogen content of the immature plant, but that the correlation is too low for accurate and practical prediction (29). Therefore, this research was conducted to determine which parts of the immature plant would be most highly correlated with the protein content of mature grain. Since the protein content is highly correlated with the baking characteristics, an attempt also was made to correlate nitrogen content of the head and stem of the plant with the baking characteristics. Several groups of workers have established that there is a direct relationship between protein content and loaf volume and other quality factors. Varieties and/or detrimental climatological conditions, however, may drastically alter this relationship (33).

MATERIALS AND METHODS

Four Hard Red Winter varieties - Bison, Kaw, Ottawa and Triumph - were grown at eleven locations in Kansas. The stations included Belleville, Colby, Hays, Hutchinson, Manhattan, Parsons, Powhattan, St. John, Tribune and Garden City. The latter stations provided fallow and irrigated plots.

The plan of sample procurement was the same at each location. Samples were collected in triplicate at two stages of maturity.

Wheat plants were cut approximately three inches above the ground of a three-foot section of a single row from each of the triplicate plots. The time of cutting was when one half of the heads had reached the 50 per cent bloom stage; i.e., one month before harvest. Air- or oven-dried samples were separated into stem and head manually and finely ground on a 1 mm. sieve on a Wiley mill before chemical analysis for nitrogen was performed.

Mature heads were cut in triplicate from a three-foot section of a row adjacent to the immature plant cut previously and shipped to Manhattan. Wheat grains were threshed, cleaned for dockage and milled in a Hobart grinder to a fine grind, for nitrogen analysis.

Nitrogen content of each sample was determined in duplicate by the Kjeldahl method. The nitrogen content was converted to percentage protein by the factor of 5.7 (1) and expressed on a 14 percent moisture basis. Moisture content was determined according to the A.A.C.C. Air Oven method (1).

Certified wheat seed of the four varieties described above and eleven other varieties were planted at the experimental fields in approximately 1/16-acre plots in triplicate at each of the eleven locations. When the grain was ripe, it was harvested, threshed, composited and shipped to Manhattan for quality evaluations.

The wheat samples were received in 6-pound lots, cleaned for dockage, blended and scoured. Two thousand grams of each sample were tempered for 24 hours to a 17 percent moisture level. Milling was performed on the Buhler pneumatic experimental flour mill (1).

All samples of wheat and flour were analyzed for moisture, ash and protein following the A.A.C.C. methods of analysis (1). Farinograms were made with the 50-gram bowl, using a constant flour weight on a 14 percent moisture basis (1).

All samples of flour were baked into bread, using the straight-dough procedure (1). Flours were weighed on a 14 percent moisture basis. The absorption of each sample was adjusted to bring all doughs out of the mixer with the same consistency. This was predetermined with the Farinograph (1). Optimum amount of mixing for each sample was determined by sight and feel of the dough. The farinogram provided preliminary indication of the optimum mixing time. The doughs for baking pup loaves were mixed in the National dough mixer with a 100-gram capacity mixer bowl.

The straight-dough formula was as follows:

Ingredient	Percent
Flour (14% moisture basis)	100.00
Sugar	6.00
Nonfat dry milk	3.00
Shortening	3.00
Malt (barley)	0.12
Potassium bromate	0.002
Yeast	2.00
Water (variable)	

Each dough was given 180 minutes primary fermentation at 85°F. The first punch occurred after 100 minutes, with the second punch 50 minutes later. The National hand molder was used. After 20 minutes rest, the molding was completed on a Thompson laboratory molder. The loaf was panned in a 2 1/8" x 4 7/8" x 2 1/2" pup pan and proofed at 86°F. for 55 minutes. The loaf was baked in an electric revolving hearth oven for 25 minutes at 425°F. Loaf volume and weight were recorded immediately when the bread was removed from the oven, and subjective quality scores were recorded the day after baking. The loaves were scored for external appearance, grain, texture and crumb color.

RESULTS AND DISCUSSION

Protein Content of Vegetative and Mature Grain

The protein content of the stem, head and mature wheat kernel for four wheat varieties grown at 11 locations in Kansas is presented in Table 2. It is apparent from these data that the mature kernel had a higher protein content than either the stem or the head of the green plant. Similar results are reported in a previous study of similar type (29). The present data represent the protein content of the stem and head at a particular stage of maturity; i.e., one month before harvest. The fact must be recognized that the protein content would be expected to be different at some other stage of maturity.

The head portion of the plant shows higher protein than the stem, for all varieties at all locations except for two varieties at Minnoela. The location mean difference between head and stem ranges from 1.12 percent for Bison to 1.76 percent for Triumph. Variation in protein content due to environmental influence was greater in the stem than in the head portion of the plant. This probably is due to differences in the time of maturity in relation to time of sampling or cutting. The head portion shows a maximum variation of 1.46 percent for Bison and 1.97 percent for Kaw-61, due to environment, whereas the variation due to variety amounts to only 0.38 per cent (Table 2). In other words, the effect of environment was approximately four to five times greater than the effect of inherited characteristics.

It is not uncommon to find that the protein content of the mature wheat grain of one variety may vary from 9 percent in eastern Kansas to more than 16 percent when grown in the semi-arid region of western Kansas (31). In the mature stage, the protein content of Kaw-61 ranged from 10.53 percent when grown in Hutchinson to 16.1 percent at Minnoela (Table 2).

Table 2. Protein content of stem, head and mature wheat kernels of different wheat varieties grown at several locations.

Location	Bison			Triumph			Kaw-61			Ottawa		
	Stem %	Head %	Mature %	Stem %	Head %	Mature %	Stem %	Head %	Mature %	Stem %	Head %	Mature %
Belleville	8.0	10.0	14.0	6.3	9.9	12.7	6.2	10.1	14.1	7.1	10.6	13.1
Colby	8.8	9.6	12.5	9.2	10.2	12.9	8.8	9.4	12.6	8.7	9.7	13.4
Garden City (Fallow)	8.7	8.8	14.8	7.7	9.2	14.3	9.1	8.6	14.5	8.8	9.1	13.2
Garden City (Irrigated)	8.9	8.9	14.9	8.0	9.1	15.5	8.0	8.6	14.4	8.8	8.9	14.0
Hays	8.8	8.8	16.0	8.9	9.3	15.1	8.9	8.6	14.2	9.0	9.3	14.7
Hutchinson	4.4	8.6	10.3	5.1	8.9	11.1	4.0	8.2	10.5	4.4	8.9	9.9
Manhattan	7.1	9.0	13.7	7.6	9.1	14.3	8.5	10.0	12.0	8.0	9.7	13.2
Minneola	10.7	9.8	16.4	8.7	9.4	17.4	10.2	9.7	16.1	10.0	10.0	16.0
Parsons	8.5	9.5	13.6	7.4	9.5	13.9	7.2	9.7	13.1	7.9	10.3	13.0
Powhattan	7.3	10.1	12.7	8.1	9.4	12.6	7.8	9.6	12.3	7.8	9.5	12.8
St. John	9.3	9.4	15.0	8.7	10.4	14.7	8.6	9.1	12.2	9.4	9.7	13.4
Mean	8.2	9.3	14.1	7.6	9.4	14.2	7.8	9.2	13.4	8.1	9.6	13.4
Standard Deviation	1.68	0.55	1.76	1.19	0.46	1.74	1.74	0.67	1.60	1.55	0.57	1.55

The average protein content of mature grains at 11 locations for 1968 was 13.8 percent which was comparable to 13.4 percent for 1967 (29). On the whole, the protein content for all varieties, at all locations, was fairly high, but it is not unusual to find a wide variation due to environment. For example, mature Triumph showed a protein content of 17.4 percent at Minnoela as compared to 11.13 percent at Hutchinson. The varietal range in mature wheat protein was 1.4 percent for Bison grown at Belleville, whereas the location range was 6.1 percent (Table 2). These values show that the range in protein content both at the immature stage and in the ripe kernels is much greater between locations than between the varieties. These findings agree well with data of previous workers (32, 47), and confirm the effect of the environment on wheat protein content.

The relationship of stem protein, flour protein and other baking characteristics to mature wheat protein was analyzed statistically. The correlation coefficients between variables are summarized in Table 3. Highly significant correlations existed between stem, flour protein and mature wheat protein for all varieties. However, correlations for Kaw-61 are somewhat less significant than for the other varieties. In other words, mature wheat protein can be predicted from the stem of Bison and Ottawa with an accuracy of 89 percent, whereas for Triumph an accuracy of only 64 percent, and with an accuracy of 45 percent for Kaw-61. Probably differences in the date of maturity of different varieties account for the variation in the magnitude of correlation between stem protein and mature wheat protein. Kaw and Triumph are early maturing varieties compared to Bison and Ottawa. Hence, at this stage of sampling, the stem protein from Kaw-61 and Triumph probably had already migrated to the head portion, in comparison to Bison and Ottawa. The early translocation of nitrogen from stem to head for Triumph and Kaw-61 varieties

Table 3. Correlation coefficients between mature wheat protein, stem protein, flour protein content and certain baking characteristics (DF = 9).

	Bison	Triumph	Kaw-61	Ottawa
Stem	0.9442**	0.7976**	0.6703*	0.9306**
Flour	0.9064**	0.8260**	0.7214*	0.9054**
Bakery mix time	-0.2988	0.1204	-0.0404	0.1287
Total quality score	0.0671	0.2075	0.2977	0.1995
Loaf volume	0.1803	0.1170	0.3612	-0.0214

** = Significant 1% level
* = Significant 5% level

Table 4. Summary of correlation coefficients between stem, head, mature wheat protein content and other quality (DF = 38) characteristics.

	Immature Stem	Immature Head	Mature Wheat protein	Flour protein	Bakery mixing time	Total score	Loaf volume
Stem protein	1.0000						
Head protein	0.2457	1.0000					
Wheat protein	0.7869**	0.1331	1.0000				
Flour protein	0.7918**	0.1338	0.9677**	1.0000			
Bakery mixing time	-0.0236	0.1353	-0.0642	-0.0301	1.0000		
Total score	0.2232	0.0512	0.3968*	0.3386*	-0.3600*	1.0000	
Loaf volume	0.2118	-0.1057	0.3390*	0.3121*	-0.3114*	0.7623**	1.0000

* = Significant 5% level
** = Significant 1% level

was reflected in the correlation of lower magnitude between stem and mature wheat protein.

Flour protein was highly correlated with the mature wheat protein for all varieties. Flour protein content could be predicted from wheat protein content within an accuracy of 80 to 50 percent.

When varieties were taken into account, the correlation coefficient between mature wheat protein and mixing time, the total score and loaf volume were non-significant.

The relationship between wheat protein content and other variables without reference to varieties is shown by simple correlation coefficients in Table 4. Wheat stem protein content was not significantly correlated with the head protein content but was significantly related to the mature wheat and flour protein. While neither wheat nor flour protein could be predicted with great accuracy from the stem protein, the over-all correlation coefficient suggests that the prediction of wheat protein could be expected to be accurate 65 percent of the time.

Regardless of variety, wheat and flour protein showed significant positive correlations with loaf volume and score, though of a low magnitude. The correlation between loaf volume and flour protein was lower than might have been expected, based on close relationship of these two quality factors based on previous studies. Variation in the degree of correlation between loaf volume and protein content can be caused by several factors. In general, if the quality of protein remains constant, a high degree of correlation can be expected, but any deviation in quality of protein will reduce the correlation of protein content and loaf volume. Also, if there is any deficiency in the formulations or procedure, the potential loaf volume for any given flour may not be realized. Correlations of wheat and flour protein with loaf volume and bread score are highly significant, but not of a sufficient magnitude so that one characteristic may be safely predicted from the other. Dough-mixing time was significantly though negatively correlated with loaf volume and total score.

The baking characteristics of four wheat varieties grown at eleven locations are summarized in Table 5. The protein content of the wheat crop as a whole was fairly high in 1968, averaging 12.38 percent. At most of the locations, the flour protein was approximately 11-13 percent, but at Minneola it was as high as 15 percent and at Hutchinson as low as 9.1 percent. No consistent pattern is observed in the dough-mixing requirement as related to flour protein content. These results are contrary to the generally accepted view, that high protein flours tend to require longer mixing time than the low protein flours. In the instance of these data, the environmental effect may have influenced the dough-mixing properties different than the effects of environment on protein content. As for varieties, Kaw-61 had the longest dough mixing requirement, followed by Bison, Ottawa and Triumph. Both variety and location exerted an important influence on the mixing requirement. The effect of environment was five times greater than the effect of varietal properties.

The baking value of wheat for bread production is a summation of many factors including loaf volume, break and shred, symmetry, grain and texture. These factors have been weighted and are summarized in a total quality score. Of all measurements used to determine quality of bread, only loaf volume is objective. The baking data (Table 5) indicate a large variation in loaf volume as well as in the total quality score. The effect of environment was approximately two and one-half times greater than the effect of varietal properties on quality score, but loaf volume was equally affected

Table 5. Baking characteristics of four wheat varieties grown at eleven locations.

Location	Bison				Triumph				Kaw-61				Ottawa			
	Flour protein	Bakery mix time	Bake quality score	Spec. loaf volume	Flour protein	Bakery mix time	Bake quality score	Spec. loaf volume	Flour protein	Bakery mix time	Bake quality score	Spec. loaf volume	Flour protein	Bakery mix time	Bake quality score	Spec. loaf volume
	%	Min.	100	cc/g	%	Min.	100	cc/g	%	Min.	100	cc/g	%	Min.	100	cc/g
Belleville	12.6	3.00	81.0	4.49	11.4	3.00	76.0	4.28	12.5	4.50	75.0	4.11	11.4	2.75	76.0	4.37
Colby	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Garden City (fallow)	13.2	2.25	78.0	4.75	12.4	2.00	86.0	4.70	12.5	2.75	79.0	4.51	12.8	1.75	81.0	4.40
Garden City (irrigated)	12.6	2.25	87.0	5.36	13.8	1.50	84.0	4.97	12.9	2.50	81.0	5.02	12.3	2.00	83.0	4.95
Hays	14.6	2.50	82.0	4.72	14.0	2.00	66.0	4.19	13.4	5.75	62.0	4.02	13.1	2.50	75.0	4.67
Hutchinson	10.1	3.00	76.0	4.36	9.80	1.75	67.0	4.04	9.10	3.50	66.0	3.89	9.40	2.00	72.0	4.43
Manhattan	12.4	3.75	86.0	4.70	12.3	3.00	83.0	4.67	10.4	4.50	62.0	3.65	11.7	2.50	88.0	4.90
Minneola	15.3	2.75	80.0	4.50	15.5	3.00	77.0	4.31	14.7	3.25	84.0	4.78	14.7	2.50	78.0	4.50
Parsons	12.6	3.50	77.0	5.37	12.5	2.25	75.0	4.80	11.8	3.75	78.0	4.55	12.1	3.00	78.0	5.08
Powhattan	11.5	3.00	80.0	4.58	11.2	1.75	70.0	3.92	10.9	3.25	74.0	4.02	11.1	2.50	84.0	4.64
St. John	13.3	3.25	72.0	4.18	13.4	2.75	80.0	4.20	11.8	3.00	72.0	4.20	12.2	2.50	71.0	4.00
Mean	12.8	2.92	79.9	4.70	12.6	2.30	76.4	4.41	12.0	3.68	73.1	4.28	12.1	2.40	78.6	4.60
Std. Dev.	1.46	0.50	4.51	0.39	1.63	0.59	7.04	0.35	1.59	.99	7.82	0.43	1.38	0.38	5.42	.33
1967 Average	13.00	3.4	74.6	5.8	13.3	2.70	74.9	5.70	12.30	4.20	69.0	5.3	12.6	3.20	76.5	5.8

by both environment and variety.

The Effect of Environment and Variety on Baking Characteristics

More extensive data relating the baking characteristics of more wheat varieties grown at a large number of locations were available. These data were much more extensive than the data representing four varieties in the study of the relationship of vegetative growth to mature wheat protein content. The wheat and flour analysis and the baking data representing the effect of variety and location on quality are presented in Tables 6 and 7. Mean values and least significant differences for the several quality characteristics also are shown. The analysis of variance for flour protein, water absorption, farinograph mixing time, dough stability, valorimeter value, baking mixing time, specific loaf volume and total quality score are presented in Table 9. Correlation relationships are summarized in Table 9. Tables 10 to 16 show the relationship of flour protein content to baking variables in terms of regression and correlation coefficients.

The protein content of the wheat as a whole was fairly high for 1968. At the majority of the stations, protein content was approximately 11-12 percent, but at a few, the protein content was as high as 13-15 percent. Since wheat protein content is so highly correlated with flour protein, the discussion might as well be based on the latter. Flour protein content is one of the most important quality factors affecting bread-making properties. From the analysis of variance (Table 8), it is evident that variety of wheat caused a significant effect on the protein content of the flour. However, a much more important factor affecting the protein content was the environment or location. The range in protein content of the flour by variety was

Table 6. Variety means of baking value of wheats grown at 16 locations in 1968.

Variety	Flour protein content	Water absorption	Dough mixing time Farinograph	Dough stability	Valorimeter	Dough mixing time	Specific loaf volume	Total quality score
	%	%	Min.	Min.	B.U.	Min.	cc	(100)
Bison	12.96	63.42	6.59	9.28	67.50	2.86	4.68	79.25
Triumph-64	12.82	63.00	4.44	5.85	56.13	2.20	4.40	76.25
Parker	12.69	62.98	4.50	6.97	58.63	2.98	4.31	73.69
Triumph	12.63	62.40	4.25	4.84	54.38	2.25	4.33	75.25
Concho x_2 Triumph[2]	12.46	62.72	3.94	4.84	53.50	2.03	4.23	72.81
Gage	12.34	62.79	4.84	6.25	58.75	2.80	4.42	76.63
Ottawa	12.30	65.70	4.28	6.97	57.25	2.41	4.59	78.88
Kaw-61	12.08	61.24	5.56	10.22	63.75	3.52	4.26	72.94
Scout-66	12.06	62.55	4.67	7.63	59.25	2.62	4.50	77.88
Shawnee	12.05	63.70	6.66	11.09	67.50	3.38	4.58	77.94
Guide	11.98	60.62	6.03	9.25	64.75	3.34	4.32	73.75
Scout	11.98	62.26	4.72	7.09	59.13	2.78	4.42	77.75
Least Significant Difference for 5% level	0.351	0.714	1.029	1.814	3.316	0.290	0.153	2.723
Least Significant Difference for 1% level	0.463	0.938	1.364	2.394	4.399	0.385	0.203	3.593

Table 7. Location means of baking value of wheats grown at 16 locations in 1968.

Variety	Flour protein content	Water absorption	Dough mixing time Farinograph	Dough stability	Valorimeter	Dough mixing time	Specific loaf volume	Total quality score
	%	%	Min.	Min.	B.U.	Min.	cc	(100)
Tribune (dryland)	15.22	66.20	9.31	13.00	74.83	3.13	4.72	76.50
Minneola	15.02	66.75	6.88	8.33	67.33	2.96	4.51	78.08
Hays	13.36	64.23	6.00	7.92	64.33	3.15	4.39	70.75
Garden City (irrigated)	12.76	63.97	4.54	4.42	56.83	2.19	4.95	82.25
St. John (dryland)	12.56	64.93	5.71	8.92	64.17	2.92	4.22	74.83
Mankato	12.42	63.64	5.50	9.04	64.17	2.85	4.53	78.33
Garden City (dryland)	12.40	63.78	4.96	4.88	57.67	2.21	4.59	80.58
Tribune (irrigated)	12.34	64.00	3.50	3.88	49.67	1.81	4.05	71.91
Parsons	12.20	61.10	5.79	10.04	65.33	3.25	4.88	76.83
Hutchinson	12.10	61.10	2.08	4.96	47.50	2.50	4.09	67.83
Newton	12.17	61.24	4.79	7.67	60.00	2.88	4.47	73.58
Manhattan	11.83	59.43	4.63	10.46	60.50	3.29	4.46	80.08
Belleville	11.82	62.26	5.42	10.17	64.33	3.15	4.19	77.0
Ottawa	11.68	58.36	4.54	6.88	57.83	3.00	4.53	80.92
Colby (irrigated)	11.25	62.65	3.25	5.00	49.67	2.31	3.94	73.42
Powhattan	11.22	60.85	3.75	4.83	53.83	2.65	4.21	74.42
Mean	12.36	62.78	5.04	7.52	59.88	2.76	4.42	76.08
Standard deviation	1.45	2.74	2.29	4.06	9.43	0.75	0.37	5.77
LSD for 5%	0.404	0.819	1.189	2.095	3.830	0.290	0.174	3.142
LSD for 1%	0.533	1.082	1.574	2.765	5.081	0.385	0.231	4.147

Table 8. Analysis of variance for 1968 wheat flour baking quality data.

Source of variance	Degree of freedom	Flour Protein Content		Water absorption		Dough mix time (Farinograph)		dough stability	
		Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq	F.
Variety	11	1.94	7.66**	25.30	24.37**	14.01	6.36**	66.45	9.80**
Location	15	22.44	88.71**	65.30	62.91**	32.47	14.74**	86.10	12.69**
V X L	165	0.25	_	1.038	-	2.203	-	6.79	-

Source of variance	Degree of freedom	Valorimeter		Dough mix time (baking)		Specific loaf volume		Total quality score	
		Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F
Variety	11	326.09	14.24**	3.78	20.62**	0.32	6.77**	87.33	5.72**
Location	15	642.02	28.03**	2.33	12.70**	1.012	21.10**	191.88	12.56**
V X L	165	22.09	-	0.18	-	0.05	-	15.27	-

** Significant at 1% level

Table 9. Correlation coefficients between variance of the baking characteristics of the 1968 crop. (DF = 190)

	Flour protein	Water absorption	Farinograph mix time	Dough stability	Valorimeter value	Bread quality score	Specific loaf volume
Flour protein	1.0000						
Water absorption	0.6428**	1.0000					
Farinograph mix time	0.6117**	0.3384**	1.0000				
Dough stability	0.2745**	0.0120	0.5908**	1.0000			
Valorimeter value	0.5697**	0.2537**	0.9094**	0.7596**	1.0000		
Bread quality	0.2836**	0.1328	0.2978**	0.1406*	0.3180**	1.0000	
Specific loaf volume	0.4253**	0.2091**	0.4583**	0.2328**	0.4780**	0.7002**	1.0000
Bakery mixing time	0.8020**	-0.2027**	0.4960**	0.6702**	0.6357**	0.0507	0.1726*

** = Significance at 1% level
* = Significance at 5% level

Table 10. Relationship of protein content to certain baking variables (DF = 190) expressed by regression and simple correlation statistics.

Variable	Contribution to r^2	F	Intercept	Regression Coefficient	Standard deviation	t
	r^2		Y	B	of B	
Absorption	0.413	133**	47.8	1.22	0.11	11.6**
Farinograph mixing time	0.374	133**	7.0	0.97	0.09	10.7**
Dough stability	0.075	15**	2.0	0.77	0.19	3.9**
Valorimeter value	0.325	91**	13.9	3.72	0.39	9.6**
Bread quality score	0.080	16**	62.1	1.13	0.28	4.1**
Specific volume	0.181	41**	36.1	0.11	0.02	6.5**
Bakery mixing time	0.006	1	2.2	0.04	0.04	1.1

** = Singificant at 1% level

Table 11. Relationship of absorption to certain baking variables expressed by regression and simple correlation statistics.

Variable	Contribution to r^2	F	Intercept	Regression coefficient	Standard deviation	t
	r^2		Y	B	of B	
Farinograph mix time	0.115	24**	-12.8	0.28	0.06	5.0**
Dough stability	0.001	0.3	6.4	0.02	0.11	0.7
Valorimeter value	0.064	13**	4.9	0.87	0.24	3.6**
Bread quality score	0.018	3	58.5	0.28	0.15	1.8
Specific loaf volume	0.044	9**	2.6	0.03	0.01	2.9**
Bakery mixing time	0.041	8**	6.2	-0.06	0.0	-2.8**

** = Significant at 1% level

Table 12. Relationship of Farinograph mixing time to certain baking variables expressed by regression and simple correlation statistics (DF - 190)

Variable	Contribution to r^2	F	Intercept	Regression coefficient	Standard deviation	t
	r^2		Y	B	of B	
Dough stability	0.349	102**	2.3	1.05	0.10	10.1**
Valorimeter value	0.827	909**	41.0	3.74	0.12	30.2**
Bread quality score	0.089	18**	72.3	0.75	0.17	4.3**
Specific loaf volume	0.210	50**	4.0	0.07	0.01	7.1**
Bakery dough mixing time	0.246	62**	2.0	0.16	0.02	7.9**

** = Singificant at 1% level

Table 13. Relationship of dough stability to certain baking variables expressed by regression and simple correlation statistics.

Variable	Contribution to r^2	F	Intercept	Regression coefficient	Standard deviation	t
	r^2		Y	B	of B	
Valorimeter	0.577	259**	46.6	1.77	0.11	16.1**
Quality bread score	0.020	4*	74.6	0.20	0.10	2.06*
Specific loaf volume	0.054	11**	4.3	0.02	0.01	3.3**
Bakery mixing time	0.449	155**	1.8	0.12	0.01	12.4**

** = Significant at 1% level
* = Significant at 5% level

Table 14. Relationship of Valorimeter values to certain baking variables expressed by regression and simple correlation statistics.

Variable	Contribution to r^2	F	Intercept	Regression coefficient	Standard deviation	t
	r^2		Y	B	of B	
Bread quality score	0.101	21**	64.4	0.19	0.04	4.6**
Specific loaf volume	0.228	56**	3.3	0.02	0.00	7.5**
Bakery mixing time	0.404	129**	-0.2	0.05	0.00	11.4**

** = Significant at 1% level

Table 15. Relationship of bread score to certain baking variables expressed by regression and simple correlation statistics (DF = 190).

Variable	Contribution to r^2	F	Intercept	Regression coefficient	Standard deviation	t
	r^2		Y	B	of B	
Specific loaf volume	0.490	183**	1.0	0.044	0.00	13.52**
Bakery mixing time	0.003	0.5	2.3	0.01	0.01	0.70

** = Significant at 1% level

Table 16. Relationship of loaf volume to other dependent baking variables (DF = 190).

Variable	Contribution to r^2	F	Intercept Y	Regression Coefficient	Standard deviation	t
	r^2		Y	B	of B	
Bakery mixing time	0.030	6.00*	1.2	0.35	0.14	2.42*

* = Significant at 5% level

approximately one percent (Table 5), while the range due to location was four times as high (Table 6). Correlations of flour protein with water absorption, Farinograph mixing requirement, valorimeter value and baking mixing time were of higher magnitude than other baking characteristics. Strong flours generally carry high absorptions, require longer mixing time and have a higher index of strength.

The water absorption was fairly high and tended to vary directly with the protein content. The wheat crop at Manhattan and Ottawa showed slightly lower absorptions than expected from the flour protein content. Analysis of variance suggests that both the variety and location had significant effects on absorption, with the location exerting greater influence. The varieties arranged in order of decreasing absorption are as follows: Ottawa, Shawnee, Bison, Triumph 64, Parker, Gage, Concho x Triumph[2], Scout 66, Triumph, Scout, Kaw-61 and Guide. Correlations of flour protein with absorption was of fairly high magnitude (0.64) but not as high as would be expected based on previous work (6, 17, 32).

Mixing characteristics of flour for the 1968 crop are shown in Tables 6 and 7. In general, the strong location effects are evident in the mixing time required to reach a peak with the Farinograph. However, varietal effects also were highly significant. In contrast, variety exerted greater influence on actual bakery mixing time than the location. Among the varieties with the longest mixing time requirements and greater mixing stability are: Kaw, Shawnee and Guide. The varieties Parker, Bison, Gage, Scout and Scout 66 exhibited greater uniformity in baking-mixing time though not in dough stability. Triumph 64, Triumph, Ottawa and Concho x Triumph exhibited great uniformity in baking-mixing time requirement and also in mixing stability, as measured by the Farinograph. Generally, high protein flours tended to require longer mixing time. Flour protein of Bison and Triumph is not significantly different, but both differ in dough mixing requirement which may be attributed to inherited varietal characteristics. Locations including Parsons, Hutchinson, Manhattan, Belleville, Ottawa, Colby and Powhattan show approximately the same protein level, but the baking-mixing requirement ranges from 2.5 to 3.3 minutes. This variation may be attributed to the effect of environment on protein quality. Correlations of flour protein with dough mixing requirements were the highest, followed by correlations with valorimeter value and dough stability. In other words, the baking-mixing requirement could be predicted with greater accuracy from flour protein than any other value from the Farinograph.

The baking data indicate a large variation in loaf volume as well as in the total quality score (Tables 6 and 7). Analysis of variance (Table 8) suggests that most of the variation in loaf volume and quality can be attributed to location, although variety effect also is highly significant. The close relation of loaf volume and protein content has been established (8, 18, 32, 33, 39). Finney et al. (18, 19) have shown that these two factors were essentially linear between limits of protein content encountered; i.e., eight to 18 percent. Wheat from Garden City (irr.) and Parsons produced larger loaves than would be expected, based on the protein content. The correlation coefficient between flour protein content and loaf volume for the 1968 crop (Table 9) was 0.42 which is closer to the 0.53 reported for the 1961-62 crop. Very high correlations were reported for Kansas Hard Winter Wheats by Johnson et al. (31). Bison produced the largest and the best loaves, followed by Ottawa, Shawnee, Scout-66, Scout, Gage, Triumph-64, Triumph, Guide, Parker, Kaw-61 and Concho x Triumph^2. Among the stations, Garden City (irr.), Parsons and Tribune (dryland) produced the largest and the best loaves. Colby, Tribune (irr.) and Hutchinson produced the smallest loaves. Correlations between loaf volume, bread score and flour protein, water absorption, Farinograph mixing time, dough stability and valorimeter value were highly significant but of low magnitude.

The effects of irrigation on protein content and wheat quality were inconsistent at different stations. For example, at Tribune, irrigation decreased the protein content, Farinograph mixing requirement and dough stability considerably. It also produced smaller loaves with lower quality score. Irrigation at Garden City did not reduce the protein content but slightly reduced the loaf volume. Other quality characteristics were not affected.

These data cannot be used to indicate the effects of irrigation on wheat quality because the time and amount of irrigation water will influence the final grain quality. Also, the quality will be influenced by soil factors such as fertility and texture. To determine the influence of irrigation on wheat quality, carefully controlled experiments will be required.

As shown in Table 10, protein content is significantly correlated with all dough properties except bakery mixing time. Some variables are more highly correlated than others. Since flour protein content is significantly related to the other dough properties, it would be expected that these dough properties would be related to each other. That they are significantly related to each other is attested to by statistical treatment summarized in Tables 11 through 16. It will be noted in Table 11 that dough stability and bread quality score are not significantly related to absorption.

Also listed in Tables 11 through 16 are the statistics related to the regression between any two variables. These statistics may be used to construct the graphic relation if deemed necessary. Also included are the standard deviation and test values. The latter indicated the significance of regression coefficient.

SUMMARY AND CONCLUSIONS

The importance of environment upon the protein content of wheat has been recognized for years. The effect of environment on protein content and baking quality of wheat has been studied extensively by many. The relationship of protein content of the green plant (one month before harvest) to mature wheat also has been studied, but previous evidence of the relationship was inconclusive. In the present study, head and stem of the green plant were analyzed for protein content to determine if the correlation existed between the head and stem protein content of the green plant with the mature wheat protein content and also with baking quality characteristics. Four Hard Red Winter wheat varieties from 11 locations were selected at two stages of maturity; i.e., early head and mature stage. The nitrogen content was determined in the stem, the head and the mature wheat kernel. These data were used to calculate the correlation coefficient between the protein content of other quality baking measurements. The flour was tested also for physical dough properties and bread baking quality to observe the influence of environment and variety on wheat quality. The following conclusions can be made:

1. There was a highly significant correlation between the protein of the stem and the mature wheat for all varieties, but this correlation was not sufficiently high for the purpose of an accurate and practical prediction. Correlation between the head and mature wheat protein was non-significant.

2. In both the immature plant and the mature grain, the protein content was affected by the environment.

3. The influence of variety on the protein content at either the green or the mature stage was relatively not as high as the environment.

4. When varieties were taken into account, the correlation coefficients between mature wheat protein and mixing time, loaf volume and total score were non-significant.

5. Regardless of variety, wheat and flour protein showed overall significant correlations with loaf volume and total score though of a low magnitude.

6. Both variety and environment caused a highly significant effect on baking characteristics. However, the environment exerted greater influence than variety.

7. Correlations of flour protein with water absorption, Farinograph mixing requirement, valorimeter value and bakery mixing time were of fairly high magnitude compared to other dough properties.

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VITA

The writer was born in Kericho, in Kenya, where she had her elementary and high school education. In 1957 she went to India for her higher studies and had her Master of Science in Foods and Nutrition from Maharaja Sayajirao University, Baroda, India in 1963. She taught in the same department from 1963 to 1966 before returning to Kenya. She taught in Kenya for a year before she came to seek her Master's Degree in Food Science in the Department of Grain Science and Industry at Kansas State University, Manhattan, Kansas.

EARLY PREDICTION OF PROTEIN IN WHEAT CROP

by

KUSUM M. PATEL

M.Sc., M. S. University
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Approved by:

John A. Johnson
Major Professor

ABSTRACT

Early Prediction of Protein in Wheat Crop

The importance of environment upon the protein content of wheat has been recognized for years. The effect of environment on protein content and baking quality of wheat has been studied extensively. The relationship of protein content of the green plant (one month before harvest) to mature wheat has also been studied but previous evidence of the relationship was inconclusive. In the present study, four Hard Red Winter Wheat varieties grown at eleven locations in Kansas were selected at two stages of maturity i.e. early head and mature stage. After the green plants were dried, they were separated into stem and head. The wheat was harvested when mature. Kjeldahl method was used to determine nitrogen content of all parts. These data were used to calculate correlation coefficients between the protein content of stem, head and mature grain and other quality characteristics. In addition to these data, flour from twelve wheat varieties grown at sixteen locations were tested for physical dough properties and bread baking quality to observe the influence of environment and variety on wheat quality. A highly significant correlation between the protein of stem and mature wheat for all varieties was evident, but it was not sufficiently high for the purpose of accurate and practical prediction. Correlation between head and mature wheat protein was non-significant. Both, the environment and variety had significant influence on protein content at either stage of maturity. The same effect was observed on the baking characteristics. The effect of environment was predominant in every case. Correlations of flour protein with water absorption. Farinograph mixing requirement, valorimeter value, and

bakery mixing time were of fairly high magnitude compared to other dough properties. Correlations between wheat and flour protein and loaf volume and total score were significant though of a low magnitude.