CHANGES IN RHEOLOGICAL AND CHEMICAL PROPERTIES OF A CANADIAN WESTERN HARD RED SPRING WHEAT CULTIVAR NEEPAWA DURING STORAGE

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Basil Al-Farisi

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ABSTRACT

Al-Farisi, Basil A. Aziz, M.Sc., The University of Manitoba, October, 1982. Changes in the Rheological and Chemical Properties of a Canadian Western Hard Red Spring Wheat Cultivar Neepawa During Storage. Major Professor; B.L. Dronzek.

The rheological and chemical properties of stored Canadian western hard red spring wheat (Neepawa) from the 1979 and 1980 crops (freshly harvested) at 12, 16 and 18% moisture contents, stored at different temperatures (30, 40 and 50° C) for various periods (10, 20 and 30 days) were investigated. In order to control the storage conditions of the wheat samples, sealed containers were used to control the moisture level while a controlled environment cabinet and an air oven were used to control the temperatures.

The samples at high moisture levels stored at high temperatures for long periods of time developed fungal infestations, which resulted in changes in the organoleptic properties such as color and odor. Storage at three temperatures, as well as storage times, had little effect on the percentage of recovered flour, bran and shorts for the wheat stored at the three moisture levels. The proximate compositions of stored wheat flour samples were directly related to the storage conditions. Ash content, starch damage and free amino acid composition showed marked changes compared to the control, especially in the samples at high moisture levels and high temperatures stored for a long period of time. On the other hand, protein content and amino acid composition were unaffected by the storage conditions. The storage conditions

adversely affected the rheological behavior of stored wheat dough as measured by the farinograph, extensigraph and amylograph; the effects were pronounced when the storage conditions such as temperature, moisture and storage period increased. The samples stored at high moisture levels and high temperatures for long periods of time showed a marked decrease in sedimentation value, percent of wet gluten, as well as a significant decrease in loaf volume.

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I. INTRODUCTION

Man has been storing grain and its products since the Stone Age period. Over the years, man has learned by trial and error that grain can be stored for long periods of time without damage or deterioration.

Grain storage conditions are very important in order to avoid deterioration of the grain and its products. Parpia (1976) reported that the Food and Agriculture Organization estimated that 5% of all food grain harvested are lost prior to consumption. Post-harvest losses of up to 50% of the total production have been observed quite often in countries like India, where inadequate storage facilities have existed.

Storage aims to preserve grain with minimal loss in weight and quality of grain. Losses in quantity and quality of stored grain are caused principally by fungi, insects and rodents. In this study, attention will be focused on the physical and chemical changes which occur during post-harvest storage and the effect of these changes on the quality on the stored grain crop.

Studies on the changes which occurred during storage have, in many cases, produced somewhat conflicting results. McCalla et al. (1939) in tests at room temperature and Cuendet et al. (1954) in tests at slightly higher temperatures have reported flour deterioration occurring within 3 months or less of storage. On the other hand, Saunders et al. (1921) reported minor deterioration in quality of flour which had been stored for up to 14 years. Greer et al. (1954) reported that canned flour was still in a good condition after 27 years of storage at 10 to 20° C.

All grain and milled products undergo a variety of changes throughout post-harvest storage regardless of how they are stored. These changes can be beneficial when storage conditions are favourable. However, some deterioration in quality can occur under adverse storage conditions (Bushuk and Lee 1978).

This thesis was initiated to study the effect of different storage conditions on the Canadian Western hard red spring wheat cultivar, Neepawa (*Triticum aestivum s. sp. vulgare*) for two different crop years. The wheat was stored at three moisture levels, 12, 16 and 18%, at three different temperatures, 30, 40 and 50° C and for various periods of time (10, 20 and 30 days). The objectives of this thesis were to examine the changes in rheological and chemical properties of the stored wheat as affected by different storage conditions.

II. LITERATURE REVIEW

A. Physical Properties of the Stored Grain

1. Moisture

Air which moves from a high temperature region to a low temperature region gives up moisture to maintain its relative humidity. In extreme cases, the air which comes into contact with a cold surface may be cooled below the dew-point. The result is water condensing onto the wall of the storage bin or on the surface of the grain. This water causes the relative humidity in the region to rise and hence increases the risk of grain deterioration. In addition, when grain which contains a high moisture level is exposed to the air, the moisture moves from the grain to the air until there is an equilibrium between the grain moisture and the atmosphere (Hall 1970, Burrell 1974, Bushuk and Lee 1978).

Moisture is the key to safe storage of grain and their products. Grain at low moisture content in equilibrium with 70% relative humidity can be stored for a long period of time with little deterioration (Hunt and Pixton 1974). When the moisture content exceeds this critical level, storage fungi begin to grow. This results in an increased rate of respiration in the stored grain which may cause excessive heating. Sinha and Wallace (1965) termed this excessive heating damp grain heating. Hall (1970) and Hunt and Pixton (1974) reported that different types of grain in storage had a specific critical moisture level which influenced the growth of the storage fungi which in turn influenced the chemical deterioration of the

grain. The safe moisture content for storage is grain in equilibrium with 70% relative humidity. Above 75% relative humidity fungi develop rapidly, cause heating of stored grain, followed by subsequent deterioration of the grain and loss in quality.

Smith (1969) cited that 40% of the total volume between the stored grain was air space. The grain was also characterized by a low thermal conductivity with an ability to exchange moisture with the air within the grains and with the air around the grain.

Absorbed water, due to the moisture levels and relative humidity of the storage grain, may be held loosely in the grain by capillary forces and could play an important role in storage. Another type of water is adsorbed water which is held firmly by molecular attraction and is not as important in stored grain (Smith 1969, Trisvyatskii 1969, Hunt and Pixton 1974).

2. Temperature

Grain is an excellent insulator. Therefore, grain temperature changes very slowly. Smith (1969) and Burrell (1974) reported that the thermal insulation characteristics of the grain were five to 10 times better than a similar bulk of concrete. If cold grain is stored in bins in winter, the grain remains cold throughout most of the summer and its temperature will rise only a few degrees. Due to the low thermal conductivity of grain, the temperature effects on the outside of the grain mass in storage are slowly transmitted to the centre. On the other hand, the temperature of the grain at the centre of the bulk may rise due to the presence of insect, microorganism and dockage.

During the various stages of insect life cycles, insects require and consume food and oxygen producing carbon dioxide, water and heat. The

heat produced by the insect cause a localized increase in temperature which is called "hot spot". This can also lead to migration of moisture to the cooler upper grain surface resulting in a condensation near the cool surface. This in turn promotes grain sprouting and mold growth.

3. Flow Property

In addition to the factors which cause "hot spot" during storage, there is in grain a flow property factor. This property depends on the natural segregation of the grain during the movement and handling, which in turn depends on the gravity, the specific weight and the heterogeneity of the grain. The flow property factor can create undesirable storage conditions such as spontaneous heating and caking.

Trisvyatskii (1969) explained this phenomenon and reported that when grain is loaded into an elevator, the sound and heavy grains having a high specific weight, falls vertically and rapidly towards the bottom of the bin. On the other hand, the small, shrivelled grain, insects and spores having a low specific weight fall slower and are thrown by air currents against the bin walls.

As a result of natural segregation, therefore, sectors of grain are formed in the bin which differ from each other to some extent in composition. Shrivelled grains, dust, micro-organisms and insects accumulate mainly along the bin walls where the moisture level and temperature are normally above the mean of the whole batch. This condition facilitates micro-organism and insect growth (Bushuk and Lee 1978).

Trisvyatskii (1969) reported that when grains of different specific weights are discharged from a bin by gravity, the grains with a high specific weight moved out from the central part of the bin first. This grain is replaced by grain with a lower specific weight, micro-organisms

and insects which were previously found along the bin walls.

4. Respiration

During storage, grain respires and produces moisture (water) and carbon dioxide. Hummel et al. (1954) and Trisvyatskii (1969) observed that there are two kinds of respirations: aerobic and anaerobic. In aerobic respiration the sugars (hexoses) are completely oxidized to form carbon dioxide, water and energy. This respiration predominates in normal grain storage where there is an excess of air. Aerobic respiration is shown by the following formula:

$$C_6 H_{12} O_6 + 6O_2 \longrightarrow 6 CO_2 + 6 H_2O + \text{energy}$$

In anaerobic respiration, grain is stored under unfavourable conditions and a lack of oxygen. During respiration, the sugars are decomposed to form the oxidized organic product, such as ethyl alcohol, as shown by the following formula:

$$C_6 H_{12} O_6 \longrightarrow 2 CO_2 + 2C_2H_5OH + \text{energy}$$

Trisvyatskii (1969) reported that most of the energy produced during respiration is liberated. This energy produces heat which is released into the surrounding space. The heat, formed by the stored grain, may as a result of poor thermal conductivity be retained. Consequently, this heat may be one of the causes of spontaneous heating (a hot spot) in stored grain.

B. Rheological Properties

It is generally accepted that the rheological properties of dough are very important for the baking performance of a product and its final quality. Charm (1962) defined rheology as the branch of physics dealing with forces and deformations, their relationship and interrelationships

with time. Proteins play a very important role in determining the rheological properties of the dough. About 85% of the proteins in wheat flour consist of the gluten components, gliadin and glutenin (Bushuk 1977). These fractions differ markedly in their physical properties. Gliadin is extensible and inelastic, whereas glutenin is elastic but relatively inextensible. The gluten of a good breadmaking flour contains gliadin and glutenin in approximately equal amounts. Gluten is the insoluble protein material remaining after the water solubles and starch are washed out of dough in a stream of water. Gluten content in flour is a measure of breadmaking potential (Bushuk 1977).

Flour strength refers to wheat protein or flour protein and encompasses both protein quality and quantity. On the basis of flour strength, wheats can be classified into two major types, namely hard (strong) and soft (weak) types of wheat (Pyler 1967). Hard wheat flours have relatively high protein content, high water absorption and forms an elastic gluten with good gas retaining properties. Soft wheat flours, on the other hand, have a lower protein content and yield a gluten which is less elastic. This type of flour is generally better suited for baked goods such as biscuits and cakes (Wheat Flour Institute 1971).

Protein quality criteria are related primarily to the gluten protein. Quality is appraised largely by subjecting the flour to several physical testing devices which measure various rheological properties. The tests are performed usually on flour water doughs and are widely employed in quality measurements. These tests characterize the gluten protein of the protein by measuring such factors as extensibility and resistance to extension of dough at rest, hydration time, maximum development time and tolerance or resistance to breakdown at a predetermined consistency during

mechanical mixing (Pratt Jr. 1971).

Larmour et al. (1961) stored flour and farina (coarse flour) for 5 years in a variety of packaging material and storage conditions. Dried flour (8% moisture content) showed a minimum change in farinograph properties during storage, while the normal flour (14.5% moisture content) showed marked changes in farinograph properties after 3 and 5 years of storage. On the other hand, the extensigraph indices for the dried sample stored in standard packs showed some evidence of an accelerated, apparently irregular, rate of change in dough properties. The increase in resistance to extension accompanying storage was slightly more rapid for the dried samples rather than for the normal moisture flour and farina.

Yonegama et al. (1970a, b) measured the SH content of freshly milled flour stored for 90 days at 30° C in air and in nitrogen. The flour stored in air showed a marked decrease in SH content, while the flour stored under nitrogen showed a much smaller decrease in SH content. This, in turn, seemed to directly affect the changes in rheological properties of the dough and hence the breadmaking quality.

Westermarck-Rosendahl and Ylimaki (1978) and Westermarck-Rosendahl (1978) stored for 5 and 7 days, winter and spring wheat, which was harvested at moisture contents between 18.6 and 38.0%. Under such storage conditions, spontaneous heating developed. The farinograph tests on these samples showed a very short dough development time for the winter wheat stored at 37.5% moisture content for 2 days. On the other hand, the spring wheat stored at 37.5% moisture content showed a marked decrease in development time following 2 days of storage. The extensigraph properties declined in the winter wheat following 3 days of storage while in the spring wheat the extensigraph properties declined following 1 day of storage.

Bell et al. (1979) found that there were no detectable changes in rheological or baking properties of flours milled from English ('Weak'), Canadian ('Strong') and mixed English and Canadian wheat ('Medium') held at -20° C for 66 months' storage with the exception that the free lipid acidity increased slightly. However, at ambient temperature, the deterioration in baking quality of the stored flours was highly dependent on the nature of the baking test used.

Shuey and Tipples (1980) cited that Lange (unpublished data) found a direct relationship between storage time at different temperatures and the loss in malt activity. After 11 weeks' storage at 22.7° C the loss in malt activity was estimated at 36%. Also, they reported that as the storage temperature increased, the rate of loss in malt activity increased, i.e. at 23.9° C storage temperature, a 2% per week loss in malt activity occurred; at 35° C a 11% loss per week and at 46° C a 25% loss per week in malt activity.

C. Chemical Changes During the Storage

1. Protein and Amino Acid Changes During Storage

Very few authors have studied the changes that occur in grain proteins during storage. At present, the information concerning these changes in grain protein during storage remains unclear.

Jones and Gersdorff (1941) studied the effect of storage under different conditions at various intervals over a 2 year period upon the protein of white flour, whole flour and wheat kernels. The results showed that three different types of changes occurred: (i) a decrease in the solubility of the proteins, (ii) a partial breakdown of the proteins indicated by a decrease in protein content and a decrease in the

amount of nitrogen precipitable by trichloroacetic acid and by an increase in amino nitrogen and (iii) a decrease in digestibility. The extent of these changes depended on the temperature, the type of container, the duration of storage and the moisture of the material stored.

Pixton et al. (1964), Pixton and Hill (1967), Pixton et al. (1975) and Pixton (1980) reported that wheat, when stored for 6, 8, 16 and 18 years in cooled bins at -15° C at moisture levels less than 14%, showed a slight decrease in the salt soluble proteins during the first 2 years of storage and remained constant thereafter. Crude protein, however, remained unchanged during the 6, 8, 16 and 18 years of storage. Similar results were reported by Fifield and Robertson (1959), Westermarck-Rosendahl (1978) and Westermarck-Rosendahl and Ylimaki (1978).

Daftary et al. (1970a, b) investigated the effect of temperature on the chemical composition of two hard red spring wheat flours stored at about 18% moisture content for 16 weeks at 23, 30 and 37° C. The study found a slight change in the protein content of the stored wheat samples with the mold-damaged sampled having a slightly higher protein content than the corresponding sound flours. The relative increase, on a percentage basis, could be explained by the respiratory losses of carbohydrates. However, the gluten from the damaged flours was difficult to wash out and had impaired rheological properties. In damaged flour, the yield of gluten was reduced and that of the starch fraction was increased with the starch fraction rich in protein. Starch-gel electrophoretic patterns of the gluten showed a decrease in glutenin and an increase in gliadin-like components; the water-soluble fraction contained an unusual component migrating to the anode and essentially no fast-moving component. Baking studies of reconstituted wheat doughs indicated damage to lipids, gluten

and water-soluble proteins; no damage to the starch was demonstrated

Shearer et al. (1975) reported that no changes had occurred in wheat flour gliadin and glutenin proteins extracted from flour stored at 25, 12 and -20° C for 18 months. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis showed minor changes in the molecular weight distribution of the gluten protein on storage.

Patey et al. (1977) found that prolonged storage of wheat for several years resulted in a progressive decline in the amount of acetic acid soluble protein, whereas the protein solubility remains unchanged. Westermarck-Rosendahl and Ylimaki (1978) and Westermarck-Rosendahl (1978) studied the effect of spontaneous heating on the protein properties of stored wheat at high moisture content. The reports found that the gluten content and the sedimentation value of wheat flours decreased when spontaneous heating occurred.

Devay (1952) reported that 18 free amino acids and an unknown ninhydrin-reacting substance were found in sound and moldy wheat. In addition, gamma-amino butyric acid was identified only in moldy wheat stored at relatively high moisture contents. Visual comparisons of chromatograms of sound and moldy wheat indicated changes in the concentrations of certain free amino acid. Alanine, gamma-amino butyric acid, proline, serine and lysine increased while histidine decreased in concentration in moldy wheat relative to the concentrations of the other amino acids in sound wheat.

Yoneyama et al. (1970a, b) found that the soluble SH content decreased markedly during the first 10 days of storage when the flour was stored at 30° C. For the flour stored at -30 and 0° C, soluble SH content decreased slowly but continually during 90 days of storage. These

results indicated that the oxidation of the soluble SH groups in air depends to a large extent on the storage temperature of the flour.

Ferrel et al. (1970) stored samples of highly fortified wheat (by adding lysine HCl) at 9, 11 and 13% moisture contents at 32.2 to 37.7° C. The study indicated that lysine HCl added to the wheat under reasonable conditions of storage is stable for at least 1 year.

2. Carbohydrate

Grain taken from an ancient Egyptian tomb, more than 3,000 years old, was reported to contain dextrins and considerable amounts of reducing sugars. This indicated that the amylase activity appeared to continue in the stored grain even after respiration could no longer take place (Geddes 1935, Pomeranz 1974).

Loney and Meredith (1974) showed that peak amylograph viscosity increase with aging time, both for active and inactive enzyme states. The data indicated that the aging effect is not attributable to a decline of amylase activity but involved changes in other components such as starch. Storage at -25° C held the pasting ability relatively constant

Pixton et al. (1964), Pixton and Hill (1967), Pixton et al. (1975) and Pixton (1980) recorded that the non-reducing sugar of a Manitoba hard wheat and a soft English variety declined very quickly in the period between 6 and 8 years of commercial storage. Wheat at 12% moisture content stored between 8 and 16 years in the same storage conditions showed no marked effect on the proportions of reducing and non-reducing sugars. Again during the storage period from 16 to 18 years the reducing and non-reducing sugars decreased for both types of wheat in all bins.

Glass et al. (1959) stored grain under aerobic and anaerobic (nitrogen) conditions at different moisture levels (13 to 18%). Samples were removed

at intervals of 2 to 4 weeks and tested for mold counts, viability and reducing and non-reducing sugars. An increase in reducing sugars at all moisture contents was observed. This change was more pronounced at the higher moisture contents and in particular with those samples stored in nitrogen. At 18% moisture content there was a 285% increase in reducing sugars in the nitrogen stored sample as compared to 120% in the air-stored sample. Non-reducing sugars decreased in all samples above 13% moisture. This change was somewhat greater at the higher moisture contents, although the samples stored in air showed a greater decrease in non-reducing sugars than those stored in nitrogen.

Lynch et al. (1962) carried out additional work on the changes that occurred in the wheat sugars during storage, in presence or absence of mold. Sound wheat was stored in atmospheres of air, nitrogen or carbon dioxide for 8 weeks at 30° C and 20% moisture content. By most of the criteria used, the samples stored under anaerobic conditions, and hence without mold growth, deteriorated almost as rapidly as did a sample stored in aerobic conditions. All stored samples had undergone extensive changes in sugar content and gave flour of extremely poor baking quality after 8 weeks. In air, the sucrose content of wheat decreased markedly, whereas minor changes occurred in glucose, fructose, galactose or maltose content. In carbon dioxide and nitrogen, the sucrose content decreased concomitant with a large increase in glucose, fructose and galactose.

3. Lipids

Sound grains contain fairly active antioxidants so the fats are effectively protected against the effects of oxygen during storage. Milled products in storage pose a serious problem, particularly whole grain milled products. Whole wheat flour can be kept for only a short

time because it readily becomes rancid, regardless of its moisture content and storage temperature (Zeleny 1954). When the moisture content and temperature are high, fats in grain are broken down by lipases into free fatty acid and glycerol during storage. Mold growth also increases this type of change because of the high lipolytic activity of the mold. Fat hydrolysis takes place much more rapidly than protein or carbohydrate hydrolysis in stored grains (Pomeranz 1974). Two types of reactions, oxidation and hydrolysis, can occur in grain lipids during storage. The reactions produce a variety of products which contribute to the development of a rancid taste and odor. Hydrolytic degradation of grain lipids during storage is catalyzed by exogenous (fungal) and to some extent, by exogenous lipases, resulting in the production of free fatty acids and glycerol (Pomeranz 1974, Bushuk and Lee 1978).

Zeleny and Coleman (1938), Hummel _et al_. (1954), Glass _et al_. (1959), Larmour _et al_. (1961), Yoneyama _et al_. (1970a) and Westermarck-Rosendahl and Ylimaki (1979) have reported that the acids produced by the lipases include free fatty acids, acid phosphates and amino acids. The levels of fat acidity increase most rapidly during the early stages of deterioration. The fatty acid content of grain has often been suggested as an indicator of grain deterioration.

Daftary and Pomeranz (1965) stored hard and soft winter wheat for about 6 months after harvest at 4° C. The original moisture of the wheat samples was 12.8 and 13.4%, respectively and each was moistened to 18 to 22%. The study found that titratable acidity was about 7% higher in benzene extracts than in petroleum ether extracts of wheat. Benzene extracts of moistened wheat contained more free fatty acids than did extracts of wheat redried to 11 to 12% moisture contents. Changes in

lipid composition during grain deterioration were followed by qualitative and quantitative thin-layer chromatography and fractionation on silicic acid columns. Deterioration of wheat was accompanied by the formation of at least four unidentified compounds that showed autofluorescence under ultraviolet light. Grain deterioration was accompanied by lowering of polar lipids and rapid disappearance of at least five ninhydrin positive polar lipids. The breakdown of polar lipids was more rapid and more intensive than the formation of free fatty acids or the disappearance of triglycerides.

Daftery et al. (1970a) analyzed flour at 18% moisture content from wheat stored for 16 weeks at 23, 30 and 37° C. The study found that the free lipids decreased more in samples stored at 23 than at 30 or 37° C; bound lipids decreased as the temperature of flour storage increased. Residual lipids in all storage damaged flours contained markedly reduced amounts of polar components and of lipoprotein. The breakdown of bound lipids apparently was accompanied by transformation of polar to non-polar-like components. The ratio of non-polar to polar components in residual bound lipids increased as the storage temperature of the flour increased.

Clayton and Morrison (1972) stored wheat with 13% moisture content at 15, 25 and 37° C and the lipids were then extracted with water-saturated n-butanol. The study found that the fatty acid composition of all lipids remained constant and there was no evidence of any lipoxygenase or other enzymic degradation of fatty acids. The changes found in the flour lipids differed from those reported to occur in germinating wheat and in stored damp wheat flour which had been damaged by molds.

D. Effect of Storage on Breadmaking Quality

Grain can undergo biological, physiological and physical changes

during storage. The extent of these changes depends on the composition of the grain and on external factors such as moisture content, temperature, oxygen and parasites. The decline in viability and quality can lead to significant economic losses when grain is stored under adverse conditions. On the other hand, decline is very slow when dry grain is stored under normal conditions. The breadmaking quality of freshly harvested wheat tends to improve for a time depending on the nature of product and conditions of storage. Fisher et al. (1937) reported that aging improved baking potential. However, long-term storage is generally accompanied by a gradual decline in breadmaking quality.

There are several reports on long-term storage under normal conditions for wheat and wheat flour. Greer et al. (1954) found no major change in breadmaking quality and organoleptic properties when flour was stored at 10 to 20° C in gas-tight cans for a period of up to 27 years. Fifield and Robertson (1959) stored hard red spring and hard red winter wheat in a dry, unheated room for up to 33 years. The study reported that about one-third of the samples had a slight decrease in protein content. In addition, flour milled from wheat stored for long periods of time showed an increase in fat acidity and as well as a higher ash content. These changes did not affect the breadmaking quality and loaf volume but affected the bread crumb grain and texture.

Larmour et al. (1961) conducted 5 years of practical experiments to determine the effect of various types of packaging on the keeping quality of wheat flour and farina stored outdoors with moisture levels below 15% and at 7 to 10° C. The study found changes in fat content, fat acidity, farinograms and loaf volume for both of flour and farina. The changes in farina were lower than those in flour.

Moisture content and temperature are the main factors determining the respiration rate and damage of stored grain and its products. Daftary and Pomeranz (1965), Daftary et al. (1970a) and Daftary et al. (1970b) investigated changes in lipids and breadmaking quality of wheat stored at increased moisture levels and high temperatures. These studies reported an increased mold count along with decreased total lipid content during storage. Bread baked from the damaged flour was lower in loaf volume and poorer in crumb grain than bread baked from the sounder flour. Baking results of fractionated and reconstituted doughs indicated that lipids from the sound flours restored the loaf volume potential of damaged flour. Bread crumb grain was nearly restored by the addition of lipids.

The presence of thiol groups in wheat flour generally indicated by SH was recognized by Sullivan et al. (1936) when a sulfur-containing compound was isolated from wheat germ and other milling products. The amino acid cysteine contains a rather reactive thiol group, which is readily oxidized to cystine. Pyler (1967) reported that the disulfide linkage plays an essential role in determining the visco-elastic properties of dough. The thiol groups become involved in dough development by a mechanism in which SH groups are united by the action of flour oxidant, such as bromate and iodate, to form disulfide bonds.

Most of the research suggested that the oxidation of the thiol group is responsible for this improver effect. Jorgensen (1936) found that oxidants such as bromate inhibit proteinases which attack gluten proteins, thus increasing the gas retaining capacity and the baking strength of the dough proteins.

Rao et al. (1978) reported that freshly harvested wheat contained a large amount of low molecular weight gliadins, which aggregated during

storage in air. This resulted in an improvement of the rheological and baking properties of stored grains. Thus, gluten content in wheat or, more precisely, the interchange reactions between thiol and disulfide during storage, determined the dough rheology. The same effects could be achieved by addition of an oxidizing agent such as bromate. Radiation treatment (up to 200 Krad) also improved the baking quality of newly harvested wheat by modifying some of its rheological properties. A significant correlation between SS/SH ratio and loaf volume was observed. Lower loaf volume in newly harvested wheat was associated with its low SS/SH ratio, high maximum gelatinization viscosity and low gas retention capacity.

III. MATERIALS

Two different wheat samples of the Canadian Western hard red spring wheat cultivar Neepawa (*Triticum aestivum s. sp. vulgare*) were used in this study. The first sample was grown in 1979 as "Registered Seed" and purchased from the "Remillard Seed Service, St. Joseph, Manitoba" at 13.5% moisture content. The second sample was grown in 1980 at Domain, Manitoba by Mr. Don Johnston, a registered seed grower. The second wheat sample was harvested on August 15, 1980 at a moisture content of 22.2%. The harvested wheat was then cleaned with a Carter Dockage Tester, using a #1 riddle and a 5/64" x 3/4" slot perforation.

IV. METHODS

A. Storage Methods

In this study, various methods were tried to control the temperature and moisture content of the wheat samples during the different storage periods. In order to control the moisture content, two methods were used. The first method involved the control of humidity with potassium hydroxide, while the second method involved the use of different kinds of containers. To control the temperature, a controlled environment cabinet and an oven were used.

The tests to determine the efficacy of these methods are described as follows.

1. Controlling the Moisture Content of the Stored Wheat Samples

i. Control of humidity with potassium hydroxide. Since the publication of well-known papers by Buxton (1931) and Buxton and Mellanby (1934), the control of atmospheric humidity in biological experiments by means of potassium hydroxide solution has been widely used. Solomon (1951) has updated the data on potassium hydroxide solutions useful for atmospheric humidity control.

In order to maintain a constant 16 and 18% moisture content in wheat samples stored in desiccators, the relative humidity of 77 and 83%, respectively must be maintained (Hunt and Pixton 1974). Potassium hydroxide in the amounts of 26 and 20 g per 100 g solution were used to achieve

77 and 83% relative humidity in the desiccators (International Critical Tables 1928).

Two wheat samples, each weighing 500 g at 16 and 18% moisture content, were placed in 1,000 cc plastic containers and stored in desiccators for 7 days at 50° C. Subsequently, the samples were checked for moisture content.

ii. Different types of containers. This method was used to determine the proper containers which would maintain a constant moisture content for 35 days.

Uncovered containers. Three wheat samples weighing 500, 1,000 and 1,500 g were placed into 1,000, 1,500 and 2,300 cc volume plastic containers, respectively. These weights of the wheat samples completely filled these containers. The wheat samples were tempered to 18% moisture content and then stored at 22° C at 64% relative humidity for 35 days.

Containers having two holes in the lid. The wheat samples were placed in the same storage conditions and in the same containers as in the previous experiment but with lids that had two holes each 2 cm in diameter.

Sealed containers. The same containers placed in the same storage conditions with sealed covers were used in this experiment.

2. Controlling the Temperature of the Stored Wheat Samples

i. Cabinet and oven. A cabinet which was made by Controlled Environment Ltd., Canada, MOD (EF7H) with inside dimensions of 1.05 X 0.60 X 1.05 m was used to control the storage temperature. The maximum temperature for the cabinet was 40° C. Therefore, the cabinet was used to control the temperature for the wheat samples stored at 30 and 40° C. For the wheat samples stored at 50° C a forced air oven was used. All

the samples were placed in the oven and the cabinet in sealed containers to control the moisture.

B. Preparation of Samples

1. Preparation of the 1980 Crop Samples

In the 1980 crop samples, freshly harvested wheat samples with a moisture content of 22.2% were spread out in thin layers on trays in the milling laboratory for several days to dry. The temperature of the laboratory was controlled at 22° C and 65% relative humidity. Continual checks for moisture content of the samples were made at regular intervals until the desired moisture content of 12, 16 and 18% were recorded.

2. Preparation of the 1979 Crop Samples

Wheat samples from the 1979 crop with a moisture content of 13.5% were tempered for 24 hours to obtain 16 and 18% moisture contents for the storage experiment. The following formula was used for tempering.

$$X = \frac{W(Z-Y)}{100-Z}$$

where W = Weight of grains in grams,

Z = Final moisture content,

Y = Initial moisture content,

X = Amount of water to be added (ml).

The samples at 12% moisture content were dried by spreading out in thin layers on trays in the milling laboratory for several days until the 12% moisture content was reached.

3. Preparation of the Control Samples for the 1979 and 1980 Crops

The control samples for the 1979 crop were taken before the wheat was tempered, while the three control samples from the 1980 crop were

taken as soon as the desired moisture levels (12, 16 and 18%) were reached. All the control samples were artificially dried by air to a 12% moisture content using a Wurster Air Suspension Equipment and then stored in a cold room at 4° C.

4. Treatment of the Wheat Samples Following the Storage Experiments

For the storage experiment, the experimental samples at different moisture contents were placed in containers and stored at different temperatures (30, 40 and 50° C) for 10, 20 and 30 days. Tables 1 and 2 identify the sample numbers and storage conditions for the 1979 and 1980 wheat crop. At the end of the storage period, the wheat samples were dried to a 12% moisture content using the Wurster Air Suspension Equipment. All the dired wheat samples were then stored in the cold room at 4° C until further analysis.

C. Milling Procedure

The wheat samples were tempered overnight to 15.5% moisture content and milled into flour using a Buhler experimental mill according to the approved method of the American Association of Cereal Chemists [Method 26-20, AACC (1969)].

The flour was rebolted through a 8xx (188 μ) Swiss silk bolting cloth for 2 minutes and then blended for 5 minutes.

D. Analytical Methods

Analytical methods were conducted in duplicate on the basic flour. The average percent error of the duplicate for the ash content, starch damage, Zeleny sedimentation test and wet gluten were 0.01, 0.17, 1.40 and 1.02%, respectively. These analyses were undertaken to obtain information on the effects of storage conditions on flour properties.

TABLE 1. The wheat storage condition and the identification of the samples for 1979 wheat crop.

	Moisture Content					
	12%		16%		18%	
Temperature	Sample no.	Days	Sample no.	Days	Sample no.	Days
30° C	1A	10	10A	10	19A	10
30° C	2A	20	11A	20	20A	20
30° C	3A	30	12A	30	21A	30
40° C	4A	10	13A	10	22A	10
40° C	5A	20	14A	20	23A	20
40° C	6A	30	15A	30	24A	30
50° C	7A	10	16A	10	25A	10
50° C	8A	20	17A	20	26A	20
50° C	9A	30	18A	30	27A	30

TABLE 2. The wheat storage condition and the identification of the samples for the freshly harvested 1980 wheat crop.

	Moisture Content					
	12%		16%		18%	
Temperature	Sample no.	Days	Sample no.	Days	Sample no.	Days
30° C	1	10	10	10	19	10
30° C	2	20	11	20	20	20
30° C	3	30	12	30	21	30
40° C	4	10	13	10	22	10
40° C	5	20	14	20	23	20
40° C	6	30	15	30	24	30
50° C	7	10	16	10	25	10
50° C	8	20	17	20	26	20
50° C	9	30	18	30	27	30

1. Wheat and Flour Moisture Contents Determination

i. Moisture content in wheat. The moisture content in the wheat was determined according to the approved method of the American Association of Cereal Chemists [Method 44-11, AACC (1969)]. Two hundred fifty grams of wheat were weighed out and the moisture content determined on a Moisture Meter Model 919.

ii. Moisture content in flour. The moisture content in flour samples was determined according to the approved method of the American Association of Cereal Chemists [Method 44-15A, AACC (1969)], using a Brabender Rapid Moisture Tester.

Ten grams of flour were placed in each moisture dish in the oven for 60 minutes at 130° C (± 1° C). The dishes were weighed immediately after 1 hour of heating and the moisture content of the flour determined.

2. Ash Content

The ash content was determined according to the approved method of the American Association of Cereal Chemists [Method 08-01, AACC (1969)].

Five grams of wheat were weighed in an ashing dish and then placed in a muffle furnace for 24 hours. The temperature of the furnace was maintained at 590° C. After 24 hours, the flour was converted into a gray ash. The ash was cooled in desiccator and weighed at room temperature.

3. The Gluten Washing Procedure

The gluten was determined by using the Theby gluten washer according to the approved method of the American Association of Cereal Chemists [Method 38-11, AACC (1969)].

Ten grams of flour was mixed with 6 ml of 0.3 M sodium chloride solution buffered to pH 6.8 with 0.003 M potassium phosphate and 0.004 M sodium phosphate to form a dough ball. The dough ball was placed on the nylon screen of the Theby washer. The washer was regulated with a constant drip of the buffered salt solution at a drip rate of two to three drops per second. The starch was washed from the gluten by the kneading action of the gluten washer pad. After 12 minutes, the gluten ball was removed and washed by hand with the buffer solution for 2 minutes. Excess water was removed from the gluten by hand manipulation until a tacky consistency was reached. Subsequently, the gluten was weighed and the percent wet gluten calculated.

4. Amino Acid Analysis

Amino acid compositions of the flour were determined by the Beckman Model 121 Automatic amino acid analysis. This method was carried out according to the standard procedure of Spackman *et al*. (1958) and Orth *et al*. (1974).

Thirty milligrams of the flour were placed in culture tubes and 4 ml of triple-distilled 6 N HCl containing one drop of caprylic acid as an anti-foaming agent was added. The culture tubes were flushed with nitrogen for 5 minutes. The hydrolysis was carried out under nitrogen for 24 hours at 110° C. After hydrolysis, the HCl was removed by drying the sample over solid sodium hydroxide in a desiccator. The dried sample was then suspended in 8 ml of sodium citrate buffer at pH 2.2 and centrifuged to remove the insoluble material.

5. Determination of Protein Content

The protein content of the flour samples was determined by the

standard macroKjeldahl procedure according to the approved method of the American Association of Cereal Chemists [Method 46-12, AACC (1969)], using 1 g of flour at 0% moisture content.

6. Zeleny Sedimentation Value

The Zeleny Sedimentation Value was determined by the approved method of the American Association of Cereal Chemists [Method 56-61A, AACC (1969)].

7. Starch Damage

Starch damage of the flour was determined according to the procedure of Farrand (1964), and was reported in arbitrary units (farrands) expressed as a percentage of the total starch.

E. Rheological Measurement

1. Farinograph

Farinograph curves were obtained according to the constant flour weight procedure [Method 54-21, AACC (1969)]. Fifty grams of flour (14% moisture basis) were used and water was added to produce a curve with maximum consistency centered on the 500 BU line.

2. Extensigraph

Extensigraph curves were obtained by a Brabender extensigraph according to [Method 54-10, AACC (1969)]. Doughs were made by mixing 100 g of flour (14% moisture basis), 25 ml of 2% sodium chloride solution and sufficient water to give an absorption of two percentage units less than the farinograph absorption. The dough was mixed for 2½ minutes in a

Grain Research Laboratory (GRL) mixer at a slow speed (69 rpm). Extensigrams were obtained after 45, 90 and 135 minutes rest periods; the latter rest period was used for the evaluation.

3. Amylograph

Starch pasting curves were obtained with a Brabender visco-amylograph according to [Method 22-10, AACC (1969)]. The curves were obtained using 65 g of flour dispersed in 460 ml of water at 30° C. The temperature was increased at a rate of 1.5° C per minute to 95° C.

F. Baking Procedure

The baking properties of the stored wheat flour were determined by the GRL Remix experimental baking procedure of Irvine and McMullan (1960).

One hundred grams of flour (14% moisture basis) were mixed with the ingredients: yeast (3%), salt (1%), sugar (2.5%), malt syrup (0.3%), ammonium phosphate (0.1%) and potassium bromate (0.0015%) for 3½ minutes in a GRL mixer (Hlynka and Anderson 1955) and folded seven times and left to ferment for 2 hours and 45 minutes at 30° C. The dough was remixed for 2½ minutes in GRL mixer, folded seven times and returned to the fermentation cabinet for 25 minutes. The dough was then passed through the sheeting rolls three times, molded for ½ minute and placed into the proofing cabinet for 55 minutes at 30° C. The pan dough was then taken from the proofing cabinet and baked in an oven at 221° C for 25 minutes.

The loaf volumes were measured by rapeseed displacement 25 minutes after the bread was removed from the oven.

IV. RESULTS AND DISCUSSION

A. Storage Conditions

1. Controlling the Moisture Content of Stored Wheat Samples

Two methods were used in this study to control the moisture content of the stored wheat samples.

i. Humidity control with potassium hydroxide. This method was used to control the moisture content of the stored wheat samples. The wheat samples, each weighing 500 g at 16 and 18% moisture content, were placed in 1,000 cc plastic containers and stored in desiccators for 7 days at 50° C. Subsequently, the samples were checked and no marked changes in moisture content were found in either of the samples.

This method was used in preliminary studies or where only few samples were required to be handled. Where a greater number of samples were necessary, this approach was not seen as practical since each sample required a separate desiccator.

ii. Different types of containers. In order to determine the proper type of containers which would maintain a constant moisture content of the wheat samples for 35 days, three types of containers of different sizes were used: 1) uncovered containers, 2) containers having two holes in the lid and 3) sealed containers. The wheat samples were tempered to 18% moisture content and then stored at 22° C at 64% relative humidity for 35 days. The moisture content was recorded weekly

for each sample. The uncovered containers and containers with two holes in the lid showed changes in moisture content during storage (Table 3). No changes in the moisture content were found in the sealed containers after 35 days. The wheat samples in these containers still had the initial moisture content of 18%.

The following observations were made from these preliminary experiments designed to maintain the desired 12, 16 and 18% moisture contents at 30, 40 and 50° C for 10, 20 and 30 days of storage. In general, controlling humidity with potassium hydroxide resulted in constant moisture content in the stored wheat sample, but was found to be impractical for a large number of samples. The uncovered containers and containers with two holes in the lid showed marked changes in moisture content depending on the size of container and the weight of stored samples. The sealed containers, on the other hand, were found to be precise and efficient in controlling moisture content of the samples and were therefore used in subsequent experiments.

B. The Effect of Different Storage Conditions on the Organoleptic Properties of Wheat Flours From the 1979 and 1980 Crops

1. Color of Stored Wheat

It is well known that wheats are classified into the red or white color types depending upon the color of the bran. These basic colors are varietal characteristics. However, the variations within each color classification are frequently due to environmental factors.

The wheat which was used in this study was the hard red spring variety, Neepawa. The wheat samples of the 1979 and the 1980 crops at 12% moisture content which were stored for 10, 20 and 30 days at 30,

Table 3 . The effect of container size and covering on the moisture content of wheat samples stored for 35 days at 22° C and 64% relative humidity.

Days	Moisture Content %								
	Uncovered Samples			Covered With Two Holes			Sealed		
	1000 cc	1500 cc	2300 cc	1000 cc	1500 cc	2300 cc	1000 cc	1500 cc	2300 cc
0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
7	17.7	17.6	17.5	17.4	17.9	17.9	18.2	18.0	18.0
14	17.0	17.1	17.0	17.0	17.3	17.9	18.2	18.1	18.1
21	16.6	16.7	16.8	15.6	17.0	17.3	18.1	18.1	18.1
28	16.1	16.1	16.3	15.4	16.6	17.0	18.0	18.1	18.1
35	15.7	15.9	15.9	15.2	16.5	17.0	18.0	18.0	18.1

40 and 50° C showed no changes in color when compared to the control samples. The samples stored at 16 and 18% moisture content developed a brown color, with the 18% moisture content samples having a darker brown color than the samples stored at 16% moisture content. The wheat samples at 18% moisture content stored for 30 days at 50° C developed the darkest brown color.

The changes in wheat color during storage were due primarily to the browning reaction of the Maillard type. Cole and Milner (1953) and McDonald and Milner (1954) found that this type of reaction occurred in fresh wheat germ and was promoted by storage at elevated moisture and temperatures. The Maillard reaction was first reported by Maillard (1912) who observed the formation of a brown pigment when a solution of glucose and glycine was heated. Eskin et al. (1971) maintained that the Maillard reaction appears to be the major cause of browning developed during heat or prolonged storage of food. Thus, the results obtained in our study are consistent with those reported previously.

2. Odor of Stored Wheat

The wheat samples stored at 12% moisture content for 30 days at 40 and 50° C produced a malt type of smell. No other samples stored at 12% moisture content gave off a malt type of smell. All the wheat samples stored at 16 and 18% moisture contents produced a malt type of smell. However, the samples which were stored at 16 and 18% moisture content for 20 and 30 days at 40 and 50° C, respectively, also produced a rancid type of smell. This was probably due to fungal growth.

Glass et al. (1959) noted that a pronounced malty "fermented" odor developed in wheat after 24 weeks which was stored under oxygen at 16 and 18% moisture contents at 30° C. This odor persisted in bread baked

from the derived flours of the stored samples. Hyde (1974) reported that grain stored under hermetic conditions at a moisture content above 16% developed a sour type of smell and a bitter taste during anaerobic fermentation. At high moisture levels and long periods of storage, of more than a few months, the sour type of smell could not be removed by aeration and persisted in bread produced from this grain. Our results are in agreement with these observations which indicate that the wheat samples stored at 16 and 18% moisture contents for 20 and 30 days at 40 and 50° C produced a malt and rancid type of smell.

3. Influence of Fungal Infestation on the Organoleptic of Storage Wheat

No fungal growth was observed in the wheat samples from the 1979 and 1980 crops which were stored at 12% moisture content for 10, 20 and 30 days at 30, 40 and 50° C. The wheat samples which were stored for 20 and 30 days at 40 and 50° C, respectively, at either 16 or 18% moisture content developed green and brown colored fungal colonies which produced a rancid type of smell. These fungi were identified to be a species of *Penicillum* and *Aspergillus* by the Plant Pathology Laboratory of the University of Manitoba. The spore production by the fungi appeared to be higher in samples stored for 30 days at 50° C than in samples stored under any other set of conditions.

Fungi are known to infect seeds once the grains are placed in storage (Wallace 1973). A particular succession of growth by different storage fungi follows depending upon the storage conditions (Wallace *et al*. 1976). Fungi such as *Alternaria*, *Gonetobotrys* and *Nigrospora* that infect field grains and are carried within seeds, gradually disappear and are replaced by *Aspergillus* and *Penicillium* spp. (Sinha 1979). Growth and dominance of *Penicillium*, *Aspergillus*, *Fusarium* and *Alternaria*

in the stored grains are found to vary with the storage conditions (Glass et al. 1959, Daftary et al. 1970b, Moubashar et al. 1972, Flannigan 1978). Our findings, therefore, are consistent with these observations. It appears that Penicillium and Aspergillus are first to appear on grain stored at a temperature of 40° C or above for 20 to 30 days at 16 or 18% moisture content.

C. The Effect of Different Storage Conditions on the Milling Yield of Wheat Flour from the 1979 and 1980 Crops

The flour yields obtained from the 1979 and 1980 stored wheat samples are presented in Tables 4, 5 and 6. The percentage of flour, bran and shorts from the 1979 crop stored at 12% moisture content were between 72.3 to 73.2, 20.1 to 21.4 and 5.9 to 6.7, respectively. These results showed no marked changes compared to the control values 72.0, 20.9 and 7.0% for the flour, bran and shorts yield, respectively. A similar trend in milling recovery was found for samples from the 1980 crop stored at 12% moisture content and for samples from both crops stored at 16% moisture content. These results indicated that storage at the three temperatures, as well as storage times, had little effect on the percentage of recovered flour, bran and shorts for the 12 and 16% moisture content wheat compared to the control values (Tables 4 and 5).

The percentage of recovered flour from the 1979 crop stored at 18% moisture content and at 30° C for 10, 20 and 30 days (Table 6) showed no marked differences from the samples stored at 12 and 16% moisture contents (Tables 4 and 5) compared to the controls. The percentage of recovered flour from the 1979 crop stored at 18% moisture content and at 40° C for 10, 20 and 30 days were 73.0, 74.0 and 74.1, respectively, while the percentage of recovered flour for the control

TABLE 4. Milling data for the 1979 and 1980 wheat crop samples which were stored at 12% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop[1]			1980 Crop[1]		
		Flour %	Bran %	Shorts %	Flour %	Bran %	Shorts %
Temperature	Days						
30° C	10	72.7	20.6	6.7	71.8	19.7	8.4
30° C	20	73.1	20.7	6.2	72.3	20.1	8.1
30° C	30	72.5	20.8	6.7	71.9	20.0	7.9
40° C	10	73.2	20.1	6.6	72.3	20.1	7.4
40° C	20	72.7	21.4	5.9	72.6	20.1	7.2
40° C	30	72.3	21.0	6.7	72.5	20.0	7.4
50° C	10	72.5	21.1	6.3	72.3	19.9	7.8
50° C	20	72.3	21.2	6.5	72.9	20.1	7.1
50° C	30	72.9	20.9	6.2	71.9	21.0	7.0
4° C[2]	0	72.0	20.9	7.0	71.9	18.3	9.7

[1] Yield based on total milled material.

[2] Controls.

TABLE 5. Milling data for the 1979 and 1980 wheat crop samples which were stored at 16% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop[1]			1980 Crop[1]		
		Flour %	Bran %	Shorts %	Flour %	Bran %	Shorts %
Temperature	Days						
30° C	10	72.5	20.1	7.4	71.7	19.0	9.2
30° C	20	72.7	21.5	5.7	71.7	19.5	8.6
30° C	30	71.7	21.1	7.2	71.0	18.8	10.0
40° C	10	72.3	20.8	6.8	71.3	19.7	9.0
40° C	20	72.6	22.0	5.4	72.1	19.7	8.0
40° C	30	71.5	21.8	6.7	71.9	20.0	8.1
50° C	10	73.9	20.5	5.5	72.6	19.7	7.7
50° C	20	72.8	21.4	5.8	72.8	19.9	7.3
50° C	30	72.2	21.4	6.4	72.4	19.9	7.7
4° C[2]	0	72.2	20.4	7.3	71.9	19.4	8.7

[1] Yield based on total milled material.

[2] Controls.

TABLE 6. Milling data for the 1979 and 1980 wheat crop samples which were stored at 18% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop[1]			1980 Crop[1]		
		Flour %	Bran %	Shorts %	Flour %	Bran %	Shorts %
Temperature	Days						
30° C	10	72.5	20.4	7.0	70.8	19.1	10.0
30° C	20	72.4	20.4	7.1	71.0	19.2	9.8
30° C	30	72.7	19.6	7.7	71.7	19.4	8.9
40° C	10	73.0	19.5	7.4	72.6	19.5	7.9
40° C	20	74.0	19.3	6.7	72.4	19.0	8.5
40° C	30	74.1	18.0	7.2	73.1	18.8	8.0
50° C	10	74.7	18.7	6.6	74.1	18.5	7.4
50° C	20	73.9	18.8	7.4	73.8	18.0	8.2
50° C	30	73.9	18.3	7.5	74.1	16.9	9.0
4° C[2]	0	72.2	21.1	6.6	72.3	19.3	8.4

[1] Yield based on total milled material.

[2] Controls.

was 72.2. This increase in flour yield was considered to be significant. A similar increase in flour yield was found for the samples of the 1979 crop stored at 18% moisture content and at 50° C and the samples of the 1980 crop stored at 18% moisture content and at 40 and 50° C.

The percentage of bran for the 18% moisture content samples of both crops stored at 40 and 50° C (Table 6) decreased compared to control values. These results paralleled the increase in ash content for the same samples which will be discussed later.

The percentage of shorts recovered from the 1980 crop showed an increase in all the treatments including the controls over the corresponding percentage of shorts recovered from the 1979 crop, irrespective of the moisture content of the samples (Tables 4, 5 and 6). This percentage increase of shorts recovered for the 1980 crop ranged from .6 to 3.0% greater than that recovered for the 1979 crop.

In general, high moisture content (18%) and high temperature (40 and 50° C) during storage affected the percentage of flour, bran and shorts recovered from the stored wheat. Similar results were obtained by Westermarck-Rosendahl (1978) who found an increase in flour content and a decrease in bran content following a 7 day storage of spring wheat and 23.5% moisture content.

D. The Effect of Different Storage Conditions on the Proximate Analyses of Wheat Flour from the 1979 and 1980 Crop

1. Ash Content

The flour ash content of the stored wheat samples from the 1979 and 1980 crops are presented in Tables 7, 8 and 9. The flour ash content for the controls were 0.43% for the 1979 crop and 0.36, 0.37 and 0.37%

TABLE 7. The ash and protein content for the 1979 and 1980 wheat crop samples which were stored at 12% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop		1980 Crop	
		Ash[1] %	Protein[2] %	Ash[1] %	Protein[2] %
Temperature	Days				
30° C	10	0.44	15.7	0.36	15.8
30° C	20	0.43	15.7	0.36	15.8
30° C	30	0.42	15.6	0.36	15.8
40° C	10	0.44	15.5	0.36	15.7
40° C	20	0.43	15.5	0.37	15.8
40° C	30	0.44	15.5	0.39	15.6
50° C	10	0.43	15.4	0.39	15.6
50° C	20	0.43	15.3	0.38	15.8
50° C	30	0.44	15.3	0.39	15.8
4° C[3]	0	0.43	15.4	0.36	16.0

[1] On 14% m.b.

[2] On 0% m.b.

[3] Controls.

TABLE 8. The ash and protein contents for the 1979 and 1980 wheat crop samples which were stored at 16% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop		1980 Crop	
		Ash[1] %	Protein[2] %	Ash[1] %	Protein[2] %
Temperature	Days				
30° C	10	0.45	15.4	0.37	15.9
30° C	20	0.45	15.5	0.37	15.8
30° C	30	0.46	15.3	0.39	16.0
40° C	10	0.43	15.6	0.34	15.9
40° C	20	0.45	15.5	0.35	16.0
40° C	30	0.47	15.3	0.36	16.0
50° C	10	0.50	15.8	0.36	16.0
50° C	20	0.57	15.5	0.42	15.9
50° C	30	0.62	15.4	0.47	15.9
4° C[3]	0	0.43	15.4	0.37	15.8

[1] On 14% m.b.

[2] On 0% m.b.

[3] Controls.

TABLE 9. The ash and protein content for the 1979 and 1980 wheat crop samples which were stored at 18% moisture content for various periods of time and at different temperatures.

Storage conditions		1979 Crop		1980 Crop	
		Ash[1] %	Protein[2] %	Ash[1] %	Protein[2] %
Temperature	Days				
30° C	10	0.46	15.7	0.38	15.8
30° C	20	0.48	15.7	0.38	15.7
30° C	30	0.48	15.5	0.39	15.9
40° C	10	0.47	15.6	0.39	15.9
40° C	20	0.52	15.7	0.41	15.8
40° C	30	0.56	15.7	0.42	15.9
50° C	10	0.59	15.6	0.44	16.0
50° C	20	0.63	15.8	0.53	16.0
50° C	30	0.69	15.5	0.57	16.0
4° C[3]	0	0.43	15.4	0.37	15.9

[1] On 14% m.b.

[2] On 0% m.b.

[3] Controls.

for the controls of the 1980 crop for the 12, 16 and 18% moisture contents samples, respectively. The flour ash contents for the wheat at 12% moisture content (Table 7) stored for 10, 20 and 30 days at 30, 40 and 50° C were very similar to the controls. The samples at 12% moisture content stored for 10, 20 and 30 days at 50° C recorded 0.43, 0.43 and 0.44% ash contents for the 1979 crop and 0.39, 0.38 and 0.39% ash content for the 1980 crop, respectively. The flour ash content of the wheat samples at 16% moisture content (Table 8) stored for 10, 20 and 30 days at 30, 40 and 50° C were higher than the samples stored at 12% and the controls. The ash content of the samples at 16% stored for 10, 20 and 30 days at 50° C were 0.50, 0.57 and 0.62% for the 1979 crop and 0.36, 0.42 and 0.47% for the 1980 crop, respectively. These results indicated that when the moisture content increased during the storage, the flour ash content of the stored wheat also increased. The wheat samples stored at 18% moisture content (Table 9) at 30, 40 and 50° C had a higher ash content than the samples stored at 12 and 16% moisture contents and the controls. The differences were particularly pronounced for the 18% moisture samples stored for 10, 20 and 30 days at 50° C. The ash content of these samples were 0.59, 0.63 and 0.69% for the 1979 crop and 0.44, 0.53 and 0.57% for the 1980 crop, respectively. These values were the highest when compared to the rest of the samples and the controls.

These results indicated that the ash content of the stored wheat increased with increased temperature, moisture and periods of storage. These findings are in agreement with those of Fifield and Robertson (1959) who reported an increase in flour ash content of the wheat samples stored up to 33 years. The increase was attributed to the formation of

more brittle bran coat of wheat when stored for long periods of time.

2. Protein Content

The protein content (N X 5.7) of the flour from the stored wheat samples from the 1979 and 1980 crops are presented in Tables 7, 8 and 9. The protein content of the wheat flour remained constant for the wheat which was stored at different moisture levels and temperatures for various periods of time. The protein content for a control sample from the 1979 crop was 15.4% and for three control samples from the 1980 crop was 16.0, 15.8 and 15.9%. The flour protein fluctuated between 15.3 to 15.8% and 15.6 to 16.0% (on 0% moisture basis and $\pm$ 0.2% experimental error) for both the 1979 and 1980 crops, respectively. These values, when compared to the control values, indicated that the storage conditions did not affect the protein content of the flour obtained from the stored wheat. When the protein contents of two crop years were compared, the protein content of the 1980 crop was slightly higher than that of the 1979 crop.

These findings are, in general, in agreement with the results of Jones and Gersdroff (1941) who found no significant change in either the total nitrogen or the protein nitrogen content in stored grain. Pixton and Hill (1967) also reported that there were no changes in the protein content for the wheat which was stored for 8 years under commercial storage conditions. However, Shutt (1909, 1911) and Daftary et al. (1970b) reported that the protein content was slightly, but consistently, higher in mold-damaged samples than in the corresponding controls. The relative increase on a percentage basis could be explained by respiratory losses of carbohydrates.

3. Starch Damage

Starch damage or the disruption of the natural structure of the starch granules may be attributed to biochemical (amylase), chemical (alkali) or physical (grinding or milling) actions (Bushuk 1977). In this study starch damage values were obtained in order to determine if the storage conditions affect the starch granule and subsequently the quality of the stored wheat.

The starch damage values (Farrand unit) (F.U.) for the wheat flour samples from the 1979 and 1980 crops stored at 50° C at different moisture levels, are presented in Table 10. The starch damage analyses were conducted in duplicate and the average error was 0.17%.

The flour samples from the 1979 crop had higher starch damage values than the flour samples from the 1980 crop. The starch damage values for the control samples from the 1979 and 1980 crops were 18.4 and 11.6 F.U., respectively. The flour obtained from the stored wheat samples at 50° C for both crops at 12, 16 and 18% moisture content showed no marked differences in the amount of starch damage when compared to the control samples, except for the 18% content samples for the 1979 and 1980 crops stored for 30 days. These samples had higher starch damage value, 24.0 and 22.5 F.U., compared to the control samples. These high values probably resulted from the heavy mold growth associated with these samples as discussed previously in the organoleptic studies. However, Acker (1962) had indicated that starch damage was possible during prolonged storage though probably only at the most advanced stages of mold damage.

The starch damage values obtained in this study agree favourably with the findings of Daftary et al. (1970a) who found no change in functional properties of starch; in wheat samples stored at 18% moisture

TABLE 10. Starch damage data for the 1979 and 1980 wheat crop samples which were stored at 50° C and different moisture levels for various periods of time.

Storage Conditions		Starch Damage, Farrand Units	
		1979 Crop	1980 Crop
Moisture	Days		
12%	10	18.4	10.0
12%	20	19.2	10.0
12%	30	17.7	8.7
16%	10	17.7	9.3
16%	20	19.2	8.7
16%	30	21.9	8.7
18%	10	17.7	10.0
18%	20	19.2	10.0
18%	30	24.0	22.5
12%(1)	0	18.4	11.6

(1) Controls.

content and at different temperatures for 4 months.

4. Amino Acids

The amino acid composition of the wheat flour from the 1979 and 1980 crops, which were stored at different temperatures and moisture levels for various periods of time were determined and the results are presented in Tables 11 and 12. All the amino acid values are expressed in grams of amino acid per 100 g of protein. The nitrogen recovered for all stored samples ranged from 84.22 to 98.12% for the 1979 crop and from 89.68 to 98.41% for the 1980 crop. The amino acid composition of the flour from the stored wheat samples for the 1979 and 1980 crops showed little variation in amino acid composition when compared to the control samples. The most abundant amino acids in all samples were glutamate and proline. Furthermore, these amino acids accounted for over 50% of the amino acids present in the flour. Glutamate and proline content were similar in the flour samples for both crop years. Minor changes were found in the lysine content of the flour for both crops. The lysine results are in agreement with those of Ferrel et al. (1970) who stored fortified wheat for 12 months at 9, 11 and 13% moisture contents and at 32.2 and 37.7^{o} C. The study reported that lysine.HCL added to wheat was stable under these conditions of storage for at least 1 year.

Generally, the stored wheat samples showed little variation in amino acid composition. These results are in general agreement with those of Zeleny and Coleman (1938) who found no changes in amino acid composition of wheat and corn undergoing deterioration in storage, except for some increases in very badly damaged grain. Larmour et al. (1961) found little or no change in amino acid composition for the majority of stored wheat samples.

TABLE 11. Amino acid composition[1,2] for the 1979 wheat crop samples which were stored for 30 days at different temperatures and moisture levels.

Amino acid	Moisture Content									
	Samples									Control
	12%			16%			18%			12%
	Temperatures									
	30° C	40° C	50° C	30° C	40° C	50° C	30° C	40° C	50° C	4° C
Lysine	2.00	1.85	2.11	2.04	2.14	1.95	2.16	2.14	1.89	1.97
Histidine	2.08	1.91	2.19	2.11	2.21	2.15	2.20	2.23	2.20	2.06
Ammonia	4.13	3.91	4.45	4.43	4.66	4.66	4.61	4.55	4.68	4.25
Arginine	3.29	2.97	3.40	3.42	3.61	3.30	3.38	3.59	3.51	3.33
Asparate	4.35	3.94	4.36	4.31	4.70	4.39	4.51	4.45	4.14	4.13
Threonine	2.72	2.48	2.78	2.71	2.93	2.68	2.78	2.81	2.77	2.69
Serine	4.84	4.46	5.01	4.84	5.25	4.66	4.87	4.97	4.96	4.86
Glutamate	42.17	39.46	43.89	39.98	43.58	40.77	41.62	40.61	41.73	41.63
Proline	11.75	10.79	12.07	12.23	13.20	12.68	12.02	11.85	12.20	11.91
Glycine	3.58	3.30	3.78	3.58	3.87	3.65	3.74	3.77	3.80	3.57
Alanine	2.95	2.71	3.08	2.94	3.19	3.05	3.12	3.18	3.19	2.92
Valine	4.25	3.91	4.47	4.24	4.56	4.23	4.40	4.37	4.35	4.28
Methionine	1.24	1.23	1.35	1.31	1.34	1.25	1.37	1.41	1.23	1.37
Isoleucine	3.84	3.49	3.85	3.79	4.08	3.88	3.91	3.87	3.92	3.91
Leucine	7.58	6.89	7.65	7.43	8.02	7.54	7.67	7.62	7.67	7.63
Tyrosine	2.77	2.51	2.90	2.88	3.13	2.41	2.44	2.89	3.07	2.89
Phenylalanine	5.25	5.11	5.64	5.40	5.75	5.34	5.61	5.53	5.67	5.47
N % Recovery	90.69	84.22	94.78	91.58	98.12	93.01	94.13	93.84	94.78	91.27

(1) Expressed as g amino acid/100 g protein.

(2) Cystine and tryptophan were not determined.

TABLE 12. Amino acid composition[1,2] for the 1980 wheat crop samples which were stored for 30 days at different temperatures and moisture levels.

Amino acid	Moisture Content									
	Samples									Control
	12%			16%			18%			12%
	Temperature									
	30° C	40° C	50° C	30° C	40° C	50° C	30° C	40° C	50° C	4° C
Lysine	2.00	2.06	2.06	1.91	2.07	1.96	2.13	1.98	1.89	2.11
Histidine	2.13	2.19	2.21	2.05	2.24	2.18	2.25	2.13	2.20	2.24
Ammonia	4.21	4.37	4.51	4.16	4.73	4.73	4.69	4.39	4.68	4.69
Arginine	3.33	3.36	3.30	3.05	3.53	3.42	3.41	3.31	3.51	3.47
Aspartate	4.03	4.34	4.06	3.75	4.14	4.16	4.38	4.00	4.14	4.32
Threonine	2.65	2.90	2.70	2.53	2.79	2.72	2.90	2.67	2.77	2.70
Serine	4.77	5.24	4.87	4.64	5.08	4.95	5.19	4.79	4.96	4.82
Glutamate	42.75	46.46	44.41	42.86	42.68	42.49	44.46	39.85	41.73	41.40
Proline	11.92	12.32	12.34	12.58	13.13	12.68	12.96	11.95	12.20	11.67
Glycine	3.58	3.99	3.78	3.41	3.75	3.74	3.93	3.63	3.80	3.66
Alanine	2.95	3.30	3.05	2.78	3.06	3.08	3.25	3.03	3.19	2.98
Valine	4.20	4.82	4.40	4.01	4.40	4.35	4.64	4.23	4.35	4.31
Methionine	1.27	1.65	1.38	1.31	1.24	1.29	1.41	1.29	1.23	1.18
IsoLeucine	3.88	4.23	3.92	3.64	3.99	3.94	4.20	3.82	3.92	3.93
Leucine	7.57	8.26	7.71	7.07	7.66	7.66	8.19	7.46	7.67	7.62
Tyrosine	2.85	3.19	3.02	2.79	3.13	3.04	2.73	2.83	3.07	2.82
Phenylalanine	5.37	6.37	5.89	5.27	5.65	5.71	6.11	5.52	5.67	5.65
N % Recovery	91.45	98.02	95.22	89.68	96.53	95.47	98.41	90.79	94.78	93.9

[1] Expressed as g amino acid/100 g of protein.

[2] Lystine and tryptophan were not determined.

5. Free Amino Acids

The free amino acids of wheat flour of the 1979 and 1980 crops, which were stored at different temperatures and moisture levels for various periods of time were determined and the results are presented in Table 13. The free amino acid values are expressed in grams of amino acid per 100 g of protein. The nitrogen recovery of the samples at 12% moisture content stored for 30 days and at 18% moisture contents stored for 20 days from the 1979 crop were 0.66 and 1.80% and from the 1980 crop were 0.35 and 1.17%, respectively. The nitrogen recovery of the control samples were 0.63% for the 1979 crop and 0.30% for the 1980 crop.

The samples at 12% moisture content stored at 50° C for 30 days showed no marked differences in free amino acid values compared to the control samples. The free amino acid contents increased as the temperature and moisture levels increased. The samples at 18% moisture content stored at 50° C for 20 days showed a marked increase in free amino acid content compared to the samples at 12% moisture content stored for 30 days and the controls. The differences were particularly pronounced in glutamate, glycine and alanine contents. The values for these free amino acids for the samples at 18% moisture content from the 1979 crop were 0.12, 0.14 and 0.25%, respectively, while the values for the three controls were 0.08, 0.01 and 0.03%. A similar trend was found for the samples of the 1980 crop at 18% moisture content stored for 20 days.

The increase in free amino acid contents were probably due to fungal infestation. The fungal fragments and spores would have been milled with the wheat and probably caused an increase in amounts of free amino acids. Samples free of fungi showed only minor variations in free amino acid contents.

TABLE 13. Free amino acid composition[2,3] for the 1979 and 1980 wheat crop samples which were stored at 50° C and different moisture levels for various periods of time.

	Moisture Content					
	1979 Crop			1980 Crop		
	12%[1]	12%	18%	12%[1]	12%	18%
	Storage Time (Days)					
Free Amino Acid	0	30	20	0	30	20
Lysine	0.01	0.01	0.07	0.01	0.01	0.04
Histidine	0.01	0.01	0.03	Tr.	Tr.	0.02
Ammonia	0.01	0.01	0.05	Tr.	0.01	0.04
Arginine	0.02	0.02	0.10	0.02	0.01	0.06
Tryptophan	0.09	0.09	0.15	0.05	0.05	0.13
Asparate	0.35	0.36	0.41	0.12	0.12	0.17
Threonine	0.01	0.01	0.07	Tr.	0.01	0.05
Serine	0.13	0.13	0.18	0.05	0.04	0.10
Glutamate	0.08	0.09	0.21	0.03	0.04	0.10
Proline	0.01	0.01	0.09	0.01	0.01	0.07
Glycine	0.01	0.01	0.14	0.01	0.02	0.11
Alanine	0.03	0.03	0.25	0.02	0.03	0.20
Valine	0.02	0.02	0.07	0.01	0.01	0.04
Methionine	0.01	0.01	0.02	Tr.	Tr.	0.01
Isoleucine	0.01	0.02	0.04	0.01	0.01	0.02
Leucine	0.01	0.02	0.06	0.01	0.01	0.04
Tyrosine	0.01	0.01	0.05	0.01	0.01	0.03
Phenylalanine	0.02	0.01	0.05	0.01	0.01	0.03
N % Recovery	0.63	0.66	1.80	0.30	0.35	1.17

[1] Control.

[2] Expressed as g amino acid/100 g of protein.

[3] Cystine was not determined.

In general, the results of the free amino acid contents of the stored wheat samples are consistent with the findings of DeVay (1952) who found marked changes in the concentrations of certain free amino acids in wheat stored in sealed containers for 6 weeks at 19.5% moisture content. Concentrations of alanine, gamma-amino butyric acid, proline, serine and lysine apparently increased while histidine decreased in the moldy wheat relative to the concentrations of the other free amino acids. These changes in free amino acid content of wheat were reported to be due mainly to respiration, mold growth or both.

E. The Effect of Different Storage Conditions on the Rheological Properties of Wheat Flour from the 1979 and 1980 Crops

Rheology is the science that deals with deformation and flow of matter. The aims of basic dough rheology research are to provide: 1) a complete quantitative description of mechanical behavior, 2) relations between rheological parameters and structure and composition, 3) relations between rheological parameters and performance in the commercial bakery (Hibberd and Parker 1975). The rheological properties of the dough are very important in determining baking performance of a product and its final quality. In the present studies, rheological properties as determined by the farinograph, extensigraph and amylograph were used to appraise the quality of stored wheat flour.

1. Farinograph

Farinograph curves of stored wheat flour from the 1979 and 1980 crops were determined to assess water absorption (14% moisture basis), arrival time, mixing time (development time), stability (nearest 0.5 minute) and mixing tolerance index (nearest 5 Brabender Units) of wheat

stored under different conditions. The farinograph data of the stored samples and the controls are presented in Tables 14, 15, 16 and 17. The farinograms, which reflect the mixing requirements and other important physical dough properties of the stored wheat flour samples, are shown in Figures 1, 2, 3, 4, 5, 6 and 7.

For the farinograph studies, the control sample from the 1979 crop at 13.5% moisture content was dried to 12% moisture content and was replicated three times. For the 1980 crop, three control samples, control 1, control 2 and control 3 at 18, 16 and 12% moisture content, respectively, were dried to 12% moisture content and were replicated only once.

i. Ten-day storage. The studies on the farinograph properties of wheat flour from the 1979 and 1980 crops stored for 10 days at 30 and 40° C at 12 and 16% moisture levels showed no marked changes compared to the controls (Tables 14 and 17; Figures 1, 2 and 7). The samples at 18% moisture content stored at 40° C from the 1979 crop showed only an increase in mixing time. On the other hand, the samples at 18% moisture content stored at 40° C from the 1980 crop showed increases in mixing time and stability and a decrease in mixing tolerance index. The 12% moisture content samples stored at 50° C showed minor changes in farinograph properties compared to the controls. The samples at 16% moisture content stored at 50° C showed a large increase in mixing time, a decrease in mixing tolerance index and a constant stability for both crops. However, the 18% moisture content samples stored at 50° C showed a decrease in mixing time and stability and an increase in mixing tolerance index compared to the controls from the 1979 and 1980 crops. The mixing tolerance index for the remaining samples did not differ significantly

TABLE 14. Farinograph data for the 1979 and 1980 wheat crop samples which were stored for 10 days at different temperatures and moisture levels.

Storage conditions		1979 Crop						1980 Crop					
		Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]	Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]
Temperature	Moisture												
30° C	12%	62.7	3.0	5.5	10.0	12.5	30	62.0	2.0	4.5	14.5	16.5	20
30° C	16%	63.0	2.5	4.5	13.5	16.0	20	62.5	2.5	8.0	13.5	16.0	25
30° C	18%	62.7	2.5	7.5	14.0	16.5	20	60.8	2.0	6.5	14.0	16.5	20
40° C	12%	62.5	3.5	6.0	10.0	13.5	20	62.9	2.5	5.0	13.0	15.5	20
40° C	16%	62.9	3.0	6.0	14.0	17.0	20	61.8	2.0	7.5	14.5	16.5	20
40° C	18%	61.7	2.0	8.0	14.0	16.0	20	61.4	2.0	3 and 8	constant	-	0 and 15
50° C	12%	62.8	2.5	5.5	13.0	15.5	20	62.0	3.5	8.0	13.0	16.0	20
50° C	16%	60.9	2.5	12.5	constant	-	0	59.9	1.5	3 and 11.5	constant	-	5 and 5
50° C	18%	60.7	1.0	1.5	2.5	3.5	80	59.1	1.0	2.0	4.5	5.5	30

(1) (14% moisture content).

(2) (Nearest 0.5 minute).

(3) Mixing tolerance index (nearest 5 Brabender Units).

TABLE 15. Farinograph data for the 1979 and 1980 wheat crop samples which were stored for 20 days at different temperatures and moisture levels.

Storage conditions		1979 Crop						1980 Crop					
		Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]	Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]
Temperature	Moisture												
30° C	12%	62.2	2.5	5.0	12.5	15.0	20	62.3	2.0	5.0	13.5	15.5	20
30° C	16%	63.0	3.5	7.0	12.5	16.0	20	62.3	2.0	7.5	14.5	-	25
30° C	18%	60.3	1.5	6.5	16.0	17.5	20	60.5	2.5	7.0	14.5	17.0	20
40° C	12%	62.1	3.5	6.5	12.0	15.5	25	62.0	2.5	6.0	14.0	16.5	20
40° C	16%	62.5	2.5	9.0	15.0	17.5	20	61.2	2.0	3.5 and 9	15.0	17.0	5 and 5
40° C	18%	60.7	1.5	3 and 11	constant	-	5 and 10	59.7	2.0	3.0	constant	-	10
50° C	12%	62.9	2.5	6.0	13.5	16.0	25	61.8	1.5	3 and 5	18.0	17.5	0 and 15
50° C	16%	58.9	1.0	2.0	13.0	15.0	40	58.7	1.5	2.5	16.5	18.0	10
50° C	18%	58.6	1.0	1.5	1.0	2.0	100	58.4	1.5	2.0	2.5	4.0	65

(1) (14% moisture content).

(2) (Nearest 0.5 minute).

(3) Mixing tolerance index (nearest 5 Brabender Units).

TABLE 16. Farinograph data for the 1979 and 1980 wheat crop samples which were stored for 30 days at different temperatures and moisture levels.

Storage conditions		1979 Crop						1980 Crop					
		Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]	Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]
Temperature	Moisture												
30° C	12%	63.2	3.0	6.0	13.0	16.0	20	62.2	3.0	5.5	12.0	15.0	25
30° C	16%	61.4	2.5	6.5	12.0	14.0	20	61.2	2.5	6.0	12.5	15.0	15
30° C	18%	60.5	1.5	9.0	18.0	19.5	20	59.5	2.0	9.0	15.0	17.0	20
40° C	12%	63.9	2.0	5.5	14.0	16.0	20	63.2	2.0	6.0	13.5	15.5	30
40° C	16%	60.2	2.5	9.0	16.0	18.5	20	60.6	1.5	2.5 and 12	constant	-	5 and 5
40° C	18%	60.7	1.0	2.0	14.5	15.5	20	59.6	1.5	2.5	14.5	16.0	30
50° C	12%	62.2	2.0	6.0	14.0	16.0	30	61.6	2.0	6.0	constant	-	10
50° C	16%	58.7	1.5	2.0	2.5	4.0	50	58.4	1.5	2.0	4.0	5.5	40
50° C	18%	60.0	2.0	3.0	3.5	5.5	70	58.8	1.0	1.5	1.0	2.0	90

(1) (14% moisture content).

(2) (Nearest 0.5 minute).

(3) Mixing tolerance index (nearest 5 Brabender Units).

TABLE 17. Farinograph data for control samples for the 1979 and 1980 wheat crop samples which were stored at 4° C temperature and 12% moisture content.

Storage conditions		1979 Crop						1980 Crop					
		Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]	Absorption[1] %	Arrival time[2]	Mixing time[2]	Stability[2]	Departure time[2]	MTI[3]
Temperature	Moisture												
4° C	12%	63.8	3.0	5.5	13.0	16.0	20	62.3	2.0	4.5	13.5	15.5	25
4° C	12%	63.3	2.5	5.0	13.5	16.0	20	63.3	2.5	6.0	12.5	15.0	20
4° C	12%	63.5	2.5	5.5	13.5	16.0	20	62.3	2.5	6.0	12.5	15.0	30

(1) (14% moisture content).

(2) (Nearest 0.5 minute).

(3) Mixing tolerance index (nearest 5 Brabender Units).

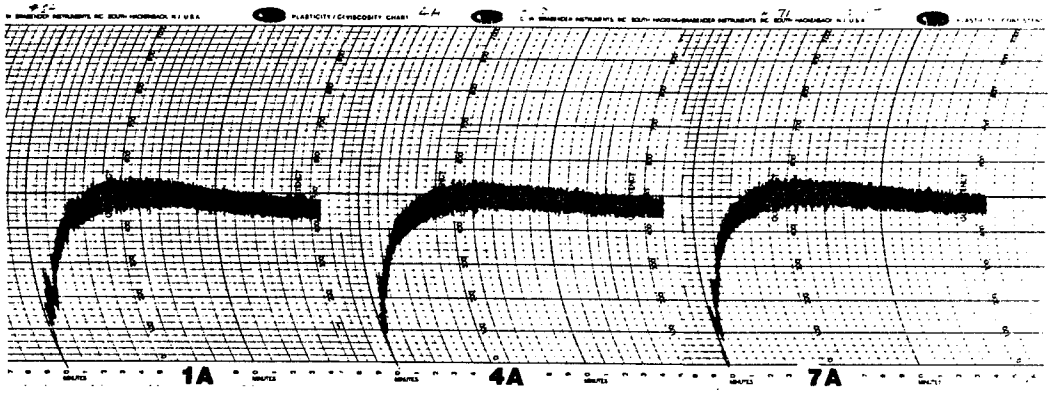
Figure 1. Farinograms of the 1979 wheat crop samples stored for 10 days at different temperatures and moisture levels.

WHEAT CROP 1979

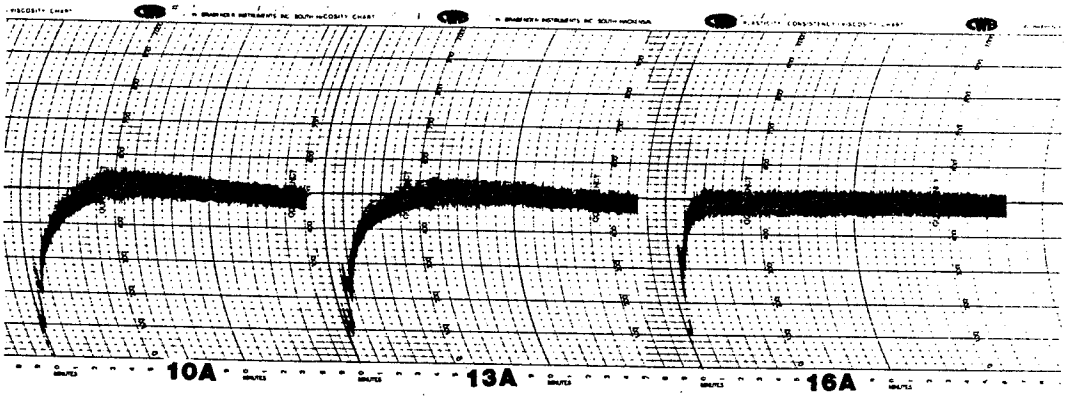
10-DAY STORAGE

30°C 40°C 50°C

12%



16%



18%

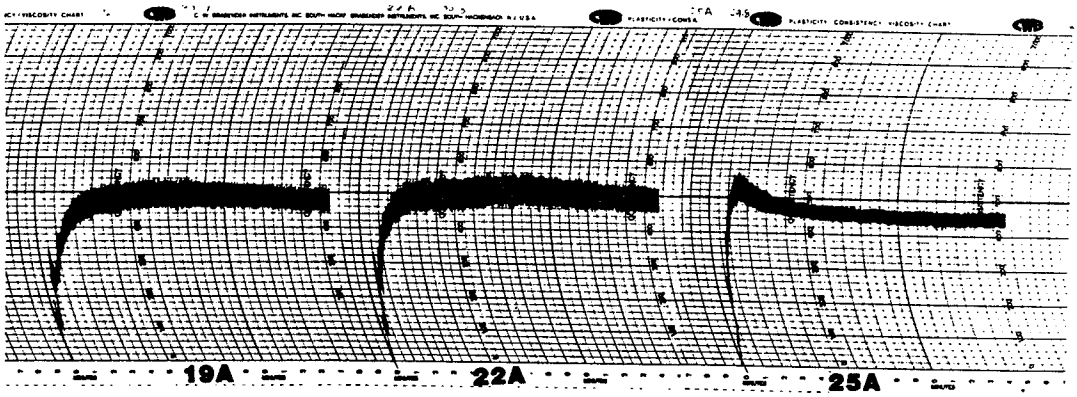


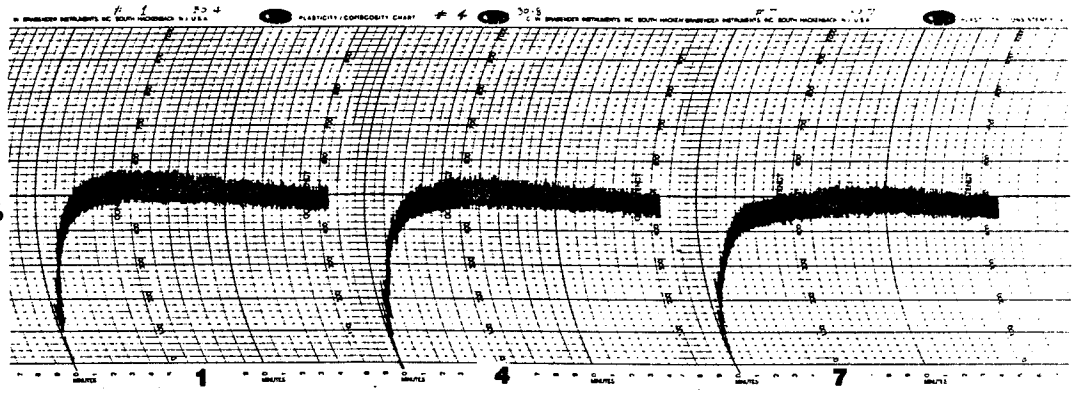
Figure 2. Farinograms of the 1980 wheat crop samples stored for 10 days at different temperatures and moisture levels.

WHEAT CROP 1980

10-DAY STORAGE

30°C 40°C 50°C

12%



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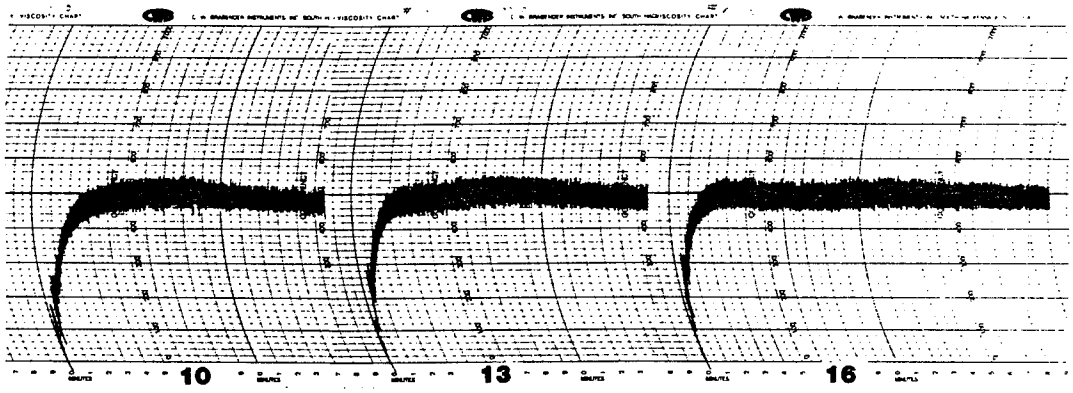

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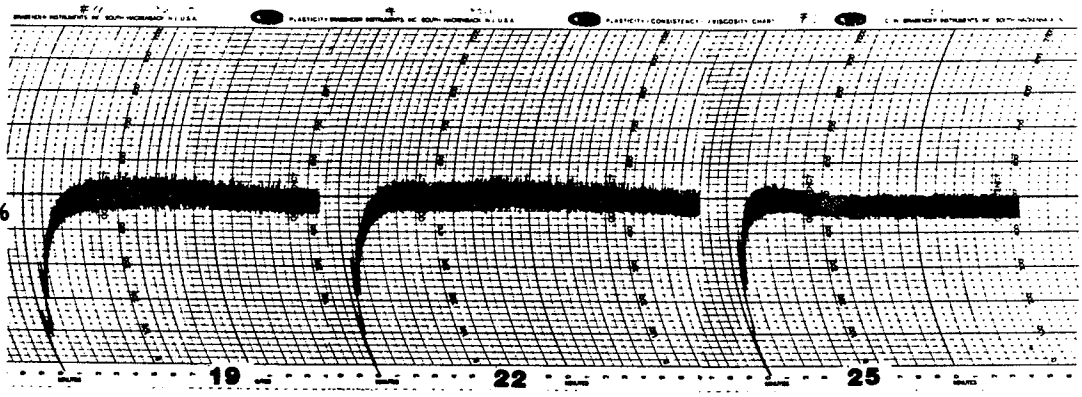


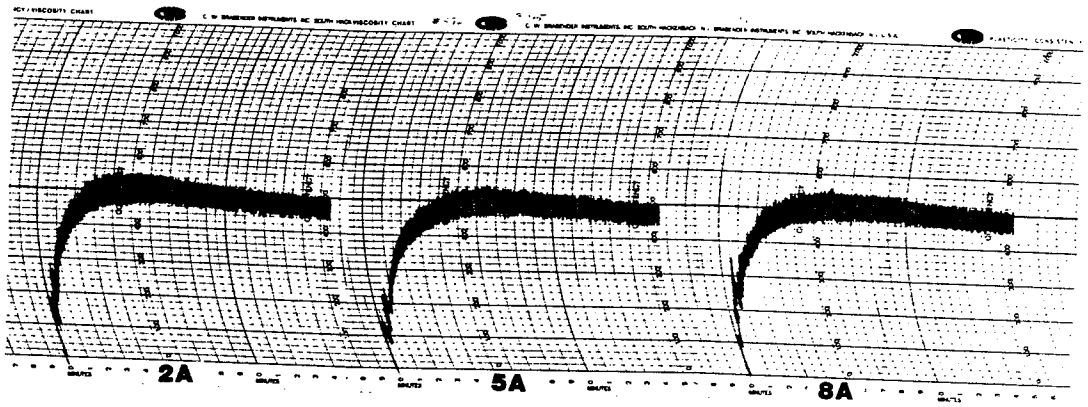
Figure 3. Farinograms of the 1979 wheat crop samples stored for 20 days at different temperatures and moisture levels.

WHEAT CROP 1979

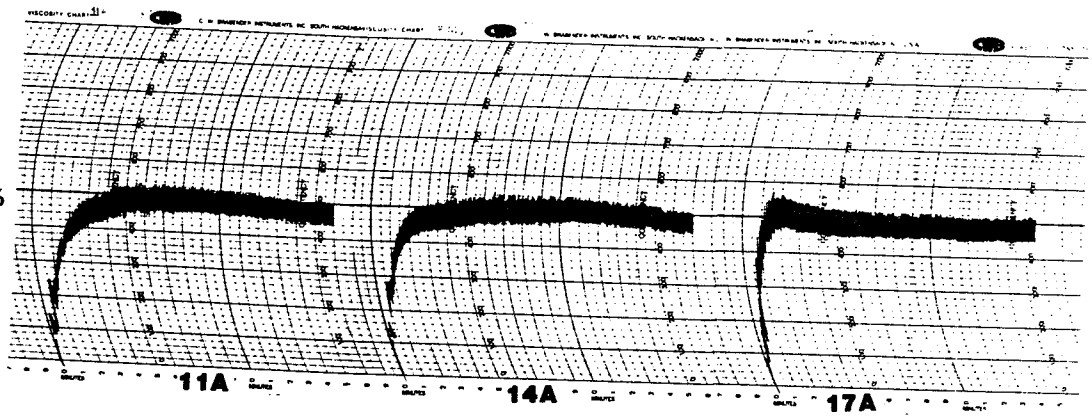
20-DAY STORAGE

30°C 40°C 50°C

12%



16%



18%

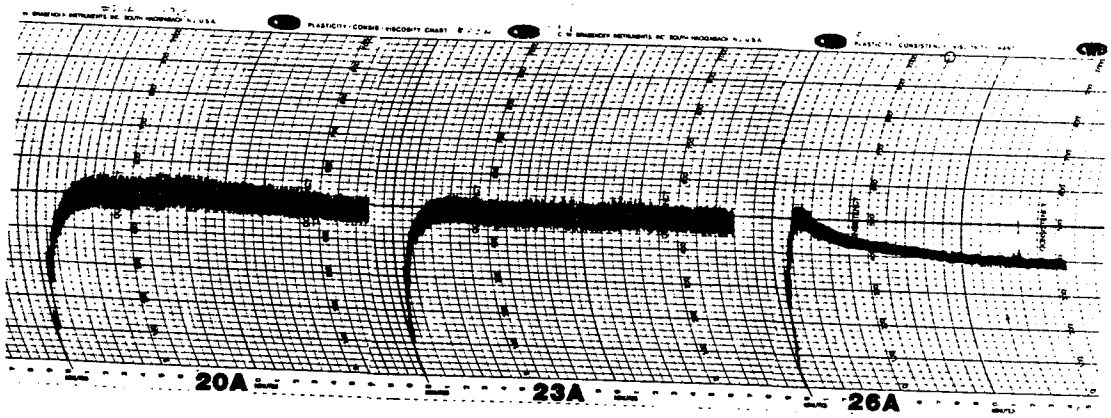


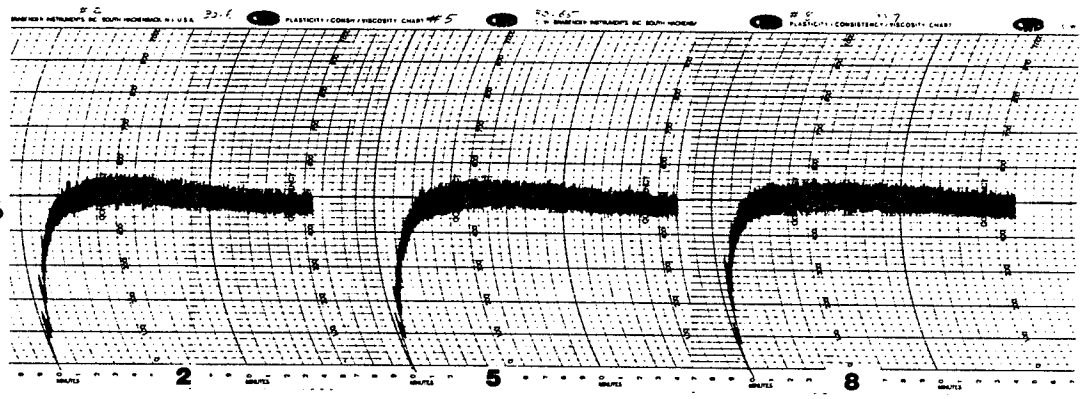
Figure 4. Farinograms of the 1980 wheat crop samples stored for 20 days at different temperatures and moisture levels.

WHEAT CROP 1980

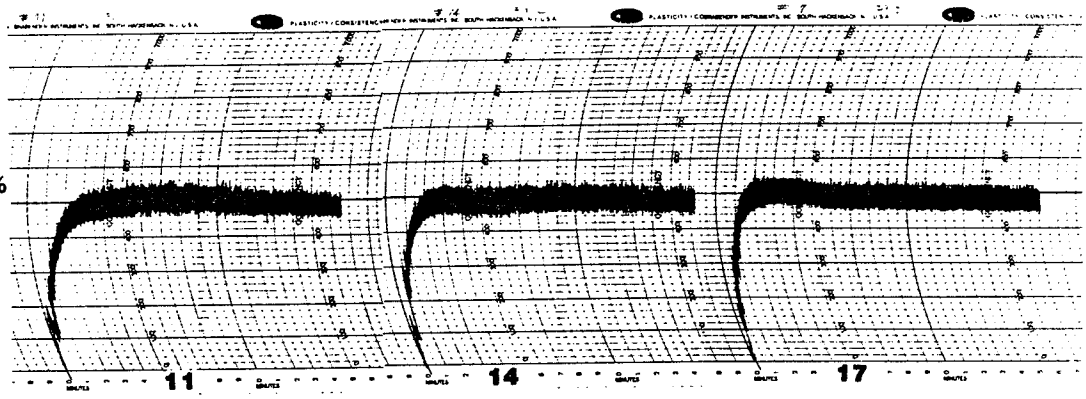
20-DAY STORAGE

30°C **40°C** **50°C**

12%



16%



18%

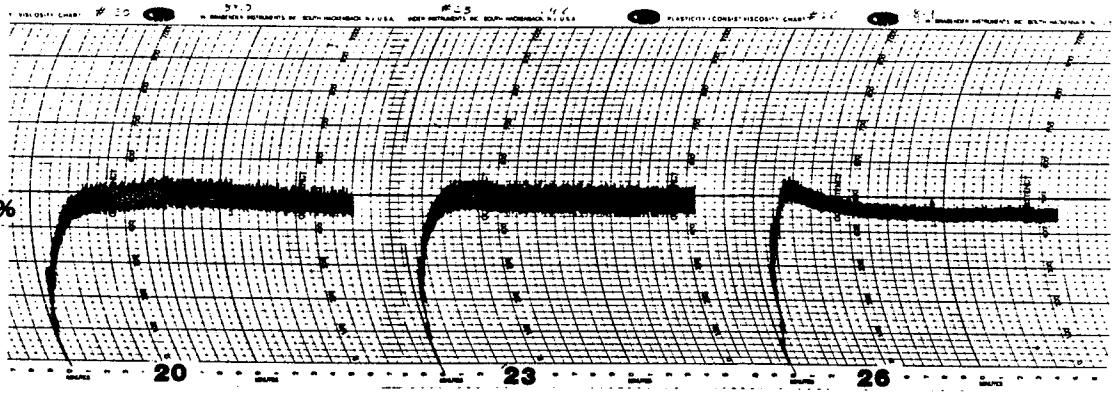


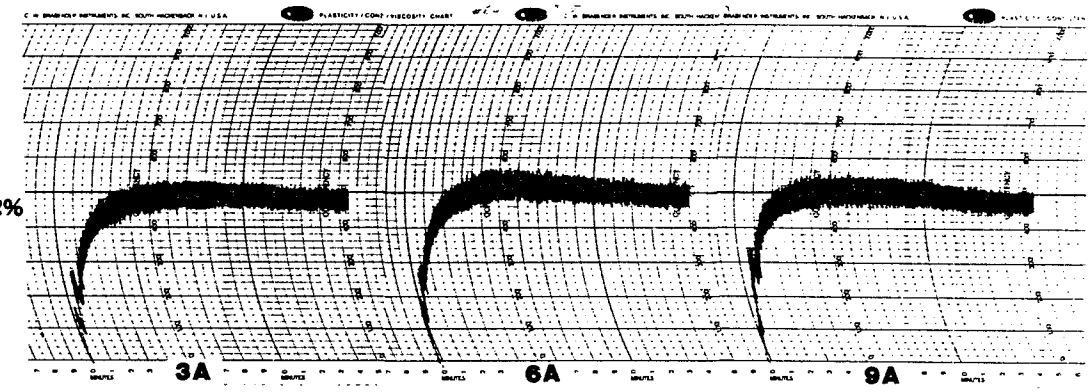
Figure 5. Farinograms of the 1979 wheat crop samples stored for 30 days at different temperatures and moisture levels.

WHEAT CROP 1979

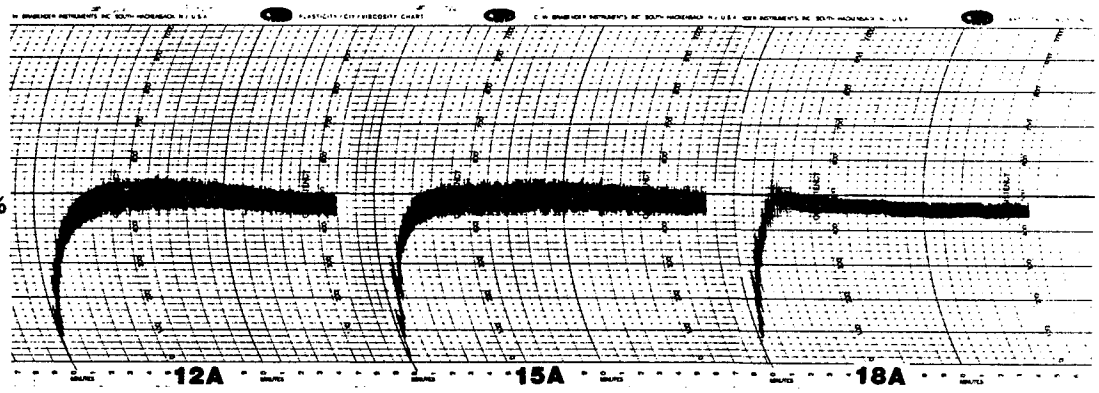
30–DAY STORAGE

30°C **40°C** **50°C**

12%



16%



18%

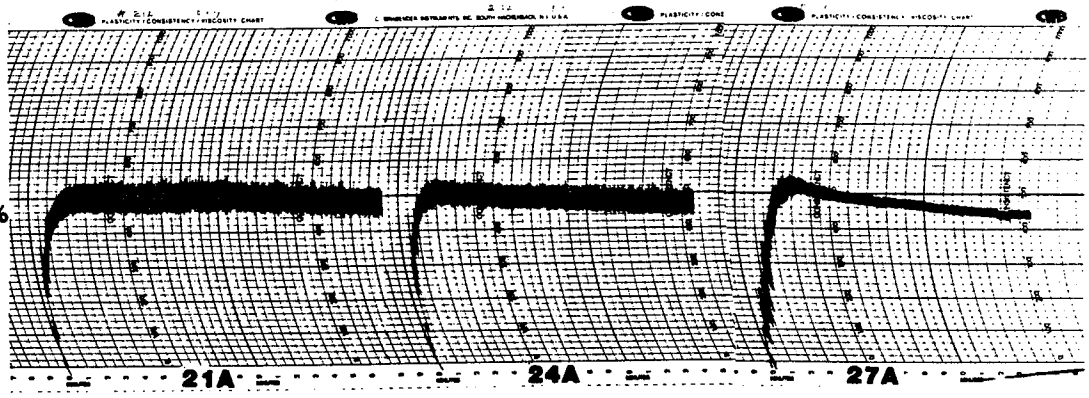


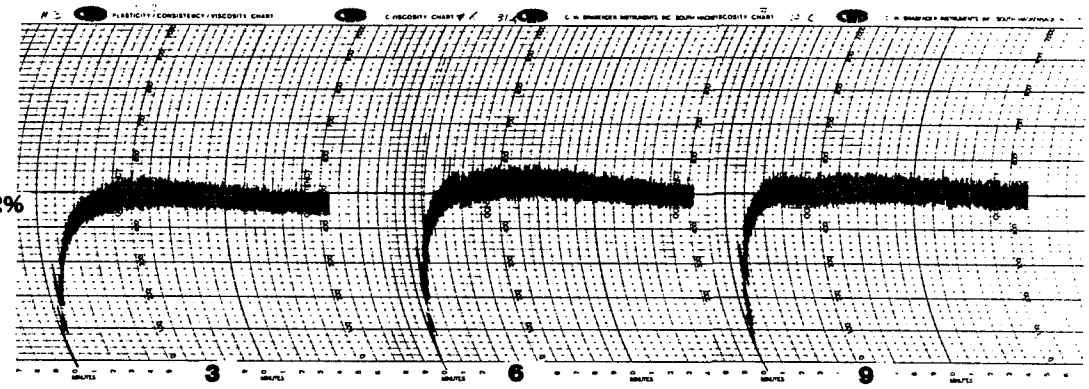
Figure 6. Farinograms of the 1980 wheat crop samples stored for 30 days at different temperatures and moisture levels.

WHEAT CROP 1980

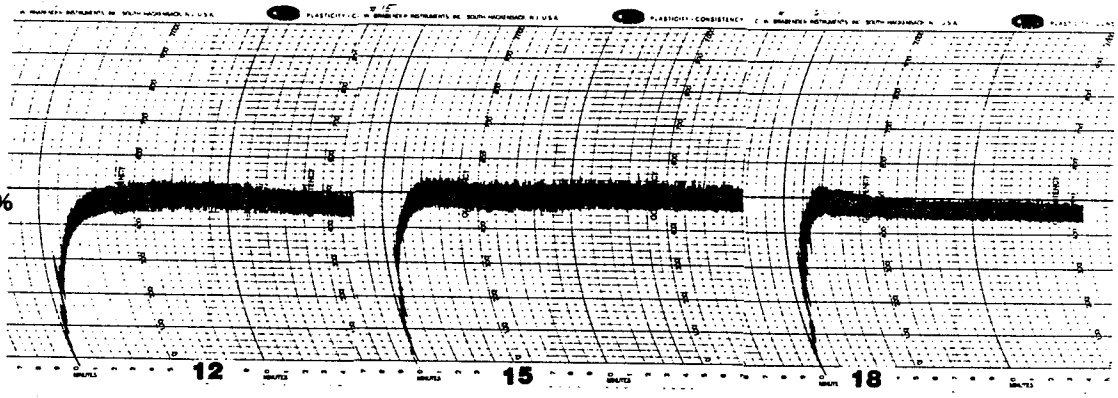
30-DAY STORAGE

30°C **40°C** **50°C**

12%



16%



18%

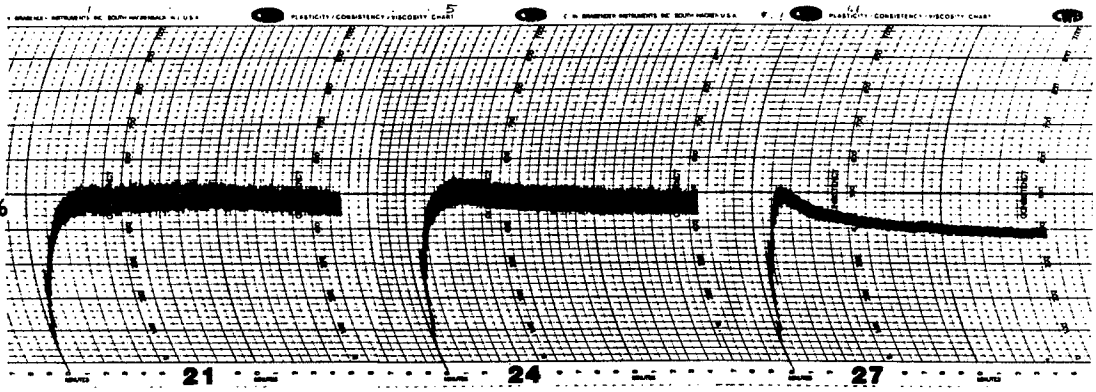
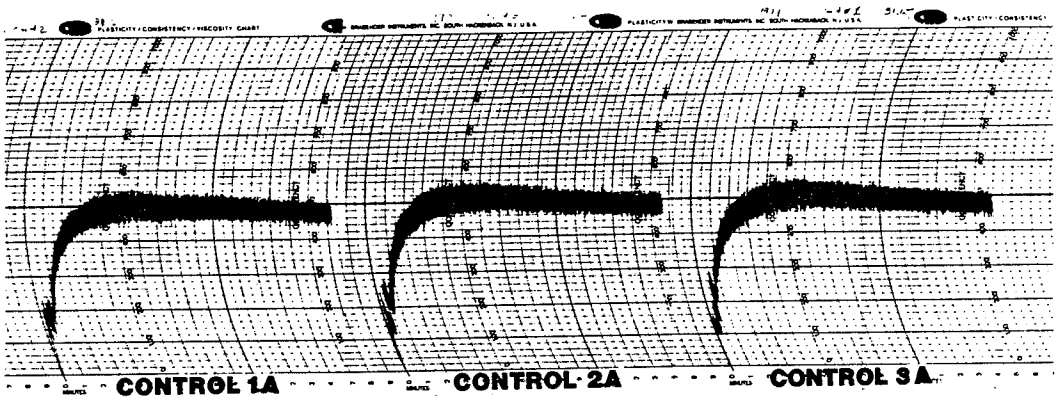
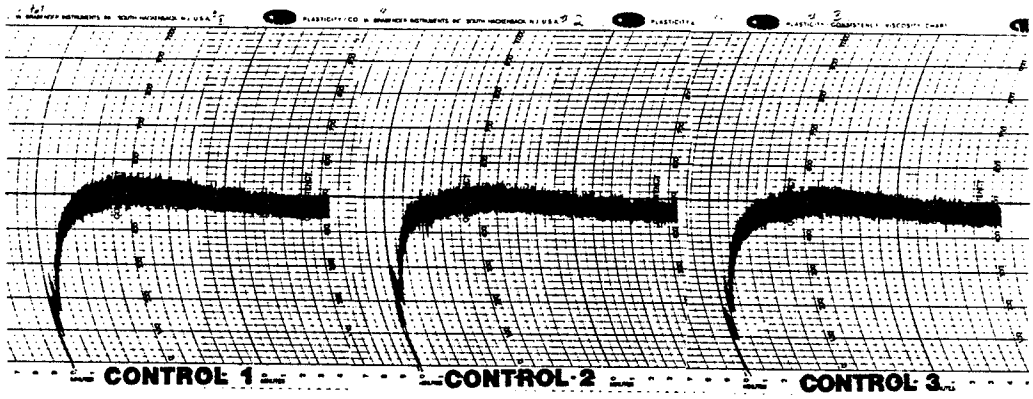


Figure 7. Farinograms for the control samples for the 1979 and 1980 wheat crop samples.

WHEAT CROP 1979



WHEAT CROP 1980



from the controls.

ii. Twenty-day storage. In general, the stability and mixing time increased in samples stored at 30 and 40° C at 12, 16 and 18% moisture content for 20 days (Tables 15 and 17, Figures 3, 4 and 7). The farinograph data of the 12% moisture content sample stored at 50° C from the 1979 crop remained stable compared to the control, while the sample from the 1980 crop showed an increase in stability compared to the control. However, the 16% moisture content sample from the 1979 crop stored at 50° C showed a marked decrease in mixing time and an increase in mixing tolerance index. The 16% moisture content sample from the 1980 crop stored at 50° C showed marked decrease in mixing time and mixing tolerance index and an increase in stability. On the other hand, the samples at 18% moisture content stored at 50° C resulted in a drastic decrease in both stability and mixing time and an increase in mixing tolerance index in samples from both the 1979 and 1980 crops.

iii. Thirty-day storage. The farinograph data of the wheat flour samples stored at 12, 16 and 18% for 30 days at 30° C showed minor variations compared to the controls (Tables 16 and 17, Figures 5, 6 and 7). A pronounced farinograph behavior was detected in samples at 18% moisture content from the 1979 and 1980 crops stored at 30° C. The farinograph data showed an increase in both mixing time and stability. The samples stored at 16% moisture content and 40° C for both crops showed an increase in mixing time and stability. The samples at 18% moisture content stored at 40° C, on the other hand, showed a decrease in mixing time. A drastic decrease in mixing time and stability and an increase in mixing tolerance index was also shown for the sample

stored at 50° C at 16 and 18% moisture content for both crops.

iv. Other farinograph properties. The water absorption, arrival time and departure time, in general, declined when the moisture levels of the stored samples and temperature increased during prolonged storage (Tables 14, 15, 16 and 17). The water absorption declined in the 16 and 18% moisture content samples stored for 20 and 30 days at 50° C for both crops. A similar trend was found in arrival time and departure time for the 18% moisture content samples stored for 10, 20 and 30 days at 50° C.

The farinograph studies of the stored wheat have indicated that there were no effects of storage conditions on the wheat when stored at 12% moisture content at 30, 40 and 50° C for various periods of time (10, 20 and 30 days). The samples stored at 16 and 18% moisture content under the same storage conditions showed an increase in the dough strength except for the samples stored at 50° C which showed a deterioration in quality when stored for longer periods of time. These results are in agreement with Larmour *et al*. (1961) who found marked changes in physical properties (farinograph and extensigraph) on doughs prepared from the stored flour and farina.

2. Extensigraph

Considering the large number of storage samples and the enormous time required to study the extensigraph properties, only a few samples were chosen for further studies. Earlier studies on the rheological properties indicated marked changes in farinograph properties in samples stored at 50° C, therefore, the stored wheat samples from the 1979 and 1980 crops stored at 50° C were chosen to be analyzed for extensigraph

properties at a 135 minute rest period.

i. Evaluation of the extensigrams. In order to evaluate the extensigrams of the stored samples, the following parameters were measured and studied:

a) The resistance to extension, obtained from the height of extensigram (measured 50 mm after the curve is started) in Extensigraph Units (E.U.),

b) The extensibility, measured in mm and taken from the length of the curve,

c) The ratio figure, resulting from the relation that exists between the resistance to extension and the extensibility.

ii. Samples at 12% moisture content. The samples at 12% moisture content stored at 50° C for 10, 20 and 30 days showed a decline in extensibility, especially for the samples stored for 30 days from the 1979 and 1980 crops compared to the controls (Table 18, Figures 8 and 9). These samples stored for 30 days recorded an extensibility of 95 and 170 mm, respectively, while the controls for the 1979 and 1980 crops recorded an extensibility of 245 and 255 mm, respectively.

The samples at 12% moisture content for both crops stored at 50° C showed an increase in resistance to extension when the period of storage increased. The highest resistance to extension was found in the samples stored for 30 days. These samples recorded more than 1,000 E.U. for the 1979 crop while the control recorded 380 E.U. The samples from the 1980 crop under the same storage conditions, recorded 690 E.U. while the control recorded only 320 E.U. At the same time, the ratio figure value, an important criterion in determining dough behavior, was found

TABLE 18. Extensigraph data for the 1979 and 1980 wheat crop samples which were stored at 50° C for various periods of times and different moisture levels.

Storage conditions		1979 Crop			1980 Crop		
		Extensibility (mm)	Resistance (E.U.)	Ratio[3]	Extensibility (mm)	Resistance (E.U.)	Ratio[3]
Moisture	Days						
12%	10	210	360	1.71	210	520	2.5
12%	20	205	520	2.54	195	600	3.1
12%	30	95	- [1]	-	170	690	4.1
16%	10	145	- [1]	-	165	740	4.5
16%	20	95	- [1]	-	135	- [1]	-
16%	30	80	- [1]	-	110	- [1]	-
18%	10	80	- [1]	-	140	- [1]	-
18%	20	75	860	11.5	80	- [1]	-
18%	30	70	300	4.3	70	360	5.1
12%[2]	0	245	380	1.5	255	320	1.2

[1] Off-scale (resistance greater than 1,000 E.U.).

[2] Controls.

[3] $\frac{\text{Resistance to extension}}{\text{extensibility}}$

Figure 8. Extensigrams for the 1979 wheat crop samples which were stored at 50° C for various periods of time and different moisture levels.

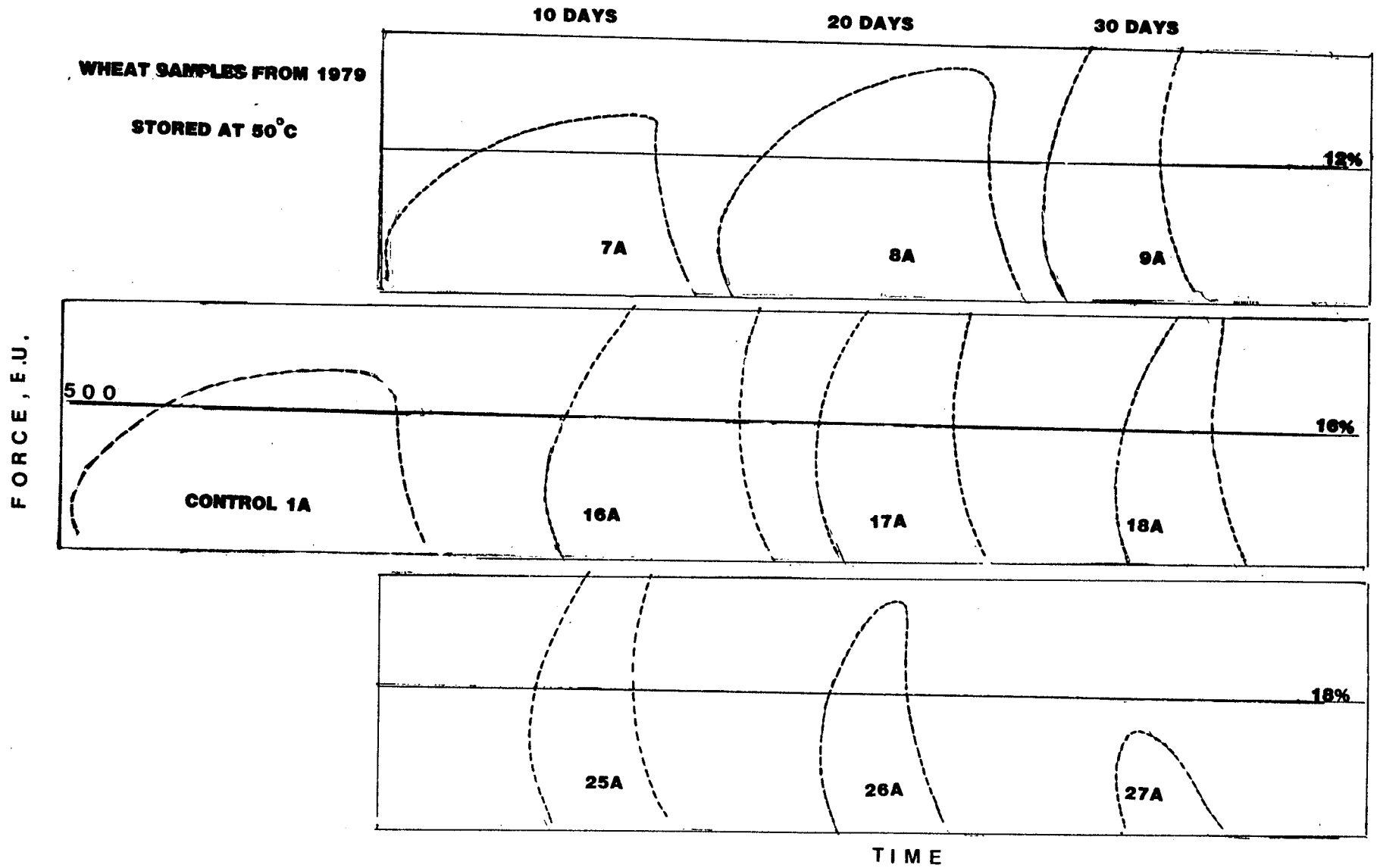
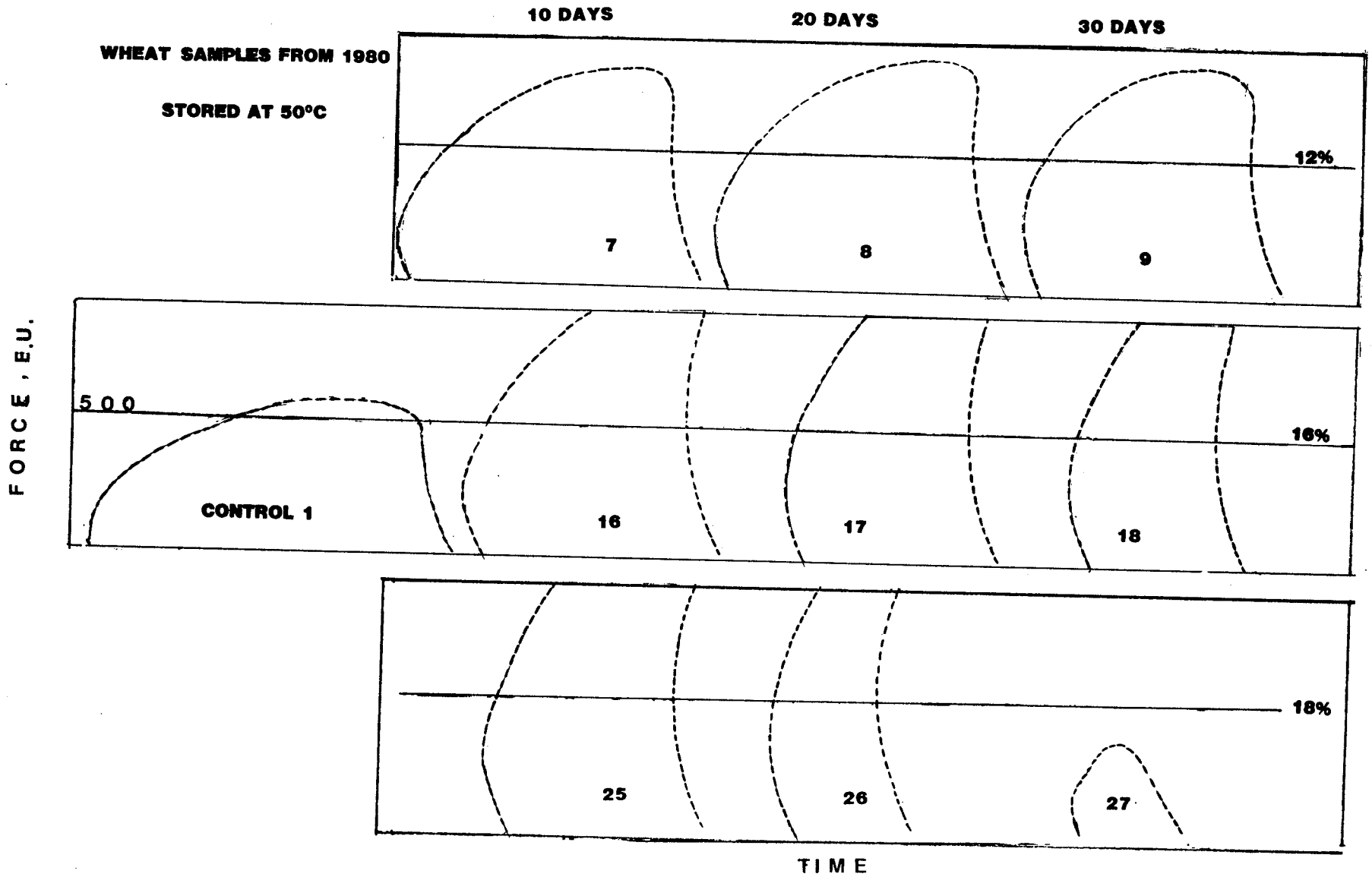

WHEAT SAMPLES FROM 1979
STORED AT 50°C
10 DAYS
20 DAYS
30 DAYS
12%
7A
8A
9A
FORCE, E.U.
500
16%
CONTROL 1A
16A
17A
18A
18%
25A
26A
27A
TIME

Figure 9. Extensigraph for the 1980 wheat crop samples which were stored at 50° C for various periods of time and different moisture levels.


10 DAYS
20 DAYS
30 DAYS
WHEAT SAMPLES FROM 1980
STORED AT 50°C
12%
7
8
9
FORCE, E.U.
500
16%
CONTROL 1
16
17
18
18%
25
26
27
TIME

to increase for longer storage periods.

iii. Samples at 16% moisture content. The extensibility of the stored samples at 16% moisture content for both crops decrease while the resistance to extension increased during prolonged storage (Table 18, Figures 8 and 9). The decrease in extensibility values and the increase in resistance values were more pronounced in samples stored at 16% moisture content compared to the samples stored at 12% moisture content. All the resistance to extension values were off-scale (> 1,000 E.U.) for all samples except for the 10-day sample from the 1980 crop. The resistance values were considerably greater than the 12% moisture content samples from the 1979 crop and the controls. The ratio figure values for the 16% moisture content samples were not calculated because the resistance values were off-scale.

iv. Samples at 18% moisture content. The extensibility and the ratio figure values for the stored 18% moisture content samples from both crops declined as the storage periods increased (Table 18, Figures 8 and 9). On the other hand, the resistance to extension values for these samples remained high except for the samples stored for 30 days.

The extensigraph data indicated that at 12% moisture content, the stored wheat flour showed only minor changes in extensigraph properties compared to the stored wheat flour from the 16 and 18% moisture content samples for the controls. The samples at 16% moisture content showed an increase in the resistance to extension indicating that the strength of the dough for these samples was very high. However, the ratio figure values for most of the samples was very high. The large ratio figure values indicated a possible decline in flow properties of the dough.

Generally, the results obtained in this study indicated that storage at high moisture contents and temperatures influenced the properties of wheat flour. These findings are in agreement with Larmour et al. (1961) and Westermarck-Rosendahl (1979) who also recorded increases in resistance to extension with decreases in extensibility in wheat during storage.

3. Amylograph

The amylograph is commonly used to determine the cereal α-amylase activity in wheat flour. The test is really a measure of the diastatic activity which involves the combined action of α- and β-amylase as well as the susceptibility of the starch in wheat flour to enzymatic attack (Selman and Sumnar 1947, Marnett et al. 1948).

In these studies the amylograph was used to indicate the enzyme activity, predominantly the α-amylase in wheat stored under different conditions. The amylograph viscosity (B.U.) of the wheat flour samples of the 1979 and 1980 crops stored at 50° C for different periods of time were determined. These samples were chosen because of the differences found in the rheological properties as determined by the farinograph and extensigraph.

The amylograph peak viscosity and the temperature at peak for the controls from the 1979 crop were 620 B.U. and 90.0° C and from the 1980 crop 760 B.U. and 93.0° C, respectively, as shown in Table 19 and Figures 10 and 11. The wheat samples from both the crops at 12% moisture content and stored at 50° C for 10, 20 and 30 days resulted in a slight increase in amylograph peak viscosity compared to the controls. The viscosity values were particularly high (1,510 B.U.) in samples from the 1980 crop stored for 30 days.

TABLE 19. Amylograph data for the 1979 and 1980 wheat crop samples which were stored at 50° C for various periods of time and different moisture levels.

Storage conditions		1979 Crop		1980 Crop	
		Viscosity at peak (B.U.)	Temperature at peak (° C)	Viscosity at peak (B.U.)	Temperature at peak (° C)
Moisture	Days				
12%	10	730	91.5	840	93.0
12%	20	760	91.5	930	91.5
12%	30	620	88.5	1510	91.5
16%	10	860	93.0	910	91.5
16%	20	1530	91.5	1540	91.5
16%	30	1710	93.0	1720	93.0
18%	10	750	91.5	1480	91.5
18%	20	1660	93.0	1760	91.5
18%	30	1740	93.0	1790	91.5
12%(1)	0	620	90.0	760	93.0

(1) Controls.

Figure 10. Amylograms for the 1979 wheat crop samples which were stored at 50° C for various periods of time and different moisture levels.

WHEAT SAMPLES FROM

1979 STORED AT 50°C

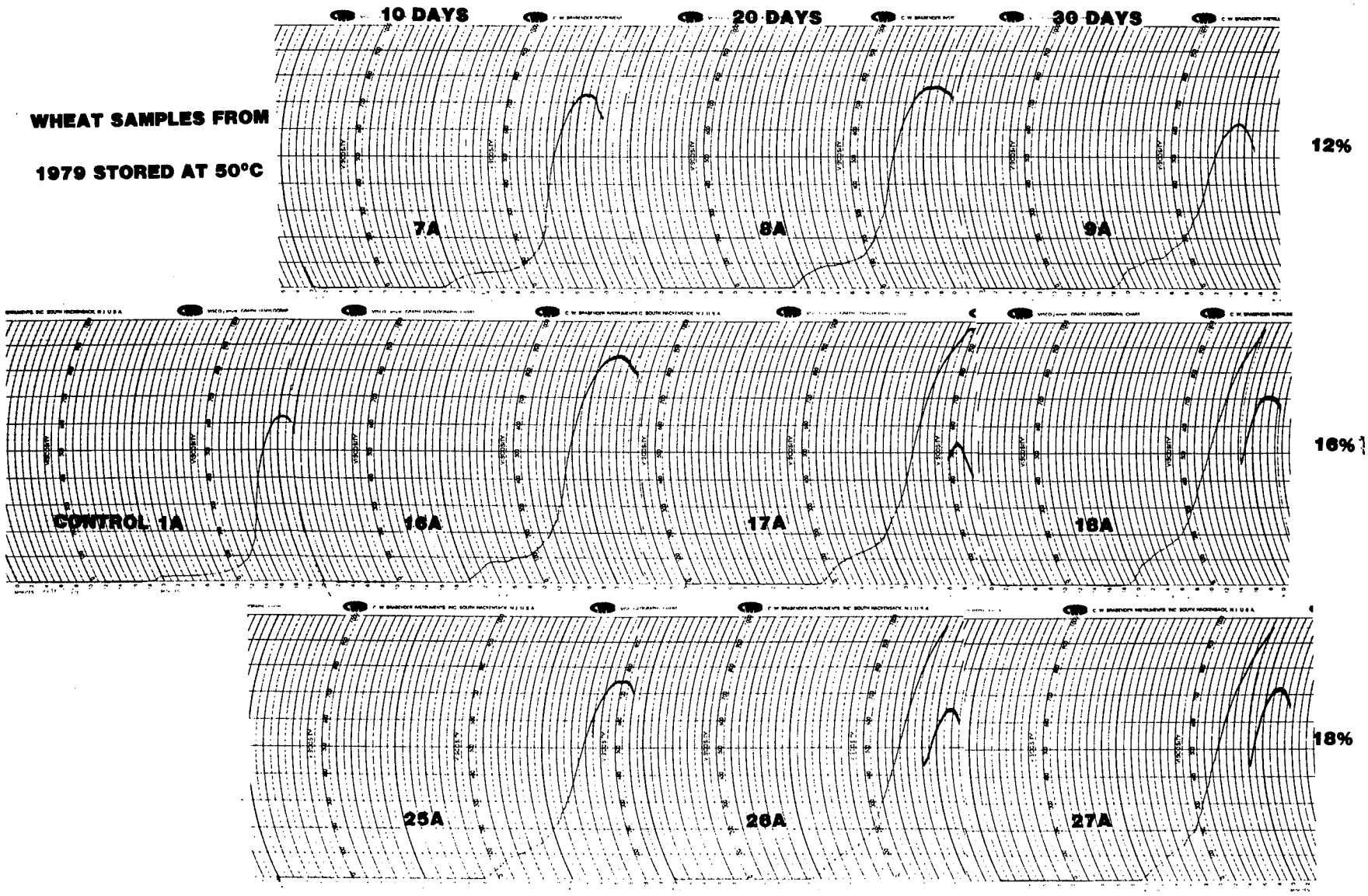
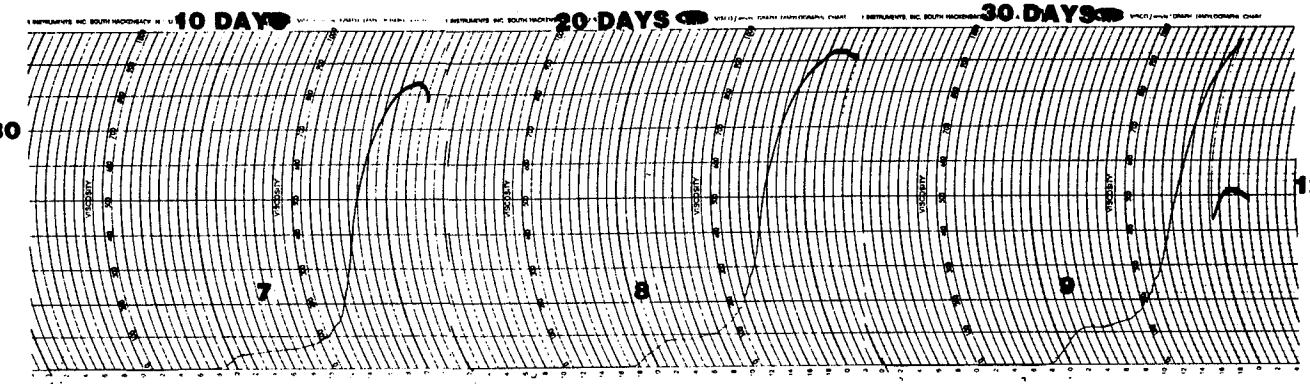
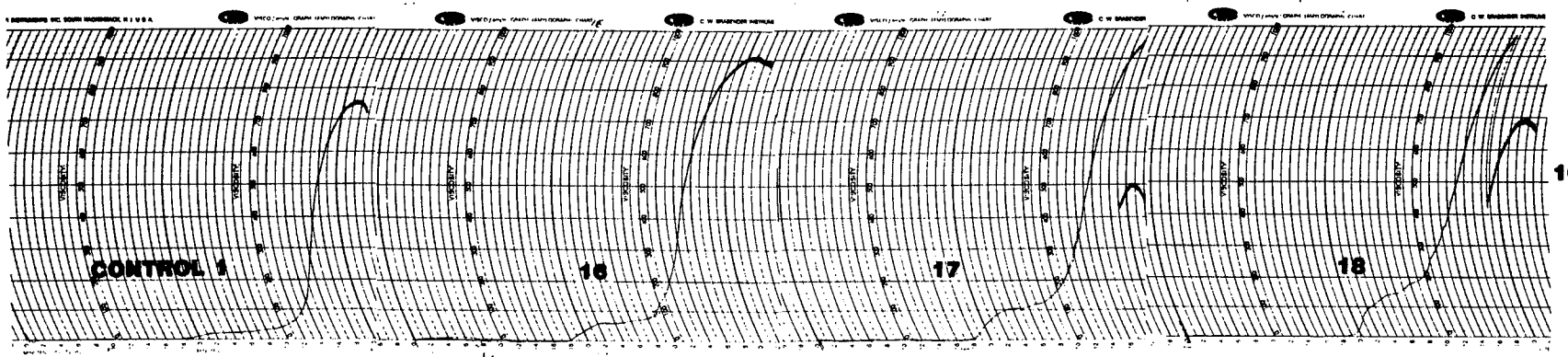


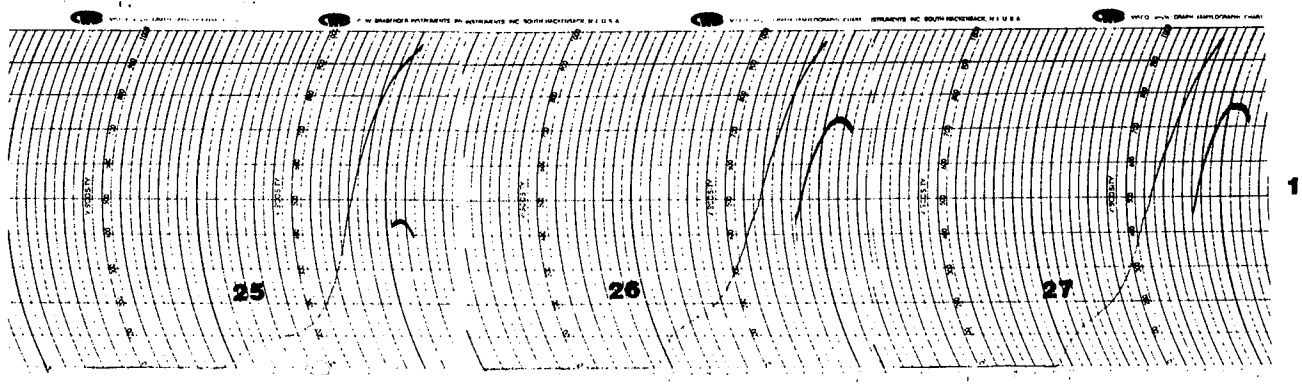
Figure 11. Amylograms for the 1980 wheat crop samples which were stored at 50° C for various periods of time and different moisture levels.

WHEAT SAMPLES FROM 1980

STORED AT 50°C







The wheat samples at 16 and 18% moisture contents, stored for the same period of time showed marked increases in the amylograph peak viscosity. This was most pronounced in the 16% moisture content sample stored for 30 days. These samples had a high viscosity value recorded at 1,710 and 1,720 B.U. for the 1979 and 1980 crops, respectively. The 18% moisture content samples stored for 20 and 30 days recorded a peak viscosity of 1,660 and 1,740 B.U., respectively, for the 1979 crop and 1,760 and 1,790 B.U., respectively, for the 1980 crop. All the samples stored at 50° C produced minor changes in amylograph peak temperature compared to the controls.

These results indicated that the amylase activity was very low in the wheat samples stored at high moisture levels and at high temperatures. Few amylograph studies have been conducted on stored wheat. However, the present study agrees with the findings of Shuey and Tipples (1980) who reported that there is a direct relation between storage time at different temperatures and loss in malt activity. The Shuey and Tipples (1980) report found that the rate of malt activity decreased when the storage temperatures increased.

F. The Effect of Different Storage Conditions on Gluten Proteins and Baking Properties of Wheat Flour from the 1979 and 1980 Results

1. Zeleny Sedimentation Test

The Zeleny Sedimentation Test is generally used as a measure of wheat quality for breeding programs and for the quality evaluation of commercial wheat samples. The value of this test for predicting bread-making quality of wheat flour can be demonstrated by the relationship obtained between the sedimentation value and loaf volume. It has been

shown for most wheats that the sedimentation value is directly proportional to its protein strength. In the present study, the Zeleny Sedimentation Test was used to determine the effects of storage conditions on wheat quality, especially breadmaking quality.

The sedimentation values of stored wheat flour samples for the 1979 and 1980 crops at 12, 16 and 18% moisture contents stored for 10, 20 and 30 days at 30, 40 and 50° C are presented in Table 20. The sedimentation values for the controls were 69.0 ml for the 1979 crop and 72.0 ml for the 1980 crop. The 12% moisture content samples of both crops stored at different temperatures (30, 40 and 50° C) for various periods of time (10, 20 and 30 days) showed a decrease in the sedimentation values with increased temperature, moisture levels and storage period. The flour samples from the 1979 crop stored at 12% moisture content and at 50° C showed a decrease in sedimentation values compared to the samples stored at 30 and 40° C. The flour samples stored at 12% moisture content and at 50° C for 10, 20 and 30 days recorded sedimentation values of 51.0, 44.0 and 41.0 ml, respectively. A decrease in sedimentation value was found for the samples from the 1979 and 1980 crops stored at 16 and 18% moisture content. The sedimentation values were considerably lower in the 16 and 18% moisture content samples from both the crops stored at 50° C for 30 days. The corresponding sedimentation values were 31.0 and 22.0 ml for the 1979 crop and 36.0 and 28.0 for the 1980 crop.

These results showed that an increase in the moisture content, temperature and period of storage resulted in a decrease in the sedimentation values of the stored wheat. The results are in agreement with those of Westermarck-Rosendahl (1978) who also found a decrease in the sedimentation values of wheat samples stored at high moisture levels as

Table 20. Sedimentation values for the 1979 and 1980 wheat crop samples which were stored at different moisture contents and different temperatures for various periods of time

Storage conditions		Sedimentation Value (ml)					
		1979 Crop			1980 Crop		
		Moisture Content			Moisture Content		
		12%	16%	18%	12%	16%	18%
Temperature	Days						
30° C	10	68.0	67.0	65.0	72.0	72.0	72.0
30° Cq	20	65.0	66.0	63.0	72.0	71.0	70.0
30° C	30	64.0	62.0	58.0	71.0	71.0	70.0
40° C	10	67.0	66.0	63.0	71.0	71.0	70.0
40° C	20	61.0	62.0	49.0	70.0	66.0	66.0
40° C	30	57.0	53.0	45.0	66.0	66.0	51.0
50° C	10	51.0	43.0	33.0	62.0	54.0	41.0
50° C	20	44.0	32.0	31.0	48.0	42.0	34.0
50° C	30	41.0	31.0	22.0	45.0	36.0	28.0
4° C[1]	0	69.0	69.0	69.0	72.0	72.0	72.0

[1]Controls

a result of short term storage (7 days).

2. Wet Gluten

The wet gluten content of the wheat flour samples from the 1979 and 1980 crops at 12, 16 and 18% moisture contents stored for 30, 20 and 10 days, respectively, at different temperatures (30, 40 and 50° C) are presented in Table 21. The wet gluten values of stored wheat samples decreased as the moisture content and temperatures increased. The percentage of wet gluten for the control samples of the 1979 crop and 1980 crop were 49.7 and 51.2%, respectively. The 12% moisture content samples stored for 30 days showed a decrease in wet gluten percentage when the temperature increased from 30 to 50° C in both crops. The 16 and 18% moisture content samples stored for 20 and 10 days, respectively, also showed a decrease in the wet gluten percentage. The wet gluten content of the 16 and 18% moisture content samples from the 1979 crop stored at 50° C for 20 and 10 days were 26.7 and 23.6%, respectively. These values were approximately half of the control values. The samples from the 1980 crop stored under similar conditions recorded a wet gluten content of 35.0 and 35.6%. These results indicated that at high temperatures and moisture levels, the gluten was damaged. The result of this damage was a reduction in the percentage of wet gluten in the stored wheat. The wet gluten results are in agreement with those of Daftary et al. (1970a) who reported that gluten, from the wheat flour at 18% moisture content stored at different temperatures for 4 months, was difficult to wash out. The storage conditions had impaired rheological properties of the gluten and reduced the gluten yield.

TABLE 21. Wet gluten data for the 1979 and 1980 wheat crop samples which were stored at different moisture levels and different temperatures for various periods of time.

Storage conditions			1979 Crop	1980 Crop
			Wet gluten %	Wet gluten %
Moisture	Temperature	Days		
12%	30° C	30	49.1	49.9
12%	40° C	30	47.9	46.5
12%	50° C	30	44.7	43.2
16%	30° C	20	46.8	46.8
16%	40° C	20	43.5	44.7
16%	50° C	20	26.7	35.0
18%	30° C	10	40.7	49.4
18%	40° C	10	41.5	44.7
18%	50° C	10	23.6	35.6
12%[1]	4° C	0	49.0	51.2

[1] Controls.

3. Baking Results

The baking tests were determined for the samples from the 1979 and 1980 wheat crops stored at 50° C for 10, 20 and 30 days at 12, 16 and 18% moisture content. The Grain Research Laboratory (GRL) "Remix" baking test of Irvine and McMullan (1960) which gives a good differentiation among wheat flour samples of varying protein content and quality was selected and used as the main baking test procedure for this study. For each sample, the farinograph absorption was used for the baking absorption.

The loaf volumes for the control samples from the 1979 crop were 820 and 797 cc and control samples from the 1980 crop were 880 and 910 cc as shown in Table 22 and Figures 12 and 13. The loaf volumes for the control of the 1980 crop were higher than that of the 1979 crop. Unexplainable baking difficulties were experienced with the control sample for the 1980 crop which resulted in large holes in crumb. The loaf volumes for the wheat samples from the 1979 and 1980 crops at 12% moisture content stored at 50° C for 10, 20 and 30 days decreased, compared to the control samples. Significant changes in loaf volume occurred in the 16% moisture content samples stored at the same temperatures and for the same periods of time. Samples stored for 30 days (#6) recorded loaf volumes of 261 and 325 cc for the 1979 and 1980 crops, respectively (Table 22, Figures 12 and 13). Similarly, the bread baked from the 18% moisture content sample stored at the same temperature and for the same periods of time showed extremely low loaf volumes, 305, 282 and 250 cc for the 1979 crop and 435, 270 and 260 cc for the 1980 crop for 10, 20 and 30 days storage, respectively.

A deterioration in loaf appearance, crumb color, grain and crust color was observed in the samples stored for 20 and 30 days at 16%

TABLE 22. Baking data for the 1979 and 1980 wheat crop samples which were stored at 50° C and different moisture levels for various periods of times.

Storage conditions		1979 Crop		1980 Crop	
		Identification no.	Volume CC	Identification no.	Volume CC
Moisture	Days				
12%	10	1	805	1	770
12%	20	2	792	2	750
12%	30	3	722	3	680
16%	10	4	585	4	670
16%	20	5	335	5	470
16%	30	6	261	6	325
18%	10	7	305	7	435
18%	20	8	282	8	270
18%	30	9	250	9	260
12%(1)	0	10	820	10	880
12%(1)	0	11	797	11	910

(1) Controls.

Figure 12. Characteristics of bread made with the 1979 wheat crop which were stored at 50° C and different moisture levels for various periods of time.

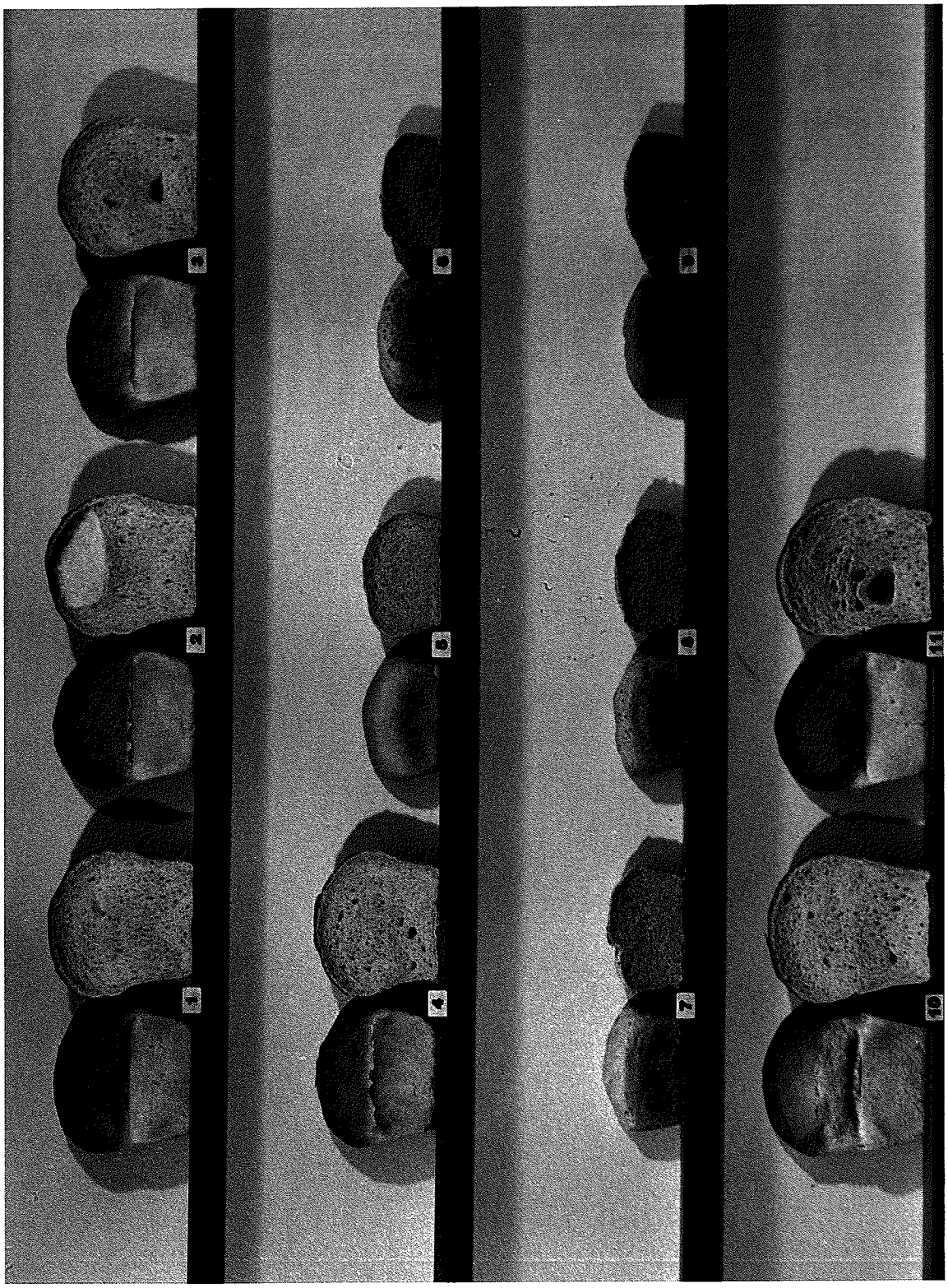

1
2
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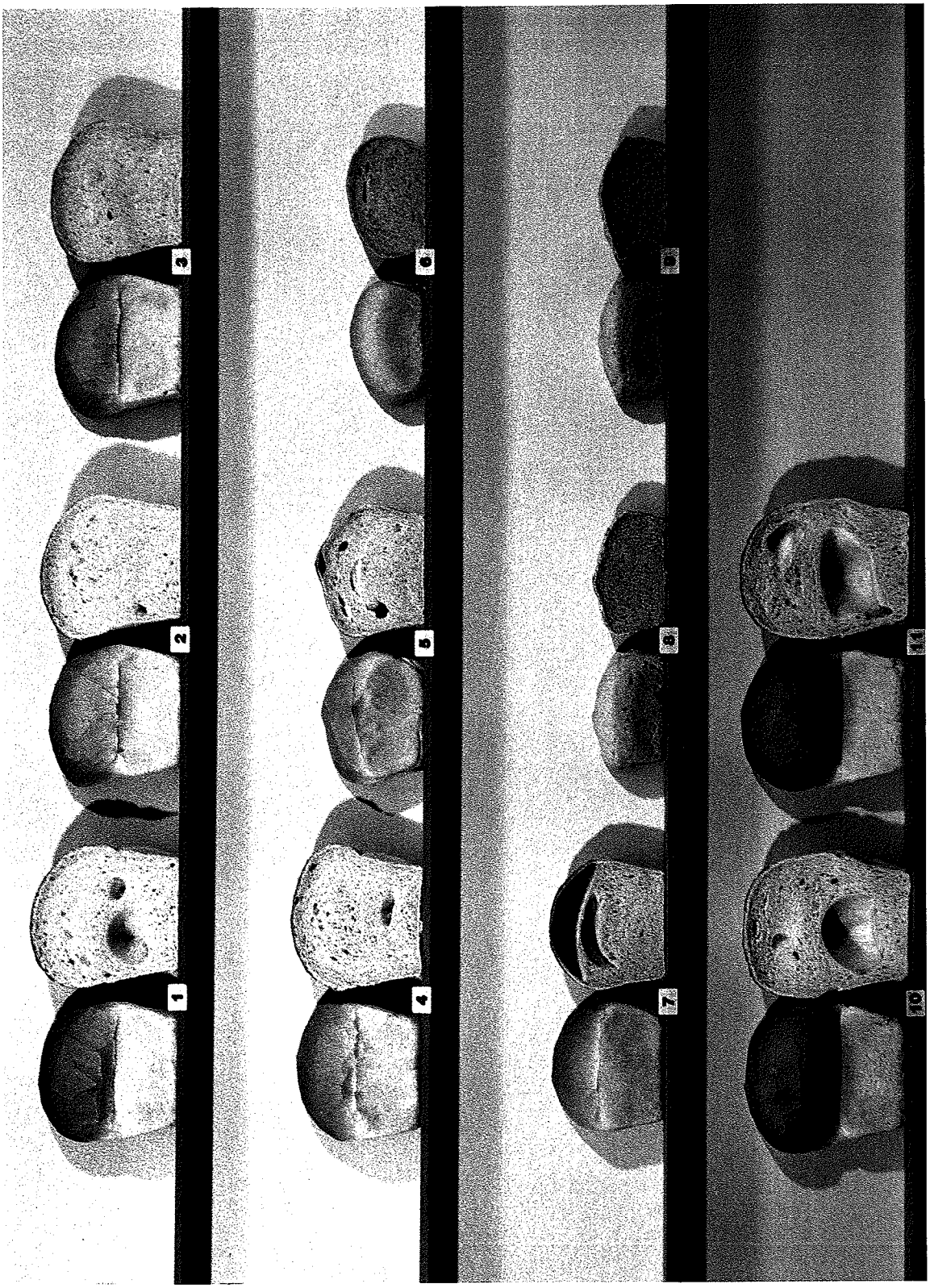
Figure 13. Characteristics of bread made with the 1980 wheat crop which were stored at 50° C and different moisture levels for various periods of time.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moisture content and samples at 18% moisture content stored for 10, 20 and 30 days for the 1979 crop. The same trend was found in samples at 16 and 18% moisture contents for the 1980 crop which were stored for 20 and 30 days. In these samples, the crumb color gradually changed from light to dark, and the crust color from amber to white. As anticipated from farinograph and extensigraph measurements, the dough behavior during mixing, sheating and molding was not as satisfactory as was found for the control samples. The dough from the samples at high moisture content and long period of storage was tight, solid and dry during the make-up stage of the breadmaking.

The results presented in this study are in agreement with Westermarck-Rosendahl (1978) who found decreases in the loaf volumes of the stored wheat at high moisture levels and temperatures during 7 days of storage.

VI. GENERAL DISCUSSION

The main objective of this thesis was to study the effect of storage conditions, which included moisture, temperature time, on the rheological and chemical properties of a Canadian western hard red spring wheat, Neepawa (*Triticum aestivum s. sp. vulgare*), for two different crop years (1979 and 1980). The two different crop years were studied separately and not treated as a replicate for each other.

The organoleptic, rheological and chemical properties of the stored wheat samples as affected by the storage condition, as well as the influence of fungal infestation, were investigated. In this study, various methods were used to control the storage conditions. Finally, in order to control the desired moisture content of 12, 16 and 18%, it was decided to use sealed containers. To control the desired temperatures of 30, 40 and 50° C, a controlled environment cabinet and an air oven were used for the storage experiment.

The organoleptic properties for both crops were affected by storage conditions at high moisture contents and high temperatures. In addition, the stored wheat and flour developed a dark brown color with increasing moisture levels, temperature and storage time. The change in wheat color during storage was primarily due to browning reaction of the Maillard type. Our findings are consistent with the studies by Cole and Milner (1953) and MacDonald and Milner (1954) on fresh wheat which was stored at elevated moistures and temperatures.

A malt and rancid type of smell was also associated with high temperature. This was probably caused by anaerobic respiration and/or

because of fungal growth (Glass et al. 1959, Hyde 1974). Penicillium sp. and Aspergillus sp. were found in wheat stored at 16 and 18% moisture contents for 20 and 30 days. No fungal growth was observed on wheat stored at 12% moisture content. These findings are in agreement with Glass et al. (1959), Daftary et al. (1970b), Moubashar et al. (1972) and Flannigan (1978) who found that the growth of these fungi in stored grain varied with the storage conditions.

The percent of flour extracted from the stored wheat of both crops were similar except for differences in the wheat stored at high moisture contents and high temperature. Flour yield obtained from these samples were considered higher.

The control samples and all the stored wheat samples were analyzed for ash content, protein content, starch damage, amino acid compositions, as well as free amino acid compositions. The ash content increased in stored wheat flour with increasing moisture levels, temperatures and storage time. These results are in agreement with those of Fifield and Robertson (1959) who reported an increase in flour ash content for wheat samples stored for up to 33 years. The increase was attributed to the formation of a brittle bran coat in the wheat which was stored for long periods of time. When the protein content of the stored wheat flour samples were determined, no marked differences were observed in protein content. This indicated that the storage conditions did not influence the protein content. These findings are consistent with the findings of Jones and Jersdorff (1941) and Pixton and Hill (1967).

There were no differences in the starch damage values for the stored wheat samples within each crop year. However, the starch damage value for the 1979 crop was higher than the values for the 1980 crop. This difference might be explained by the different weather conditions

in the two growing seasons. The samples at 18% moisture content stored for 30 days at 50° C showed a high starch damage value. This was probably due to the heavy mold growth associated with this sample (Acker 1961, Daftary et al. 1970a).

It was found that the stored wheat flour samples showed little variation in amino acid compositions. These results are in agreement with those of Zeleny and Coleman (1938). However, the stored 18% moisture content samples at 50° C for 20 days showed an increase in free amino acid values. These increases were probably due to fungal infestation. The samples free from fungi showed only a marginal increase in free amino acid contents. These results are, in general, consistent with the findings of DeVay (1952) who found marked changes in some free amino acid in stored wheat. These changes were reported to be due mainly to respiration, mold growth, or both.

The results of the rheological studies revealed that the stored wheat samples produced a gradual change in rheological properties of the dough as measured by the farinograph and extensigraph, with increasing moisture levels, temperature and storage time. The results revealed that there was no effect of storage on the rheological properties when the moisture levels and temperature were low. High temperature at low moisture levels appeared to increase the dough strength by increasing the mixing time and stability. A similar trend was found when the storage temperatures were low along with high moisture levels. However, the combinations of high temperature and high moisture level, as well as the prolonged storage, progressively deteriorated the wheat quality and subsequently the baking quality. These results are consistent with the findings of Larmour et al. (1961) who found marked changes in farinograph

and extensigraph properties on doughs prepared from the stored flour and farina. Storage conditions also had a pronounced effect on the amylograph results. The increase in amylograph peak viscosity during the storage was attributed to the different storage conditions.

The Zeleny sedimentation test on the stored wheat showed a decrease in sedimentation values with increasing moisture content and storage time. Storage conditions produced a decrease in the sedimentation value, even though the protein content of the stored wheat remained constant. Therefore, the stored wheat proteins were altered by the storage conditions. This resulted in a change in protein quality, and was subsequently confirmed by actual baking tests. These results are in agreement with Westermarck-Rosendahl (1978) who also found a decrease in the sedimentation values of wheat stored at high moisture levels over a short period of time.

The wet gluten percentage, obtained from the stored wheat flour, showed a marked difference among the various samples. The samples at higher moisture levels stored at higher temperatures gave correspondingly lower percentages of wet gluten. These findings supported the view that gluten was one of the most important components affected by storage conditions. Similar findings were reported by Daftary _et al_. (1970a).

Finally, the bake test was used to assess the effect of storage on the breadmaking quality of the wheat flour. The baking test showed that the stored wheat flour at high moisture content and high temperature resulted in a decrease in loaf volumes and deterioration in bread quality. The bake test confirmed the quality prediction tests obtained in the rheological studies.

In general, this study indicated that the wheat stored at low moisture levels and low temperatures was less susceptible to mold damage

and rheological and chemical changes than wheat stored at high moisture levels and high temperatures. The most significant changes were observed in the quality and quantity of gluten proteins. As was mentioned previously, about 85% of the protein in wheat flour consist of the gluten components, gliadin and glutenin. These fractions differ markedly in their physical properties. Damage to gluten proteins varies with storage conditions and mold growth. Under extreme storage conditions gluten proteins lost their properties such as stability and extensibility, as indicated by the farinograph and extensigraph. This was confirmed by the baking test. Furthermore, the gluten washing procedure indicated that the gluten proteins of wheat deteriorated under adverse storage conditions resulted in a deterioration of protein quality. A similar result was found by Daftary et al. (1970a). These authors also reported that the gluten from sound flour represented 85% of the total protein, while the gluten from damaged flour represented only 30% of the total protein. It is likely that the least damaged or unaltered part of the protein in their study and ours was recovered as a gluten protein by the gluten washing technique.

The sedimentation test also confirmed the decline in gluten quality with increasing moisture, temperature and storage period. Since this test is simple, reliable and fast, it is recommended that for a quick preliminary evaluation of the quality of stored wheat, this method be used.

It is hoped that the information presented in this thesis will be helpful in the safe storage of wheat, especially in countries that have tropical and sub-tropical climates, but lack proper storage facilities, and in assessing the utilization potential of stored wheat for bread production.

VII. LITERATURE CITED

ACKER, L. 1962. Enzymic reactions in foods of low moisture content. Advan. Food Res. 11: 263-330.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1969. AACC Approved Methods (7th ed.), The Association: St. Paul, Minnesota.

BELL, B.M., CHAMBERLAIN, N., COLLINS, T.H., DANIEALS, D.G.H. and FISHER, N. 1979. The composition, rheological properties and breadmaking behaviour of stored flours. J. Sci. Food and Agric. 30: 1111-1122.

BURRELL, N.J. 1974. Chilling. In Storage of Cereal Grain and Their Products. C.M. Christensen (editor). American Association of Cereal Chemists, St. Paul, Minnesota, 422-449.

BUSHUK, W. 1977. Wheat proteins - Their properties and role in bread-making quality of flour. In Grain and Oilseeds Handling, Marketing, Processing. Canadian International Grains Institute, Winnipeg, Manitoba, 420-438.

BUSHUK, W. and LEE, J.W. 1978. Biochemical and functional changes in cereals: Maturation, storage and germination. Food & Nutrition Press, Inc., U.S.A. 1-33.

BUTAKI, R.C. and DRONZEK, B.L. 1979. Effect of protein content and wheat variety on relative viscosity, solubility and electrophoretic properties of gluten proteins. Cereal Chem. 56(3): 162-165.

BUXTON, P.A. 1931. The measurement and control of atmospheric humidity in relation to entomological problems. Bull. ent. Res. 22: 431-447.

BUXTON, P.A. and MELLANBY, K. 1934. The measurement and control of humidity. Bull. ent. Res. 25: 171-175.

CHARM, S.E. 1962. The nature and role of fluid consistency in food engineering applications. In Advances in Food Research, Vol. 11. C.O. Chichester, M.E. Mark and G.F. Stewart (editors). Academic Press, New York.

CLAYTON, T.A. and MORRISON, W.R. 1972. Changes in flour lipids during the storage of wheat flour. J. Sci. Fd. Agric. 23: 721-736.

COLE, E.W. and MILNER, M. 1953. Colorimetric and fluorometric properties of wheat in relation to germ damage. Cereal Chem. 30: 378-391.

CUENDET, L.S., LARSON, E., NORRIS, C.G. and GEDDES, W.F. 1954. The influence of moisture content and other factors on the stability of wheat flours at 37.8° C. Cereal Chem. 31: 362.

DAFTARY, R.D. and POMERANZ, Y. 1965. Changes in lipid composition in wheat during storage deterioration. J. Agr. Food Chem. 13(5): 442-446.

DAFTARY, R.D., POMERANZ, Y., HOSENEY, R.C., SHOGREN, M.D. and FINNEY, K.F. 1970a. Changes in wheat flours damaged by mold during storage effects in breadmaking. J. Agr. Food Chem. 18(4): 617-619.

DAFTARY, R.D., POMERANZ, Y. and SAUAR, D.B. 1970b. Changes in wheat flour damaged by mold during storage effect on lipid, lipoprotein and protein. J. Agr. Food Chem. 18(4): 613-616.

DEVAY, J.E. 1952. A note on the effect on mold growth and increased moisture content on the free amino acids in hard red spring wheat. Cereal Chem. 29: 309-311.

ESKIN, N.A.M., HENDERSON, H.M. and TOWNSEND, R.J. 1971. Browning reactions in food. In Biochemistry of Foods. N.A.M. Eskin et al. (editors). Academic Press, New York, 69-100.

FARRAND, E.A. 1964. Flour properties in relation to the modern bread processed in the United Kingdom, with special reference to alpha-amylase and starch damage. Cereal Chem. 41: 98-111.

FERRELL, R.E., SHEPHERD, A.D. and GUADAGNI, D.G. 1970. Storage stability of lysine in lysine-fortified wheat. Cereal Chem. 47: 33-37.

FIFIELD, C.C. and ROBERTSON, D.W. 1959. Milling, baking and chemical properties of Marquis and Konred wheat grown in Colorado and stored 25 to 33 years. Cereal Science Today 4(6): 179-183.

FISHER, E.A., HALTON, P. and CARTER, R.H. 1937. Studies on the storage of wheat on flour: 1. The influence of storage on the chemical composition and baking quality of flour. Cereal Chem. 14: 135-159.

FLANNINGAN, B. 1978. Primary contamination of barley and wheat grain by storage fungi. Trans. Br. Mycol. Soc. 70(1): 37-42.

GEDDES, W.F. 1935. Can. Grain Research Lab, Winnipeg 9th Ann. Rep., 62-64. (cited by Pomeranz 1974)

GLASS, R.L., PONTE, J.G., Jr., CHRISTENSEN, C.M. and GEDDES, W.F. 1959. Grain storage studies. XXVIII. The influence of temperature and moisture level on the behavior of wheat stored in air or nitrogen. Cereal Chem. 36: 341-356.

GREER, E.N., JONES, C.R. and MORAN, T. 1954. The quality of flour stored for periods up to 27 years. Cereal Chem. 31: 439.

HALL, D.W. 1970. Factors affecting food value and deterioration. In Handling and Storage of Food Grain in Tropical and Subtropical Area. Food and Agric. Organization, Rome, 38-63.

HIBBERD, G.E. and PARKER, N.S. 1975. Measurement of the fundamental rheological properties of wheat-flour doughs. Cereal Chem. 52(3): 1r-23r.

HLYNKA, I. and ANDERSON, J.A. 1955. A laboratory dough mixer with an air-tight bowl. Cereal Chem. 22: 83-87.

HUMMEL, B.C.W., CUENDET, L.S., CHRISTENSEN, C.M. and GEDDES, W.F. 1954. Grain storage studies. XIII. Comparative changes in respiration, viability and chemical composition of mold-free and mold-contaminated wheat upon storage. Cereal Chem. 31: 143-150.

HUNT, W.H. and PIXTON, S.W. 1974. Moisture - Its significance, behavior and measurement. In Storage of Cereal Grains and Their Products. C.M. Christensen (editor). American Association of Cereal Chemists, St. Paul, Minnesota, 1-38.

HYDE, M.B. 1974. Airtight storage. In Storage of Cereal Grains and Their Products. C.M. Christensen (editor). American Association of Cereal Chemists, St. Paul, Minnesota, 383-419.

INTERNATIONAL CRITICAL TABLES. Ed-in-chief, E.W. Washburn. Publ. for Nat. Res. Council by McGraw-Hill Co., N.Y. and London, Vol. 3, 1928, (cited by Solomon 1951).

IRVINE, G.N. and MCMULLAN, M.E. 1960. The "Remix" baking test. Cereal Chem. 37: 603-613.

JONES, D.B. and GERSDORFF, E.F. 1941. The effect of storage on the protein of wheat, white flour and whole wheat flour. Cereal Chem. 18: 417-433.

JORGENSEN, H. 1936. On the existence of powerful but latent proteolytic enzymes in wheat flour. Cereal Chem. 13: 346-355.

LARMOUR, R.K., HULSE, J.H., ANDERSON, J.A. and DEMPSTER, C.J. 1961. Effect of package type on stored flour and farina. Cereal Science Today 6(5): 158-146.

LONEY, D.P. and MEREDITH, P. 1974. Note on amylograph viscosities of wheat flour and their starches during storage. Cereal Chem. 51: 702-705.

LYNCH, B.T., GLASS, R.L. and GEDDES, W.F. 1962. Grain storage studies. XXXII. Quantitative changes occurring in the sugars of wheat deteriorating in the presence and absence of mold. Cereal Chem. 39: 256-261.

MAILLARD, L.C. 1912. Action des acides amines sur les sucres; formation des melanoidines par voie methodique. C.R. Acad. Sci. 154, 66; (cited by Eskin et al. 1971).

MARNETT, L.F., SELMAN, R.W. and SUMNER, R.J. 1948. A modified amylograph method for the rapid determination of flour amylase activity. Cereal Chem. 25: 127-132.

MCCALLA, A.G., MCCAIG, J.D. and PAUL, A.D. 1939. Effect of various conditions of storage on baking quality of flour. Can. J. Research 17C: 452-460.

MCDONALD, C.E. and MILNER, M. 1954. The browning reaction in wheat germ in relation to "sick" wheat. Cereal Chem. 31: 279-295.

MOUBASHER, A.H., ELNAGHY, M.A. and ABDUL-HAFZ, S.I. 1972. Studies on the fungus flora of three grains in Egypt. Mycopath. Appl. 47: 261-274.

ORTH, R.A., DRONZEK, B.L. and BUSHUK, W. 1974. Studies of glutenin. VII. Inheritance of its physicochemical factors in triticale. Cereal Chem. 51: 281-288.

PARPIA, H.A.B. 1976. Postharvested losses - impact of their prevention on food supplies, nutrition and development. In Nutrition and Agricultural Development. N.S. Scrimshaw and M. Behar (editors). Plenum Press, New York, N.Y.

PATEY, A.L., SHEARER, G. and MCWEENY, D.J. 1977. A study of gluten extractability from doughs made from fresh and stored wheat flours. J. Sci. Fd. Agric. 28: 63-68.

PIXTON, S.W. 1980. Changes in quality of wheat during 18 years storage. In Controlled Atmosphere Storage of Grain. J. Shejbal (editor). Elsevier Scientific Publishing Co., New York, 301-310.

PIXTON, S.W. and HILL, S.T. 1967. Long term storage of wheat. II. J. Sci. Fd. Agric. 18: 94-98.

PIXTON, S.W., HYDE, M.B. and AYERST, G. 1964. Long term storage of wheat. J. Sci. Fd. Agric. 15: 152-161.

PIXTON, S.W., WARBURTON, S. and HILL, S.T. 1975. Long term storage of wheat. III. Some changes in the quality of wheat observed during 16 years of storage. J. Stored Prod. Res. 11: 177-185.

POMERANZ, Y. 1974. Biochemical, functional and nutritive changes during storage. In Storage of Cereal Grains and Their Products. C.M. Christensen (editor). American Association of Cereal Chemists, St. Paul, Minnesota, 56-63.

PRATT, D.B., Jr. 1971. Criteria of flour quality. In Wheat Chemistry and Technology. Y. Pomeranz (editor). American Association of Cereal Chemists, St. Paul, Minnesota, 201-226.

PYLER, E.J. 1967. Elements of flour performance. Bakers Digest 41(3): 55-59.

RAO, V.S., URMILA, K.V. and SREENIVASAN, A. 1978. Comparative studies on physicochemical and baking properties of newly harvested and stored Indian varieties of wheat. J. Sci. Agric. 29: 155-164.

SAUNDERS, C.E., NICHOLLS, R.W. and COWEN, P.R. 1921. Researches in regard to wheat, flour and bread. Bull. 97, Can. Dept. Agri., Cereal Div., 1-57.

SELMAN, R.W. and SUMNER, R.J. 1947. The use of the amylograph for flour malt control. Cereal Chem. 24: 291-299.

SHEARER, G., PATEY, A.L. and MCWEENY, D.J. 1975. Wheat flour proteins: The selectivity of solvents and the stability of gliadin and glutenin fractions of stored flours. J. Sci. Fd. Agric. 26: 337-344.

SHUEY, W.C. and TIPPLES, K.H. 1980. The amylograph handbook. The American Association of Cereal Chemists, St. Paul, Minnesota.

SHUTT, F.T. 1909. Influence of age on wheat and flour. Canadian Expt. Farms Rept., 144-147.

SHUTT, F.T. 1911. Influence of age on wheat and flour. Canadian Expt. Farms Rept., 168-171.

SINHA, R.N. 1979. Ecology of microflora in stored grain. Ann. Technol. Agric. 28: 191-209.

SINHA, R.N. and WALLACE, H.A.H. 1965. Ecology of a fungus-induced hot-spot in stored grain. Canada J. Pl. Sci. 45: 48-59.

SMITH, C.V. 1969. Physical characteristic of grain bulk. In Meteorology and Grain Storage. C.V. Smith (editor). World Meteorological Organization, Geneva, Switzerland, 11-13.

SOLOMON, M.E. 1951. Control of humidity with potassium hydroxide, sulphuric acid or other solutions. Bull. Entomol. Res. 42: 543-559.

SPACKMAN, D.H., STEIN, N.H. and MOORE, S. 1958. Automatic recording apparatus for use in chromatography of amino acids. Anal. Chem. 30: 1190-1206.

SULLIVAN, B., HOWE, M. and SCHMALZ, F.D. 1936. On the presence of glutathione in wheat. Cereal Chem. 13: 665.

TRISVYATSKII, L.A. 1969. Physiological processes occurring in grain and seed during storage. In Storage of Grain. L.A. Trisvyatskii (editor). National Lending Library for Science and Technology, Boston, Spa, 1: 106-200.

WALLACE, H.A.H. 1973. Fungi and other organisms associated with stored grain. In Grain Storage: Parts of a System. R.N. Sinha and W.E. Muir (editors). The Avi Publishing Co., Inc., 71-93.

WALLACE, H.A.H., SINHA, R.N. and MILLS, J.T. 1976. Fungi associated with small wheat bulks during prolonged storage in Manitoba. Canadian J. Bot. 54(12): 1332-1343.

WESTERMARCK-ROSENDAHL, C.W. 1978. Spontaneous heating in newly harvested wheat and rye. II. Effect the technological quality of flour. Acta Agricultural Scandanavica 28(2): 159-168.

WESTERMARCK-ROSENDAHL, C. and YLIMAKI, A. 1978. Spontaneous heating in newly harvested wheat and rye. I. Thermogenesis and its effect on grain quality. Acta Agricultural Scandanavica 28: 151-158.

WHEAT FLOUR INSTITUTE. 1971. From flour to bread. "The Staff of Life". Chicago, Illinois, 60604.

YONEYAMA, T., SUZUKI, I. and MUROHASHI, M. 1970a. Natural maturing of wheat flour. I. Change in some chemical components and in farinograph and extensigraph properties. Cereal Chem. 47: 19-25.

YONEYAMA, T., SUZUKI, I. and MUROHASHI, M. 1970b. Natural maturing of wheat flour. II. Effect of temperature on changes in soluble SH content, and some rheological properties of doughs obtained from the flour. Cereal Chem. 47: 27-33.

ZELENY, L. 1954. Chemical, physical and nutritive changes during storage. In Storage of Cereal Grains and Their Products. J.A. Anderson and A.W. Alock (editors). Monograph Series, American Association of Cereal Chemists, St. Paul, Minnesota 11: 46-76.

ZELENY, L. and COLEMAN, D.A. 1938. Acidity in cereals and cereal products, its determination and significance. Cereal Chem. 15: 580-595.